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Stakeholder-driven adaptive research (SDAR): better research products

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Abstract

Rapid changes in economic, environmental and social conditions generate both problems and opportunities in agriculture. The cycle from problem identification through discovery of potential solutions is lengthy. The objective of this study was to use collaborative methods to speed the cycle of discovery in sustainable organic strawberry (Fragaria × ananassa) production systems in the southeastern USA. This method, stakeholder-driven adaptive research (SDAR), combines farmers' experiential knowledge with scientists' experimental knowledge to develop rigorous research design collectively. Farmers evaluated our biological research and co-designed research experiments with scientists. Farmers and other stakeholders (1) evaluated on-station experiments individually and then made recommendations as a group, (2) served as advisory council members to direct our goals and objectives, and (3) conducted farmer field trials where they implemented aspects of our on-station experiments under their management regimes. The results eliminated potential solutions that were not feasible, ineffective or too costly for farmers to adopt. Key results included eliminating treatments using high tunnel systems altogether on one field trial on a University of Florida (UF) research facility, adding a leguminous cover crop mix treatment, adding companion planting, and eliminating strawberry cultivars Strawberry Festival and Florida Beauty from our research trials. Our proposed methodology allows farmers and other stakeholders to inform the biological research from design through dissemination to reduce the time needed to create research products in an era of rapid bio-physical, social and economic change. Accelerating the discovery cycle could significantly improve our ability to identify and address threats to the USA and global food and fiber production system.

Introduction

Agricultural challenges demand faster science

The pace of changes that affect agriculture has increased rapidly over the past 20 years. These changes are global and include economic, environmental and social conditions that generate both problems and opportunities in US agriculture (Lamichhane *et al.*, 2015; Gilardi *et al.*, 2018). The pace of discovery in the agricultural sciences has also increased. One example of this is the number of plant patents awarded over the past two decades. The US Patent and Trademark Office reported 175,979 total patent grants issued in 2000, of which only 548 were new plant patent applications. Total patents issued were 338,900 in 2020, of which 1398 were new plant patent grants (US Patent and Trademark Office, 2019).

Despite increased funding devoted to agricultural research and a growing body of agricultural scientists in the USA and globally, responses to both problems and opportunities in agriculture often cannot meet the challenges the industry faces quickly enough to avoid significant disruptions. Two examples illustrate the problem. Phasing out methyl bromide as a broad-spectrum soil fumigant in the USA began in 1999 (Environmental Protection Agency, 2020) and funding for research to find alternatives started at the same time. Despite an intensive research effort over the last 20 years (Stevens and Freeman, 2018; Yu *et al.*, 2019, 2020), alternatives generated to date are not as productive and are more expensive than methyl bromide. Huanglongbing (HLB) is another case. Also known as citrus greening, HLB arrived in Florida in 2005, and the state lost half of the $1.5 billion value of citrus from 2005 to 2015 (National Institute of Food and Agriculture, 2017). Citrus production continues to decline, and Florida Farm Bureau estimates losses up to 82% by 2026 if researchers cannot respond

quickly enough to the tough challenges posed by HLB (Florida Farm Bureau, 2020). Solutions are emerging, but the damage to the industry may be near irreparable.

Finding approaches that accelerate the discovery process could significantly improve our ability to address threats to the US and global food and fiber production systems. One reason the discovery process can be so lengthy is the time it takes to reject solutions that seem promising but are ultimately found to be impracticable, ineffective or too costly for farmers to adopt. Farmers and scientists working together throughout the discovery process can expedite this elimination process and free resources to focus on developing research products that address rapidly changing conditions.

Farmer-driven research: a key to accelerating discovery

Farmers' full participation in the discovery process can also create higher quality research products because the research focuses more quickly on potential solutions that are apt to be economically viable and technically feasible. Farmers bring experiential knowledge accumulated in the practice of farming to the research process (Hoffmann *et al.*, 2007). Farmers acquire years of experience dealing with the social, biological and geo-physical factors that require consistent decision-making under conditions of uncertainty where flexibility and adaptability are critical (Krzywoszynska, 2016). Researchers may have little or no experience in farming as an economic enterprise in which poor decisions result in severe repercussions. Farmers are also experimenters and do test innovations on their farms, often on a small scale before adopting on a larger scale (USDA Sustainable Agriculture Research and Education, 2017). Incorporating farmers' experiential knowledge into the scientific discovery process brings social, economic and environmental considerations that farmers face daily into generating adoptable solutions (Lindblom *et al.*, 2013; Lundstrom and Lindblom, 2018).

