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Education/Extension

Assessing and Visualizing Agricultural Management Practices: A Multivariable Hands-On Approach for Education and Extension

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Agroecosystems are inherently complex, and practices aimed at managing one component of the system can have unintended consequences for other components of the system. Management decisions, therefore, can be improved by assessing and understanding the multivariate nature of agricultural systems and the multifunctional character of particular agricultural management practices. The act of simultaneously assessing and evaluating multiple characteristics or functions in agriculture also can be a valuable education and extension activity, because it draws on active and experiential methods of learning and because the process effectively reveals important functions and tradeoffs associated with agroecosystems and their management. Here we introduce a tool (the spider plot) and present a case-study exercise in which we used this tool to evaluate the multiple characteristics and functions of different cover crops within a field day workshop format. We also provide examples of how this approach could be used to assess other management practices or properties of agroecosystems and communicate multivariate concepts within a weed science classroom or extension environment.
Key words: Active learning, cover crops, ecosystem services, multivariate, multifunctional, participatory, spider plots.

Los agro-ecosistemas son intrínsicamente complejos y las prácticas enfocadas al manejo de uno de los componentes del sistema pueden tener consecuencias no intencionadas en otros de los componentes. Por lo tanto, las decisiones de manejo, pueden ser mejoradas mediante la evaluación y comprensión de la naturaleza multi-variable de los sistemas agrícolas y el carácter multifuncional de prácticas específicas de manejo agrícola. El acto de medir y evaluar simultáneamente las múltiples características o funciones en la agricultura puede también ser una valiosa actividad educativa y de extensión, ya que se deriva de métodos activos y experienciales de aprendizaje y debido a que el proceso revela efectivamente funciones importantes, así como también, ventajas y desventajas asociadas con los agro-ecosistemas y sus manejos. Aquí presentamos una herramienta (gráfica de araña) y un ejercicio de estudio de caso en el cual usamos esta herramienta para evaluar las múltiples características y funciones de los diferentes cultivos de cobertura, en el formato de un taller-día de campo. También proporcionamos ejemplos de cómo este enfoque puede usarse para evaluar otras prácticas de manejo o propiedades de agro-ecosistemas y para comunicar conceptos multi-variables en una clase de ciencias de la maleza o en un escenario de extensión.

Weed scientists and extension educators alike recognize that agricultural systems are complex and that individual components of and practices used in cropping systems (crops, weeds, and associated management practices) can be multifunctional (Kelly et al. 1996; Paul and Robertson 1989; Wilke and Snapp 2008). Individual management practices or components of cropping systems can provide both positive and negative functions, with each representing a suite of tradeoffs in terms of their effects on agroecosystem performance (Kelly et al. 1996; Lu et al. 2003; Nelson et al. 2009; Snapp et al. 2005). For example, in addition to being an effective weed management practice, tillage is useful for preparing the ground for planting and ensuring proper seed placement within the soil. However, tillage also can have negative impacts on soil quality and erosion. Similarly, use of herbicides can reduce weed abundance, but also can contaminate ground and surface waters, reduce diversity of both within and field edge vegetation, and restrict subsequent crop rotations.

Alfalfa (*Medicago sativa* L.) provides an excellent example of a weed suppressive crop that serves multiple functions (both positive and negative) within an agroecosystem. As a crop, the primary function of alfalfa is to provide a nutritious forage and marketable product (i.e., hay). In addition, the alfalfa stand also provides opportunities for nitrogen fixation, soil stabilization, development of soil structure and carbon sequestration, disruption of insect pest and pathogen cycles as part of crop rotation, and provision of habitat and floral resources for beneficial insects (Snapp et al. 2005). A stand of alfalfa also can provide less desirable functions, such as acting as a green bridge or reservoir for crop pathogens, providing over-wintering habitat or alternate hosts for insect pests, depletion of soil moisture available to succeeding crops, and temporary loss of arable land that could be planted to more profitable crops (Hampton and Weber 1983; McGuire et al. 1998; Snapp et al. 2005).

Recognition and assessment of the multivariate nature of and potential tradeoffs associated with particular management practices might not be straightforward due to the need to

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identify and account for multiple variables, some of which can be difficult to measure or might manifest off-site. In some cases, tradeoffs can be more obvious, as in the case of tillage (Lu et al. 2003). In other cases, tradeoffs associated with a particular management practice can be less obvious, such as the widespread application of mineral fertilizer or herbicides to promote crop growth and the consequential downstream (sometimes many hundreds of kilometers away) impacts on water quality (Isensee and Sadeghi 1993). Furthermore, potential tradeoffs might be unknown or in need of further assessment, such as landscape-level impacts associated with widespread adoption of certain genetically-modified crops (Mortensen et al. 2009). In situations where tradeoffs might result in significant negative consequences, the ability to understand and assess the multiple consequences of a particular management practice can lead to the development of strategies that minimize potential subsequent impacts.

