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Producers' Adoption Behaviors for Precision Agriculture (PA) Technologies to Improve Nitrogen Use Efficiency: Diffusion of Innovations Theory as an Explanatory Lens

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Abstract

Advancements in precision agriculture technologies enable producers to achieve higher yields; however, in some cases, these innovations have not reached widespread adoption despite years of availability. We sought to understand producers' adoption experiences with two precision agriculture technologies: Nitrogen (N)-Rich Strips and the Sensor Based Nitrogen Rate Calculator (SBNRC). These technologies can help producers optimize their application of nitrogen fertilizer on growing crops, especially small grains such as wheat. Using Rogers' (2003) diffusion of innovations theory as an explanatory framework, this descriptive-exploratory study examined the adoption behaviors of producers from two midwestern states. Rogers' (2003) theoretical lens guided instrument development and interpretation of results. To better understand the effects of change agents' actions and potential adopters' behaviors during the innovation-decision process, more research is needed regarding disenchantment discontinuance and replacement discontinuance, the potential for pro-innovation bias, and of the innovation attribute compatibility. The future development of precision agriculture technology with the perceptions of potential adopters in mind, especially those averse to adoption and continuance, may assist in overcoming barriers to widespread diffusion.

Keywords

Innovation-decision process, nitrogen fertilizer, sustainability

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Introduction and Problem Statement

Lee et al. (2021) reviewed Precision Agriculture (PA) adoption literature from 1999 to 2020 as published in peer-refereed journals. They concluded that producers' adoption of PA was not occurring at its highest potential because communication was lacking between change agents and farmers regarding the technology's attributes (Lee et al., 2021). Nitrogen (N)-Rich Strips (NRS) and the Sensor Based Nitrogen Rate Calculator (SBNRC) are examples of PA tools available for more than 20 years (Desta et al., 2017). These technologies help producers optimize their use of N, the most limiting nutrient for plant growth, and augment more sustainable production practices. If adopted together, the tools represent a *technology cluster* (Rogers, 2003). Widespread use of such, however, is limited, uneven, or non-existent among producers who ostensibly would benefit from adopting the technologies. NRS are "an integral part of correctly determining the appropriate amount of N needed by the crop mid-season" (Desta et al., 2017, para. 1) and could prevent producers from under-applying or over-applying N fertilizer. Using the sensors, handheld and other modes, to calculate N rates, is made possible by the NRS indicating whether a crop responds to the application of additional fertilizer.

Understanding why producers adopt or reject an innovation can guide the development of new tools and techniques, reveal needed modifications of existing technologies, and inform researchers and extension educators about how to better serve their stakeholders. Camp (2001), however, asserted that "a major stumbling block for many researchers in conceptualizing research is the development of an adequate theoretical framework for a study" (para. 2). Another failing can be using data collection instruments without embedding relevant observables or variables of interest resonating with a study's theoretical frame. We sought to avoid this oversight by using Rogers' (2003) diffusion of innovations to guide this investigation.

Theoretical and Conceptual Framework

Diffusion of innovations theory has been used in many studies across various settings and contexts, including for the advancement of agriculture and its many practices and forms worldwide (Rogers, 2003). Often, effectiveness of the diffusion of new technologies can be attributed to the efforts of change agents affecting potential adopters' willingness to adopt and implement such innovations (Rogers, 2003). Rogers (2003) described change agents as individuals who influence clients' innovation-decisions toward a new tool or practice as deemed desirable by a change agency. Change agents work to guide potential adopters through the innovation-decision process during which they either adopt or reject an innovation (Rogers, 2003). They usually describe and often demonstrate the *characteristics* or *attributes of an innovation* that influence its rate of adoption (Rogers, 2003).