Conversely, scientists bring theoretical and analytical knowledge that focuses on understanding cause and effect relationships that generate the outcomes that emerge under controlled experimentation (Newell, 1994; Walker, 2005). Scientists test an array of hypotheses and potential solutions in multiple replications across several years (Proctor, 1998). Their key tasks are to identify and explore a range of possible solutions to a problem and verify which of those solutions produce measurable treatment effects. The distinguishing strength of an experimental approach is to ensure rigor through the manipulation of experimental variables in a controlled environment over an extended period (Walker, 2005; Carey and Stiles, 2016) and the exclusion of non-experimental factors like excessive rainfall or drought, high pest pressure, or unavoidable delays in planting or harvesting (Duffy, 1985).

These aspects of traditional experimental research are the foundation for establishing direct cause and effect—for knowing that new products, technologies or processes do produce the hypothesized outcomes. However, the need to control sources of variance reduces the researcher's ability to test the degree to which a given treatment will have the hypothesized effect when the treatment is exposed to the full range of variance that occurs on farms. Hence, a treatment may perform well under controlled experimental conditions but prove less effective on farms. All of these uncontrollable factors increase variance whether a trial is on-station or on a farm and one task for agricultural scientists is to assess the capacity of an innovation, like a new cultivar, to perform in the face of this unintended and unplanned or 'non-experimental' variance.

Experimental research in multiple locations and on farms can test an innovation in a variety of agricultural systems and environmental conditions. Nonetheless, the need to control non-experimental factors in research trials limits the range of variance that occurs in these settings and limits the researcher's ability to assess the potential impacts of different events on a given innovation. Therefore, understanding how treatments respond to variance is important for generalizing results beyond the original research setting. While biophysical factors like soil type and pest pressures vary from site to site and farm to farm, the farmer's individual decision-making is a critical source of variance. Researcher-managed trials conducted on farms often do expose treatments to greater bio-physical variance than on-station trials, but they do not subject treatments to the range of management regimes typical of operating farms, which are themselves a major source of variance. When farmers become active members of a research team, they bring the totality of their experiences to the research setting which can significantly improve outcomes. The combination of scientists' experimental knowledge with farmers' experiential knowledge provides a stronger research base than either alone and can speed the discovery cycle by earlier identification of treatments that perform well under controlled conditions but have restricted utility under the variance in farm conditions.

Stakeholder-driven adaptive research

Stakeholder-driven adaptive research (SDAR) is a method we propose in which farmers plan, implement and assess the outcomes of research programs from the earliest stages of design throughout the research process. SDAR focuses on taking full advantage of the different forms of knowledge that farmers and scientists generate. SDAR differs from several other existing participatory approaches, such as participatory action research (PAR). PAR is a research methodology in which researchers and participants work collectively to empower participants' agency (Grbich, 1998; Baum *et al.*, 2006; Minkler and Wallerstein, 2011). Researchers have used PAR in agricultural sciences by incorporating stakeholder feedback through methods like workshops, asking participants to test proposed new technologies, organizing informal discussions and incorporating local knowledge into existing research projects (Carberry *et al.*, 2002; Hossard *et al.*, 2013; Bousbaine and Bryant, 2016; Douthwaite and Hoffescker, 2017; Kinhoegbe *et al.*, 2020). PAR has been a very fruitful approach to building community-based involvement in a wide range of projects that focus on community development. Our focus is on the scientific discovery process rather than processes associated with dissemination of new ideas or community development. SDAR is a methodology that is intended to enhance the productivity of the scientific research process, providing input that affects the outcomes of research prior to dissemination of results or attempts to engage in community development. SDAR looks 'inward' at the scientific research process to better inform the proposed solutions for agricultural research. SDAR is intended to speed the discovery of workable solutions for farmers and ultimately should have an effect on adoption of new practices and technologies, but it is not meant to replace other approaches like PAR.

Impact assessments are a methodological tool to determine the effect of a phenomenon or technology on the surrounding environment or people (Kohli *et al.*, 2020). Agricultural scientists have used impact assessments in research involving stakeholders. They may be useful as post-research evaluations but lack the

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collaborative design component that makes research adaptive to stakeholders' knowledge and expertise. (Purushothaman *et al.*, 2013; Prechsl *et al.*, 2017). Researchers may also conduct impact assessments prior to starting a research project to help determine the trajectory of the research (Michalscheck *et al.*, 2018). Both needs and impact assessments are critical to the development of new approaches to meeting the needs of farmer and SDAR replaces neither. In fact, an initial needs assessment is critical to agricultural research. SDAR's role is in the processes that must occur between discovery of a problem and producing viable solutions that stand the rigor of scientific testing and show persistent success when subjected to the human and bio-physical variance that is inherent to the practice of agriculture.

