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Weed Science Research and Funding: A Call to Action

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Weed science has contributed much to agriculture, forestry and natural resource management during its history. However, if it is to remain relevant as a scientific discipline, it is long past time for weed scientists to move beyond a dominating focus on herbicide efficacy testing and address the basic science underlying complex issues in vegetation management at many levels of biological organization currently being solved by others, such as invasion ecologists and molecular biologists. Weed science must not be circumscribed by a narrowly-defined set of tools but rather be seen as an integrating discipline. As a means of assessing current and future research interests and funding trends among weed scientists, the Weed Science Society of America conducted an online survey of its members in summer of 2007. There were 304 respondents out of a membership of 1330 at the time of the survey, a response rate of 23%. The largest group of respondents (41%) reported working on research problems primarily focused on herbicide efficacy and maintenance, funded mainly by private industry sources. Another smaller group of respondents (22%) reported focusing on research topics with a complex systems focus (such as invasion biology, ecosystem restoration, ecological weed management, and the genetics, molecular biology, and physiology of weedy traits), funded primarily by public sources. Increased cooperation between these complementary groups of scientists will be an essential step in making weed science increasingly relevant to the complex vegetation management issues of the 21st century.

As scientists, and collectively as a scientific society focused on basic and applied research, we engage in reflective thinking in order to take stock of how our work addresses narrow and more broadly-defined societal problems. There have been times when such reflection has revealed much about the origin of our discipline. For example, in Zimdahl's *Weed Science: A Plea for Thought*, we see that the weed science discipline arose in response to a rapidly expanding herbicide industry and by accelerated adoption of herbicides by farmers (Zimdahl 1991). This identity has been difficult to change despite many papers challenging weed scientists to think outside the herbicide efficacy/herbicide fate box. Such papers appear to come in waves. In the early 1990s we were reminded that our discipline must broaden beyond herbicide-centered weed management (Radosevich and Ghersa 1992; Wyse 1992; Zimdahl 1991). Nearly a decade later, the Weed Science Society of America (WSSA) Research Committee proposed that "weed science would be advantageously positioned for the future if research focused on decision processes, weed biology and ecology, weed management practices, herbicide resistance, issues related to transgenic plants, environmental issues, and potential benefits of weeds" (Hall et al. 2000 p. 647). The opinion that weed science would benefit from a broader and more ecologically-focused research agenda was also the theme of several other publications that appeared during that time period (Booth and Swanton 2002; Buhler 2002; Liebman and Davis 2000; Liebman and Dyck 1993; Martinez-Ghersa et al. 2000; Mortensen et al. 2000; Norris 1999; Zimdahl 2004).

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Predictions of increased demand for broader and more ecologically-focused weed research have been validated as more and more funding is being allotted to interdisciplinary problem solving. To see this rise in interdisciplinary funding opportunities in the United States, one need look no further than the recent request for proposals for such U.S. Department of Agriculture Cooperative State Research, Education, and Extension Service (USDA-CREES) funding programs as Biotechnology Risk Assessment, Weedy and Invasive Organisms, IPM Risk Avoidance and Mitigation, etc. Here, those with expertise in systems analysis, plant population and community analysis, molecular biology and genetics, restoration ecology following vegetation control, methods of monitoring, and assessment of pre- and post-control, among others, are called on to address the complex problems that today face society. We believe that weed scientists are ideally suited for interdisciplinary vegetation management, but are members of the society heeding this call, or does the society remain narrowly focused on herbicide research?

Given our stated concern about avoiding a narrowly-defined discipline, we sought to gauge how our membership perceives itself. Specifically, we were interested to know what types of research WSSA members are engaged in and to determine what subject matter and funding sources were prominent within the discipline by polling our colleagues. The WSSA Research and Competitive Grants committee conducted a member survey in the summer of 2007 to gather information about the research and funding priorities of the membership. The survey was designed to probe two fundamental issues for WSSA members: 1) what types of research are perceived to be most critical for advancing weed science and management, and 2) how will weed scientists fund the basic and applied science needed to develop the next generation of weed management tactics and provide advanced training and education for graduate students?

Materials and Methods

Survey Design. The WSSA Research and Competitive Grants committee designed the Research and Funding Survey in spring of 2007, and implemented it using commercial online survey software.[1] The WSSA Research and Funding Survey was posted online at www.surveymonkey.com between July 10 and August 21, 2007, with the goal of obtaining a representative sample of the WSSA membership. An initial invitation to participate in the survey was sent out to all members 2 wk in advance of posting the survey, and two follow up messages were sent during the posting interval to solicit further responses. Our target for the number of survey respondents was 298 out of 1,330 members, the number required to attain a 5% margin of error at a 95% confidence level ($\alpha = 0.05$). The margin of error of a survey is equal to the half width of the $1 - \alpha$ confidence interval of sample proportions, C_p, obtained as the product of cumulative normal probability, Z_α, and the standard error of sample proportions, $[p(1 - p)/n]^{0.5}$. In this case, because the desired response level was greater than 10% of the total WSSA membership, the margin of error calculation also included a finite population correction, $[(N - n)/(N - 1)]^{0.5}$ (Rea and Parker 1997) to yield

$$C_p = \pm Z_\alpha \sqrt{\frac{p(1-p)}{n}} \sqrt{\frac{N-n}{N-1}} \qquad [1]$$

where n is the sample size, p is the response proportion (often set at 0.50 when determining maximum allowable error), and N is the total WSSA membership size. To determine the necessary sampling level to arrive at a 5% margin of error, we used Equation 2, obtained by solving Equation 1 for sample size n (Rea and Parker 1997):