Rogers (2003) described five characteristics or attributes, terms he used interchangeably, most likely to influence the adoption of an innovation, especially during the persuasion stage of the innovation-decision process: relative advantage, compatibility, observability, trialability, and complexity. *Relative advantage* is how beneficial an innovation is perceived by potential adopters, especially as compared to the innovations superseding it. *Compatibility* is how well an innovation is perceived by potential adopters as meeting their needs and conforming with existing attitudes, practices, and societal norms. *Observability* reflects the extent to which potential adopters can see innovations perform and their results prior to adoption. *Trialability*, either partially or entirely, is the opportunity for potential adopters to use an innovation before deciding to adopt. *Complexity* is the degree of difficulty potential adopters perceive associated with implementing an innovation and such negatively influences the rate of adoption (Rogers, 2003).

At first, change agents usually engage potential adopters with knowledge of an innovation and then use its attributes with the intent to *persuade* them to decide to adopt it. If an individual chooses to adopt, they move to the implementation stage (Rogers, 2003). Thereafter, the adopter may transition to the confirmation stage for continued adoption and use, or instead *discontinuance* may occur if the innovation was not sufficiently compatible or failed to provide the relative advantage it initially promised. Rogers (2003) called this *disenchantment discontinuance*, i.e., the later decision to actively reject an innovation was due to an adopter's dissatisfaction with its performance. Another reason for adopters discontinuing the use of an innovation may be *replacement discontinuance* (Rogers, 2003); in this instance, the former innovation is superseded by another that arises which adopters prefer more.

In the diffusion of new innovations, communication channels and the effectiveness of change agents' efforts are often imperative to informing and persuading potential adopters. For these innovations, the channels employed to reach producers included interpersonal and mass media. Oklahoma State University Plant and Soil Science extension personnel used interpersonal forms of communication to connect with producers, and their university's online resources acted as channels of mass media communication, e.g., the issuance of bulletins and use of social media. These resources served as a landing page for existing users and potential adopters to gain knowledge and understanding of the PA technologies. Such was described by Rogers (2003) as *how-to knowledge* regarding an innovation's proper use or implementation.

Personal connections and relationships among members of a social system also can be important catalysts influencing an innovation's adoption (Rogers, 2003). Interactions between and among change agents, opinion leaders, and potential adopters, which often involve creating *awareness-knowledge*, using persuasion, decreasing perceptions of complexity or uncertainty, and offering opportunities for observability and trialability, can positively affect an innovation's rate of adoption (Rogers, 2003).

Purpose

We sought to understand producers' adoption behaviors regarding this PA technology in two midwestern states. Our four objectives included (a) understanding producers' perceptions of the technologies' attributes, as defined by Rogers (2003); (b) knowing when, how, and from whom they had learned about and received training on the technologies; (c) knowing whether their adoption was continuing, or rejection had occurred and why; and (d) identifying ways to improve diffusion, adoption, and use of these and related technologies in the future.

Methods

This was a descriptive-exploratory study. Other than mostly anecdotal data, very little information existed about adopters' perceptions of the PA technologies we studied, i.e., N-Rich Strips and SBNRC. In 2020, we developed a survey instrument to collect data on the adoption behaviors of crop producers in two midwestern states regarding PA technologies. Our Qualtrics online questionnaire included forced-choice (*Yes/No*), Likert-type scale, and open-ended items. Producers' perceptions of Rogers' (2003) key attributes of an innovation were assessed by nine response items. Five-point, Likert-type response scales were developed to measure producers' views on relative advantage and complexity of the PA technologies, N-Rich Strips and the SBNRC. For example, their perceptions of the relative advantage (Rogers, 2003) associated with using the PA technologies were measured using the following response scale: 1 = *No value* to 5 = *High value.* And Rogers' (2003) attribute of complexity was assessed with a perceived level of difficulty scale: 1 = *Not difficult* to 5 = *Very difficult*. Other items were developed to determine the year during which producers likely adopted, as an indicator of innovativeness (Rogers, 2003); from whom they learned about the innovations; number of related trainings attended; and their highest levels of education. A panel of experts, including two plant and soil scientists and an agricultural education and extension educator, reviewed the instrument to verify its face and content validity. A group of key informants (Rogers, 2003), including producers and crop service providers, also provided guidance during the instrument development phase.