Agricultural scientists have used expert elicitation as a research methodology involving stakeholders in research projects. Like the name suggests, researchers invite experts, usually individuals who work for government agencies or agricultural businesses like input suppliers to reach conclusions based on their knowledge in a given field (Truong and Heuvelink, 2013). Experts make judgments about existing research projects and researchers then use informed expert opinions to develop research objectives (Ilic *et al.*, 2017; Johnson *et al.*, 2017). Expert judgment of research is an important aspect of collaborative research but represents just one mode of SDAR (Kamali *et al.*, 2017; Osunkoya *et al.*, 2019).

SDAR builds on the experience of ecologists who use adaptive management in developing conservation programs, particularly the component of this approach that involves reflection and learning through trial and error (Folke *et al.*, 2002; Williams and Johnson, 2017; Morgan *et al.*, 2018). Collaborative adaptive management (CAM) is a participatory extension of adaptive management. The CAM framework combines context-specific stakeholder knowledge, the diffusion of shared learning, and increased trust to identify solutions to a management problem (Innes and Booher, 2010; Lubell, 2015; Fernandez-Gimenez *et al.*, 2019). The shared new knowledge is rich, but practitioners recognize that it takes considerable time and commitment from stakeholders (Hopkinson *et al.*, 2017; Wilmer *et al.*, 2018; Fernandez-Gimenez *et al.*, 2019).

Each of these methodologies and the intermediate methods developed over the years have been important steppingstones to developing a formalized adaptive research design. The primary differences lie in the degree to which farmers are decision-makers in research design and implementation rather than focusing on farmers' roles in needs identification and dissemination of research products. Farmer decision-making authority in the research process from on-station experiments to large-scale on-farm trialing sets SDAR apart from other methodologies typically employed in agricultural research and profits from long-term and short-term collaboration with farmer-researchers who serve as full members of the research team. These farmers have decision-making power in research design just as the other members of the team do and farmer-researchers conduct research on their own farms, selecting treatments and data to collect, and play important roles throughout a research project, start to finish. Farmer team members also have access to data and results which fosters long-term decision-making in the trajectory of a research program, including programmatic goals and objectives, as well as research design and experimental treatments. This approach moves beyond short-term consultation and acquisition of information from farmers.

Biological and social scientists at the University of Florida (UF) and farmers working with them developed this approach. This methodological research has focused on the development of procedures and protocols to guide the shared discovery process. We have developed and used the SDAR methodology from 2013 to 2020 in various research projects. This paper addresses how SDAR influenced experimental research design over time and how farmer-designed trials contributed to research priorities in our work on organic strawberry production, where we first used the approach.

Materials and methods

Project goals and objectives

In this paper, we present examples of how we have used SDAR in research about organic strawberry production systems. We do not present biological results here, but rather present what we have learned about this collaborative model of agricultural research. Development of SDAR began in a collaborative project with the National Strawberry Sustainability Initiative (NSSI) and Walmart Foundation. The goal of this project was to develop sustainable organic strawberry open field and high tunnel production systems for the Southeast. The NSSI project aimed to develop a resilient system with pest-suppressive and soil health-enhancing cover crops, identify strawberry cultivars adaptable to organic production, and improve the management of two arthropod pests, spotted wing drosophila [*Drosophila suzukii* (Matsumura)] and twospotted spider mite (*Tetranychus urticae* Koch). We used split-plot experimental designs to test various cover crop and strawberry cultivar combinations. The NSSI project concluded in 2015, but researchers at UF, Florida Agricultural & Mechanical University (FAMU) and North Carolina Agricultural and Technical University (NCAT) continued their research with funding from the National Institute of Food and Agriculture's Organic Research and Extension Initiative (NIFA-OREI) program. Drawing on the farmer recommendations from the NSSI project, the research team adjusted the goals and objectives of the research and then reassessed them each year of the project from 2016 to 2020. The rest of this chapter describes how we used SDAR in the strawberry research.