$$n = \frac{Z_\alpha^2[p(1-p)]N}{Z_\alpha^2[p(1-p)] + (N-1)C_p^2} \qquad [2]$$

The survey consisted of 29 multiple choice and short answer questions divided into three major sections: demographic data, research priorities, and funding outlook (see online-only appendix for survey questions). Demographic questions covered educational background, length of service as a science professional, primary focus of appointment, institution type, and location, among other details. Members were surveyed on their research priorities, using the categories listed in Hall et al. (2000) as a starting point. Respondents were asked to list their top two priorities for work performed for their primary stakeholders, research expertise sought in collaborators, and research expertise sought in new hires. The funding section of the survey included questions on primary funding sources and funding levels.

Statistical Analysis. The results presented in this article consist largely of binned response proportions to multiple-choice questions. To understand how demographic information about the respondents was related to their answers, we used two-way contingency tables (Gotelli and Ellison 2004), implemented in the TWOWAY subroutine of SYSTAT 11.0.[2] For each demographic variable (i.e., institution type, area of expertise, etc.), we created dummy variables to extract information about subgroups. Analyses of subgroups were conducted only if tests of the unpartitioned demographic variables were significant at $P < 0.05$.

Results and Discussion

There were 304 responses to the survey, out of a total WSSA membership of 1,330 in the summer of 2007, for an overall response rate of 23%, which exceeded our original target. Data on institutional affiliation, however, revealed that our survey sample was not representative of the WSSA membership as a whole: employees of academic and government institutions were overrepresented by 9 and 6%, respectively, in the survey, whereas industry employees were underrepresented by 16% ($\chi_3^2 = 32.7$, $P < 0.001$). Therefore, inferences from the results of this survey are limited to what amounted to a convenience sample rather than a simple random sample (Rea and Parker 1997). Because our sample represented a considerable proportion of the WSSA membership, however, we believe the results are still instructive.

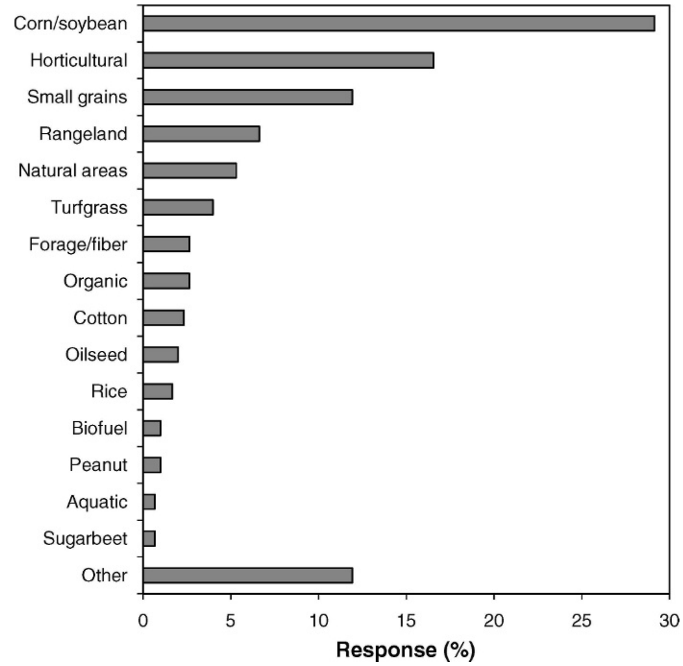

Figure 1. Primary study systems of survey respondents.

Demographic Profile of Respondents. Respondents to the survey spanned a wide range in experience as principal investigators, with the largest proportion (42%) having been a primary investigator (PI) for over 20 yr, 28% having been PIs for 10 to 20 yr, and 30% of PIs having less than 10 yr of experience. There was also considerable disciplinary diversity among respondents. Although more than 50% of the respondents were trained as weed scientists, others were trained in a wide variety of disciplines, including agronomy, ecology, genetics, molecular biology, plant physiology, chemistry, soil science, entomology, forestry, plant pathology, plant breeding, botany, zoology, horticulture, agribusiness, biochemistry, and many others. In addition to belonging to WSSA, respondents reported affiliations with 56 other professional societies spanning the globe. Over 50% were employed as academics; the majority of the remainder was split between industry (22%) and government (19%), with a smaller proportion in regulatory (1%), consulting (3%), and a variety of small businesses (3%). Most respondents identified research (59%), outreach (22%), or teaching (5%) as the majority of their appointment. The remaining 14% had primary appointments that included policy, consulting, administration, technical work, global information system (GIS), business, and inspection, among others. Respondents