The online questionnaire was distributed through a listserv of subscribers (*N* = 564) who had requested to receive updates on research and extension meetings from the Plant and Soil Sciences department at Oklahoma State University. Twenty-five requests were returned as undeliverable or defective; so, messages requesting participation in the study were delivered to 539 individuals.

These listserv subscribers were a purposive sample of producers who had shown interest in the Extension and research efforts of plant and soil scientists at Oklahoma State University, including PA technologies, during a 10-year period. In purposive sampling, "the researcher specifies the characteristics of the population of interest and locates individuals with those characteristics" (Johnson & Christensen, 2017, p. 268). In this study, however, the possibility of coverage error existed due to its sampling frame (Dillman et al., 2009), i.e., adopters who were not listserv subscribers went unsolicited and some subscribers may not have adopted nor been interested in PA technologies. This limits the generalizability of our results.

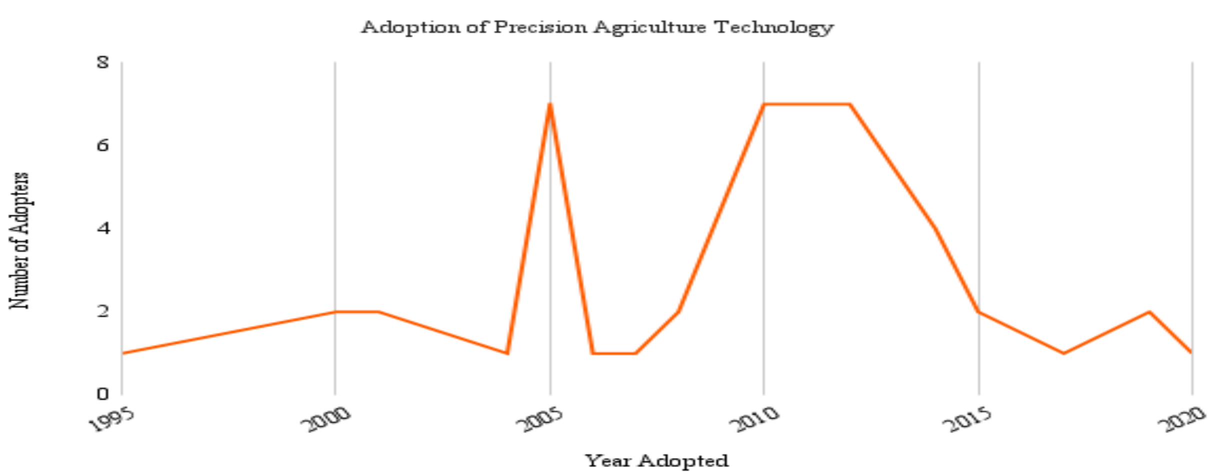
Dillman et al. (2009) recommendations for data collection were followed: a prenotice electronic mail message was sent to the intended respondents; an invitation message with a link to the online survey questionnaire was sent next; and two follow up, reminder electronic mail messages were sent to increase the response rate. Sixty or 11.13% of the producers responded to the questionnaire. They farmed in three counties of Kansas and in 33 Oklahoma counties. As appropriate, some data were analyzed using descriptive statistics via the Qualtrics data collection and management platform; *Yes/No* and Likert-type responses to the online survey questionnaire were counted and related percentages calculated. Respondents' answers to the instrument's open-ended questions were sorted and categorized according to corresponding innovation attributes, as negotiated and determined by the researchers. Rogers (2003) assertions about and descriptions of attributes were consulted by members of the research team to determine the placement of respondents' comments in the attributional categories. One researcher had taught Rogers' (2003) diffusion of innovations theory at the graduate level for two decades and two others were graduate students who completed said course.

