From Data to Decisions – Ag Technologies Provide New Opportunities and Challenges with On-Farm Research

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A paper from the Proceedings of the
14th International Conference on Precision Agriculture
June 24 – June 27, 2018
Montreal, Quebec, Canada

Abstract. *U.S. farmers are challenged to increase crop production while achieving greater resource use efficiency. The Nebraska On-Farm Research Network (NOFRN), enables farmers to answer critical production, profitability, and sustainability questions with their own fields and equipment. The NOFRN is sponsored by the University of Nebraska – Lincoln Extension and derives from two separate on-farm research efforts, the earliest originating in 1990. Over the course of the last 29 years, new agriculture technologies have become more common on farms, providing opportunities to both evaluate the utility of these technologies through on-farm research (such as multi-hybrid planting and crop canopy sensors) and use these technologies to expedite on-farm research implementation and data collection (such as variable rate applications and yield monitors). Additionally, spatially dense data such as yield monitor data, EC data, and aerial imagery are more readily obtained, allowing for new approaches to data analysis and interpretation. Specific skills and additional time are required to fully utilize data from these available technologies; access to individuals and teams with skills in data management systems and spatial data analysis are invaluable, yet many extension educators express low knowledge in using these technologies. Training opportunities are needed to enable educators and researchers to be confident in using these technologies when conducting on-farm research.*

As the NOFRN participation and geographic footprint has grown, new tools have been developed *and employed to facilitate on-farm research data collection, analysis, and sharing. A variety of mediums including twitter, email newsletters, and YouTube are leveraged to extend opportunities and research findings to a technologically proficient generation of farmers and crop consultants. A smartphone app was developed to aid in plot layout and data recording. Additionally, an interactive archive of study results is available online. To assess long-term impacts of the program, cooperating farmer perceptions, motivations, and behavioral changes resulting from study participation were documented in 2002 and 2016. In 2016, a study of 40 past on farm research participants documented experiences in an on farm research program. The study found that an increase in use of new agriculture technologies has made conducting on-farm research more feasible and less demanding at harvest, reducing the number of participants who thought about quitting participation in on-farm research.*

Keywords. *On-farm research, citizen science, technology adoption, social media, big data, precision agriculture data management.*

Introduction: Nebraska On-Farm Research Network

Over 91% of the land area of Nebraska is in farm operations (USDA National Agricultural Statistics Service, 2016). Cropping diversity is limited, with corn and soybeans making up the majority of planted acres; however, there is tremendous climatic and geologic diversity. This makes research results from traditional research stations difficult to apply to the vastly different conditions found across the state. Therefore, on-farm research is a valuable tool allowing products or practices to be researched in a variety of conditions and environments where they possibly would be implemented.

At the University of Nebraska – Lincoln, a formal on-farm research program began in 1990 in Saunders County in east-central Nebraska. This localized group of 12 pilot growers committed to conducting a research project for three years. The members identified their own topics of research. Private industry representatives contributed time and expertise annually. Another on-farm research effort began in the mid-90s in south-central Nebraska. Producers participating in this group worked together to identify potential research topics of mutual interest, and were able to collect several site-years of data quickly by using similar protocols. Wortmann et al. (2005) discussed the history of these two groups. The different approaches within these two early Nebraska groups is indicative of the wide variety of approaches taken to on-farm research. In 2012, these programs and other scattered efforts were combined to form the Nebraska On-Farm Research Network, a statewide program sponsored by the University of Nebraska-Lincoln Extension and supported by the Nebraska Soybean Board, the Nebraska Corn Board, and the Nebraska Corn Growers Association. The program has evolved and grown over the years. Currently there are several approaches to research within the program; research projects may be initiated by university faculty, industry representatives, farmers, and combinations of these three groups.

The Nebraska On-Farm Research Network embodies the trifold mission – research, instruction, and extension – of the land grant university. The network provides an avenue for research faculty to connect to farmers interested in participating in research. Therefore research faculty are able to extend their findings to farmers, validating their research at an on-farm scale and allowing producers first-hand experience with the proposed management change. Producers are able to take an active role in learning and discovery, evaluating products and practices that impact their farm profitability, productivity, and sustainability. On-farm research summary reports are used by teaching faculty to provide real-life case studies for students in the classroom.