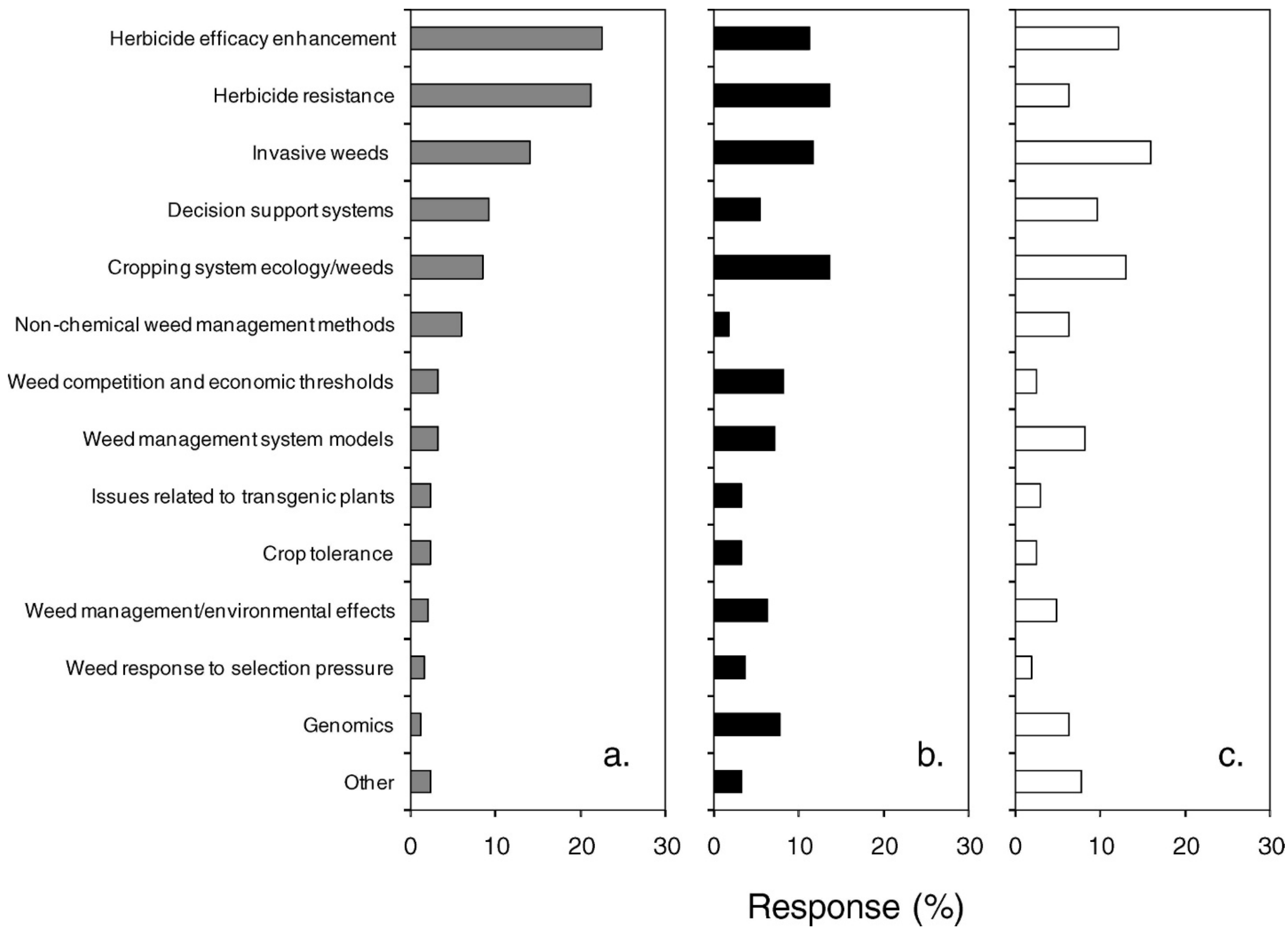

Figure 2. Top areas of research identified by respondents with respect to (a) their primary stakeholders, (b) whom they seek as collaborators, and (c) whom they choose to hire.

worked in a wide variety of management systems (Figure 1), with over 30 different systems reported in the survey.

Over the past 5 yr, 55% of the institutions represented in this survey maintained the same number of weed science full time employees (FTEs), 10% increased the number of weed scientists, while 35% decreased the number of weed science FTEs. For those respondents training graduate students, 55% said that they were training fewer weed science graduate students compared to 10 yr ago. Lack of funds and career opportunities for new graduates were cited as top reasons for this change. Another possibility is that graduate students working on weed science related issues are receiving training in other departments, by those who may not identify themselves as weed scientists. For example, at Pennsylvania State University, two-thirds of the students working on weed ecology and management problems are pursuing their degree in an interdisciplinary graduate program in ecology. Therefore, the perceived reduction in weed science graduate students may signify a broadening of the research skill-set among students studying weedy plant ecology and management, rather than a reduction in the number of future qualified "weed scientists," narrowly defined.

The top three hiring opportunities perceived by respondents were industry (42%), academia (25%), and government (14%). These numbers are roughly in proportion to the current distribution of employer institutional types among survey respondents.

Research Priorities of Survey Respondents. Research is a central activity for WSSA, with nearly 60% of respondents having research as the primary aspect of their appointment (hereafter referred to as "researchers"). Those respondents who publish do so at a steady, moderate rate: 56% of respondents had between 16 and 30 publications in the last 5 yr, 35% had between 1 and 15 publications, and 5% had more than 30 publications.

There was a difference in academic backgrounds associated with different PI experience levels ($\chi^2_{45} = 49.5$, P = 0.30). Respondents with less than 10 yr of experience as a PI were more likely to have been trained as weed scientists (68%) than in some other discipline ($\chi^2_1 = 12.2$, $P < 0.001$). Those respondents with more than 10 yr of experience as a PI were more than twice as likely to have been trained in other disciplines, including agronomy (33% in the $>$ 10 group compared to 16% in the $<$ 10 group), ecology (10% in the $>$ 10 group compared to 0% in the $<$ 10 group) and plant pathology (22% in the $>$ 10 group compared to 3% in the $<$ 10 group) ($\chi^2_1 = 9.93$, P = 0.002). Differences in training were not linked to differences in funding sources or funding levels ($\chi^2_{90} = 106.72$, P = 0.11).