Experiential learning activities aimed at identifying, measuring, and simultaneously evaluating multiple agroecosystem characteristics and/or tradeoffs can be the basis for understanding how weed management practices can be implemented to optimize agroecosystem performance and sustainability (Andrews et al. 2002). In contrast to traditional lecture-based approaches, experiential hands-on activities are particularly well-suited to adult learners typical of our classroom and outreach audiences (Knowles 1990; Ota et al. 2006). Such activities place the learner in relational situations where they are able to draw on their diverse experiences, thereby enhancing learning and higher-order thinking (Gallagher et al. 2007; McNeal and D'Avanzo 1997). The objectives of this paper are to: (1) introduce a graphical approach (the spider plot) for assessing and evaluating multiple variables and elucidating potential tradeoffs in agriculture; (2) present a case-study exercise in which spider plots were used to evaluate the multiple characteristics and functions of different cover crops within a workshop format; and (3) provide additional examples of how this approach could be used to assess other properties of agroecosystems (such as different herbicides or soil management practices) and communicate multivariate concepts within a classroom or extension environment.

The Spider Plot: A Graphical Tool for Assessing and Visualizing Multiple Variables

Multivariate concepts inherently are difficult to grasp and communicate to others in a classroom or extension learning environment because learners must consider and evaluate multiple variables simultaneously. Therefore, tools that facilitate the conceptualization, evaluation, and visualization of multiple variables can improve understanding and decision-making capabilities on the part of the learner (Andrews et al. 2002). One particularly useful tool for displaying multivariate data is the spider plot. Spider plots, also known as radar, web, star, flower, and amoeba plots (Chambers et al. 1983; Foley et al. 2005; ten Brink 1991) can be used to illustrate the characteristics or functions of any multivariate system, and provide a visual representation of that system in two dimensions. Spider plots have been used in the environmental and sustainability science literature to illustrate the multiple objectives that can be achieved through participatory plant breeding programs (Weltzien and Christinck 2008), to compare biodiversity indicators across conventional and genetically-modified crops (Firbank et al. 2003), and to illustrate potential for provisioning of multiple ecosystem services under different hypothetical land-use scenarios (Foley et al. 2005). A spider plot also can be a useful graphical tool for representing concepts relevant to crop management and applied weed science.

A spider plot incorporates three or more axes, with each axis representing a particular variable and sharing a common origin. The axes are identical in length and to facilitate visualization, each should be scaled relative to the maximum value attainable for that variable (Chambers et al. 1983). Data are plotted on the axes and the data points are connected with a line. The size and symmetry of the resulting "spider web" indicates the relative magnitude of each variable and the overall performance of the system (with respect to the suite of variables that were measured), respectively.

Spider plot axes can be arranged or represented in ways that aid interpretation. If variables have intrinsic value or desirability, the scaling should reflect this in a logical way. For example, a high score for crop yield is desirable, whereas a high score for weed abundance is not, so the latter variable could be converted to weed suppression, in which a high score is desirable. Similarly, axes can be related to one another in ways that are meaningful, such as by grouping above- and belowground variables (example below).

Figure 1 illustrates these concepts and provides an example of how a spider plot can be used to visualize and compare the response of specific agroecosystem variables to three crop management systems (conventional tillage, conventional no-tillage, and tilled organic). The variable values were taken from five published studies reporting data collected from the W. K. Kellogg Biological Station Long Term Ecological Research project in row-crop agroecology in southwestern Michigan. Variables reported in the studies included corn (*Zea mays* L.) yield and yield variability (Smith et al. 2007); weed abundance (Davis et al. 2005); earthworm abundance (Smith et al. 2008); activity density of granivorous ground beetles (Menalled et al. 2007); and the accumulation rate of carbon in the soil (Grandy and Robertson 2007). We arranged the position of the axes to correspond to aboveground (yield and weed abundance variables) and belowground (soil organism and carbon variables) components. Arranging the axes in this way also helped to illustrate potential trade-offs between management systems. For each variable, we relativized the values by setting the highest reported mean at 100% and converting the other two system's means to a percentage of the maximum reported mean. For example, soil carbon accumulation rate was highest in the no-till system (22 g m^{-2} y^{-1}). The rate of carbon accumulation in the organic system was 41% (12.3 g m^{-2} y^{-1}) lower than the conventional no-tillage systems, and the conventional tillage system did not accumulate carbon (0.0 g m^{-2} y^{-1}). We then plotted the relativized values for each variable on the spider plot axes (Figure 1).