Findings

Most of the producers were White/non-Hispanic males (*f* = 49, 81.67%) and reported having earned bachelor's degrees or higher levels of education. The group's mean age was 57 years, they had farmed for about 30 years on average, and two-thirds farmed 1000 acres or less. The crop for which most used the technologies was wheat (*f* = 52, 53.61%), forages were second (*f* = 9, 9.28%), and corn third (*f* = 8, 8.25%). The most cited communication channel for knowing about the PA technologies was the Oklahoma Cooperative Extension Service (*f* = 51, 85.00%). As a group, the producers reported attending an average of about two Extension meetings each year. With the possibility of recall problem (Rogers, 2003) notwithstanding, producers' self-reported adoption of N-Rich Strips ranged from 1995 to 2019; their adoption spiked around 2005 and again from about 2010 to 2012 (see Figure 1).

Figure 1

Producers' Self-Reported Adoption of N-Rich Strips Over Time, 1995 to 2020



Note. Forty-two of the 60 respondents (70.00%) indicated their year of adoption.

As a potential complementary tool to further improve nitrogen use efficiency, the producers could have also adopted the SBNRC to use in tandem with N-Rich Strips, i.e., implemented a technology cluster (Rogers, 2003). Slightly more than one-fifth of the respondents (*f* = 13; 21.67%) indicated they were using the calculator, almost one-fourth (*f* = 14; 23.34%) had used it but stopped, one-half (*f* = 30; 50.00%) reported having never used the technology, and three did not respond. Producers' perceptions of the relative advantage (Rogers, 2003) associated with using the N-Rich Strips was measured with a Likert-type scale: 1 = *No value* to 5 = *High value.* If considering the scale's real limits, the producers perceived the N-Rich Strips had *Average value* (*M* = 3.17; *SD* = 1.14) [see Table 1]. Rogers' (2003) attribute of complexity was assessed with a perceived level of difficulty response scale: 1 = *Not difficult* to 5 = *Very difficult*. Applying the same real limits, both technologies were viewed as *Slightly difficult* to use: N-Rich Strips, *M* = 1.75 (*SD* = 1.01); and the SBNRC, *M* = 1.83 (*SD* = 0.92) [see Table 1].

Regarding producers' opportunities to observe the use of N-Rich Strips prior to adoption, 70% (*f* = 42) said *Yes*, and nearly two-thirds (*f* = 15) of the SBNRC users had first observed it in practice before adopting. As for using the PA technologies on a trial or limited basis before making their initial adoption decisions, 60% (*f* = 36) of the producers had tried the N-Rich Strips as had nearly two-thirds (*f* = 15) of the SBNRC users (see Table 1). Both attributes – observability and trialability – support the likelihood of adoption (Rogers, 2003).

Table 1

Producers' Quantified Perceptions of Selected Attributes of Two PA Technologies

Attributes	NRS [a]		SBNRC [b]	
	M	*SD*	*M*	*SD*
Relative Advantage: How much value do N-Rich Strips bring to your farming operation?	3.17	1.14		
Complexity: How difficult do you find N-Rich Strips <u>or</u> the SBNRC [b] to use?	1.75	1.01	1.83	.92

Attributes		NRS [a]			SBNRC [b]	
		f	%		*f*	%
Observability: Were you able to observe N-Rich Strips <u>or</u> the SBNRC [b] before using in your farm operation?	Yes	42	70.00	Yes	15	65.22
	No	18	30.00	No	8	34.78
Trialability: Were you able to use N-Rich Strips <u>or</u> the SBNRC [b] on a trial or limited basis?	Yes	36	60.00	Yes	15	65.22
	No	24	40.00	No	8	34.78

[a] N-Rich Strips; [b] Sensor Based Nitrogen Rate Calculator.

The questionnaire included open-ended items for which the producers provided 73 responses; 67 addressed the N-Rich Strips and five related to the SBNRC. We categorized these responses regarding which of Rogers' (2003) key attributes of an innovation the data aligned with or implied. In the case of the attributes relative advantage and compatibility, the producers' comments varied from evidence or support for such to perceived lack of the attributes. This overall analysis and categorization resulted in 27 statements aligned with relative advantage; 34 comments expressed perceptions related to compatibility; and 11 implied that the attribute of complexity existed, and one did not (see Table 2). Fifty-five percent (f = 33) of the producers reported discontinuance of their adoption of the N-Rich Strips, which also likely implied discontinuing use of the SBNRC for those who had adopted the calculator to complement use of the strips.