If the differences in academic backgrounds described above had been associated with a breakpoint in PI experience levels of 30 or 40 yr, one possible explanation for more newer scientists being trained primarily as weed scientists might have been the prior scarcity of such programs. However, since the

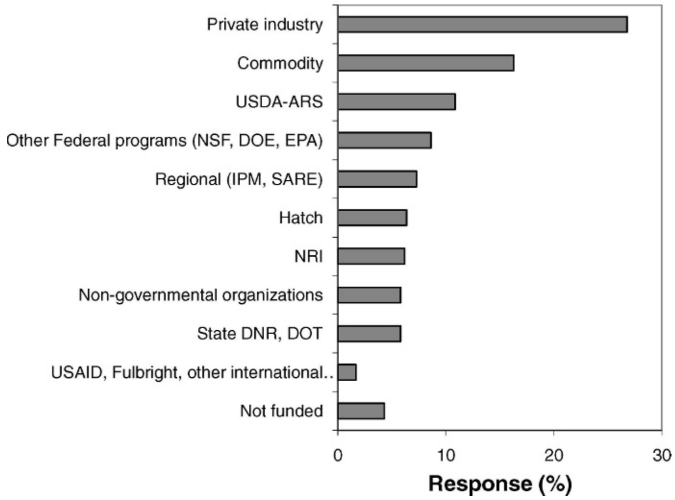

Figure 3. Primary funding sources of survey respondents.

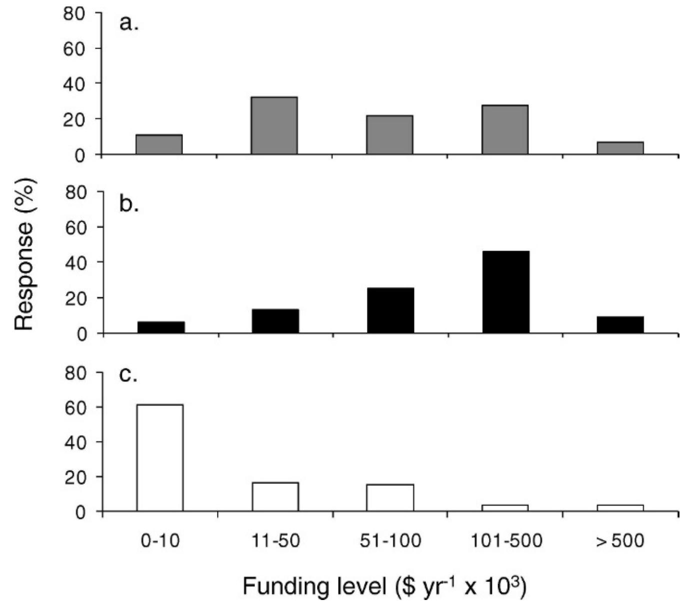

Figure 4. Funding status of survey respondents. Panels represent (a) size of award from top source of funding, (b) overall funding level (base and extramural), and (c) size of shortfall.

1970s, there have been weed science programs located at most of the land grant universities. Another possible explanation may be that younger scientists not trained in traditional weed science, but who nevertheless work on weeds or invasive plants, might be less likely to be members of WSSA so that our younger scientists do not represent a random sample of weed scientists. For example, the students of one survey respondent work on weeds and consider themselves weed scientists and applied ecologists, but consider WSSA too applied and agricultural for their tastes, gravitating instead to more ecological organizations. Reaching out to such early career scientists may be a promising avenue for increasing both WSSA membership and a diversity of skills within the organization.

Research performed by respondents for their primary stakeholders (Figure 2) was heavily dominated by studies of herbicide efficacy (22%) and herbicide resistance (21%). Next in importance were invasive plants (14%), decision support systems (9%), and cropping system ecology and weed/crop ecology (8%). Academic preparation was tightly linked to research priorities ($\chi^2_{130} = 176.51$, P = 0.004). Over 75% of the respondents working on herbicide efficacy and herbicide resistance were trained as weed scientists and agronomists; other research priorities were more evenly spread across disciplinary lines. Research priorities were also related to the nature of the respondent's institution ($\chi^2_{39} = 100.20$, $P < 0.001$), with industry employees focusing on herbicide efficacy and resistance work, and academic and government researchers more likely to cover ecological relationships between crops and weeds, invasive species, and integrated or non-chemical weed management.

Respondents who worked for industry were more likely ($\chi^2_3 = 8.71$, $P < 0.05$) to collaborate with, and to make new hires of, those with the same research priorities (40% of respondents) than were respondents affiliated with academic (25%) or government (15%) institutions. This difference may be due to the greater preponderance of set tasks to be performed in industrial settings, requiring many scientists with a specific type of training and research focus, compared to academic and government settings where the emphasis is on diversity of expertise, and where scientists largely set their own research agendas.

Other important research areas that were not listed in the survey but were identified by survey respondents included, in order of decreasing frequency, 1) herbicide discovery, 2) integrated weed management, 3) site specific management, 4) herbicide fate, 5) weed management in organic systems, 6) biocontrol, 7) weed seed biology, 8) basic weed biology and ecology, 9) biofuels, 10) drift management, 11) social aspects of weed management, 12) weed physiology, 13) weed evolution, 14) weed community shifts, 15) global change and invasive species, and 16) allelopathy.