Within the current Nebraska On-Farm Research Network, a core principle is strong farmer involvement. In most cases farmers implement the trials and collect the data using their own equipment. Protocols are designed to fit each farmer's situation and address specific interests and questions. Extension educators, students, and technicians may visit research sites throughout the year to collect data. The participating farmers harvest the treatments and record the yields using a yield monitor or a scale. Data is processed and analyzed by University faculty and evaluated for quality control. Sound experimental design and statistical analysis is mandatory. Only projects that are randomized, replicated, and harvested accordingly are reported. The project objectives, methods, observations, and results are compiled annually into a research report. Research result update meetings are held throughout the state annually. These meetings are attended by farmers, agronomists, industry representatives, government employees, and university faculty and students. The participating farmer usually takes the lead in presenting their research project to the group, facilitating a peer-learning environment. The meetings are characterized by robust discussion.

As much as possible, farmers are brought into all phases of research including idea development, planning, and interpretation of the results. Research participation is voluntary. The majority of research studies do not involve monetary compensation for farmers. The experience a farmer has participating in on-farm research may vary as local extension educators have a great deal of latitude in how they chose to interact with participating farmers and how they develop research projects.

The Nebraska On-Farm Research Network has also sought to leverage numerous technologies to facilitate and disseminate research. Summaries of on-farm research results were developed into infographics and shared on Twitter; short videos were produced and shared on YouTube, Facebook, and Twitter. A smartphone application was developed which enables producers to create randomized research plot layouts and collect research data. An interactive online database with search and filter functionality was created which enables users to access over 700 on-farm research study results.

Precision Agriculture's Role in On-Farm Research

Demonstrating and refining agriculture technologies

On-farm research can be leveraged as a means to extend new or underutilized agriculture technologies as well as a way to research or refine new technologies in a field scale setting. In recent years, the Nebraska On-Farm Research Network has conducted coordinated projects related to two such technologies.

Mutli-hybrid planting is a relatively new technology in the commercial market. The objective of multi-hybrid planting is to switch hybrids or treatments as the planter moves across predetermined zones. While the operation of multi-hybrid systems has been validated, many questions still need to be answered in order to prepare for mainstream adoption of the technology. This technology was evaluated on fourteen fields in 2016 and 2017.

Another agriculture technology, crop canopy sensors, have been available for many years, however they are only sparsely adopted. A three-year effort demonstrated this technology through on-farm research on over 50 fields. This effort allowed producers to experience the technology through use on their fields and through demonstration days.

Agriculture technology makes on-farm research more conveinent for farmers

Precision agriculture technologies can facilitate on-farm research as well as allow for more in-depth analysis of on-farm research studies. Since formalized on-farm research efforts began at the University of Nebraska-Lincoln in 1990, 140 farmers participated in the program. Forty of these farmers were interviewed between Aug. 8, 2016 and Nov. 23, 2016. The farmers who had participated in on-farm research were stratified based on region of the state, year first involved with the on-farm research program, and the number of years the farmer conducted research with the on-farm research program (Table 1). While a participant may have begun involvement in an earlier year, they may have continued participation beyond the categorical date range to subsequent date ranges. If this was the case, they are only documented in the original date category in which they began participation.

Table 1. Categories of interview participants from the Nebraska On-Farm Research Network.

	-------------Population-------------		-------------Sample-------------	
Participating Farmer Category	**n**	**%**	**n**	**%**
Year first participating				
1990-1999	36	25.7	10	25.0
2000-2009	40	28.6	9	22.5
2010-2015	64	45.7	21	52.5
Number of years in project				
1-2 years	87	62.1	21	52.5
3+ years	53	37.9	19	47.5
Geographical region in Nebraska				
Western	15	10.7	5	12.5
Central	30	21.4	9	22.5
Northeast	28	20.0	9	22.5
Southeast	67	47.9	17	42.5

The study was conducted through phone interviews which were digitally recorded and transcribed. Interviews ranged from 7 to 52 minutes and averaged 22 minutes. Percent sampled in each category was selected to be similar to the percent of that category that made up the total population. Interview participants were recruited first through emails, then phone calls using scripts approved by the internal review board. All farmers interviewed were asked the same set of 13 general questions with probes for more details based on their answers. These questions ranged from general topics including their motivations for involvement, expectations, overall experience, and future suggestions, to more detailed descriptions of a research project they had conducted, how they determined the project topic, technologies they used to conduct the research, time required to conduct the research, the economic impact of the results, and implementation of the results.