The three-step process of stakeholder-driven adaptive research

SDAR has three distinct components. (1) Field assessments are conducted by panels of farmers, service providers and other industry experts, usually six to eight individuals. Each individual is assigned one replication in a standard randomized field trial. S/he knows the nature of the treatments, but the plots are not labeled which keeps knowledge of the specific treatment in a plot from the observer, done to reduce bias in observation. All observations are noted on forms that we provide. After noting observations, the participants engage in a facilitated discussion, identifying the strengths and weaknesses of the plots they observed. After step 2, the treatment in each plot is identified for the participants. They then are asked to reach consensus on changes to the research protocol *for the on-going trial* (treatments, data collected or form of data analysis). (2) The advisory councils are charged with providing guidance for the overall research program. The council members (usually four to six) serve for the duration of a given project and have access to all data collected, including the data from the research assessments. The council's task is to provide recommendations concerning about the long-term research program—the organic strawberry production

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system in the example provided here. These are broader recommendations that address the overall research goals and objectives for the enterprise. The farmer field trials move research onto farms, asking a sample of four to six farmers to create their own research designs involving any aspect of the on-going research. Farmers design, implement and report the findings of the research, calling upon the expertise of the scientists involved as needed or wanted. Together, these activities produce results that are (1) a direct product of year-to-year stakeholder assessments of on-station trials, (2) inform longer-term research objectives based on the results of field trials and assessed by an advisory council made up of experts in the strawberry industry, and (3) exposed to variance across time, space and management techniques.

Research assessments

Farmers and technical advisers assessed our on-station trials each season. Participants made detailed individual observations of research plots. These included assessments of plant growth and development, pest injury, disease damage, plant vigor and fruit characteristics. Participants made their observations on unlabeled plots to reduce the potential for bias based on prior experience with the strawberry cultivars or cover crops. We asked participants to avoid discussing their observations with each other to ensure that the participants would be able to offer their own ideas based on personal knowledge in the group decision-making, unbiased by what others thought. After completing the in-field assessment, participants shared their observations in a facilitated group discussion that progressed from identifying the best and worst performing treatments to reaching consensus about the most and least valuable aspects of the research and ended with recommendations for the upcoming round of station trials. We revealed treatments midway through this process. We conducted two research assessments per growing season, one with farmers and another with technical advisers like extension agents or certified crop consultants.

Advisory council

An advisory council assessed project goals, objectives and results throughout the project to improve outcomes and made recommendations for future research. The council consisted of four to six members made up of strawberry producers, other industry representatives and county extension agents. We met with the advisory council twice per year. At the start of the season, council members analyzed our objectives, research design and data collection methods for the year. At the end of the season, council members assessed our progress in achieving priorities identified in the previous meeting. The advisory council serves as a strategic planning group that determines the trajectory of a project. The advisory council assumes a strategic role in the research process through its overall assessment of progress and recommendations regarding the longer-term direction for a research program.

Farmer field trials

Farmer field trials are ideal for results that are well-established in classic on-station experimental studies, but require exposure to greater variance over time, geography and management style to be broadly generalizable. In the farmer field trials, two farmers tested the cover crops and strawberry cultivars that they found to be most interesting on their farms. They based their choices on their participation in farmer assessments. They chose to test all three cover crops used in the on-station trials on their farms, including sunn hemp (*Crotalaria juncea* L.), the standard for both farms. They also selected three strawberry cultivars from those evaluated in the on-station trials. The trials, which took place in the 2017–2018 and 2018–2019 seasons, were side-by-side comparisons of the farmers' management practices combined with the experimental treatments selected. We wanted to understand how the selected treatments responded to farmer management decisions because they are arguably the largest source of variance in agricultural production. Farmer-managed treatments are one way to capture this variance. Scientists can then determine if treatment effects observed on-station endure across management regimes on farms.

Participant sampling

We recruited participants for our research through judgmental sampling. Judgmental sampling is appropriate, even imperative, when the role of the participant in a study depends on having specific, usually rare, traits that provide expertise or experiences that are shared by relatively few people in the target population. We needed to collaborate with farmer-researchers who have extensive experience with organic strawberry production, are innovators who experiment on their own farms, and are willing to share their knowledge and experience with others. We reached farmer participants by identifying key informants in the target community and requesting suggestions for potential participants. In this study, we asked personnel in local and regional Extension offices to nominate horticultural and agricultural agents to attend our research assessments. We also asked them to suggest other technical advisers and farmers who would be interested in participating and who could give thoughtful feedback based on experience in strawberry production. We recruited six to eight participants per session, a sample size that was large enough to split participants into two or three small working groups yet not so numerous that group discussions and consensus would be unmanageable (see Table 1 for a breakdown of participants per activity). We recruited two farmer-researchers from the farmer research assessments to participate in farmer field trials. All participants received monetary compensation for their voluntary time, space and knowledge. Advisory council members received $100–$200 for Zoom and in-person attendance, respectively. Research assessment participants received $200. Farmers who conducted field trials received $2000 per season. UF's Institutional Review Board approved this research, study ID IRB201602322.