Most respondents reported having significant stakeholder impact. Industry affiliates were more likely (80%; $\chi^2_1 = 10.58$, P = 0.001) than nonindustry respondents (50%) to have developed a patented product that had been widely adopted. Those who had impact from technology transfer were more likely (64%; $\chi^2_1 = 17.79$, $P < 0.001$) to have made management recommendations that had been widely adopted than those who did not have substantial technology transfer (31%). Of respondents who had been PIs more than 10 yr, 80% had made widely adopted recommendations compared to 60% of those who had less than 10 yr experience ($\chi^2_1 = 6.07$, P = 0.014).

Current Funding Sources of Respondents. Commercial organizations (private industry and commodity groups) were the primary source of funding for most (43%) of the respondents (Figure 3). Publicly funded extramural grant programs were the primary source of funding for 35% of respondents. State and federal governments accounted for 17% of primary funding sources. More than 60% of respondents' awards from their top sources were less than \$100,000 yr^{-1}; however, overall funding levels (including both extra- and intramural funding) for 55% of respondents were between \$100,000 and \$500,000 yr^{-1} (Figure 4). This indicates that respondents had either relatively widespread success in obtaining funds from multiple sources, substantial base funding, or both. Although 65% of respondents said that their activities were in some way affected by shortfalls in funding, funding shortfalls were comparatively modest, with over 60% of respondents reporting shortfalls of less than

$10,000 yr^{-1}$. This level of funding discrepancy is well within the reach of many extramural funding sources.

Duration of respondents' experience as PIs was not related to top funding source ($\chi^2_{45} = 49.5$, P = 0.30), award size from top source ($\chi^2_{20} = 20.9$, P = 0.40), overall funding level ($\chi^2_{20} = 26.8$, P = 0.14) or shortfall in funds ($\chi^2_{16} = 8.53$, P = 0.93). However, scientists working at the basic science and implementation end of the research continuum (hereafter referred to as "BI scientists") had different top funding sources than those working at the implementation and maintenance end of the research continuum (hereafter referred to as "IM scientists") ($\chi^2_9 = 21.3$, P = 0.01). Among BI scientists, 47% obtained most of their funding from federal sources ($\chi^2_1 = 12.5$, P < 0.001), whereas IM scientists obtained 60% of their funding from private sources ($\chi^2_1 = 5.8$, P = 0.016). BI scientists brought in larger awards from their top extramural sources ($\chi^2_5 = 12.34$, P = 0.03), with 53% of their awards greater than $50,000 yr^{-1}$, whereas 68% of IM scientists' extramural awards were less than $50,000 yr^{-1}$ ($\chi^2_1 = 5.60$, P = 0.018). Overall funding level, however, did not differ between BI and IM scientists ($\chi^2_5 = 6.47$, P = 0.263), presumably because IM scientists brought in a larger number of small grants or had greater base funding from their institutions. Funding shortfalls also did not differ between BI and IM scientists ($\chi^2_4 = 5.84$, P = 0.211).

Principal investigators affiliated with different institutional types pursued different funding sources ($\chi^2_{27} = 103.5$, P < 0.001). At opposite extremes, respondents working for industry obtained 89% of their funds from private sources ($\chi^2_1 = 21.2$, P = 0.009), whereas government employees obtained 75% of their funding from U.S. federal government sources ($\chi^2_1 = 18.7$, P < 0.001). Academics were evenly split in obtaining funds from private and public sources ($\chi^2_1 = 0.004$, P = 0.95), and within public sources of funding, were evenly split between federal and state dollars ($\chi^2_1 = 2.46$, P = 0.12). Respondents affiliated with industry were more likely (25%; $\chi^2_4 = 11.19$, P = 0.025) than nonindustry respondents (4.3%) to have research funding shortfalls of more than $100,000, perhaps representing oscillations associated with the business cycle.

Those working in field crop research were more likely to be funded by private sources than public sources ($\chi^2_9 = 25.58$, P = 0.002), whereas rangeland and natural areas research was more likely to be funded by federal sources ($\chi^2_9 = 19.87$, P = 0.019). Award size, overall funding levels, and size of shortfalls were not related to primary study system of the PI ($\chi^2_{45} = 42.13$, P = 0.59).

Moving beyond Disciplinary Boundaries. Several important points emerge from this survey of the WSSA membership. First, the society continues to have a large proportion of its membership engaged in herbicide efficacy research, with 43% of respondents indicating that their primary research concerned herbicide efficacy, herbicide resistance, or both. This result is not entirely surprising, considering the history of weed science as a discipline, and highlights a disciplinary strength in chemically-based weed management within the WSSA. Also not surprising is the finding that the majority of those respondents that identify herbicide efficacy and/or resistance as their primary research focus were trained as traditional weed scientists and continue to rely on industry financial support as the single largest source of funds to drive their weed science research programs. The survey was not intended to obtain information from non-WSSA members, but it is reasonable to infer that those scientists with weed science training and interests in herbicide efficacy would find value in WSSA membership and thus gravitate to the society.

Although unsurprising, these results are also troubling because they suggest that a significant portion of the WSSA membership may be overlooking opportunities (or be overlooked by others when opportunities arise) to engage in critical multidisciplinary research dealing with complex environmental challenges such as invasive species and ecological restoration. In addressing such challenges, expertise on the practical aspects of herbicides and applied weed management would be invaluable. Yet a persistent cultural divide appears to separate agronomists and ecologists. Weed scientists working on weed management in agricultural systems have much to contribute to invasive species research, as they have been dealing with many of the same issues that are currently challenging land managers interested in controlling invasive plants (Smith et al. 2006), but are rarely called upon to offer such contributions (see, for instance, Catford et al. 2009). We therefore challenge the more traditional weed scientists within the society to identify opportunities to contribute their expertise in herbicides to a broader array of environmental issues, such as invasive species management, in which significant funding opportunities exist or are emerging.