Use of precision agriculture technologies

Thirty-three of the 40 participants reported using precision agriculture technologies such as GPS, guidance systems, yield monitors, or variable rate technology (VRT). Many of these also used a weigh wagon. The remaining six reported using no precision agriculture technology or using only a weigh wagon. Among those who reported not using precision agriculture technologies, reasons given included that they participated in the program before such technology existed or was commonplace, or they couldn't justify the use of the technology.

As expected, technology usage increased for those with later initial involvement in the program (Figure 1). For those who began in 1990 to 1999, 50% used no technology or only a weigh wagon compared to 22% for those who began in 2000 to 2009, and 0% for those who began in 2010 to 2015. The increase in technology use with time is consistent with the 2015 Precision Agriculture Services Dealership Survey Results which reports an increase in GPS, yield monitor sales, and variable rate technology from 1997 to 2015 (Erickson and Widmar, 2015) and a 2016 precision agriculture technology adoption survey in Nebraska (Castle el al., 2017). There was also an increase in use of variable rate technologies used for those who began involvement in the program later. Ten percent of those starting in 1990 to 1999 reported using variable rate technologies, compared to 22.2% of those starting in 2000 to 2009, and 28.6% of those starting in 2010 to 2015.

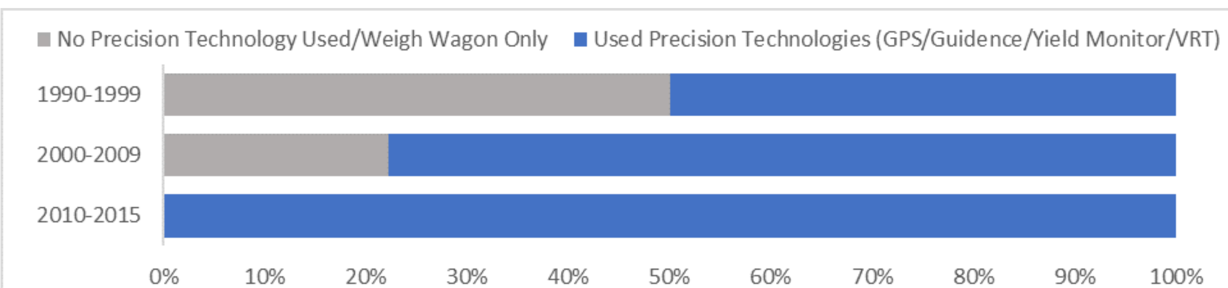

Fig. 1. Technologies used during the time the farmer-researcher was initially involved with the project.

Use of precision agriculture technologies as related to time spent doing on-farm research

On average, the amount of time annually spent on studies was 16 hours (n=38). The time required ranged from no additional time to several days. Thirty of the 40 reported they did not feel like the research was taking up too much time or that they felt like quitting, while ten of the 40 reported that they felt the research was taking too much time and/or they felt like quitting. When asked further for a reason why they felt it was taking too much time, respondents cited that it was annoying during the harvest season.

Historically, to document yield differences, research experiments would need to be harvested one experimental unit at a time and weighed with a weigh wagon or grain cart equipped with a scale. The time required to repeatedly auger out the grain from the combine to weigh and possibly drive the combine to the weigh wagon while not harvesting is especially undesirable due to the time-sensitivity of harvest. Precision agriculture technologies have increased the feasibility of collecting research data. Yield monitors have allowed farmer conducting on-farm research to collect spatial yield data as they harvest the crop, eliminating the need for frequent stopping and unloading. Variable rate technologies have provided a convenient way to test various rates of fertilizer, seed, and other inputs. Rather than physically changing fertilizer rates or planting rates, this can be done automatically with a prescription map or on an in-cab monitor. These technologies have costs as well, largely related to additional time requirements. For example, yield monitors should be calibrated (Luck and Fulton, 2014) and prescriptions need to be developed for implementing variable rates. Many of these activities can be done prior to the time-sensitive field work. Additionally, if the combine head width is not a multiple of the treatment applicator width (be that planter, sprayer, or other implement) selected rows may have to be harvested to ensure various treatments are not harvested simultaneously. This may cause some combine passes to be less than full header widths, reducing harvest efficiency. Overall, these technologies are generally seen as making on-farm research more feasible.

Among those that reported the project took too much time, 30% used only weigh wagons or no technology, while of those that reported the project did not take too much time, only 13% used only weigh wagons or no technology (Figure 2). There were fewer who reported that the research was too time consuming or that they felt like quitting in the 2000 to 2009 group and 2010 to 2015 group than in the 1990 to 1999 group. This is likely due to increased precision agriculture technology resources which were available to make the project quicker to harvest.