By comparing the spider plots for the three cropping systems, we can see the similarities and differences between

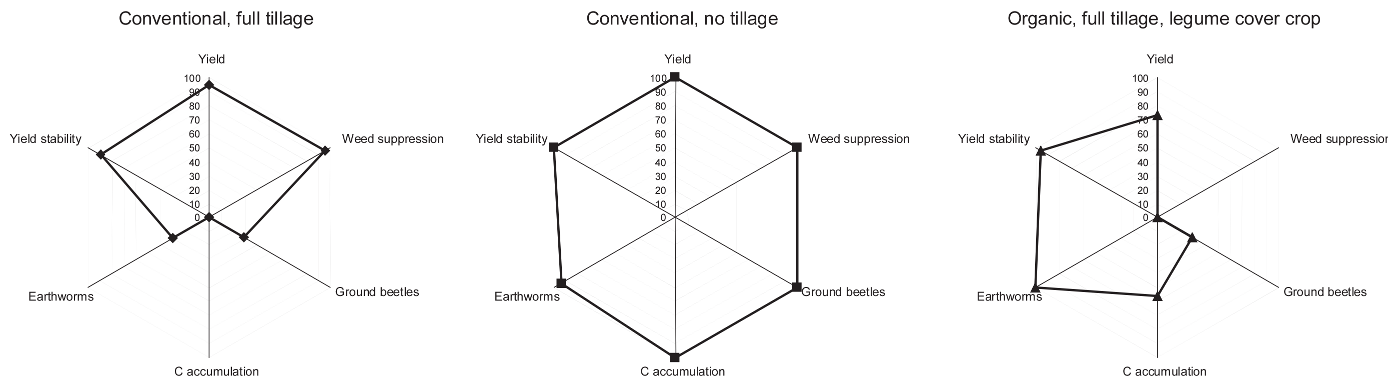

Figure 1. Example showing how spider plots can be used to qualitatively assess and compare the effects of crop management systems on multiple response variables. Data are literature values (relativized by the maximum reported value for each factor) reported from the W. K. Kellogg Biological Station Long Term Ecological Research Project in Agroecology in Hickory Corners, Michigan. Data are corn yield and yield variability (Smith et al. 2007); earthworm abundance (Smith et al. 2008); carbon accumulation (Grandy and Robertson 2007); granivorous ground beetle activity density (Menalled et al. 2007); and weed abundance (Davis et al. 2005). Prior to graphing, corn yield variability and weed abundance data were converted to reflect stability (i.e., highest variability = lowest stability) and suppression, respectively.

the systems for the six variables of interest. For instance, although the conventional tillage and no-tillage systems both have similar values for the aboveground variables related to corn yields and weed abundance, the no-till and organic systems scored higher for soil-related variables, such as earthworm abundance and rate of carbon accumulation (Figure 1). In this case, the spider plots provide a convenient and intuitive way of synthesizing and presenting data from multiple cropping system studies in a way that effectively conveys multivariate concepts and tradeoffs among different management systems that might not be apparent when the variables are examined or reported independently.

Case Study: Comparing the Multifunctionality of Different Cover Crops

We developed a hands-on educational field day workshop activity aimed at illustrating the multifunctionality of different cover crops (and mixtures) planted for weed suppression or soil quality enhancement. The activity was designed to allow participants (farmers, agriculture professionals, and students) the opportunity to collect data and to assess the potential for each cover crop to provide multiple ecosystem services at the farm–field and landscape level. Our primary objective was to demonstrate to the participants that cover crops provide multiple functions within an agroecosystem, beyond just weed suppression or soil quality enhancement, and that tradeoffs exist between different cover crops. A secondary objective of the activity was to provide participants with a visualization tool, the spider plot, which they could use to further conceptualize and assess the multivariate nature of their own cropping systems or extension programs. The cover crops included both spring-sown (buckwheat, *Fagopyrum esculentum* Moench.; yellow mustard, *Sinapis alba* L.; and a mixture of pea, *Pisum sativum* L. and triticale, *Triticale hexaploide* Lart.) and fall-sown (wheat, *Triticum aestivum* L.; and a mixture of cereal rye, *Secale cereale* L. and hairy vetch, *Vicia villosa* Roth.) species. The five cover crops were chosen to (1) represent common cover crops grown for weed suppression and soil quality enhancement in our region (northeastern United States) and (2) reflect the potential for variation in a range of potential functions that might be provided by cover crops in general.

