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Science Communication in Agriculture: The Role of the Trusted Adviser

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SCIENCE COMMUNICATION IN AGRICULTURE: THE ROLE OF THE TRUSTED ADVISER

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SCIENCE COMMUNICATION IN AGRICULTURE: THE ROLE OF THE TRUSTED ADVISER

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Agronomy is not simply the selling of agricultural products to farmers, nor is it the process of solving singular production problems. Agronomy is defined as the integrated, holistic perspective of agriculture (ASA, 2019) and “agronomists are specialists in crop and soil sciences, as well as ecology” (ASA, 2019). While scientific investigation and discovery are essential to understanding systems function, the tangible benefits from our knowledge stems from the application to solve problems. Clear communication is vital to successfully help stakeholders understand the importance of the science and help scientists understand the challenges stakeholders face. However, to successfully put science into action, solutions need to address the whole system and strategies need to be customized. To this end it is critical to be able to detect, accurately diagnose and prioritize the problems and challenges within agricultural systems. These steps cannot be carried out remotely or by those who lack the skills or knowledge. Rather, they must be performed by well-trained, experienced people who can translate information into actionable practices. Furthermore, stakeholders need to trust that the advice is accurate and applicable to their system, hence the important role of the trusted adviser. The trusted adviser is someone with the knowledge and skills to assess the entire system, access to scientists and full comprehension of the research. They also must understand the needs and challenges faced by the stakeholder farmers and gain their trust.

These trusted advisers play a pivotal role in the capability of agriculture to respond to climate change, population increase and establishing sustainable systems. Our future depends not only on the discovery of scientific knowledge but more so on the application of it. What good are the solutions if no one ever uses them?

The following document was written to address communication challenges discovered during an internship working with university extension specialists to deliver programming to farmers and directly advising university researchers on practical challenges that farmers face. These on-farm barriers often prevent farmers from adopting new practices. It is also the culmination of twenty years of field experience serving farmers by scouting, identifying, prioritizing, problem solving, communicating, compromising and building trust. This document is intended to urge all practitioners of agronomy and the related agricultural sciences to become trusted advisers, elevate their practice to a new level and approach the challenges of agriculture from a systems point of view. They also need to create actionable strategies not only to protect crop yields but also to protect the soil, the environment, the ecosystem and the wellbeing of the farmer and of everyone who partakes of the bounty.

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CHAPTER 1

The Trusted Adviser

Science Communication in Agriculture

Despite decades of effort, the science community continues to struggle to clearly communicate scientific facts and elicit citizens to apply science effectively. Echo chambers (Zollo et al, 2017), that reinforce misinformation (van der Linden et al, 2017), different perceptions of risk (Etkin and Ho, 2007) and political and social beliefs that are not supported by scientific consensus (Benegal and Scruggs, 2018) cloud numerous discussions of science. This confusion leads stakeholders away from actions that benefit them, their communities and the environment (Benegal and Scruggs, 2018). One particularly important current example of this phenomenon is climate change.

Agriculture is recognized as a critical industry that can help reduce carbon dioxide, methane and other greenhouse gas emissions that could prove instrumental in the mitigation of climate change (Robinson et al, 2018; Del Corso et al, 2015; Prokopy et al, 2015). However, changes in farming practices are difficult to implement because new practices often bring unknown risk to an industry that already deals with many uncertainties, including pest pressures, weather variability, and the influence of local and world markets. In developed countries, narrow profit margins mean farmers do not have much room for failure (Del Corso et al, 2015). Thus, narrow margins encourage farmers to stick with proven practices with more predictable risk rather than trying new practices with unknown yield and economic risks (Del Corso et al, 2015). In developing countries crop failure due to unproven techniques could mean starvation for the farmer and her family (Kansiime et al, 2018). Therefore, trust in the input and advice from an adviser is essential to implementing change at the farm level. Building this trust with farmers requires a personal relationship and understanding of the challenges that each farmer faces (Bernacchi and Wulfhorst, 2017; Coquil et al, 2018).

Discussions of environmental policy often involve two opposing perspectives (Etkin and Ho, 2007; Benegal and Scruggs, 2018). From their perspective policy makers and researchers viewing from the top-down identify what should or needs to be done, but stakeholders and citizens viewing things from the bottom-up identify what can be done or what is practical in light of the perceived financial and social risks involved. Power dynamics along with cultural and philosophical differences often lead to conflict and distrust between these two groups (Gaymer et al, 2014). However, there is a third group in agriculture known as crop advisers, who currently work to help bridge the gap between researchers and stakeholders. Effective crop advisers and crop consultants are recognized as trusted advisers by farmers, researchers, and university extension (Coquil et al, 2018; Bernacchi and Wulfhorst, 2017; Robinson et al, 2018; Gabel et al, 2018). These privately employed professionals trained in science, directly assist farmers with the application of scientific knowledge and technologies to solve agricultural problems and provide more realistic perspectives on the risks involved (Ates and Sendundar, 2013). This review demonstrates that these professional advisers and others like them in different industries can provide critical leadership in the communication of science leading to implementation of improved management practices that will benefit the environment and people locally as well as globally.

Top Down Information Dissemination

Another potential source of scientific information available to the citizens is public access journals (PLOS ONE, 2018). However, in many cases obtaining information directly from scientists is not the most efficient, practical or popular method. What are the primary methods by which people access scientific information? Family, friends, university extension and media are all potential sources (Ollerer, 2015). Education about environmental issues emanates from all these sources. Which ones are trust worthy or accurate? Is trust and accuracy the same thing? Ollerer (2015) points out that these sources can perpetuate misinformation and misconceptions even if they are well intentioned. Once again, we are faced with a divide between the top-down (scientists) and bottom-up (citizen/stakeholders). As discussed, agriculture utilizes intermediaries (extension and crop advisers) to deliver science to the end user (farmer). While there are specialists in extension that focus on agriculture, extension is not strictly targeted to support farmers. The charge of extension is to deliver science to all end users, all citizens, rural and urban, young and old alike. However, many scholars have addressed the financial and personnel shortages of extension which are likely to increase in the future (Ates and Sendundar, 2013; Bernacchi and Wulfhorst, 2017; Calvin, 2018; Clyde et al, 2018; Collins and Gaolach, 2018; Coquil et al, 2018; Del Corso et al, 2015; Kansiime et al, 2018; Ollerer, 2015; Robinson et al, 2018; Prokopy et al, 2015; Tyson, 2014).

Trusted Adviser to Practitioner (Middle Down)

Farmers have an inherent connection with plants, animals and soils and depend on healthy biology to support their family and business. Therefore, it is in their best interests to employ management strategies that protect the biological processes that they use to produce a crop. If farmers are so adept at managing biology, why then do we continue to experience large scale environmental problems associated with agricultural practices?

The answer to this is at least in part due to the perceptions that management for maximum yield must rely heavily on the use of fertilizers, pesticides and soil tillage and that high yield maximizes economic return. Several of these practices can increase crop yield but are also associated with erosion and nonpoint source pollution. However, there are alternative practices such as no-till, minimum till, cover crops and crop rotation that can balance productivity and environmental risk. Innovative farmers are also experimenting with intercropping, livestock integration and other techniques that could potentially be developed and refined for broader application to address specific agricultural challenges. Difficulty arises because changing production practices involves risk, capital investment, experimentation as well as the precise application of science. Local knowledge of soils, weather, nutrient cycling, and crop adaptation are critical for successful agricultural production. Modification of existing systems that have developed over centuries requires expertise in the science of crop production as it applies locally (Del Corso et al, 2015; Robinson et al, 2018; Kansiime et al, 2018). As mentioned previously, this process also must include a realistic assessment and communication of the risk of change. In addition to traditional knowledge, agriculture continues to embrace advancing digital technology such as satellite and aerial imagery, yield mapping and plant stress indicators such as infrared and near-infrared sensing (Erickson et al, 2018). The ability to obtain and process traditional and precision management information as well as assisting farmers in applying scientifically sound site-specific solutions to solve problems is paramount in implementing on-farm change.

Role of Extension

Delivery of scientific information is the charge of university extension in the US and many other countries (Calvin, 2018; Clyde et al, 2018; Collins and Gaolach, 2018; Robinson et al, 2018; Del Corso et al, 2015; Prokopy et al, 2015). However, budget cuts, loss of personnel and high demands on staff have led to difficulty of extension carrying out this mission. Increasingly, private advisers are filling the role of information specialists and delivering science directly to farmers (Prokopy et al, 2015). For decades extension programs aware of the many challenges they face, the limited resources available to them and the value that farmers place on private advisers have purposely developed programming to increase their influence with crop advisers to assist with this model of science delivery (Roseler et al, 1994; Schmitt et al, 2000). Extension programs have taken on the train-the-trainer philosophy (Bernacchi and Wulfhorst, 2017). Thus, crop advisers and extension have a long history of cooperation and mutual respect. Advisers go to extension specialists to obtain current science and technology training in order to provide this information to their clients (Prokopy et al, 2015). More recently extension is viewing crop advisers as force multipliers to assist in delivering the message. Not only can crop advisers increase the amount of science delivery to farmers, they also have the skills to tailor this information to meet the specific needs of individual farming systems (Bernacchi and Wulfhorst, 2017).

Crop Advisers

Farmers list private crop advisers as one of the four most trusted sources of information (Prokopy et al, 2015). The other three are family, chemical dealers and seed dealers. In North America, the Certified Crop Adviser program (CCA) is one way for advisers to distinguish themselves as reputable purveyors of science. This voluntary certification program is administered by the Agronomy Society of America. To become certified the applicant is required to pass two agronomic knowledge tests (International and local), gain experience in the field providing advice to producers and agree to and sign a code of ethics. The required experience only includes time spent assessing crops and providing advice to farmers and ranges from two to four years depending on the level of education obtained by the applicant. Once certified, crop advisers need to complete 40 hours of preapproved continuous education every two years to maintain certification. As of November 2018, there were over 13,000 CCA's in North America (CCA, 2018). This number of CCA's is nowhere near enough to service the needs of each farm, but it provides an existing framework that has proven successful and is quite capable of expanding. The CCA program is also recognized by government agricultural agencies in the US and Canada as experts in the management of on-farm agricultural challenges. Some federal programs that provide funding for farmers to implement environmentally friendly management practices require the services of technical service providers. The NRCS in the US recognizes CCA certification as satisfying some of the credentials required to become a technical service provider (NRCS 2018). One example is comprehensive nutrient management plans. These plans are designed to reduce nutrient losses from agricultural fields and protect the environment from nutrient runoff by using soil tests, knowledge of plant physiology and weather observations to detail when, how and how much manure and other fertilizers are applied to the crop. In sensitive regions such as the Chesapeake Bay, nutrient management plans are required for manure applications (Maryland, 2019). This process helps to ensure that the farmers receive and apply sound science to improve on-farm and environmental outcomes.