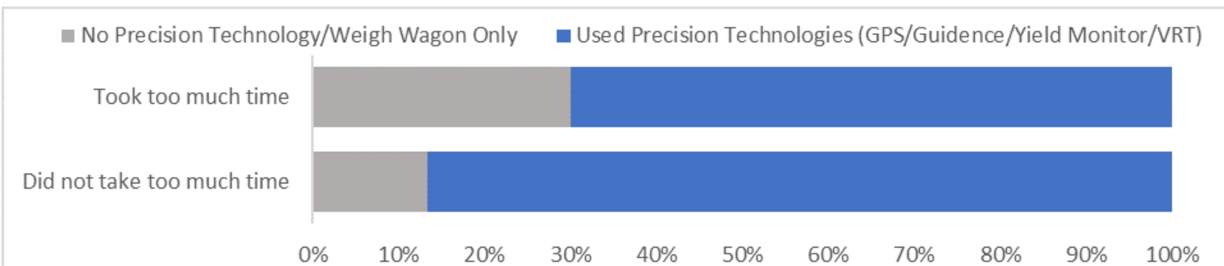

Fig. 2. Technology used by farmer-researchers in conducting on-farm research as related to perceptions of the project taking too much time.

Agriculture technologies enables previous infeasible research and in-depth analysis

Beyond making on-farm research more convenient for participating farmers, the use of agriculture technologies such as yield monitors and variable rate technology also enables research designs that were not traditionally possible in an on-farm setting with full scale field equipment. One example is the use of a center pivot irrigation system to apply varying treatments in a field in pie shaped wedges. In this example (Figure 3), nitrogen fertilizer was applied through the center pivot system for the treatments labeled "control" and nitrogen fertilizer with an additive was applied through the center pivot for the treatments labeled "additive". Harvesting and weighing grain from each of these wedged shaped treatments would be very difficult or impossible. However, using a yield monitor, the yield data from each wedge shaped treatment can be extracted and analyzed.

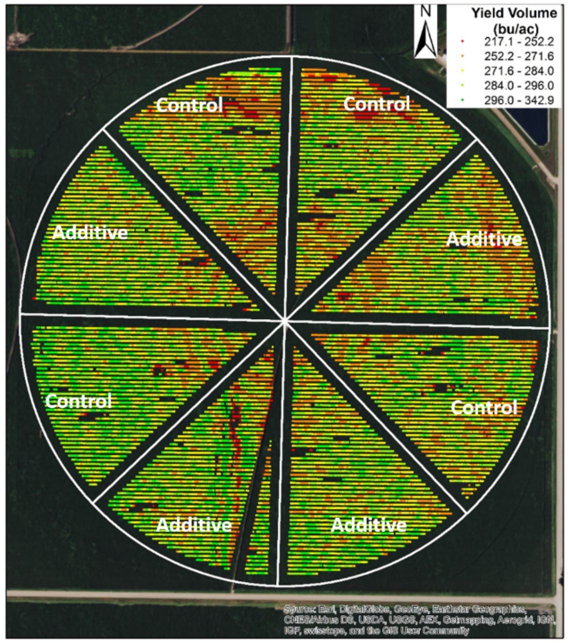

Figure 3. A research project where treatments were applied through a center pivot system and yield monitor data was used to extract average yields from each wedge shaped treatment.

Variable rate technology can also be used to facilitate research of numerous rate of a product within a field, such as with seeding rates in Figure 4. By pairing the seeding rate prescription and as-applied data with yield monitor data, we can evaluate the overall yield response to seeding rate as well as within field, site-specific response to seeding rate.