Preparations for the field day, which was held in June 2009 at the Russell E. Larson Agricultural Research Center near Rock Springs, PA, were initiated 9 mo in advance. We planted the fall-sown species in the fall of 2008 and the spring-sown species in May 2009. All cover crops were managed organically. A week before the field day, we conducted multiple dry runs of the activity with student volunteers. The activity involved several hands-on assessments of cover crop functionality. The worksheet and additional instructions and materials necessary for conducting the activity can be found at http://agsci.psu.edu/organic/academic-courses. On the day of the event, participants were divided into groups of three to five people, and each group was assigned to a specific cover crop. From there, groups were instructed to collect data on the following indicators of multifunctionality.

Beneficial Insect Diversity. Our intention with this indicator variable was to demonstrate that cover crops can provide resources (food and refuge) for beneficial insects and spiders (Fiedler et al. 2008). We instructed participants to spend 2 min observing the insects that visited the cover crops. We also installed pitfall (a cup buried in the soil to trap surface dwelling insects) and sticky traps in the cover crop plots several days before the event. Participants were instructed to inspect the traps and record the diversity and abundance of soil-dwelling and aerial insects in or on the traps. We developed a pictorial key of the most common groups of beneficial insects and spiders, and participants used this to identify and obtain totals for the arthropod groups represented in their samples.

Floral Resources. When flowering, cover crops can be an important floral resource for pollinators and other beneficial insects. Quantification of this floral resource allows one to estimate the potential for a cover crop to support pollinators and other beneficial insects that can have positive effects on the agroecosystem. Our intention with this variable was to

Table 1. Cover-crop dry-weight conversion factors used in a field-day exercise to assess the multifunctionality of different cover crop systems. Estimates based on values presented in Sarrantonio (1994).

Cover crop	Dry weight factor
Rye/hairy vetch	0.25
Winter wheat	0.25
Pea/triticale	0.20
Mustard	0.15
Buckwheat	0.15

Table 2. Percent of nitrogen (N) in the tissues of cover crops used in a field-day exercise to assess the multifunctionality of different cover crop systems. Estimates based on values presented in Sarrantonio (1994).

Cover crop	%N (preflowering)	%N (postflowering)
Rye/hairy vetch	3	2
Winter wheat	2.5	1.5
Pea/triticale	4	3
Mustard	3	2
Buckwheat	3	2

demonstrate that the potential for cover crops to provide floral resources will depend on the type of cover crop and the timing of cover crop establishment. We instructed the participants to hold a 0.25 m^2 quadrat at canopy level above a representative area of the cover crop and estimate the proportion of the cover crop canopy within the quadrat that was in flower.

Weed Density. Cover crops can suppress weeds by creating a dense canopy that limits light for weed germination and growth, by competing with weeds for nutrients and water, or by altering the chemistry of the soil (e.g., through allelopathy) and making the environment less suitable for weed growth (Teasdale 1996). Participants were instructed to estimate the density of weeds growing within the cover crop by placing a 0.25 m^2 quadrat in a representative area in the cover crop and counting the number of weeds present (alternatively, we could have visually estimated percent cover of weeds). On the spider plot, we expressed this variable as weed suppression so that low weed densities would correspond to high axis scores. Organizers also might want to consider having the participants determine the number of different weed species present if weed species richness is a variable of interest.

Cover Crop Biomass. A dense cover crop canopy serves several functions within an agroecosystem, including reducing soil erosion and shading out weeds growing in the understory. Canopy biomass also is an indicator of the potential contribution of organic matter to the soil provided by the cover crop. We instructed participants to estimate cover crop canopy biomass by removing the cover crop from a 0.25 m^2 (2.64 ft^{-2}) quadrat. Participants used clippers to remove the cover crop biomass from the same area where weed densities were estimated. Participants placed the biomass in a paper bag and weighed it with a field scale. Participants were then instructed to convert the fresh weight of the sample to dry weight (we used pounds per acre; however, presenters should choose units that are most appropriate to the audience). They did this by multiplying the fresh weight by a dry weight factor specific to each cover crop (Table 1), then dividing this value by the area sampled (in our case 2.64 ft^{-2}), and finally multiplying the value by 43,560 (the number of sample areas within an acre).