Transition to Private Advisers: Turkey

The challenges faced by extension are not unique to the United States. High costs and limited resources led the country of Turkey to transition its extension service from a public entity to the private sector (Ates and Sendundar, 2013). Farmers in Turkey still utilize multiple sources for agricultural information, but the private advisers are becoming the primary vehicle. Advisers in Turkey need to pass examinations and earn certificates to practice. All advisers are registered service providers and most continue to attend trainings and educational programs to further their knowledge and education (Ates and Sendundar, 2013). They interact with the remaining extension and research scientists to obtain new information and practices. This system is still being developed, but some important lessons have emerged. Interviews with advisers from the district of Antalya Province identified difficulty in securing payment for services as the most challenging problem faced (Ates and Sendundar, 2013). These advisers also identified that additional agricultural research was needed to support them and the farmers they advise. Political problems have also emerged. The wording of recent government regulations is such that advisers no longer possess prescriptive powers for pesticides. Only government officials in the Ministry of Agriculture and Rural Affairs can perform this duty (MARA, 2009). This change effectively prevents advisors from performing one of their primary duties. Advisers oppose this wording and are working toward change. They also highly recommend that wording be added to create a division between product sales and advisory services (Ates and Sendundar, 2013). Finally, during the transition many growers have been reluctant to pay for advisory services; therefore, advisers are requesting the establishment of incentive payments for farmers that employ crop advisers.

Village Based Advisers: Tanzania

Extension in Tanzania also faces lack of funding and insufficient personnel to service their farmers. On average, there is only one extension worker for every 2,300 farmers (Kansiime et al, 2018 Helm, 2013). There is simply no way that extension can function as a primary source of information and assistance to each of these farmers. The limited extension resources are primarily used to support high value crops such as potato while one of the most important staple crops, common bean upon which over 75% of the farmers rely on for daily nourishment goes underserved (Kansiime et al, 2018). In order to address this issue, Tanzania extension has undertaken programs to train village representatives to serve as agricultural information providers (crop advisers) called village-based advisers (VBAs). These VBAs need to live in the village, work on their own and demonstrate good communication skills. The villagers themselves had an integral role in selecting the individuals that were chosen to become VBAs. One person from each of 40 different villages was selected and trained (Kansiime et al, 2018). The training consisted of teaching the VBA's improved techniques for growing common bean such as proper seed spacing and efficient use of fertilizer. They were also given improved seed varieties and tools such as planting strings to facilitate implementation of the new techniques (Kansiime et al, 2018). To test the utility of printed materials, some VBA's were given posters, pamphlets and other educational materials to distribute to other farmers. VBA's did not receive direct compensation for advice given to other farmers, but they did collect a retail markup on the small lots of seed that they sold. The main compensation VBA's received was being the first to receive training and increased status within the community. The goal was for each VBA to educate between 80 and 100 farmers within their community. The study found that VBA's primarily used face to face interactions to distribute the educational information. Techniques used included larger group farmer meetings within the village, small informal meetings and one on one on-farm training (Kansiime et al, 2018).

Village based advisers proved to be highly successful community advocates. On average each VBA connected with almost three times as many farmers as anticipated (282) and traveled great distances (10 km) (Kansiime et al, 2018). The printed materials were found across the study area even where they were not available to the local VBA. The VBA's visited each farm an average of 4.5 times during the season with some as high as seven visits. Surveys indicated that 80% of farmers highly valued the VBA's and resources that they distributed (Kansiime et al, 2018). Using the seed and techniques from the VBA resulted in some farmers doubling their yield of common bean on the same amount of land. Farmers stressed that the most important trait of the VBA's was that they possessed good knowledge that they shared by using the local language in a clear and easy to understand manner. Some farmers identified the VBA's as their primary source of agricultural information. Most of the farmers planned to continue using the techniques they learned from the VBA's as well as the improved seed varieties. Farmers did express a need for greater access to new seed and recommended that additional information on pest management and pesticide usage be provided to VBA's for distribution (Kansiime et al, 2018). The VBA model illustrates the benefits of extension working closely with local crop advisers to reach a larger number of farmers with practical applied scientific knowledge. Knowledge that proves useful to farmers was rapidly and widely adopted and shared from farmer to farmer (Kansiime et al, 2018).

Systems Approach: France

Farmers, crop advisers and research scientists tend to have a predisposition to manage agriculture as a collection of isolated problems with individual solutions. Research and management tactics are devised to address an individual insect pest, disease or environmental stress (Ates and Sendundar, 2013; Sanya et al, 2018). Singular problem-solving fits well into the typical scientific method of hypothesis testing. Describe the problem, generate a hypothesis that describes a possible cause, design a treatment or solution and test the probability of the hypothesis being true. This process is critically important for evaluating the effectiveness of strategies, products and methods to address individual problems. However, given that we live, work and farm in interconnected ecosystems, this model may not be the most sustainable strategy. Hypothesis testing often ignores the interactions of the practice or treatment throughout the ecosystem. Interventions that treat one problem change the balance of the system often resulting in downstream effects that may or may not be predictable.

Systems or holistic management is a strategy that considers the entire ecosystem when addressing problems. For example, pest management systems can include the creation of habitat for organisms that prey on the target pest(s) (Yuksel and Canhilal, 2018). This strategy of pest management called biocontrol has been practiced for centuries and for certain pests can be an important part of the pest management system helping to make the pest control more environmentally friendly and economical. One example is the use of predatory nematodes to control soil insect larvae (Helmberger et al, 2018). The goal is that the nematode predator population will respond to the insect prey population and establish a new equilibrium where the insect no longer reaches crop damaging population levels. In some instances, this works as intended and can result in long term suppression of the pest (UC IPM, 2012). In other cases, secondary organisms respond to the new higher population of the predatory nematode and in turn reduce its population (Helmberger et al, 2018). This interconnected complexity of ecosystems makes biocontrol difficult to study and implement (Coquil et al, 2018). However, there are proven systems-based agricultural practices that provide preventative solutions for individual problems. Long-term management strategies that make use of diverse crop rotations, reduced tillage and cover crops can help to create healthier agro-ecosystems that are more resilient to pests and weather extremes (Coquil et al, 2018).

A study conducted in France of farmers during their transition to a more ecologically based agricultural system revealed the challenges faced by the farmers were more related to the application of knowledge rather than a lack thereof (Coquil et al, 2018). In order to modify the system, the farmers needed to buy, build or modify existing equipment to perform the new tasks. They also needed to adjust their management to facilitate different work periods. For example, adding additional crops or cover crops requires a longer time period of planting, thus changing the work flow and labor needs of the farm. Information needs changed and increased. Farmers needed more observations of biological interactions within specific fields on their farms (Coquil et al, 2018). This is a role where the skills of crop advisers are well suited. Observations of plant growth, plant health, pest populations, beneficial organism populations and the anticipated response of all of these to predicted weather conditions are key skills that crop advisers develop over time. The crop advisers in this study made a distinction between two different types of advice, hot versus cold (Coquil et al, 2018). Hot advice pertains to more traditional immediate discussions to address specific problems. Crop nutrient deficiencies that require corrective action are an example of hot advice. Cold advice refers to long-term systems planning. Encouraging farmers to think about schemes that will reduce soil erosion, or which crops to include in crop rotations are examples of cold advice. Both types of advice have benefits and consequences for the local ecosystem and can be directed to actions that manage not only the problems on the farm but can also have positive environmental effects (Coquil et al, 2018).

Research scientists are the primary source of information that explains our world and the processes in it. We each make personal observations daily with which we evaluate our understanding of the world we live in. Recently, there is a movement of scientists to more directly interact with people via internet blogs and social media such as Facebook, Twitter and YouTube to deliver science to the end user (Ollerer, 2015). Yet this is a minority of scientists and is not yet a major channel for citizens to obtain scientific information.

Trusted Adviser to Researcher/Policy-maker (Middle Up)

Research is important to provide evidence-based answers to questions and problems facing agricultural production. Identifying questions and clarifying the needs of stakeholders can be challenging for research scientists (Personal communication)[1]. Extension is one of the few conduits through which practical research questions

[1] Dr. Abbey Wick, Assistant Professor, Extension Specialist. NDSU. Dr. Caley Gasch, Assistant Professor of Soil Health research. NDSU.

originating from farmers can be posed to researchers. Farmers often feel disconnected from researchers because there is no formal interaction between the two. It can be difficult for researchers to identify which problems apply to a broad audience versus those that apply to a vocal minority. Crop advisers bridge this gap by communicating emerging problems and assessment of scale to researchers. This helps to identify research needs which are more likely to benefit a large number of stakeholders. Crop advisers can also help researchers understand the details of practical agricultural production such as the planting, harvest and time management challenges faced by farmers (Personal Communication[2]). Crop advisers are also an important source of information for policy makers (NAICC 2018). Firsthand knowledge of challenges and research needs of farmers is used to support program funding on national and local levels and help elected officials prioritize funding support for critical research.

Are Banana Farmers Being Heard? Uganda

The development of crop varieties is a critical component of agricultural success. This process requires cooperation of many groups along the way. First, specific challenges need to be identified. Traits that confer drought tolerance, pest resistance, crop quality and increased yield need to be identified and ranked in importance. A high-quality crop that gets wiped out by disease provides no benefit. Similarly, a pest-tolerant crop that lacks flavor, nutrition or other desired traits will not be marketable.