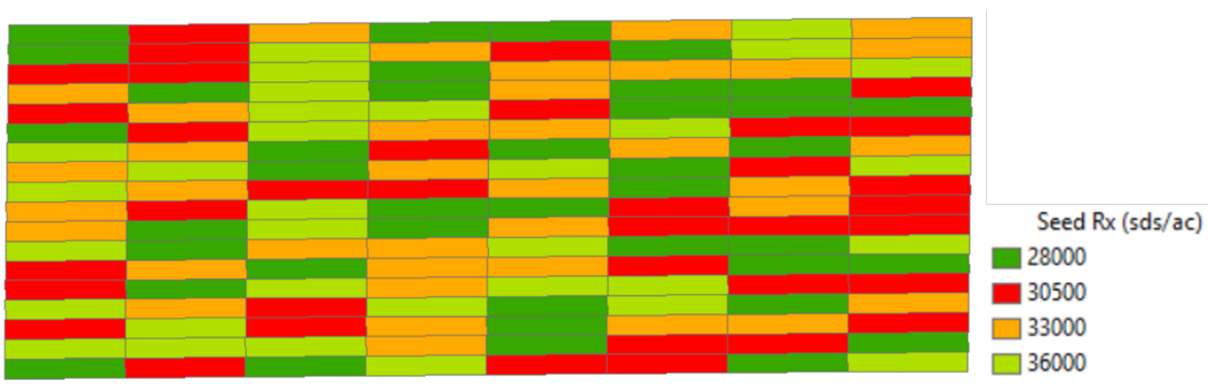

Figure 4. A research layout testing four seeding rates on an 80 acre field and implemented using variable rate technology.

In addition to facilitating different research layouts, the use of yield monitor data and other precision ag technologies can facilitate sub-strip spatial analysis, something that was not feasible when weigh wagons were used to collect yield data on research plots. Additional spatially dense data such as aerial imagery and soil electrical conductivity mapping can be used to delineate sub-field analysis zones. Imagery can also be used as quality control or to better understand other factors that contributed to the treatment response.

A Nebraska On-Farm Research Network study in 2017 compared applying pre-plant only nitrogen treatment at 210 lb/ac to applying part of the nitrogen pre-plant (70 lb/ac) and then part as a sidedress application (in three rates – 110, 140, 170) (Thompson et al., 2018). Yield analysis was first calculated on a whole strip basis; yield was 23 to 35 bu/ac greater where a sidedress nitrogen application was used compared to the pre-plant only application. Multispectral aerial imagery was collected numerous times during the growing season. The multispectral imagery from August 31 was used to calculate the normalized difference vegetation index (NDVI). Using the NDVI imagery, it was apparent there was greater N loss in the pre-plant nitrogen treatments. When soil survey boundaries (Soil Survey Staff, n.d.) was overlaid on the imagery, it was apparent that this loss was occurring more within the Fillmore silt loam, occasionally ponded soil series (Figure 5). Yield was reanalyzed by soil type; the pre-plant only N fertilizer treatments yielded 20 bu/ac less in the Fillmore silt loam than in the Moody silty clay loam. Aerial imagery was useful in delineating differential response to treatments. This study highlighted the benefit of using in-season N applications as part of a nitrogen management plan and also highlights opportunities for site-specific or variable within field crop management.