Nitrogen Content of Biomass. A potentially important service provided by cover crops is their ability to replenish soils with nutrients necessary for the following crop's development. Leguminous crops (e.g., peas, vetch, clover, alfalfa) fix nitrogen from the atmosphere with the aid of soil bacteria (rhizobia) that live inside their root nodules. Because legumes are able to fix their own nitrogen, their plant tissues have a higher nitrogen content than other cover crops (Fageria et al. 2005; Sarrantonio 1994). Legumes also decompose quickly in the soil, making them suitable green manures prior to the planting of heavy nitrogen feeders such as corn or tomatoes. We instructed participants to estimate the nitrogen inputs to the soil, via incorporation, by multiplying the cover crop biomass (lbs/acre, calculated above) by the percentage of nitrogen in the cover crop (Table 2).

Root Mass. Many of the potential benefits from cover crops come from processes occurring within the rhizosphere. Cover crops with deep, fibrous root systems stabilize and improve soil structure, whereas cover crops with deep tap roots help break up compacted soil and can access nutrients and water deep in the soil profile. As roots develop and turnover in the rhizosphere, they contribute to the organic matter and nutrient accumulation in the soil. In general, increases in cover crop root development drive improvements in soil structure and nutrient retention (see references in Fageria et al. 2005; Snapp et al. 2005). We instructed participants to estimate the root development of the cover crop by weighing a precollected sample of root mass. Ideally, participants would collect soil samples in the field and separate soil from roots themselves. However, because of recent rainfall that occurred at our site, soil conditions required that we conduct this step ahead of time.

Nutrient Retention. When cover crops are plowed under as green manure, soil microorganisms begin decomposing the organic matter. If the crop residues are rich in carbon relative to nitrogen (C : N ratios of 30 or higher), soil microbes tie up plant-available nitrogen in the soil (Nicolardot et al. 2001). Crop residues high in carbon (e.g., grass) also decompose slower than residues high in nitrogen, such as legumes. Consequently the nutrients tied up in a high carbon (high C : N) residue are made less available to the following crop, but also are less vulnerable to leaching (Fageria et al. 2005). A slower decomposition rate of the cover crop also leads to greater accumulation of organic matter in the soil over time. We asked participants to estimate the ability of the cover crop to retain nutrients in the system by using C : N ratios listed in a table (Table 3; Brady and Weil 2002).

Earthworm Density. Earthworms play an important role in the functioning of soils and are considered beneficial organisms in agroecosystems (Smith et al. 2008). Because earthworms both respond to and mediate soil conditions, earthworm densities can be a useful indicator of overall soil quality. In general, agricultural soils rich with earthworms tend to have higher organic matter content, greater porosity (due to earthworm tunneling), and reduced compaction relative to soil with low densities of earthworms (Jongmans et al. 2003). To estimate earthworm density in the soil under

Table 3. Carbon to nitrogen (C : N) ratios of the tissues of cover crops used in a field day exercise to assess the multifunctionality of different cover crops. Values are from Brady and Weil (2002).

Cover crop	C : N
Rye/hairy vetch[a]	30
Winter wheat	80
Pea/triticale[a]	20
Mustard	18
Buckwheat	18

[a] Estimates based on mixture of grass (high C : N) and legume (low C : N) and current vegetative state.

the cover crops, we instructed participants to dig a shovel-full of soil within a representative area of the plot. Participants then carefully inspected the soil, counting the number of earthworms they recovered. An alternative approach for estimating earthworms would be to use a dilute mustard solution, instead of soil extraction, to drive earthworms to the soil surface (Lawrence and Bowers 2002); however, during the initial "dry runs" of the activity we determined that this approach was ineffective.

We chose this specific set of indicator variables because we were interested in the beneficial ecosystem functions that cover crops can provide to agroecosystems. Depending on the goals of the workshop or the needs of the participants, the same activity could be conducted using different variables. Other potential variables of interest might include cost of seed, ease of cover crop termination, winter hardiness, rotational flexibility, potential to act as a pest or disease reservoir, soil compaction, and soil moisture depletion.