Banana was once a significant crop in Uganda; however, the varieties used were susceptible to insect pests and plant diseases that spread throughout the country (Sanya et

[2] Dr. Tom Desutter, Professor, Soil Science Program Leader. NDSU

al, 2018; Assefa et al, 2014). Recently, efforts to develop new hybrid banana varieties to resist these pests have been undertaken. Sanya et al, (2018) studied the actors involved in the variety development process, their linkages and influences on one another to better understand the relationships between people that ultimately result in the success or failure of adoption of a new variety. The study examined the roles of research, extension, farmers, market representatives, tissue culture and policy agencies including Ugandan government and non-government organizations (NGO's). Interviews, surveys and focus group meetings were conducted throughout the process of banana variety development to uncover the interactions between the parties. They found that the farmers role in influencing the final product was limited and primarily peripheral. Given the expense involved and technical nature of plant breeding, it is reasonable that the researchers and national government held a primary role in the development of the varieties. However, the lack of involvement of the farmers is concerning because if their needs and concerns are not addressed, adoption of the new varieties may not occur. One surprising finding of the study was that some NGO's were able to command an influential role in the process. It was not clear if the role of NGO's resulted in the development of successful varieties, but Sanya et al (2018) argued that this could also result in a disconnect between what is needed on the farm and what is delivered by the variety development program. The influence analysis showed that extension was the most important linkage for farmers. However, extension agents were also largely excluded from the development process. This is yet another example of the disconnect between scientists and farmers that can have important repercussions. If the researchers fail to consider the needs of the farmers, it is possible that their efforts will be wasted on a variety that is not adopted. Once again, the limitation of extension funding and personnel limited their capacity to be involved (Sanya et al, 2018). There were areas in the study region where extension was not available to the farmers, and in some areas where extension was available, they did not have the resources to influence the process. It is encouraging to note that in these areas, community members took up the role that extension would have played (Sanya et al, 2018).

Informing Policy

The distribution of knowledge of science-based and on-farm challenges to policymakers is a critical piece of science communication. Congressional Visits Day is an annual event that is sponsored by the American Society of Agronomy (ASA, 2018). Teams of volunteers consisting of a scientist, a CCA, and a science student are assembled and trained to concisely address the information needs of legislators and their staff regarding the importance of funding for science and agricultural programs. These meetings are conducted in Washington DC at the offices of the legislators and their staff. The team uses this opportunity to communicate the biological, economic and policy challenges faced by scientists and farmers in performing research and developing management strategies. Throughout the year, members of the science and agricultural communities each develop a list of priorities that they feel need to be addressed. The team meets prior to the congressional visit to streamline the message in order to properly articulate the needs of the stakeholders (ASA, 2018).

The National Alliance for Independent Crop Consultants (NAICC) works to build strong relationships with congressional delegates and federal agencies such as EPA and USDA. They are trusted sources of "data, information and clarification for issues relating to [agricultural] businesses" (Goldschmidt, 2018). NAICC members sponsor the Crawfish Boil on the Hill event every year. This time is used to interact with, network and advise policy makers about challenges faced by farmers and agribusinesses. NAICC also closely monitors and informs members of policy discussions and proposed changes. They also provide assistance for members to contact and advise their local representatives on how policy will affect constituent farmers and agricultural businesses (NAICC, 2018)

Certified Crop Advisers and crop consultants from the NAICC also provide expert testimony to the US Environmental Protection Agency (EPA) when it conducts use and needs reviews of labeled crop protection products. This information can be vital to preserving pest management technologies. Recently, members testified at hearings for the insecticide chlorpyriphos (Personal Communication[3]). The testimony informed members of the EPA of the alternatives available for the management of pests currently controlled with this product. Crop advisers and crop consultants provided direct information about the frequency, abundance and damage to crops caused by these pests as well as their experiential opinions about how removing the product would affect the farmers and environment (Moser, 2019). In this case, there was information that removing the product would place farmers in a position where only one type of insecticide was available, thus severely limiting the farmer and crop adviser practicing sound IPM principles (Moser, 2019).

[3] Dan Moser, CCA and Past President of NAICC

Citizen Connections

Citizen science is another opportunity to create connections between scientists, extension and the general public (Clyde et al, 2018). Extension personnel maintain strong connections with research scientists and can serve as the connection for citizens who wish to learn more about and be involved in research projects. Once again extension's expertise in volunteer management, budgeting and science communication and training can benefit both the researchers and citizens. The additional benefit to all is that extension can be an avenue for citizens to initiate, collaborate and help to develop research projects that address their needs (Clyde et al, 2018). An example of this interaction is the Oakland County Lake Monitoring Project in Michigan that has been in existence since 1974 (Lant, 2018). The Huron River Watershed Council trains and provides equipment to volunteers who own boats to sample water quality and screen for invasive species. These volunteers provide much more data than the agency could collect on its own (Lant, 2018). In another example, the American Ornithological Society hosts a website with content specifically for citizens who want to contribute to scientific studies (AOS, 2018). The webpage is designed to connect willing citizens with scientist. Several studies are listed, described and linked so that interested volunteers can contact the researchers and receive training (AOS, 2018). These citizen-to-scientist connections are increasing, but currently, there are few ways for citizens to propose research topics to scientists. Collaboration on citizen science projects could be one important way to accomplish this. Extension's connections with scientists from many disciplines allow them to present citizen ideas to collaborators who have the necessary expertise and interest. Equally, advisers can help citizens refine and articulate their ideas, and act as a conduit to bring their concerns and research needs to extension, scientists, and policy makers.

Hot Shots Program

The delivery of science to citizens can also utilize advisers similar to agriculture. The Hot Shots project in Denver County Colorado is one example of how extension can partner with local experts to deliver science to citizens in a mutually beneficial way. This project differs from traditional extension programs in that it is short-term (weeks-months), utilizes volunteers or part time community experts and is self-supporting. These projects address specific needs of citizens in a particular subject area. Citizen demand for a specific program initiates extension to identify community members with the skills, education and drive to deliver the program. Once vetted, extension enters into an agreement with the individual(s) to provide the training to interested citizens for a fee. Like extension partnering with crop advisers to provide information to farmers, these projects partner extension with local experts to provide the scientific information to citizens. The value of extension is that they have experience in securing funding, preparing budgets, and organizing training and volunteer events. The adviser benefits financially from fees to support the program but also socially by gaining respect and recognition from community members. These aspects mirror the VBA program in Tanzania. The citizens benefit by gaining programing that addresses their needs and interests, and extension benefits by reinforcing their value as a vehicle for the delivery of science to the public.

Filling a Need in Climate Change Solutions

Agriculture is one of the most significant industries in the world and is an important contributor to climate change though greenhouse gas emissions, land use and development and alterations of plants and animals for human needs (Howden et al, 2007). Agriculture is sensitive to changes in climate, for example El Nino/La Nina patterns affecting rainfall and temperature can account for up to 40% of yield variation in staple crops such as grains and oilseeds (Ferris, 1999). Adjustments to farming practices and energy use can provide important mitigation effects for climate change (Bernacchi and Wulfhurst, 2017; Howden et al, 2007) and resource conservation (Gabel et al, 2018).

Fossil fuel use is recognized as a root cause of anthropogenic climate change and needs to be addressed in every industry including agriculture (Robinson et al, 2018). Fossil fuels have allowed us to transport food, goods and people across the globe creating prosperity for many nations, but at the same time, we have been increasing atmospheric carbon dioxide concentration that is changing our climate with the very real possibility that we are reducing the suitability of the planet for a prosperous human future. Understanding and management of global climate change requires thinking and problem solving on a much higher level (Etkin and Ho, 2007).

The scientific consensus is that climate change is occurring, human activity is a primary cause and there is a need for immediate action to address it (Benegal and Scruggs, 2018). Despite the high degree of agreement among scientists (~97%), non-scientists continue to debate these conclusions. (Tyson, 2014; Ollerer, 2015; Benegal and Scruggs, 2018). The distinction between weather and climate for many citizens is blurred and results in misinformation and denial and the subsequent failure to act (Etkin and Ho, 2007; van der Linden et al, 2017).

Political and philosophical opinions as well as personal experiences and relationships all contribute to an individual's assessment of the true cause and severity of climate change. In the United States, political party affiliation is a strong predictor of agreement with climate change. Benegal and Scruggs (2018) showed Democrats are more likely to agree with climate change than Republicans. They also showed that statements supporting climate change made by a Republican carried more weight with all groups tested (Democrat, Independent and Republican) than if the same statements had been made by a Democrat or scientist. These strong group affiliations are also evident on social media. A study of Facebook users associated with science or conspiracy pages showed high polarization. These users commented, liked and reposted only those ideas that agreed with their existing views. Rarely did they venture out of their echo chambers. The analysis also showed that when users were faced with corrective statements, they largely ignored them (Benegal and Scruggs, 2018). Even highly compelling well-vetted arguments were dismissed. Users were also more likely to become more convinced in their stance when faced with weak statements that contradict their beliefs. This "inoculation" against differing opinions and facts that do not support preconceived ideas has been illustrated in multiple cases (Zollo et al, 2017; van der Linden, 2017). Inoculation messages can also be used to steel people against misinformation in public and social media. Presenting people with scientific facts about climate change and warning them that others will try to mislead them on these facts produced a significant protective buffer against misinformation. However, the research did not evaluate the longevity of the protection of these inoculation messages (van der Linden, 2017). While inoculation messages can be used to protect people from misinformation, they can also be used by nefarious individuals or groups to prevent them from recognizing truth (Zollo et al, 2017).

Public consensus on climate change that mirrors scientific consensus is viewed by some as a fundamental need in order to enact meaningful change (Etkin and Ho, 2007). In the realm of national policy, public support is indeed important. The lack of public support leads to time wasted arguing over politics and results in a failure to set funding priorities that could have significant national and global impact.