This argument is equally true for weed scientists with interests in the genetics, molecular biology, and physiology of weedy traits. Many nonweed scientists are making important contributions to the understanding of traits such as seed dormancy, perennial growth, response to competition, acquisition of resources, genetic adaptability, and plant communication with other organisms. These subjects are generally investigated with a nod toward potential weed implications, but without the insight that could be provided by an experienced weed scientist. We would also challenge weed scientists to investigate potential collaborations in these areas.

In addition to the finding that WSSA members predominantly engage in herbicide efficacy research, there appears to be something of a bimodality to the society, in that a significant percentage of WSSA members report having research priorities that do not rely exclusively on herbicides. Thus, a large proportion of the society is already quite broadly focused. We see this as a positive attribute of our society and see an increasing need for research collaborations, including those with an applied plant science background who are broadly trained and focused. These broadly-trained members can contribute expertise not just in chemical control of weeds, but also in non-chemical and cultural approaches to agricultural weed and nonagricultural vegetation management and restoration. We are also certain that the training/mentoring and support needed to drive our society toward more interdisciplinary approaches to problem solving requires a more diversified research and education portfolio.

As we have tried to point out throughout this paper, the current environmental challenges we face require a different kind of individual to come into our graduate programs and faculties. Subject matter expertise, narrowly defined, must be complemented with an ability and willingness to engage in more multidimensional problem solving. Of course, all of this comes down to funding, for funding influences research priorities and the ability and willingness to engage in research outside of one's disciplinary specialty. Thus, being aware of some of the less traditional funding opportunities available to weed scientists, broadly defined, may encourage a greater proportion of the WSSA membership to actively broaden their research horizons. Conversely, we as a society are not limited to pursuing available funding sources. In fact, there is often significant opportunity to influence the direction of funding; however, this requires that our membership be more proactive in talking with granting agencies and managers than currently appears to be the case. The USDA CSREES-National Research Initiative (NRI) (now AFRI, Agriculture and Food Research Initiative) program provides an example of how funding opportunities available to researchers with expertise in weed control and management may be overlooked or underappreciated when we fail to step outside of our disciplinary box. Although this program only funds U.S. scientists, we believe it may also have relevance outside of the United States.

USDA CSREES-NRI as a Case Study for Extramural Funding. For many years, the USDA CSREES-NRI Competitive Grants Program has been an important source of extramural funds for weed scientists in the United States. There has been some concern in the weed science community in recent years (Davis 2007; Shaw 2005) that changes in NRI grant panel 51.9, among them its being renamed "Biology of Weedy and Invasive Species in Agroecosystems" from "Biology of Weedy and Invasive Plants," may limit its importance to weed scientists. Concerns include a) widening the scope of the program to include non-plant taxa and non-crop ecosystems; b) focusing on the population level of organization and above, to the exclusion of basic biology at lower levels of organization that may be necessary to drive further innovation in weed management; and c) the perception that management-oriented proposals are not supported by the program. To determine the current relationship of the WSSA membership to the NRI grants program, we included a number of questions on the survey related to program participation.

Only 17% of respondents applied to NRI regularly; of the respondents who did not apply regularly, 43% said that the program's priorities did not overlap with their own. This is an unfortunate perception problem for the NRI program, as the request for proposals continues to be written with agricultural weed scientists in mind, a large proportion of the funded grants in any 1 yr go to agricultural weed science, and panel managers are often drawn from within the ranks of WSSA (Bowers 2008, personal communication). During the past 5 yr, four of five panel managers were active members of WSSA.

Ten percent of respondents had written a successful NRI grant in the past 5 yr. Among those who had been funded, the top three project topics were a) ecological relationships between crops and weeds, b) invasive species, and c) nonchemical weed management. Investigator experience was not related to NRI application rate ($\chi^2_4 = 3.6$, P = 0.46) or success ($\chi^2_4 = 1.9$, P = 0.75), and BI and IM scientists were equally (un)likely to apply to the program ($\chi^2_1 = 1.94$, P = 0.164). However, BI scientists were more than 5.5 times more likely to have had a successful grant application within the past 5 yr ($\chi^2_1 = 7.718$, P = 0.005). This discrepancy highlights an important opportunity for synergy between BI and IM scientists. Program 51.9 in AFRI now requires that all proposals be integrated projects, which were consistently undercompeted in previous competitions (Bowers 2009, personal communication). Integrated projects are expressly designed to bridge research and outreach and have routinely been awarded to research teams that span this continuum. This stringent requirement may, however, exclude basic science investigations necessary to develop future weed management tactics if there is no immediate management connection.

Funding Outlook. As we stated earlier in the paper, it is important to recognize that our discipline is evolving and that our skill-set must increasingly include systems-approaches to problem solving. This point was borne out by several invited speakers at a recent Northeast Weed Science Society symposium on the emerging bioeconomy and an associated discussion of where weed scientists fit (NEWSS 2009). The following question was put to three of the preeminent invited speakers: "What are the elements of a graduate training program for the next generation of scientists?" The words used to describe the capacity of the next generation of scientists included research that addresses a multifunctional agriculture, integrates fundamental experiments with modeling, accounts for space-time dynamics, includes many disciplines, includes the human element, and respects scale and landscape mosaics. In short, these speakers reaffirmed what we began this paper stating, that the new generation of scientists needs to be prepared as systems thinkers with practical experience, and with experimental and quantitative training that enables one to conduct such research. An increased commitment to basic understanding of complex issues in vegetation management will require interactions between scientists at many levels of scale, from molecule to ecosystem.