Results and discussion

Engaging stakeholders in our research process led to the adjustment of the scope of our research in five primary ways. Results from the NSSI project incorporated into the NIFA-OREI project included (1) eliminating high tunnel research and (2) adding a cover crop mix. (3) We eliminated 'Strawberry Festival' from our cultivar treatments after the 2016–2017 strawberry season and (4) farmer and technical adviser feedback also led us to eliminate 'Florida Beauty' from farmer field trials in the 2018–2019 season. (5) The final recommendation we adopted was companion planting of sweet alyssum during the 2018–2019 season to retain beneficial predators, particularly as it relates to strawberry

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Table 1. Participants in stakeholder-driven adaptive research (SDAR) activities

Project	Activity	Date	Location	Participants
National Strawberry Sustainability Initiative (NSSI) and the Walmart Foundation	Research assessment	January 2014	Mobile, AL	15 industry members
	Research assessment	January 2014	Citra, FL	Six industry members
	Research assessment	February 2014	Plant City, FL	Nine industry members
	Research assessment	February 2015	Hawthorne, FL	12 industry members
	Research assessment	February 2015	Citra, FL	Eight service providers
National Institute for Food and Agriculture (NIFA)	Research assessment	February 2017	Citra, FL	Six farmers
	Research assessment	February 2017	Citra, FL	Six service providers
	Advisory council meeting	November 2017	Citra, FL	Three farmers One service provider
	Research assessment	February 2018	Citra, FL	Four farmers
	Research assessment	March 2018	Citra, FL	Three service providers
	Advisory council meeting	May 2018	Gainesville, FL	Four farmers Two service providers
	On-farm trials	2017–2018 season	Hawthorne, FL and Gainesville, FL	Two farmers
	Advisory council meeting	November 2018	Gainesville, FL	Four farmers Three service providers
	Research assessment	February 2019	Citra, FL	11 farmers
	On-farm trials	2018–2019 season	Hawthorne, FL and Gainesville, FL	Two farmers
	Advisory council meeting	August 2019	Gainesville, FL	Four farmers One service provider

seed bug (*Neopamera bilobata* Say) management (Table 2). Results reported in Table 2 are recommendations from farmer-researchers and technical advisers that received consensus or overwhelming support. We also report recommendations for future research. Table 3 displays aspects of organic strawberry research that farmer-researchers and technical advisers suggest are the highest priority issues.

Our first major change was to eliminate high tunnel research from the on-station trial at the UF at the end of Year 1 in the NSSI project. From the perspective of researchers, high tunnels provide protection from rain, frost and wind, can reduce risk, improve marketable fruit yield, and extend strawberry growing season (Rowley *et al.*, 2011; Gu *et al.*, 2017). However, the strawberry farmers we worked with in the NSSI project thought the cost of high tunnels was prohibitive and increased pest pressure in a warm environment can increase pest management requirements, always a challenge in organic strawberry systems. Farmer input led researchers to investigate lower-cost alternatives to the high tunnels used in the NSSI project. Faculty members at FAMU took leadership of trials using a low-cost high tunnel system at FAMU (Bolques *et al.*, 2018) and faculty members at NCAT designed experiments to examine low tunnels within high tunnels.

Scientists designed research to evaluate alternatives to sunn hemp that could be used in a crop rotation prior to organic strawberry to enhance cropping system diversity. Our previous research focused on monoculture cover crop options with the potential to suppress weeds and sting nematode (*Belonolaimus longicaudatus* Rau). Farmer-researchers in this study reported that sunn hemp is the dominant cover crop used in organic systems in their regions. Farmers wanted to see whether a cover crop polyculture that included sunn hemp (Table 1) would outperform the most promising monoculture cover crops. The effect of a cover crop mix on soil health was of particular interest. From the farmers' perspective, a cover crop mix that included sunn hemp could be a viable option that would retain the benefits of sunn hemp and cost less than a pure sunn hemp stand since sunn hemp seed is expensive. Finally, a cover crop mix can reduce some of the potential issues of incorporating this high-biomass species into the soil without delaying strawberry transplanting.