However, in agriculture this need for climate change consensus is being challenged. Tyson (2014), argues that climate change remains a debate; one that is not likely to be resolved. Nonetheless, sustainable actions and conservation benefits that protect water, biodiversity and environmental quality have immediate and obvious value to all citizens, including climate change deniers. Even Etkin and Ho (2007) state, "…it makes more sense to ask, how can we relate to nature in a more sustainable and functional way…". Indeed, agricultural projects that seek to provide short-term soil and water quality benefits and protection from weather events can have a great positive impact on the environment, e.g. reducing soil erosion or preventing nutrient runoff into rivers, streams and lakes. These projects lead to many of the same actions necessary to mitigate climate change without the need for consensus, assuming responsibility or placing blame on individuals, industries or countries (Robinson et al, 2018; Tyson, 2014; Gabel et al, 2018). Swiss and French farmers with the help of agricultural advisers have modified their farming techniques to increase habitat to support biodiversity and reduce fertilizer and pesticide inputs without agreement on climate change. They did not agree on anthropogenic climate change, but all farmers surveyed did agree on the environmental and human goals of maintaining soil fertility, producing healthy food, treating animals with respect, using sustainable strategies and providing food security (Gabel et al, 2018).

The university extension system in the US is a primary source for continuing education for certified crop advisers (CCA's) and because of this, there is an opportunity for extension to provide information and training directly to CCA's about climate change and practical management strategies that can help mitigate agricultural contributions. Certified Crop Advisers as a group do not show the same level of agreement about climate change as scientists (Bernacchi and Wulfhorst, 2017), yet this does not mean they cannot be agents for beneficial change. Their work is targeted at helping farmers manage challenges to production, and this includes increasing the production systems resiliency by adapting to changing weather patterns. The adaptive management that CCA's and farmers collaborate on to manage annual weather patterns includes many practices that would be implemented to manage for long-term climate change (Bernacchi and Wulfhorst, 2017). The CCA's themselves agree with Tyson (2014) that their daily work addresses climate change without the need to sort through the politics and misinformation to convince farmers or coworkers of scientific consensus (Del Corso et al, 2015, Bernacchi and Wulfhorst, 2017).

Conclusion

Effective science communication is a vital yet difficult task to accomplish. Misinformation, misconceptions and the perpetuation of ideological barriers hamper discourse and utilization of scientific knowledge. Developing trusted advisers to bridge the gap between scientists and citizens can be an important way to deliver knowledge and implement actions that address some of the serious problems that we face, including climate change. These trusted advisers are trained in science and communication, members of the local community and skilled at tailoring scientific knowledge to address local problems. Numerous successes exist in the agricultural industry that demonstrate the importance of trusted advisers as agents of change to improve the management of farming systems. There are also examples of cooperation among scientists, extension and citizens in effectively communicating and utilizing science. These advisers can also facilitate two-way communication between citizens and scientists to establish research priorities and bring research ideas from the citizens/stakeholder to the scientists. There need not be a disconnect between the public and scientists if we amend the concept of top-down and bottom-up communication to include a middle agent, the trusted adviser.

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CHAPTER 2

“Boots on the Ground” Challenges for Agricultural Sustainability

Introduction

During the spring semester of 2017 seven Doctor of Plant Health (DPH) students, one DPH alum and two professors at the University of Nebraska met weekly with the intent of adding a fresh perspective to the now clichéd problem – the challenge of feeding 9.7 billion people by 2050 (United Nations, 2015; United Nations, 2017) while mitigating climate change. This idea is referred to as "sustainable intensification…defined as a process or system where agricultural yields are increased without adverse environmental impact and without the conversion of additional non-agricultural land" (Pretty and Bharucha, 2014). References to this goal can be found in many journal articles of major agriculturally significant science disciplines; plant pathology (Chakraborty and Newton, 2011; Finkel et at. 2017; Rahman et al, 2017) soil science (Lal, 2007), entomology (Rothschild, 1998), weed science (Peters and Strek, 2018) and plant science (Bouman et al, 2007). The objective of this chapter is to discuss the importance of field scouting and direct assessment of production problems by highly trained individuals. The difficulty of obtaining accurate information and providing actionable recommendations without first-hand knowledge is also discussed.

Defining the problem

The first discussions centered around defining the part of the challenge that the group felt was within their realm of expertise. We felt that the major themes are food production, food waste, land use decisions, government and political constraints, distribution of food products and the logistics of transporting and processing raw food products (grain, milk, meat). Consensus among the group was that the skills of the plant doctors are best suited to food production challenges by reimagining and innovating solutions to the practical problems of growing food as opposed to the other human-centric challenges.

Defining Regions

Three geographical areas central Asia, the East African Community (EAC) and the central United States were selected because they represent a wide range of climate, economic, and technical differences. A forth region exploring how to utilize urban and suburban landscapes was also included because the increasing human population will continue to develop agricultural land for housing and other urban use. Students groups of one to two volunteered to identify and describe the current climate, crops, systems, pests and other production problems for one of the four areas (Asia, EAC, Central US and Urban). Students were encouraged to pick representative countries, areas or cropping systems to research and describe.

Finding Information

Information on climate, primary crops and significant pests was available; however, it was difficult to prioritize problems and pests as well as economic constraints. Discipline specific searches often yielded primary pest problems for a given cropping system, yet it was difficult to assess how important that crop or system was to supplying food and wages for the people of the region. For example, the staple crops for Asia are grains including rice, corn and sweet potato (Dixon and Gulliver, 2001). However, our group found numerous articles and substantial information regarding pest control, pesticide use and Integrated Pest Management (IPM) in eggplant. While eggplant is an important crop in the Philippines, this crop is not in the top five crops in acres, food production, revenue or economic importance for most countries in Asia, including China and Indonesia (Rehman and Jingdong, 2017; Barbier, 1989). The wealth of information available regarding eggplant production seems to be more indicative of the intensity and difficulty of managing pests rather than the overall importance of the crop to the region. Extensive research is justified because eggplant production does utilize many pesticide applications to protect the crop from insects and disease and there are significant concerns for farm worker and public health as well as environmental pollution (USAID, 2019).

Current Research

The current research discovered was highly specific and narrow in focus. It was not helpful in determining the bigger picture of a region nor in prioritizing the challenges faced. Students were unable to use the literature to form a picture of the agricultural systems in place in different regions. Therefore, students conducted interviews with experts who had studied these systems and international students who are citizens of these geographies. In all twenty-seven face to face interviews were conducted, one entomologist who worked in India and Africa, two researchers from Nebraska, fifteen international students from Rwanda and nine farmers from the states of Nebraska, South Dakota and North Dakota. Each group of interviewees presented a unique perspective on the challenges facing agriculture in their region. However, each person interviewed seemed to have a strong bias toward their discipline and personal experience. One of scientists viewed the greatest challenges as stemming from his discipline. He acknowledged that other production challenges related to different disciplines were important but did not identify them as priorities that needed to be addressed. One of the Rwandan students studying agricultural engineering identified the lack of mechanization as the most important problem limiting agricultural innovation in her country. Two North American farmers who practice conservation tillage on their farms, sited erosion caused by tillage as the most important problems facing agriculture in their region. This tendency to emphasize personal priorities and downplay other factors can skew the development and application of solutions. These personal biases and the failure to recognize them can lead to miscommunication, poor choices and an inability to recognize important problems or solutions. It was difficult to evaluate whether the number of journal articles or interviewee accounts accurately reflect the needs of the farmers or applied scientists in any region. When research focuses on examining the minutia of a problem or to tries to broadly apply results from a small number of sites, it can fail to useful to practitioners because the information gathered cannot be used to develop actionable practices. In this respect it is difficult to assess if national and global projects and funding priorities are being successful in addressing the true needs of stakeholders. Often the student group questioned who the actual stakeholders were. We were unsure if funding was being directed to benefit farmers and consumers or if special interest groups and policy makers had shifted it so far that is was only benefiting their own agendas (Sheingate et al, 2017) and “stakeholders”. Outcries are being voiced to improve funding for research on subsistence farming techniques and staple crops such as cassava (U of IL, 2016) and common bean in Africa. Such research has the potential to benefit large populations and is arguably a good investment of public monies however, private philanthropists have been the major funding source for cassava research (Zuckermann, 2018). Research funding is limited, subject to budgets and prioritized based on perceived needs. In the United States alone, as many as 75% of grants recommended to be funded under the

United States Department of Agriculture (USDA) Agriculture and Food Research Initiative (AFRI) are denied due to the shortage of available funds (ASA, 2019). This limitation on research also limits our understanding of the problems facing agricultural production and the discovery of potential solutions.

Recommendation

Despite our efforts we were not able to develop a clear picture of the systems present in the different regions. Therefore, our first recommendation is to collect first-hand observations and assessments through field scouting by highly trained professionals. This is needed to identify the problems, properly diagnose pests and prioritize needs of farmers in each region. Next, a broad interdisciplinary approach is required to reduce the amount of bias based on personal interest and past experiences. These observations along with greater consideration of interdisciplinary solutions are essential to providing answers to achieve sustainable intensification.

Scouting

There are 915 million acres of land in agricultural production in the United States with an average farm size of 444 acres (USDA NASS, 2017). In North Dakota there are 27 million acres of land in cropland production (USDA ERS, 2017) with an average farm size of 1,268 acres (USDA NASS, 2018). Nebraska has 21 million acres in crop production (USDA ERS, 2017a) with an average farm size of 934 acres (UNL Crop Watch, 2017).

Field scouting is one of the cornerstones of effective IPM. It is mentioned in nearly every pest management bulletin (Purdue, 2009), extension presentation (Pierson and Pringnitz, 2018), crop report (Markell, 2014) and many journal articles (Archibald et al, 2018; Losey et al, 2003) on pest management. Field observations and proper early diagnosis of plant diseases, fertility problems, and identification of insects and weeds along with application of economic thresholds are used to guide agricultural interventions.