Facilitating Data Collection. At the outset of the activity, we provided participants with worksheets that had instructions for quantifying the eight indicator variables, a conversion table relating cover crop dry weights and nutrient values (Tables 1–3), and a table converting estimated indicator values to spider plot axis scores (Table 4), and a blank spider plot (Figure 2). During data collection, participants within each group used their worksheets to record their data, convert the data to spider plot axis scores (using Table 4), and plot their scores on the spider plots. Following completion of the field activity, a representative from each group plotted their group's scores on spider plots printed out on large poster boards. This allowed the participants to see the results for all five cover crop systems and facilitated a discussion among the participants and event organizers regarding the factors that likely contributed to the relative differences between the cover crops for the suite of

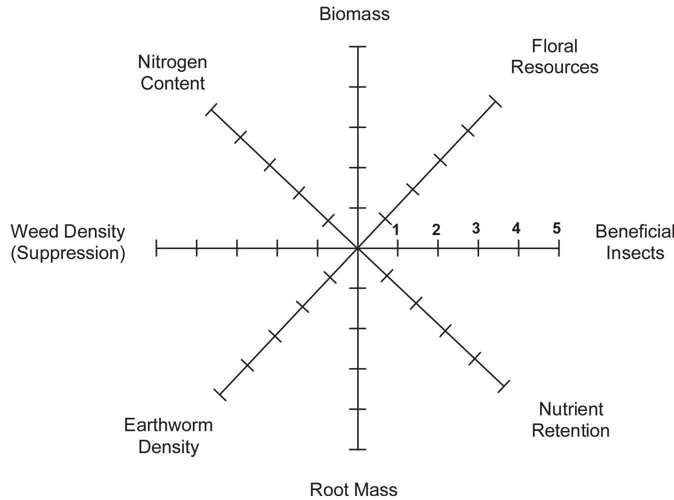

Figure 2. Blank spider plot used to measure and compare multiple indicator variables associated with different cover crops at a field day.

variables that were measured. The discussion also touched on new insights into cover crops that the participants gained from the activity and the ways that participants anticipated incorporating cover crops and spider plot analyses on their own farms. Gareau et al. (2010) provides an overview of other aspects of the activity, as well as additional considerations in general that should be taken into account when developing participatory learning exercises.

To assess how well our activity met our immediate learning objectives, we conducted a postactivity survey. Participants reported that their understanding of the material improved greatly as a result of the workshop. Prior to the activity, 62% of the participants indicated "non-existent" or "minimal" understanding of evaluating cover crop multifunctionality; however, after the activity, 95% of the participants reported "moderate" to "considerable" (the two highest categories) understanding. To assess the longer-term effectiveness of this (or any other experiential learning) activity, facilitators could follow up with activity participants at points in time (i.e., after 6 mo) to gauge the degree to which they actively are using the knowledge or tools that were presented. This not only provides information regarding the longer-term impacts of the learning exercise, but also could suggest ways that the exercise could be improved for future use. Additional examples of assessment to determine comprehension are provided in Ebert-May et al. (2003).

Table 4. Value ranges and corresponding spider plot axis scores used in a field-day exercise to assess the multifunctionality of different cover crops.

	Spider plot axis score				
Indicator variable	1	2	3	4	5
Beneficial insect diversity (no. of different groups)	≤ 1	2–3	4–5	6–7	≥ 8
Floral resources (% floral cover)	1–19	20–39	40–59	60–79	80–100
Weed density/Suppression (no. 2.64 ft^{-2})	≥ 30	20–29	10–19	1–9	0
Biomass (wet weight lbs $acre^{-2}$)	≤ 5,999	6,000–7,999	8,000–9,999	10,000–11,999	≥ 12,000
Nitrogen content (lbs $acre^{-2}$)	≤ 29	30–59	60–89	90–119	≥ 120
Root mass (lbs)	≤ 0.01	0.02–0.04	0.05–0.07	0.08–0.10	≥ 0.11
Earthworms (no. 2.64 ft^{-2})	0	1–3	4–6	7–9	≥ 10
Nutrient retention (C : N of plant residue)	10–19	20–29	30–39	40–49	≥ 50