We are encouraged to see that in addition to the AFRI program, many other regional and national competitively funded programs are funding systems research. A traditionally trained weed scientist might argue that these are not exclusive weed science programs; this is true, and is a vital point in crafting competitive applications to such programs. Since integrated programs require a meaningful outreach or education component, WSSA BI and IM scientists who form teams comprising complementary skill sets with scientists in relevant related disciplines will strengthen their chance of competing successfully for these funds. For those seeking public funds to support research underway in their lab and field programs, it is essential that they be aware of the portfolio of opportunities currently available. Those conducting a mix of applied and basic work are in a position to pursue regional IPM funds. Historically, weed scientists have received disproportionately fewer IPM funds than other pest management disciplines. There was a time where panels were biased in favor of funding entomology and plant pathology projects; however, that time has passed. In fact over the past 10 yr, regional and national IPM competitive grant programs placed a higher priority on weed science research, broadly defined, and more weed science work was funded. Ironically, in recent years, regional and national IPM panels have received very few proposals from weed scientists, and the lack of submissions has resulted in fewer weed science projects being funded. National competitive IPM funds are also available annually through the Crops at Risk (CAR) and Risk Avoidance Mitigation (RAMP) Programs. Both programs fund large projects that often involve multistate collaborations. While weed science proposals have been funded through this program, here again, weed science applications have been modest at best (Mortensen, personal communication, recent past chair of these two programs).

The reality of many pest management problems in the field is that the level of complexity requires multidisciplinary teams to develop effective solutions. Weed scientists who develop strong collaborations across disciplines (as opposed to those who write proposals from a weed science perspective and make nominal references to other disciplines) are more likely to successfully compete for funds from interdisciplinary funding sources. For example, the USDA Biotechnology Risk Assessment Grants (BRAG) program addresses risks and benefits of genetically modified crops. Given the widespread adoption of GM herbicide-tolerant crops and the increasing problem of herbicide resistant weeds, this program is ideally suited to support weed science research. Weed scientists involved in sustainable agriculture and organic research and outreach can pursue support from the regional Sustainable Agriculture Research and Extension (SARE) program or the USDA Organic Transitions program. Also, while non-WSSA member scientists have crossed over and now receive support from the NRI for invasive plants research, there is no reason why WSSA member weed scientists based in the United States can't cross over in the opposite direction into more basic funding sources like the Population Biology section of the National Science Foundation.

In closing, our scientific society is engaged in two kinds of research, privately funded herbicide performance implementation and maintenance research, and publicly funded research with a stronger systems orientation. Given that our society is approximately split between industry on one hand and publicly funded scientists and outreach educators on the other, these two approaches are not surprising. It is our view that to answer the call to address increasingly complex interdisciplinary problems involving pest management, invasive plant ecology and management, and production systems that include an emerging bioeconomy, our society will need to continue to evolve to include more systems-scientists. The WSSA Research Committee realizes that traditional weed science research will continue to underpin our society; however, we are also certain that a concerted move toward embracing multidisciplinary, systems-oriented research and education and associated funding opportunities will be necessary in order for our society members to address the complex environmental challenges of today, and the emerging questions of tomorrow.

Our survey indicates that what most imperils a vibrant future for the Weed Science Society of America is the inability to see beyond a narrowly-defined vision that continues to center on herbicide efficacy and fate. While it is certainly true that expertise in integrated weed management is an essential cornerstone in our discipline, it is important that we not put all our eggs in one basket. Let's not paint ourselves into the ''herbicide efficacy'' box while others outside our discipline choose to engage in the messier, more complex problems of systems-level vegetation management.

Sources of Materials

[1] Professional-level access, www.SurveyMonkey.com.

[2] SYSTAT Software, Inc., 225 W Washington St., Suite 425, Chicago, IL 60606.

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Online Appendix. WSSA Research and Competitive Grants Survey Questions:

I. Background

1. In which discipline did you receive your terminal degree?

A. Weed Science
B. Agronomy
C. Ecology
D. Plant Physiology
E. Genetics/Molecular Biology
F. Soil Science
G. Chemistry
H. Entomology
I. Forestry

J. Plant Pathology
K. Plant breeding
L. Other

2. What category best describes the institution you work for?

A. Industry
B. Academia
C. Government
D. Regulatory
E. Consulting
F. Other

3. Which type of activity best describes the majority of your appointment?

A. Research
B. Teaching
C. Technology Transfer/Extension
D. Policy
E. Consulting
F. Other

4. How many years have you been doing research as a principal investigator?

A. 1–5
B. 6–10
C. 10–15
D. 15–20
E. $>$ 20
F. Not applicable

5. Where are you located?

A. Eastern United States
B. Central United States
C. Western United States
D. Southern United States
E. Canada
F. Latin America
G. Europe
H. Australia
I. Africa
J. Asia
K. Middle East
L. Other

6. What is the primary management system that you work in?

A. Corn/soybean
B. Small grains
C. Forage/fiber
D. Horticultural
E. Oilseed
F. Organic/low-external input
G. Biofuel
H. Ornamental
I. Rangeland
J. Aquatic
K. Forest
L. Other

7. Which of the following professional societies do you belong to? (Pick as many as apply.)

A. WSSA
B. NCWSS
C. NEWSS
D. WSWS
E. SWSS
F. IWSS
G. EWRS
H. ESA (ecology)
I. ESA (entomology)
J. ASA / CSSA / SSSA
K. ASPB
L. ACS
M. Other

II. Priorities for Research and Education

Use research areas in Table 1 to answer questions 8, 9, and 11 in Section II.