Farmers are one group of individuals that are likely to scout their own cropland acres for pests and other problems. But it is important to consider that the farmer needs to perform many tasks in order to manage their entire crop and livestock operations and that field scouting is only one of these. The farmers that were interviewed admitted that they did not have time and in some cases the skills to scout their cropland acres. Given the wide variety of tasks farmers need to perform daily, it is no surprise that some of them do not have adequate knowledge or skills to properly detect or diagnose the wide range of problems that may exist in any given crop field. Realizing this, some farmers will hire agricultural supply companies or crop consultants to perform the field scouting duties (Malone et al, 2004). Agricultural supply businesses typically employ a range of professionals from non-degreed employees and college interns to seasoned agronomists, some of whom will hold four-year degrees and/or may also be Certified Crop Advisers (CCA). There are 344 and 595 CCA's in North Dakota and Nebraska, respectively (ICCA, 2019). For these CCA's to scout all the cropland acres in each state, a North Dakota CCA would need to cover an average of nearly 80,000 acres and a Nebraska CCA nearly 37,000 acres.

Certification requires that the adviser pass two written exams (International and Local) as well as accumulate at least two years of field experience providing recommendations to farmers. The exams evaluate minimum competencies of scientific knowledge across four categories, crop management, integrated pest management, nutrient management and soil and water management (ICCA, 2019). Certification is one important step toward demonstrating competency, but it does not ensure that the CCA has all the necessary skills or knowledge needed.

Not all scouting tasks require extensive knowledge or skills, in fact many pests are easily identified and assessed according to economic thresholds. Some pests while not difficult to identify are difficult to scout. Wireworms (*Elateridae spp.*) are distinctive larvae that are yellowish brown in color with a hard exoskeleton (Glogoza, 1998); however, they are soil dwelling insects that are difficult to quantify in the field. Wireworm damage is most severe in the early season when they feed on crop seeds and the young developing plants. They can cause stand loss, poor vigor and poor quality of below ground crops such as potato. Accurate assessment of wireworm damage risk consists of estimating the population of the pest across the field. Two methods are recommended. The first is soil screening, where the field scout excavates six-inch by six-inch area to a depth of twelve inches (Glogoza, 1998) or six inches deep by one foot wide and two feet long. The scout then sifts the soil through a mesh screen and records the number of wireworms found. It is recommended that this procedure be repeated approximately fifty times for every thirty to forty acres of the field (Glogoza, 1998). The second method uses wheat and/or corn as bait. Baits of one to two cups of wet wheat and corn seed are buried twelve inches deep, covered with a tarp and excavated one to two weeks later when the number of wireworms present are counted. The recommended density for the bait stations varies from five per field (Purdue, 2009a) to one per acre. In order to follow these recommendations, the average CCA in North Dakota would have to install from 200 up to 80,000 wireworm bait stations. While this may be the most accurate way to assess the risk of wireworm damage it is not efficient nor practical; therefore, it is rarely if ever utilized. Instead many CCA's and farmers make wireworm treatment decisions based on damage to previous crops, accidentally finding one or a few wireworms while checking field prior to seeding or they apply insecticide treatment to every field where a susceptible crop is planted. Management recommendations from other states recommend determining if wireworm is the cause of stand loss, and if replanting is necessary, treating the seed used to replant the field (Wright, 2018). This method does not prevent loss and is a very expensive way to react to wireworms. Replanting a field of corn necessitates that the surviving corn plants be removed, new seed purchased and then the field replanted. Considering the cost of these operations it is much cheaper for the farmer to apply insecticide to every corn field than to replant one. However, this defeats the purpose of IPM, treating a pest only when it reaches economic thresholds and avoiding unnecessary exposure of the pest and beneficial insects to pesticides.

Wireworm scouting is an extreme example of the time and labor needed to monitor for a specific pest. Many other pests including most weeds, aphids and foliar feeding insects and many plant diseases are far easier to scout; however, even this scouting is still labor and time intensive. Additionally, routine diagnostic tests that are critical for proper identification of pest and nutrient problems such as soil sampling or tissue sampling are viewed as menial tasks or “grunt” work. Therefore, it is typical for field scouting tasks to be assigned to seasonal employees who are often the least experienced and/or least educated members of the agricultural supply businesses staff.

This is unfortunate because effective scouting is not just conducted during an individual year. Observations across multiple years greatly inform where efforts should be focused and where time savings can be achieved. Well-trained and experienced field personnel can modify the scouting methods to suit the needs of the farmer and time constraints of the adviser. For instance, rather than installing high density bait traps for wireworm, a few sentinel traps can be placed in areas that have experienced damage in previous years or are suspected hotspots. Then the adviser can install a reasonable number throughout a territory to monitor pest populations over time. Ten to twenty bait traps strategically placed every season can be a valuable method for monitoring wireworm. Another benefit of having highly-trained and experience field personnel it that they are more likely to be able to identify new or unexpected pests and slowly developing subtle problems. Yet, senior members of agribusiness staff are routinely “promoted” to positions that take them out of the field. Their time is often entirely preoccupied with product sales and product placement. Which means that the collection of critical/fundamental information used to make many expensive and important decisions on the farm is susceptible to inexperience and lack of training or knowledge. Additionally, there is pressure from the retail businesses and product suppliers to push “lead” products based on profit margins or sales goals rather than on whether they fit particular pests or problems on an individual field. Adherence to IPM principles would dictate that product placement and thus sales would rely on the scouting observations of each field, however prophylactic or “insurance” recommendations are common, especially for pests that are difficult to scout. Finally, there is a real risk of developing blind spots because it is not uncommon for product performance to be measured by the lack of complaints rather than actual field observations of efficacy.

Need for Expert Knowledge and Training

University extension provides education for farmers, crop scouts and CCA's on how to manage crops, pests, fertilizers and equipment. Training provided by extension typically targets farmers and CCA's, neither of whom are likely to do most of the scouting. Training both lecture and in-field is available to field scouts, but this is typically limited to one-day sessions covering basic skills and techniques (NDSU, 2019; Pierson and Pringnitz, 2018).

Training for farmers and CCA's may consist of presentations at agricultural meetings and conferences (NDSU, 2019; Peters, 2019), in-field training (Pierson and Pringnitz, 2018) and/or informational bulletins in print and online. Typical topic-focused presentations last for 45 minutes and informational bulletins are an equally succinct one to three pages in length. They are largely written and delivered by scientists who have an advanced degree (MS or PhD) and mastery of the topic. Only basic information is provided and often a fundamental background knowledge must be assumed. However, according to a survey by USDA Economic Research Service (2017), approximately 34% of beginning farmers and 23% of established farmers have a four-year college degree. This means that more than two thirds of the audience members do not have formal training in science beyond high school. Consider also that some of the farmers possessing degrees will be trained in engineering, economics, or other unrelated fields and may have little or no additional biology training. This is not to imply that farmers are not intelligent or capable of effectively utilizing scientific knowledge. The point is that the fundamental understanding of biology and biological processes necessary to properly assess the success or failure of a practice or ability to make treatment/no treatment decisions cannot be assumed. For example, farmers have mistakenly concluded that since glufosinate (Liberty®) is a non-selective herbicide that it will kill all weeds. This is not true. While the Liberty® herbicide label lists perennial weeds such as dandelion (*Taraxacum officinale*) and Canada thistle (*Cirsium arvense*) as being controlled along with annual weeds such as waterhemp and kochia (Bayer, 2019), there is a distinct difference between control of an annual and a perennial according to the label as well as controlled (dead) according to the farmer. Mature perennial weeds such as dandelion and Canada thistle with initially appear dead because the leaves will rapidly turn brown; however, within one to three weeks both regrow, eventually recovering fully and normally producing seed whereas both the waterhemp and kochia can be expected to be dead. Not only will this cause disappointment it may lead to a farmer to erroneously conclude that he has glufosinate resistant dandelion and/or Canada thistle.

Need for Interdisciplinary Solutions

Common agricultural solutions identify practices and management that target one or a few problems within a specific area of study. For instance, recommendations for control of a weed such as marestail (*Erigeron canadensis*), a winter annual broadleaf weed, may include fall tillage (Jhala and Elmore, 2018), herbicide applications with rotation of multiple modes of action (Jhala and Elmore, 2018), as well as both a pre-emerge and post-emerge herbicide that are effective on this species (Loux, 2013), and using cover crops to suppress marestail growth (Jhala and Elmore, 2018). In the context of this one problem, this is a robust IPM management plan. It includes, cultural, mechanical and multiple chemical control strategies that should lead to effective long-term management of this weed. However, this approach ignores the fact that this weed prefers to grow on lighter sandy soils on top of knolls and hilltops, areas that are prone to wind erosion. Fall tillage exacerbates wind and water erosion, reduces soil infiltration rates and increases soil-water evaporation. All of these are detrimental to soil and crop productivity and can have negative effects on the local environment through soil erosion that may also carry nutrients and herbicides into local waterways. Examples like this are common any time one problem is addressed in isolation without regard to other components of the system, thus increasing the potential for adverse effects from a specific management practice.

Other examples include below threshold insecticide treatment reducing predators that help control soybean aphids (*Aphis glycines*) (Hunt et al, 2019), fungicide applications that suppress natural fungal controls of twospotted spider mite (Gent et al, 2009) and many more. These interactions occurring within the production system need to be considered prior to implementation of a management strategy targeting a single issue. There are several instances where the adage “the cure is worse than the disease” (attributed to Francis Bacon) may be true. The skills required to identify these potential negative interactions and their consequences require deep fundamental knowledge of plant science, weed science, entomology, plant pathology, soil science and economics. This also includes the ability to locate and critique primary literature and the creativity to adapt, adjust and create management strategies to mitigate non-target effects as they apply to cropping system and environment as a whole.

Conclusion

Correct identification, assessment and prioritization of agricultural pests and problems present in a field or region can only be accomplished through direct observation (scouting). Scouting observations need to be paired with strong scientific knowledge of the biology and ecology to properly ascertain the cause of each challenge and to frame this information within the context of the system. Advisers need to be able to consult and understand the primary scientific literature and the foundational science behind the data and recommendations. They also need to be able to modify the practices to fit the specific needs and context without compromising the validity or value. It is this interface where the “rubber meets the road” with “boots on the ground” that our wealth of knowledge will provide benefit. What good is the tool that is never used or the science that is never applied?