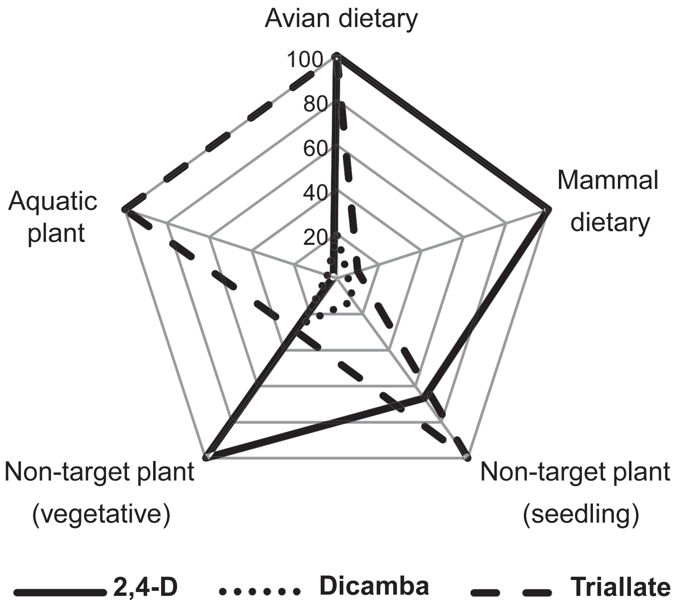

Figure 3. Comparative ecological risk relative to glyphosate for three herbicides used in spring wheat. Data are from Peterson and Hulting (2004; Tables 1–5) and were converted to percent of the maximum relative risk (among the three herbicides) for each risk category.

Other Uses of Spider Plots in Weed Science Teaching and Extension

Spider plots can be used to communicate the concepts of agricultural multifunctionality and tradeoffs for a variety of topics specific to agricultural weed science and management. For example, spider plots can be used to compare herbicides in terms of their relative risk for a number of environmental indicators. As an example, we used data from Peterson and Hulting (2004) to display the environmental risk of three herbicides commonly used in spring wheat. The data show ecological risks to avian and wild mammal diets, nontarget terrestrial plants (seedling emergence and vegetative vigor), and nonvascular aquatic plants, for 2,4-D, dicamba, and triallate, relative to glyphosate (see Peterson and Hulting 2004 for a full description of the data and methods). We converted the relative risk data to reflect the percent relative risk among the three herbicides (i.e., for each environmental risk category, the herbicide with the highest risk was set to 100%). Examination of the resulting spider plot shows that each of the three herbicides vary widely in their relative risk to the five different ecological indicators and that risks relative to glyphosate for some indicators were as much as 95% higher in 2,4-D and triallate compared with dicamba (Figure 3).

Spider plots also can be used to evaluate and present data on weed community composition at the experimental plot or farmer field level. Axes could be weed species, weed functional groups (e.g., forbs, grasses, mycorrhizal hosts, nitrogen fixers) or life histories (e.g., summer or winter annual, perennial). If axes are weed species, axes should be arranged so that species with similar characteristics are grouped together, so as to improve the informational content of the plots. For example, we used data from Ryan et al. (2010) to construct spider plots showing the response of weed seed banks as a function of life history traits (summer and winter annuals, biennials, and perennials) to three different crop management systems (Figure 4). Inspection of the plot reveals that summer and winter annual species tended to be more associated with seed banks in the two organic systems, whereas overall fewer species, but particularly perennial species, were associated with the seed bank in the conventional system. For the weed science classroom, such an exercise might involve students collecting weed percent cover data in research plots or farmers' fields under different types of fertility or tillage management. Prior to the activity, students could be instructed to develop spider plots representing the results they expect to observe (perhaps based on weed functional groups or life histories). Following data collection, students could be asked to discuss why their actual data did or did not support their predictions.