SDAR enhances on-station and on-farm research, but of course is no guarantee of working solutions for every problem. Our research with cover crops provides an example. Cover crops provide benefits beyond weed suppression. Cover crops

Table 2. Recommendations from farmer-researchers integrated into the research during National Strawberry Sustainability Initiative (NSSI) and National Institute of Food and Agriculture (NIFA) projects

Project	Recommendation
NSSI	Discontinue high-cost high tunnel research
NSSI	Investigate a cover crop that is a mix of species Four-way leguminous mix: (1) Sunn Hemp (*Crotalaria juncea* L.) cv. AU Golden (2) Slenderleaf rattlebox (*Crotalaria ochroleuca* G. Don) (3) Hairy indigo (*Indigofera hirsuta* L.) (4) American jointvetch (*Aeschynomene americana* L.)
NSSI	Separate farmers and technical advisers in research assessments
NIFA, 2016–2017	Eliminate strawberry cultivar Strawberry Festival
NIFA, 2017–2018	Eliminate strawberry cultivar Florida Beauty
NIFA, 2017–2018	Investigate companion planting

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Table 3. Recommendations from farmer researchers in the National Institute of Food and Agriculture project identified as top priorities for future research projects.

Topic	Recommended future research priorities
Strawberry cultivars	A 'no maintenance' strawberry cultivar; already has desirable traits such as sweetness, texture, shelf-life, and pest and disease resistance
	Best harvest practice
	Determine why strawberry cultivars perform differently season to season
	Consumer preferences
Cover crops	Timing of incorporation
	Determining the cover crops that contribute nitrogen adequately to reduce external inputs
Mulch	Alternatives to plastic mulch
	Paper mulch
	Biodegradable mulch
	Impact of mulch on soil health
Management practices	Most effective transplant method
	Low-cost high tunnel economic data over time
	Best practices for soil health in succession planting systems
	Freeze protection systems
Disease management	Botrytis management
Pest management	Seed bug management
	Companion planting options to manage twospotted spider mites
	How key pest populations vary with crop rotations
	How to attract pollinators and predatory insects
Nutrient management	Farmers need more information on nitrogen recommendations for organic strawberry production

that give good ground cover reduce soil erosion and can add biomass, potentially increasing soil organic matter and nitrogen (Wang *et al.*, 2008; Morris *et al.*, 2015; Baitsaid *et al.*, 2018). However, cover crops are an added cost of production and can interfere with the critical practices in crop production, delaying planting, for example. Farmers in our work wanted us to find a harvestable cover crop that had the potential to generate additional earnings that could help farmers at least recoup the investment in planting cover crops. Researchers on the NSSI project experimented with sesame (*Sesamum indicum* L.) as a harvestable cover crop. Although, sesame showed potential as a cover crop, harvest of the seed would occur in the fall, too late to allow for the establishment of a subsequent strawberry crop. Further, the best shatter-resistant sesame cultivars available in the USA are proprietary and can only be acquired through contracts. This is one example of how farmers identified a need that researchers tried to address but abandoned quickly once the potential solution proved to be unsuitable for both larger scale strawberry operations that rotate strawberries only with cover crops and for more diverse operations that do not have the economies of scale to engage in contract sesame production.

Third, we eliminated 'Strawberry Festival', known for its firmness, shelf life and resistance to damage from high rainfall—all valuable traits in a strawberry cultivar from a production perspective (Chandler *et al.*, 2000). Researchers often compare new cultivars with 'Strawberry Festival', treating it as an industry standard control (Kelly *et al.*, 2016). Our research revealed that farmers do not prefer to grow 'Strawberry Festival' because consumers often find the cultivar too seedy, not as juicy as desired, not sweet enough and too small. Nonetheless, many organic farmers consistently grew a limited acreage of 'Strawberry Festival' as a way of reducing risk because of its disease resistance. Farmers recommended we eliminate it from our trials in favor of the other cultivars that were performing well. We eliminated 'Strawberry Festival' because we came to understand that farmers will probably continue to plant some acreage in 'Strawberry Festival' regardless of experimental results showing its disadvantages. It is a sort of 'insurance policy' for disease. However, including it in experiments consumes resources better devoted to other research options that farmers prioritize. In a rapidly changing agricultural landscape, eliminating poor-performing treatments, in this case a cultivar, streamlines decision-making processes for farmers and opens avenues for scientists to investigate new variables. For example, we found that Florida Beauty performed poorly in our organic systems research. Researchers established this in multi-year, multi-venue trials, providing farmers with the information necessary to determine Florida Beauty's adoptability for organic production.