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CHAPTER 3

From Ideas to Action

Introduction

This chapter examines case studies of integrated management of agricultural systems. These case studies have been assembled from experiences gathered from the past twenty years of working directly with farmers. These challenges are real problems faced by real farmers. The solutions presented stem from the philosophy that agriculture is the management of an interconnected system rather than a collection of individual problems. The management practices that result will vary based on the parameters of the specific system in question but the overall intent is to provide examples of how system assessment, problem identification, resource inventories can be used to develop integrated systems solutions.

Initially, the process begins with identifying specific challenges that need to be addressed immediately. This includes activities such as identifying pests, monitoring crop nutrients, assessing soil conditions (salinity, water infiltration, soil aggregation), etc. Then existing knowledge is gathered from local experts, extension bulletins and published research to understand the biology, potential management strategies and logistical challenges of implementing the solutions. Conditions related to a specific location, farmer, farm, field and goals are considered and prioritized within the system. Strategies that provide promise for managing the problem while minimizing side effects are tried. Finally, modifications guided by strong scientific and practical knowledge are employed to customize the solutions. This process can be undertaken by anyone willing to invest the time and effort, whether they be farmer, adviser or scientist. However, this person needs to possess sufficient knowledge to be able to accurately diagnose, quantify and prioritize the challenges within the system.

Case Studies

EQIP Program

The first case study considers Matt, a farmer who signed up for a government program to cost share the implementation of new nutrient management practices. The Natural Resources Conservation Service (NRCS) of the USDA sponsors the Environmental Quality Incentives Program (EQIP). This program assists farmers with identifying conservation goals for their farm and helps to provide financial assistance to implement practices that will help to achieve these goals (USDA, 2019a). Matt's goal was to improve nitrogen fertility in grain corn (*Zea mays*). Under the EQIP program Matt signed a contract stating that he would implement the practices for a minimum of three years on each field. The strategies that Matt and the conservationist selected for implementation were applying nitrogen fertilizer using variable rate technology and plant tissue analysis, either in-season leaf tissue nitrate or at maturity corn stalk nitrate. Reimbursement to Matt was contingent upon his ability to verify that both practices were implemented on each field at least once during the three-year contract. Both practices are approved conservation practices to qualify for EQIP; however, NRCS guidelines do not provide specific recommendations or prescriptions for these program practices. But the farmer is required to follow land grant university guidelines (NRCS, 2006; USDA, 2015).

Corn leaf tissue analysis for nutrient content is a useful tool for diagnosing nutrient deficiencies (Battel, 2018), and corn stalk nitrate analysis can be used to inform fertility adjustments for the next time the field will be planted to the corn (Shapiro, 2011). Farmers like Matt can easily find references on how to collect, handle and "interpret" plant tissue samples (Agvise, 2019; Battel, 2018; Shapiro, 2011; Thom et al, 1991) or they can hire one of many local businesses to collect and ship the samples to an approved laboratory. However, applying this information to make specific changes to nitrogen applications is difficult. There are no rate recommendations for nitrogen management based on corn stalk nitrate tests. Interpretation guidelines state that at high nitrate levels (>2000 ppm) it may be possible to reduce nitrogen applications (Agvise, 2019; Battel, 2018; Shapiro, 2011). At moderate nitrate levels (450-2000 ppm) nitrogen was likely adequate (Agvise, 2019; Battel, 2018; Shapiro, 2011), and at low nitrate levels (<450 ppm) it may be economical to apply more nitrogen (Nielson, 2003). There are no established recommendations for fertility applications using in-season leaf nutrient tissue testing for any crops in North Dakota (Personal Communication[4]).

Rate adjustments based on tissue samples need to consider weather, field variability, crop stage and condition (Thom et al, 1991), crop markets, available equipment, labor and time available on each farm. Matt's main goal for adding tissue sampling was to help him implement in-season nitrogen applications on grain corn. However, after collecting the corn stalk nitrate tests the first fall, he had more questions than answers. Should he use dry, liquid or gas nitrogen fertilizer for the in-season application? At what timing should the fertilizer be applied? What percentage of the total nitrogen should be applied in-season? Should he apply the additional nitrogen if the corn crop is under stress, has a reduced stand, or has been damaged by storms? Should the in-season rate be increased if the corn is doing well, had heavy weed competition, or the

[4] Dr. Dave Franzen, Extension Soil Specialist. NDSU.

field was excessively wet? Should he still apply the fertilizer if weather or equipment breakdowns caused him to be later than expected? How late is too late?

To help Matt answer his questions it is important to understand his system. Matt manages 2,500 acres of cropland including spring barley (100 a), grain corn (1000 a), dry edible bean (400 a) and soybean (1000 a). He has one highly skilled full-time farm worker and one low skilled part-time farm worker. In-season fertilizer application to his corn needed to be done in a timely manner while minimizing damage to the growing crop; therefore, it was likely that this practice would need to be performed by him, his highly skilled worker or a dependable outside business.

There are no agronomic differences between the fertilizer sources (Silva, 2018); however, there are price and handling differences that are very important. The three types of nitrogen fertilizer products available to Matt for use on dryland corn are gas nitrogen (anhydrous), liquid (28% nitrogen) or dry (urea). We discussed the pros and cons of each form of fertilizer. The gas form is the least appropriate for several reasons. First, a large percentage of his farm is grain corn (40%) and over half of his acres are long-term no-till. The gas form of nitrogen needs to be injected into the soil to reduce losses. It will be difficult to inject the fertilizer into long-term no-till soils due to the aggregation of soil particles and residue remaining on the surface of his fields. Additional challenges to consider with gas fertilizer are the need to purchase or build a machine to apply the fertilizer, timing the application before the corn becomes too tall for the machine (~20-24”). There is a potential for his fields being too wet for this type of machine in the early part of season. The final complication to using gas fertilizer is he cannot hire help because there are no custom applicators in the area that have equipment to apply this type of fertilizer.

Liquid fertilizer is more reasonable but still not the best alternative. One benefit of the liquid form is that he could use his herbicide applicator (self-propelled sprayer) to apply the fertilizer with a small investment in Y style drop nozzles. He would also have the ability to apply sulfur fertilizer (ammonium thiosulfate) at the same time if needed. Liquid requires less time than gas and his machine would allow for a wider application window (up to tasseling). However, his sprayer is busy from May through June applying herbicides to all his crops and applications will need to be made in July or later. Even in July he would need to schedule the fertilizer application around the timing of important fungicide applications to his dry edible bean crop. Also, there is a limit to the rate of fertilizer his machine can apply and there are only two custom applicators in the region that can apply liquid.

Dry fertilizer is a more effective option for Matt because he has a machine that can apply the fertilizer (spinner spreader) that would only need a slight modification for in-crop use early in the season. In addition, there are several custom applicators that he can hire later in the season: he can add a dry sulfur (ammonium sulfate) or potassium (potash) fertilizer if needed. The machines that apply dry are also capable of delivering higher rates than liquid, dry takes less time to apply than gas, and it may be possible to train the low-skilled worker on the farm to use the dry application machine. The negatives for dry are that it is more susceptible to volatilization loss if rain is delayed, (Jones et al, 2007) and he will need to hire a custom applicator if the corn gets above the maximum clearance of his machine (~24" tall). The risks of using the dry product can be managed by adding a nitrogen stabilizer and planning ahead by developing a late season contingency agreement with one the local custom applicators. This discussion helped him to solve the logistical questions related to fertilizer type and application.

Considerations for implementing variable rate technology for nitrogen fertilizer applications followed a similar process. Knowledge specific to Matt and each of his fields was critical to being able to provide useful recommendations. Even though variable rate applications use high-tech satellite imagery, harvested yield maps and digitized soils maps, the field-based observations of the adviser and farmer are essential for producing quality management plans. Although technology is improving rapidly, satellite imagery is not capable of accurately identifying the cause of crop variability such as weed growth, plant disease, insect pressure or environmental problems such as drought or saturated soil (Cassidy and Palm, 2002). For this reason, ground truthing of satellite images is important especially if those images may to be used in subsequent years. It is important to know if the cause of the variability in yield is a permanent feature of that location or a transient problem due to weather, pests or the like.

Similarly, the value of harvested yield maps is highly dependent upon proper calibration (Nielson, 2018) and “cleaning” of the data (Nielson, 2016). Yield monitors need to be calibrated often to provide accurate representations of yield variability within the field (Nielson, 2018). Cleaning yield data removes or corrects erroneous data points that may result from turning or stopping within the field to check or unload the machine (Nielson, 2016). Problems that are not consistent across years should not be used to make fertility management decisions for that location. Data layers without ground truthing or with poor data can lead to inaccurate maps and poor management decisions.

Additional discussions of Matt's resources and risk tolerances led to a targeted timing for in-season nitrogen applications (12-36" tall) and the percentage of nitrogen fertilizer to apply preplant versus in-season (70:30). Following this, an in-season assessment of plant stand, plant health, pest pressure and plant tissue analysis are collected in crop from different regions in each field and used with weather forecasts, crop price estimates and fertilizer prices to modify the plan in-season. This allows Matt to adjust his management to fit the estimated economics and conditions in each field in a given year.

Educated Guess or Expert Opinion

The second case study involves a farm operated by two brothers who have been using cover crops in parts of their system for several years. They grow field pea, spring wheat, corn and soybean. They have been using no-till soil management practices for fifteen years and added cover crops to the system five years ago. No-till and cover crops practices have helped them reduce soil erosion, manage excess water, and increase water infiltration without tillage. They hope that cover crops will help build soil organic matter over time. The brothers have limited their herbicide selection to herbicides that have a very short or no residual persistence in the soil in order to prevent herbicide damage to the cover crops. However, they are having difficulty controlling several weed species, and in some fields they are experiencing yield loss due to weed competition. The brothers also suspect that some of the weeds are resistant to the herbicides they are using. The brothers realize that they need to adjust their weed management, but also want to continue to use cover crops in their system. They have not been able to find advisers willing to help or information they can use to determine the best herbicide strategy.