Table 1. WSSA Priority Research Areas (Hall et al. 2000. Weed Technol. 14:647–658).

A.	Knowledge-based decision support strategies
B.	Weed response to selection pressure
C.	Ecological relationships between cropping systems and weeds
D.	Weed competition and economic thresholds
E.	Invasive weeds
F.	Genomics
G.	Herbicide efficacy enhancement
H.	Non-chemical weed management methods
I.	Weed management system models
J.	Herbicide resistance
K.	Issues related to transgenic plants
L.	Crop tolerance
M.	Effects of weeds and weed management on environment
N.	Neutraceuticals
O.	Phytoremediation
P.	Other

8. Rank the top three research areas in the following list (WSSA Priority Research Areas, Hall et al. 2000. Weed Technol. 14:647–658) that you believe will be most pressing 5 yr from now for your primary clientele.

9. Rank the top three research areas from Table 1, in order of decreasing importance, that you will look for in potential collaborators to complement your research skills for the next 5 yr. (If "Other," please give one- to three-word title below.)

10. In your department/unit/research group, the number of weed science FTEs in the past 5 yr has:

A. Decreased
B. Increased
C. Remained the same

11. For FTEs that were added, list from Table 1 the top three research areas that describe responsibilities of those positions. (If "Other," please give one- to three-word title below.)

12. Compared to 10 yr ago, how many graduate students are you training?

A. More
B. Less
C. Same
D. Not relevant to my program.

13. If more or less (from Q12), rank below the factors contributing to this change:

A. MS/PhD-level job availability/career opportunities
B. Funding availability
C. Institutional priorities
D. Qualified applicant pool
E. Change in my priorities
F. Not applicable

14. If you train graduate students or postdocs, what category best describes the institutional type that will hire those individuals in the near future?

A. Industry
B. Academia
C. Government
D. Regulatory
E. Consulting
F. Not applicable

III. Funding

15. Have reductions in funding limited your ability to pursue high priority research topics?

A. Yes
B. No

16. Rank the top three sources of funding from the following list in order of decreasing importance to your research program:

A. Commodity
B. NRI
C. Private industry
D. Regional (IPM, SARE)
E. Hatch
F. USDA-ARS
G. NGO
H. Other Federal programs (NSF, DOE, EPA)
I. USAID, Fulbright, other international grant programs
J. State DNR, DOT
K. Not funded

17. What size award did you get from your top source of funding over the past 5 yr?

A. ≤ $10 K/yr
B. ≤ $50 K/yr
C. ≤ $100 K/yr
D. ≤ $500 K/yr
E. > $500 K/yr

18. What is a realistic level of funding (both internal and external) that you hope to achieve for your program?

A. ≤ $10 K/yr
B. ≤ $50 K/yr
C. ≤ $100 K/yr
D. ≤ $500 K/yr
E. > $500 K/yr

19. How has the rise in importance of invasive species biology and management as a federal funding priority affected your research program? (Select all that apply.)

A. Increased activity
B. Increased funding
C. Decreased activity
D. Decreased funding
E. No effect

20. Do you regularly (at least every 3 yr) apply to NRI 51.9 (Biology of Weedy and Invasive Species)?

A. Yes
B. No

21. If the answer to #20 was ''no'', please explain why:

A. Program priorities don't overlap with my research.
B. The application process takes too much time.
C. I haven't had a successful grant in so long that I've gotten frustrated.
D. My research doesn't require funding at this level.
E. Other (write in below).

22. Have you had a successful grant with 51.9 in the past 5 yr?

A. Yes
B. No

23. If your answer to Q22 was ''yes,'' what was the general research area that your proposal addressed (choose from Table 1)? (If ''Other,'' please give one- to three-word topic below.)

IV. Relevance and Impact

24. How much end-user demand is there for the primary focus of your program?

A. High level of demand, with vocal support
B. Moderate demand
C. Little immediate demand, basic research targeted towards future needs

25. Have any of your studies led directly to technologies that have been implemented and/or marketed (and directly attributable to you)?

A. Yes
B. No

26. If you answered yes to Q25, what was the most important factor in bringing these technologies to the marketplace?

A. Consumer demand
B. Right place / right time
C. Industry partner
D. Advances in other areas of science
E. Other
F. Not applicable

27. Have any of your studies led directly to widely adopted management recommendations?

A. Yes
B. No

28. If so, what was the most important factor in widespread adoption?

A. Strong producer organizations / information networks
B. Novel concept with large effect on crop/weed relations

C. Tireless extension efforts
D. Regulation requiring a change from the status quo
E. Recommended practice led to higher profits
F. Other
G. Not applicable

29. How many peer-reviewed publications have you had in the past 5 yr?

A. $\leq$ 5
B. $\leq$ 15
C. $\leq$ 30
D. $\leq$ 50

30. What proportion of your manuscripts do you send first to either Weed Science or Weed Technology?

A. $<$ 20%
B. $<$ 40%
C. $<$ 60%
D. $<$ 80%
E. $\leq$ 100%