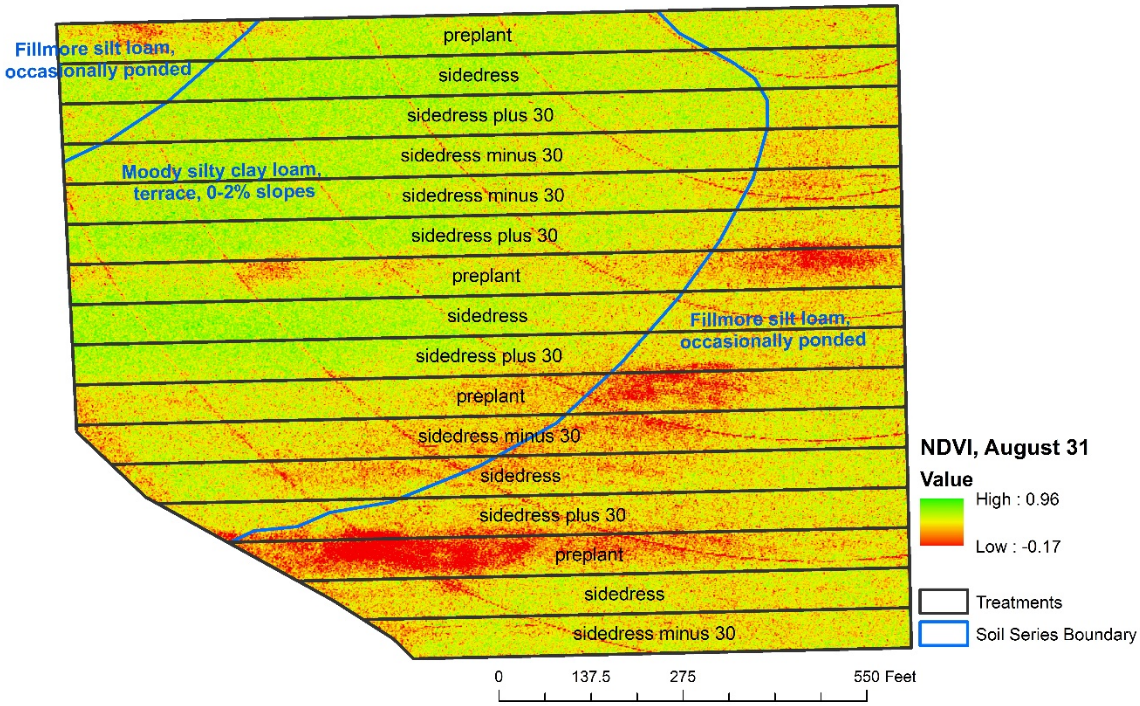

Figure 5. Normalized difference red edge imagery from August 31 with soil series and nitrogen research treatments overlaid.

Challenges related to agriculture technologies use in on-farm research

While agriculture technologies such as variable rate capabilities and yield monitors can make on-farm research more feasible, there are a number of challenges for researchers. Among those are:

- Questions related to the quality and accuracy of collected data
- Conditions occurring on the farm, which researchers may or may not be aware of, and therefore able to account for (e.g., wind damage, poor emergence, pest damage, etc.)
- Transfer of data from farmers to researchers
- Specific skills and knowledge required to process and analyze geospatial data collected by farmers in the field
- Higher computer power requirements and specific computer software needs
- Increased time and labor required to process large geospatial datasets
- Storage, backup, and accessibility of increasingly large datasets.

Access to individuals and teams with skills in data management systems and spatial data analysis are invaluable. Increasingly, extension educators involved with on-farm research need to have an understanding of these technologies and skills in working with this data. However a recent survey of extension educators (n=101) by the agriculture technology team of the North Central Extension Agriculture and Natural Resources Academy found that educators were not confident in their agriculture technology knowledge and skills (Clingerman et al., 2018). Survey participants were asked to rank their knowledge level on a scale of one to ten, where one represented knowing nothing and ten represented confidence that they could teach the information. In the category of technology services (such as Encirca or Fieldview) the average knowledge level was 3.03. In the category of farmer-driven technologies (such as maps and yield monitors) the average knowledge level was 4.49. Extension educators also ranked their perception of their clientele's knowledge level of the same technologies on a scale of one to ten, with one representing no knowledge and ten representing expert. Extension educators rated their clientele's knowledge level on average at 3.78 in the category of technology services and 5.54 in the category of farmer driven technologies. It is notable that the extension educators surveyed believed that their clientele were more knowledgeable than they were in both categories. Educators increasingly need to be familiar with these technologies in order to be comfortable utilizing them to conduct on-farm research; this survey, however, points to a lack of knowledge. Several practical guides document how to use these technologies in conducting on-farm research (On-Farm Network, n.d.; Nebraska On-Farm Research Network, 2013), however more in-depth educational opportunities and trainings should be developed to help educators become confident in using these technologies.

Conclusion

On-farm research is a valuable tool in transformational learning and new discovery. In our study of 40 past on-farm research participants, we found that twenty-three of the forty farmers interviewed reported they had put their research results into practice. Those who did not put their results into practice reported they planned to or that the results confirmed what they were doing so they did not make any changes.

Participating in research gave them the confidence they needed to go ahead with changes they had been considering. One farmer explained:

…made a change I was planning on, but it gave me confidence to go ahead with it. I had been dabbling in no-till and getting some experience with it but had not done any strip trials or analysis to determine what the yield impact was. I had a pretty good idea of the difference in cost and an intuition what the yield impact was but this confirmed my thoughts about it and at the time it was before it was widely accepted so it gave me a kind of coffee-shop confidence also.

Advancements in precision agriculture technologies has provided made on-farm research more feasible for farmers and reduced their likelihood of quitting on-farm research. Technologies have also allowed for more in-depth, site-specific analysis of data.

However, a lack of confidence and knowledge in using precision agriculture technologies among extension educators limits the realization of the full potential of these technologies. Additionally, challenges related to data processing, storing, and sharing needs need to be addresses for a successful on-farm research program.

Acknowledgements

Special thanks to the entire Nebraska Extension On-Farm Research Network team at the University of Nebraska – Lincoln and the farmers who conduct research with us.

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Nomenclature

NDVI	Normalized Difference Vegetation Index