The brothers have reached out to local agronomists, CCA's and extension personnel for help in managing their system but have largely been rejected and disappointed. According to one brother, "the people that we asked for help didn't understand what we were doing or why. They either didn't know anything about cover crops or where to find answers or didn't care enough to look. We've been on our own and have made a lot of mistakes over the years that we should have been able to avoid."

Even though they are located a considerable distance from my clientele base, I agreed to work with the brothers beginning in 2018. Scouting the fields revealed that the major weeds species present were waterhemp (*Amaranthus tuberculatus*), common ragweed (*Ambrosia artemisiifolia*), marestail (*Erigeron canadensis*), and kochia (*Bassia scoparia*). Populations of these weeds in the region are known to be resistant to both glyphosate (Group 9) and ALS (Group 2) herbicides (Stachler 2013). Glyphosate and where possible glyphosate plus 2,4-D are the main herbicides the brothers have used on all fields both for pre-emerge and post-harvest weed control. Additional herbicides in their system are carfentrazone (Group 14) plus sulfentrazone (Group 14) pre-emerge and paraquat (Group 22) as a pre-harvest desiccant on field pea (*Pisum sativum*). In-season herbicides have been glyphosate plus dicamba in corn (*Zea mays*), glyphosate only in soybean (*Glycine max*), and clopyralid (Group 4) plus fluroxypr (Group 4) plus MCP ester (Group 4) in wheat (*Triticum aestivum*). They have been using multispecies cover crop mixes that include various combinations of radish (*Raphanus sativus*), turnip (*Brassica rapa*), cereal rye (*Secale cereale*), barley (*Hordeum vulgare*), oats (*Avena sativa*), crimson clover (*Trifolium incarnatum*) field pea (*Pisum sativum*), proso millet (*Panicum milaceum*), sunnhemp (*Crotalaria juncea*), and sorghum sudangrass (*Sorghum *x drummundii*). They are willing to consider modifications to their system, but the main goals revolve around the prevention of soil degradation. Therefore, regular full tillage of their fields is a practice they are very reluctant to consider.

In order to help the brothers assess herbicide risks on cover crops, it was necessary to consult herbicide labels and other published herbicide references such as university weed control guides and the Herbicide Handbook published by the Weed Science Society of American (WSSA, 2007). Herbicide labels are considered the legal and definitive reference for the use of the herbicide. However, herbicide labels rarely include recommendations concerning cover crop usage on herbicide treated fields. In the few instances where cover crops are mentioned on the herbicide label, the recommendations are highly restrictive and often impractical. For example, the Capreno® herbicide label states that "cover crops can be planted 90-120 days after application" (Bayer, 2019). In the region where the brothers farm, Capreno® herbicide is likely to be applied in early June, thus according to the label cover crops could not be planted until September. This recommendation effectively precludes planting cover crops given that the average first frost for this region typically occurs during the last two weeks of September (NDSU, 2016) which would not leave time for adequate cover crop growth. However, it is possible to estimate the potential for herbicide injury to cover crops by using information found on the herbicide label, university weed management guides, the Herbicide Handbook and knowledge of how to determine the botanical classification of the cover crop, local cash crops and weeds.

The first step was to identify which herbicides will likely provide the best control of the target weeds. Next the scientific family of potential cover crops was determined and cross referenced with the families of agronomic crops and weed species listed in the university weed management guides. For example, radish belongs to the mustard family (*Brassicaceae*) as does the crop canola (*Brassica napus*) and the weed wild mustard (*Sinapus arvensis*) (USDA, 2019b). Crimson clover is a legume (*Fabaceae*) along with the weed black medic (*Medicago lupulina*) and the crop alfalfa (*Medicago sativa*). Weed control and crop rotation information found in the university weed control guides was used to determine which herbicides give reduced control of the cross-referenced weed(s) and which herbicides have shorter rotation restrictions to the cross-referenced crops. The risk of each cover crop and herbicide combination was rated as either low, moderate or high based on weed control and crop rotation restrictions. The next step was to consult information on herbicide half-life, degradation route and soil pH and organic matter interactions found in the Herbicide Handbook. This information was used to estimate the persistence of each herbicide given the field and weather conditions for the specific year, again classifying risk of persistence of each herbicide as low, moderate or high. Together this information was used to select a combination of herbicides that would likely give good to excellent control of the target weeds and select cover crop species most likely to survive in each situation. The degradation information was also used to estimate a reduced risk time frame when the cover crops could be seeded and were still likely to have enough time for adequate growth prior to frost.

The brothers were informed that cover crops seeded into herbicide residues should not be grazed or harvested for forage unless the label specifically states these practices are allowed. We also discussed that while this assessment helps reduce the risk of cover crop injury it does not provide information as to which herbicides will be safe for a given cover crop. We also modified the number of species they used in a cover crop mix based on specific goals in each field. Several cover crop species the brothers have used perform similar if not redundant functions in the field. For example, radish and turnip both grow rapidly, quickly covering the soil and produce taproots that can help to manage compaction (Chen and Weil, 2010); however, turnip tends to have more root mass above ground and radish tends to produce a deeper tap root. Therefore, turnip is somewhat more suitable for grazing, whereas radish is more suitable for managing compaction and helping increase soil water infiltration. Since their goal was to help increase soil water infiltration it is not necessary to put turnip in the mix. Similarly, oats and barley are very similar in speed of growth, root type and herbicide susceptibility; however, barley is much more salt tolerant (Franzen, 2013). Therefore, barley would be a better choice than oats for a saline soil.

This is an example of how a well-trained crop adviser can use knowledge and resources to provide an "educated guess" or "expert opinion" to help farmers define their goals and evaluate the risks associate with a particular practice thus helping them make more informed decisions. While research into cover crop and herbicide interactions is on-going and will further quantify herbicide injury risks, this research is broad in nature and will not be directly applicable to individual farmers, fields or goals. Hence, there will always be a need for experts willing to provide risk assessments to assist in applying the science.

Evaluating an Innovative System

Implementing known and well researched practices requires an interdisciplinary approach and mindful consideration of the whole system' But experimenting with the development of a new system can be even more intellectually challenging. The third case study explores the informational needs of an innovative farmer who is trying to puzzle out a new system. Woody does not have a specific end goal in mind, rather he is continuing a journey of improving his soils which began over twenty years ago. The journey began by incorporating no-till and later cover crops, and he is contemplating how to convert part of his no-till conventional system into a no-till organic system to take advantage of price premiums for organic commodities. Woody wants to do this without sacrificing economic returns during the conversion. He would also prefer to avoid using forage crops as a revenue source because this would require him to make a substantial investment in additional equipment. Woody's farm is approximately 400 acres of winter wheat, grain corn and soybean in the Great Lakes region of North America. Woody works closely with local university scientists to conduct research on his farm, and he has developed hypotheses that are currently being tested on his land by multiple scientists in different disciplines. This connection with the university has allowed him to present his ideas to several scientists and ask for their advice and constructive criticism. He has also posed his idea to several crop advisers. Woody has expressed disappointment in that several of those he has consulted refuse to or are unable to seriously consider his idea. He has described several occasions throughout his career where he was dismissed and discouraged by agricultural professionals as well as other farmers only to later have some of these same individuals ask his advice on how to follow in his footsteps.

One of the practices that Woody believes has been very beneficial is under-seeding winter wheat with annual and biennial clover species. He is confident that this practice reduces soil erosion, suppresses weeds and potentially fixes nitrogen for the following corn crop. Therefore, he wants to use clover as a foundation for the new system. He is planning to plant alternating strips of forty-inch wide perennial clover cover crop with twenty-inch wide cash grain crops. The crop planted on the cash grain strips would be rotated every year through winter wheat, grain corn and soybean. This spacing was chosen because he has equipment designed to work on twenty-inch centers. Thus, if he needs to modify his machinery it should be simple and come at minimal cost. Woody's main question is what problems are likely to develop within this system? Of particular interest are weeds, insects and disease. Then given the predictions of potential problems, what management strategies can be employed now that will mitigate these issues in the future.

In order to embrace this challenge, the scientist and/or adviser needs to consider the entire system from sunlight to soil. Known problem pests that are present in Woody's system include marestail (*Erigeron canadensis*) and phytophthora root rot (*Phytophthora sojae*). Additional management questions Woody has are: How can he keep the clover from encroaching upon the cash crop rows? What diseases are likely to develop? How can the clover be suppressed without killing it? Will mowing the clover and spreading the mulch into the cash crop rows be beneficial (weed control), detrimental (disease spreading) or both? How can light interception of the cash crop be maximized? How might beneficial insect populations be affected? How can fertility be maintained?

Considering these questions is a useful exercise. It encourages the participant to carefully evaluate the benefits and drawbacks of seemingly simple or obvious solutions. For instance, using a straight disk at the boundary of the clover and cash crop row to cut the clover roots might be an easy way to keep the clover from encroaching upon the cash crop rows; however, closer examination leads to important additional questions. How often would this need to be done? Can it be done successfully? Will the disk be able to go deep enough? Or will the clover roots extend beyond what can be cut? Will severing these roots encourage root diseases such as phytophthora or verticillium wilt? Similarly, the idea of mowing the cover strips to suppress the clover and spreading the clippings into the cash crop row may be an effective way to suppress weeds and cycle nutrients but it may also encourage diseases such as bacterial leaf blight and white mold. Yet, there are studies of plant chemical defense that suggest clipping the clover at specific times could be a beneficial way of repelling insects such as aphids and some leaf feeding caterpillars by releasing volatile organic compounds such as linalool and E-β-farnescene (Mithofer and Boland, 2012). If this works, clipping the clover may deter soybean aphids. Although this case study is purely a thought experiment at this point, participating in this and similar discussions is a way to re-envision crop production systems while attempting to consider the multiple reverberations of each management strategy.

Long-Term Relationships

The final case study demonstrates the value of long-term relationships between individuals with differing skills and talents. Tony is a fourth-generation farmer and the second generation of the family that I have worked with. I have been present as an adviser on this farm for over seventeen years and have known Tony since he was in high school which was prior to his involvement as a farm owner/operator. He is a highly intelligent and innovative farmer that is constantly evaluating ways to improve the long-term profitability and sustainability of his operation. His father Mark, who I started working with is still involved in the farming operation as a highly skilled laborer, but he has traded in his managerial duties for a fishing boat. For the last three years, Tony has been making all the critical decisions.