The assessments revealed that farmers and technical advisers may have conflicting assessments and different recommendations. Instead of asking a group of farmers and technical advisers to come to a consensus, we adapted the procedure so that each group conducts a separate assessment. The need to separate the two types of assessments emerged when both farmers and technical advisers rated 'Strawberry Festival' as a top-performing cultivar. Farmers advised us to eliminate this cultivar from the trials because of consumer dislike of the cultivar, even though they gave it high marks for hardiness. Technical advisers recommended we continue testing with 'Strawberry Festival', possibly because they do not have the kinds of regular interactions with consumers that farmers do and therefore do not hear the consumer dissatisfaction. Farmers also noted that they are very familiar with 'Strawberry Festival' and argued for spending scarce research resources on cultivars with far less research data. These conflicting perspectives are one example of the technical knowledge that advisers bring to assessments that farmers do not and vice versa. Technical advisers may lack the practical growing and selling knowledge that farmers have but have more ready access to research results. Both groups made important observations and recommendations that contributed to research design.

The final recommendation we adopted was companion planting. Both scientists and farmers are well aware of the growing threats to pollinator populations (Potts *et al.*, 2010; Winifree *et al.*, 2011; Simon-Delso *et al.*, 2014) and know that incomplete pollination results in small or misshapen strawberries (MacInnes and Forrest, 2019; Hodgkiss *et al.*, 2019; Martin *et al.*, 2019). Importing honeybee hives is not an economically sustainable business practice for many farmers. Farmers in our research consistently identified companion planting as a need for retaining pollinators and predatory arthropods. We planted sweet alyssum [*Lobularia maritima* (L.) Desv.] interspersed in a smaller

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strawberry trial to serve as a habitat to attract potential pollinators. Farmers assessing our plots affirmed that sweet alyssum companion planting provided clear benefits to farmers. As a result, we expanded our examination of sweet alyssum into more trials. Companion planting can have other benefits as well, such as improved pest management, because it harbors natural enemies that regulate pest pressure in a strawberry system. Twospotted spider mites are difficult to manage in Florida (Rhodes and Liburd, 2006; Fraulo *et al.*, 2008; Nyoike and Liburd, 2013). One management approach is to release predatory mites (Fraulo *et al.*, 2008). Some companion plants will retain predatory mite or other natural enemies in a given release site, reducing the need for multiple costly releases, and potential use of pesticides labeled for organic use (Balzan, 2017; Penca *et al.*, 2017). Placing greater emphasis on facilitating conservation biological control with companion planting in organic strawberry grew out of the shared objectives of farmers and researchers and provides a good example of how stakeholders and researchers together can design research projects that target robust and pertinent research outcomes.

Using SDAR improved our ability to identify and address previously unidentified threats to a given production system. Farmer-researchers identified the strawberry seed bug as a research priority based on their farming expertise. The strawberry seed bug has been a secondary pest in organic strawberry production systems (Hata *et al.*, 2019; Talton, 2019). Over the course of our work on organic systems, this pest gained importance for organic producers, and it has now been identified as an emerging pest in strawberry production more generally, one that is difficult to manage. Researchers used their experimental knowledge to develop pest management tools for strawberry seed bug in organic strawberry production systems, techniques that can be extended to conventional production systems. These research outcomes benefit farmers who lose marketable fruit to insect pest injury and enhance technical advisers' knowledge about this emerging pest.

SDAR also helped us identify consumer concerns. Farmers who sell direct-to-consumer contributed knowledge about consumer preferences that are inaccessible to biological scientists except through formal surveys. Direct sales are a growing component of the food market. The 2017 Census of Agriculture showed the value of food sold directly to consumers more than doubled from $1.3 billion in 2012 to $2.8 billion in 2017, although total sales remained virtually unchanged (United States Department of Agriculture 2019). Farmers who market direct-to-consumer can guide research design by identifying traits of products that are important to consumers. In our case, farmers identified strawberry cultivars they know consumers dislike or are impartial to and cultivars with lower sales than most. It is likely that consumers other than those involved in direct sales share the same preferences.

Growing economies increase sales that benefit farmers, but global food and fiber trade also challenges agricultural production (Bridle and Bonney, 2010; Banks *et al.*, 2015; Capinha *et al.*, 2015). Species dispersal occurs along trade routes and poses risks of invasion (Chapman *et al.*, 2016). Weed species are an example. Weeding in organic systems can be labor-intensive because available organic herbicides are not cost-effective. Reducing costs of labor is not typically an objective of biological research based on conventional production systems. Farmers recommended that we identify more affordable off-season cover crops for weed suppression. While conventional producers do have herbicide alternatives to control weeks, the availability and cost of labor is a growing problem for many horticultural crop producers. SDAR provides one way to identify potential opportunities to reduce emerging threats to production.