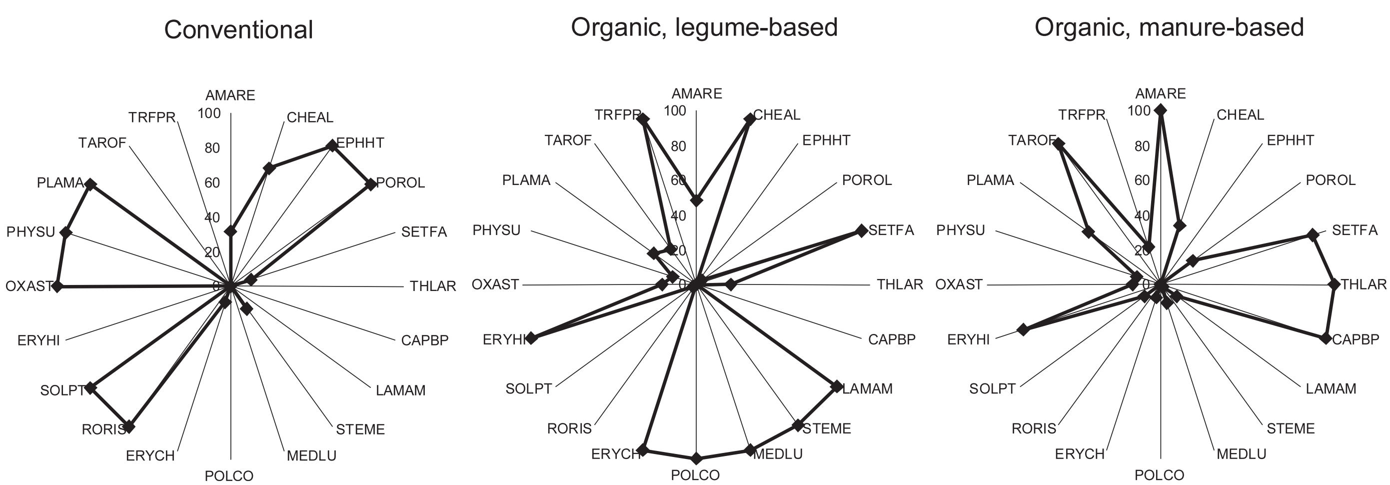

Figure 4. Weed seed bank community composition in three long-term cropping system trials in SE Pennsylvania. Data are densities of indicator species in the weed seed bank in the Rodale Farming System Trial (FST; see Ryan et al. 2010). Seed bank samples were collected in April 2006 from plots that had been planted to corn the previous cropping season. Data have been relativized (percentage of maximum (set to 100%) for each species across the three FST systems). Species are WSSA-approved BAYER codes and have been arranged on the plots based on life history traits (clockwise from top: summer annuals, winter annuals, biennials, perennials).

Spider plots might be particularly well-suited for comparing the economic and environmental costs and benefits associated with different weed management systems (e.g., chemical, mechanical, and cultural). Because these weed management systems likely would vary in their effects on variables such as expense, time of labor, efficacy of control, soil erosion, fossil fuel use, potential for the selection of herbicide resistance, and probability of nontarget effects, the incorporation of these axes in a spider plot could illustrate how weed management decisions must be made within the context of other agroecosystem considerations.

Spider plots have use within the context of invasive weed management and outreach education. Within this context, spider plots can incorporate the multiple (and often competing) goals of resource managers. Spider plot axes could be the characteristics of a site pre- and postplant invasion, or pre- and postmanagement.

Activities designed around spider plots can be incorporated into field days, workshops (as we describe above), within the weed science classroom, or any other environment in which the objectives involve helping participants better understand the concepts of multifunctionality, complexity, and/or tradeoffs in agriculture. The level of participatory data collection can vary depending on the educational goals and scope of the activity. At the lowest level of participation, learners can conduct a rapid appraisal with some field observations and experimental data made available at the field day. This technique can be useful in field days with limited time where the goal might be to demonstrate the results from field trials or experiments in which different treatments are compared and on which multiple response variables have been measured. At the highest level of participation, learners discuss and decide upon the spider plot variables of interest, develop the criteria for measuring the variables, collect and plot the data, and discuss the results. For extension educators, this approach would have the added benefit of helping to gauge grower interest in weed science issues and could be used to guide extension program development (Gareau et al. 2010).

Multivariate assessments and visualization of data using spider plots can be engaging laboratory exercises for weed science courses and other types of agricultural and environmental learning. Participatory spider plot activities provide students with an opportunity to learn about agroecosystem processes, data collection techniques, and interpretation and communication of results. Spider plot exercises can be conducted as point-in-time estimates that can provide snapshots of the performance of the agroecosystem component of interest. Conversely, spider plot activities could be conducted several times over the course of a semester to demonstrate the temporal dynamics of multifunctionality and tradeoffs operating within agroecosystems. Data collected at multiple time points can provide a more comprehensive assessment of the agroecosystem.

Because spider plots are semiquantitative, their use in analyzing potential tradeoffs operating within agroecosystems should be viewed as a preliminary exercise. Ultimately the user or learner must impute value to the individual spider plot axes, because all variables associated with the axes likely will not carry equal value in a given situation. Developing qualitative (or quantitative) judgments concerning the weight ascribed to different axes, and then representing this weighting in graphical form, likely could improve the value of spider plots as a tool for illustrating and analyzing tradeoffs in agriculture and could help to guide future management choices.

To summarize, we believe that spider plots have multiple applications in weed science and agroecology and are valuable education and extension tools that provide opportunities for active and experiential learning. By displaying data on multiple variables in an interpretable and intuitive graph, spider plots can aid in the conceptualization and evaluation of multifunctionality and thus can improve understanding and decision-making capabilities on the part of the learner. We hope that the suggestions provided in this paper stimulate others to incorporate multivariate assessments and spider plots into their weed science education and extension programs.

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