One of the first parcels of land that Tony purchased fifteen years ago was a highly eroded field with a lighter than average sandy soil and below average yield potential. In fact, these are the reasons why this land was for sale and why he was able to afford it early in his career. While not a bargain, the price was reasonable for the time, and he needed to purchase land to begin building his business.

Mark had been using minimum/no-till practices for many years, a soil management strategy that Tony continues. They typically apply anhydrous in the spring and follow that with a vertical tillage pass just before planting corn. Approximately twenty-five percent of Tony's fields are planted to corn, and not all fields have corn in the rotation. Spring wheat, field pea, barley, oats, cereal rye and soybean are all direct seeded with no field tillage.

The purchased land had been farmed conventionally with two full tillage passes each year for at least the last twenty years. Evidence of severe wind erosion was easy to find as were serious weed infestations. Tony's goals for this land included reducing erosion and controlling the weeds. His overall goals for his farm were paying his operating loan each year and making enough money to support himself. As a beginning farmer his economic tolerance for risk was low which meant that every investment he made needed to have a high chance of providing a positive return.

Tony and I agreed that the first priority for this field was getting control of the weeds. Therefore, we decided that glyphosate-tolerant soybean would be a good crop to start with. This turned out to be a mistake. We had both underestimated the devastating effects that decades of erosion had on the field. Prior to his purchase, I had consulted the soil survey and determined that there was a significant high sand (50-70%) subsoil layer beginning at eight inches and extending to three feet below the surface. This was a concern because rainfall in this area is limited and unpredictable in late summer and fall. He and I knew that late season drought was a possibility, but we had chosen an early maturing variety and planted the field early to try to manage this risk. Although rainfall in late summer was more than we expected the soybean crop still experienced severe drought stress which reduced the yield. The resulting yield was so low that he lost money on the crop that first year. In August of that year, I dug a small root pit to more closely examine the soil. I found that much of the surface layer that was mapped in the soil survey was gone. There was far less water holding capacity in this field than we had expected which meant that even in a year with fair rainfall, it was not enough to support a late season crop. One positive effect was that we did begin to get control of the weeds.

The failure of the first year caused us to reevaluate our management plan and change the primary goal to improve water management. We wanted to more efficiently use early season water, attempt to reduce water losses to evaporation and try to increase the water holding capacity of the soil. To this end we began using cool season early maturing crops such as field pea, spring wheat and winter wheat. The no-till practices seemed to help reduce erosion, but some soil loss to wind was still evident in the winter months with soil evident in the snow next to the field. We were hoping that preserving as much standing crop residue as possible would help catch snow and reduce evaporative water losses. After approximately three years, we began to plant cover crops after the cash crop had been harvested. We selected cover crops that would quickly cover the soil and use less water.

Fifteen years later, we continue to focus on cool season early maturity crops and cover crops to protect the soil and preserve moisture. We have refined the cover crops that are used on this field. Currently, we are using flax (*Linium usitatissimum*), oats, and field pea. This mixture provides early ground cover to reduce evaporation and provides standing residue that helps catch snow in the winter but has dense enough residue in the spring to reduce evaporation. There have been a few years where the fall moisture has been above average and we were able to get a good economic return by changing the next season's crop to early maturity soybean. The soil organic matter has increased by about 0.8% over the years to approximately 2.3%. This is still below average for the area but a definite improvement that likely helps retain water. However, we have seen dramatically improved soil aggregation and infiltration. This, together with using cover crop residue and early season crops, seems to be helping rebuild the soil, but it is difficult to measure improvement through a few soil property changes. Most importantly, we have learned to take advantage of resource availability to make management changes. These have resulted in small gains in water conservation which seem to have had a larger cumulative effect. Crop productivity continues to be fragile on this field, but we have learned how to manage this land profitably.

Conclusion

These and many other farmers are experimenting with different practices and ideas on their farms. Farmers that challenge the conventional practices and strategies in their regions need information, advice and support beyond the local conventional wisdom. Each of these farmers has expressed that they would benefit from information providers that could help them better understand their systems and better estimate the risks and benefits of practices they are experimenting with. These farmers have all formed partnerships with local research scientists, but they believe there is still a gap between the scientific knowledge and ability to apply it in the field.

These case studies demonstrate that developing successful solutions to systems problems relies on developing a trusted relationship between the farmer and adviser, sufficient depth of knowledge to accurately diagnose problems and the ability to put this all into the context of a particular system. This system specific approach to applying techniques and technology helps to remove barriers to adoption of new strategies. The case studies in this chapter demonstrate why on-farm challenges need to be well understood by scientists and policy makers. Challenges faced by Matt show the importance of solving logistical challenges. Financial incentives may encourage some farmers to consider new strategies, but approved tests and practices need to be paired with guidance on how to properly implement them to result in action. While leeway is necessary for customization, lack of direction can create confusion, disappointment and may ultimately result in the failure.

The story of the brothers illustrates the need for knowledgeable experts to apply broad concepts to specific situations and extrapolate knowledge to inform practical implementation. It also warns that complacency of experts can lead to the erosion of trust and the loss of their value. When I met them, both brothers had largely given up on finding an adviser who was willing to address their need for practical information and would be able to understand their goals and help achieve them. Developing a management plan in farming is about risk management. Carefully constructed expert opinions can help farmers more accurately evaluate risks and benefits and improve management choices.

Woody's challenge to anticipate the problems that may develop under a new system encourages scientists and advisers to stretch their boundaries and apply their hard-earned knowledge, education and experience to solve real world problems. It demonstrates the importance of creativity, open-mindedness and the value of careful evaluation of seemingly simple practices. Rethinking each step in a system helps to ensure that sound practices will be reinforced, and questionable ones will be examined critically and likely changed or improved.

Finally, Tony's story shows the value of long-standing relationships built upon trust and mutual respect. He and I have made mistakes together as a team, we have tried to keep them small and manageable, and we have tried to learn from these mistakes and adjust accordingly. When a long-standing trusting relationship is achieved, agronomy can transition from reactively managing immediate problems to predicting future challenges and managing them proactively. Proactive management affords the farmer and adviser time to consider, observe and investigate new strategies and evaluate how they perform and affect the whole system. Yet, what I believe is most important about Tony's story is that he continues to farm today and is currently supporting the fifth-generation farmers in the family and hopefully the third generation that I will have the privilege to work with. This is a critically important part of sustainability that is often overlooked, the economic sustainability of our farmers and their families.

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Epilogue

The scientific study of agriculture has led to the development of several solutions to many challenging problems. However, we continue to experience soil erosion, water quality issues and the loss of agricultural products due pesticide resistance by insect, weed and disease pests. Failure to implement effective strategies is due in part to poor communication, improper diagnosis and insufficient integration of these solutions as part of a specific farm production system. Clear two-way communication between researchers and farmer stakeholders can be facilitated by experienced and knowledgeable advisers. It is not only important that the advisers possess high level science literacy and effective communication skills, but also that they are worthy and capable of garnering the trust of both researchers/extension and farmer stakeholders. Knowledgeable trusted advisers can serve as mediators and translators facilitating the application of science-based solutions to address the problems farmers face as well as communicating to scientists/extension research needs that need to be addressed. Therefore, the traditional paradigm of a top-down communication model should be shifted ninety-degrees to illustrate the transfer of information as a lateral flow between partners with the trusted adviser acting as a facilitator for bi-directional flow of information between farmer and researchers. This shift in view will increase the direct interaction between research scientists and stakeholders but also emphasizes the importance of the trusted advisers.

Trusted advisers are scientific practitioners working in a supportive role translating, filtering and facilitating knowledge exchange. Translation is important to prevent confusion and frustration related to jargon and confusing terminology used by both scientists and farmers from impeding communication. This confusion not only affects stakeholder implementation of technology but also researcher understanding of on-farm problems. For example, the terms hair-pinning (occurs during planting when seeds are surrounded by residue instead of soil), gumbo (typically wet, sticky, high clay soils), and stools (tillers of grass crops) clearly convey particular ideas between farmers but often confuse researchers. Similarly, researchers tend to use the term significance in a statistical context whereas farmers will often interpret significance in an economical sense. These subtle differences can lead to profound miscommunication and frustration.

Farmers and scientists each experience different challenges in the performance of their duties. The realities and challenges related to farm logistics, equipment, labor and timing is not always clear to researchers. Similarly, the value of replication, blocking and awareness of confounding variables is not necessarily intuitive to farmers. Complete empathy between farmers and researchers is not a necessity but sympathy to each other's challenges could promote improved understanding and effective communication. The trusted adviser is an individual who can translate jargon to plain language and bridge the knowledge gap between researcher and farmer while also filtering the information. This filtering role can prevent the flood of irrelevant information from overwhelming either the farmer or researcher. Excessive information, especially that which is not relevant to the research or the application of science can lead to apathy and a breakdown of communication.

The trusted adviser also plays a crucial role in the collection and synthesis of observations, data, and other information relevant to the application of site-specific science-based solutions. The ability of the trusted adviser to accurately diagnose problems and their causes, as well as understand the logistical challenges faced by the farmer can be the difference between adoption and rejection of a new practice. Understanding the scientific principles behind research-based recommendations allows the trusted adviser to suggest modifications and compromises that address specific needs and capabilities of individual farmers while maintaining the integrity of the practice or strategy. The case studies presented in this document demonstrate that providing customized systems-based solutions can result in increased adoption of new strategies. It is important that more agronomists, agricultural salespeople and crop scouts rise to the challenge and join the ranks of the trusted adviser by increasing their scientific knowledge, addressing each field through scouting and building trust with farmers and researchers. This army of trusted advisers could dramatically increase the implementation of systems-based solutions. It is the author's belief that these small steps done on a grand scale will become the march of change needed to address the grand challenges of feeding 9.7 billion people, global climate change, agricultural sustainability and food security.