The use of SDAR reported here provide examples of ways in which this methodology can enhance the discover process in agricultural research. Several examples demonstrate the range of potential problems and opportunities that can emerge through this kind of farmer-researcher collaboration. While this research focused on organic strawberry systems, the kinds of opportunities and issues that emerged are typical of most agricultural production systems.

Future research

We will expand the scope of research trials in several ways in the future. First, we will integrate consumer-driven research priorities. These often overlap with farmers' research priorities but can help narrow the scope of research to target areas of the market that are most profitable to farmers. Second, we will expand our farmer field trials. More farmer field trials, and thus more experimental plots, will provide greater sources of variance, allowing us to evaluate the degree to which the treatments remain stable under differing producer conditions. We will extend our farmer field trials beyond the 2 years in this project. Farmers need longitudinal data to be able to make sound judgments about adopting new technology. Finally, we will add 'farm case studies' to our research. Farmer-researchers who worked with us recommended expanding field trials beyond one plot of land to profiling the entire farm and determining the suite of practices that are most cost-effective. Farm case studies will make it possible to compare farms based on specific emergent criteria. These case studies would enhance our ability to reach conclusions about whole-farm economics, something that farmers have regularly wanted to have.

Effective use of SDAR relies on the capability of interdisciplinary teams to collaborate as co-equals. Scientists, farmers and stakeholders all act as researchers starting with the design of the project, its implementation and evaluation. SDAR methodology allows research teams to make small changes early in a project and continue the process across many projects to narrow down research recommendations and address key issues. Commitment to an egalitarian research process is a prerequisite for successful execution of SDAR. All researchers must rely on one another's expertise and be willing to prioritize eliminating poor solutions in order to dedicate resources to promising technology.

Conclusions

SDAR is a valuable addition to the methodological approaches available to biological and social scientists who want to collaborate with farmers to produce valid and reliable outcomes and products that are potentially adoptable. This approach to farmer-researcher and social-biological multi-disciplinary research can be an important tool in addressing the rapid changes that affect agriculture in the USA and globally. The improvements in our research focus, design and outcomes over several years argue for wider use of SDAR. Blending expert knowledge from farmers, technical advisers, private sector actors, non-profits, and non-governmental agencies and biological scientists expedites the production and transfer of new knowledge, in part because farmers take ownership of co-produced knowledge and apply it with confidence born from direct experience.

The integration of biological research and social science research is at the crux of SDAR. Biological scientists bring critical

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experience and research capacity to address problems and constraints within agricultural systems through experimental research. Social scientists bring the ability to develop protocols and procedures that provide the organizational structure for the knowledge gained through farmer-scientist collaborative research. Our approach to SDAR is to apply research design and methodological approaches that ensure rigor and replicability while incorporating the experiential knowledge of farmers. SDAR has direct applicability for addressing critical issues in food, feed and fiber production in the contemporary global environment of rapid biological, technical, social and economic change in agriculture.

Finding ways to speed the discovery process is critical. Farming is a high-risk economic venture for many reasons, including international competition for market share and increasingly for labor. Increased global trade drives an exchange of agricultural products and a more hidden effect is the exchange of pests and diseases that trade inadvertently fosters. Climate change will not only affect rainfall patterns and water availability, but also drive changes in pest and disease populations. SDAR and other models that help engender solutions more rapidly while ensuring high scientific standards for research will be, we argue, critical to agriculture over the mid to long term. We do not propose that SDAR is only way to create a more rapid but still highly reliable agricultural research system. On the contrary, we argue that other avenues should be combined with SDAR and other innovations in agricultural research. Examples include the incorporation of remote sensing and application of artificial intelligence to provide a more complete and immediate flow of information to both scientists and farmers. Farmers we have worked with have consistently commented on the value of the field research assessments and advisory panels for them. They find the opportunities to share their perspectives on the research useful in their everyday decision-making, creating spaces for interaction with both researchers and other farmers. We anticipate that the SDAR methodology will evolve over time. We learned to conduct virtual grower field assessments and virtual advisory panels briefings for our team members as a result of COVID, techniques that we plan to implement on an on-going basis to facilitate greater participation by all of the stakeholders involved with us in our research at a reduced cost in time and money for all involved. An important next step will be to include actors in other components of the food system, particularly the intermediaries that process, distribute and sell agricultural products. SDAR does not replace conventional agricultural research, nor does it supplant other approaches to research like PAR and community development. Rather, it offers the potential to make the approaches more fruitful, including state and federal programs like the Extension Service and the work of non-profit organizations involved in agriculture. We involve these actors in SDAR and anticipate incorporating other stakeholders in the future to create a more 'seamless' process from discovery to adoption.

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