Table 2

Producers' Perceptions of Selected Attributes of PA Technologies as Written Responses

Producers' Perceptions of Relative Advantage N = 18
Easy indicator for need of topdressing wheat
Improve nitrogen use efficiency
To reduce fertilizer input cost
Profits
Increase profits
Nitrogen efficiency
Limited the amount of top dress on wheat
Usually reduce[s] N application by about 20 lbs/acre most years
I found that I was not doing too bad of a job of managing nitrogen application, so I have only had to make minor adjustments based on N-Rich strips. However, since it is an extremely low cost and easy technology to implement, the value gained from making even minor adjustments is still well worth the cost.
It is a good measuring stick.
Another way to check N
Save money on N applied
The use of N-Rich strips has saved the farm.
Really helps on wheat. I know whether to spend money or not.
Saves money
Somewhat valuable as education tools for producers I consult with that don't believe N can economically increase yields.
Easy to use, also provides an early season yield estimate in addition to nitrogen recommendations.[a]
Best way to leverage the information gained from my N strips.[a]
Producers' Perceptions of the Lack of Relative Advantage N = 9
[I] had extension agent evaluate first year. [I] bought sensor for 2nd and 3rd year. [I] never saw any difference. [I] quit using [it].
N-Rich strips would not be worthless, but they have less value than other things that I can do with my time.
Seem[ed] like my fertilizer program changed very little on cost.
[I]n dry years it was too late to tell.

The times I applied N-Rich strips I couldn't tell if I had adequate nitrogen or the conditions just didn't allow for a proper evaluation. I never really saw a deficiency.
[I] try to [N] manage by soil tests.
[Requires] time/labor to apply. [I] hired coop to apply most years.
I'm not sure how to value them. When the strips show up it's time to apply nitrogen for maximum or optimum yield.
[I] saw no difference, labor limitations, [and] wheat not profitable, so why micro-manage?[a]

Producers' Perceptions of Compatibility *N* = 3
Can be used mostly to confirm I applied enough N
Learned the technique in college and they are easy to set up
Not difficult to use or apply. But as far as using them as an AG retailer, the results are too late. If I were a producer with my own applicator, it would be a great tool. The results from a N rich strip come too late for that year as a retailer. I have used them more for an after the fact tool. Did we get enough on or where we [were] short N? If we are short, then we my need to reevaluate the amount of N that producer is applying in that farming operation.

Producers' Perceptions of the Lack of Compatibility *N* = 31
Just finding the time to put them out before the wheat came up
Timing of the application as well as time associated with the application if applied myself has been the most significant factor. I'm also aware of consulting services who will apply/install the strips, but the cost has been prohibitive. Most consultants require additional services or an agreement for services other than the strips.
Application of our nitrogen is from effluent which is pumped through center pivot.
Not applicable for us. We use effluent for our nitrogen and application is through center pivot.
By the time we see any differences it is too late to apply N in western Oklahoma. The ONLY application I can see working with N rich strips on dryland is Exactrix NH3 to provide immediate response.
I rarely see my N-strips pop up until after jointing. I have had them show up as late as heading even after using the calculator to determine my fertilizer rates.
In wheat, the system is very simple and easy. In corn, I find the system to be less valuable due to the need to delay mid-season N application later than ideal. The V7-8 growth stage in corn frequently coincides with the arrival of spring rains (May) for me. This causes problems getting the nitrogen applied.
N-strip results have adversely been affected by lack of or excessive rainfall events.
Nitrogen incorporating rains can be hard to come by.
Sometimes they don't show up, or they appear after my deadline to apply fertilizer.
They are not difficult but the[y] are inconvenient from logistical reasons.
Time and resource management, while working a full-time job off the farm.
Timing and to many other things to do.
Web page could be updated, and grazed wheat indicates a need for N later than ungrazed wheat.
Between read time and getting the nitrogen needed applied in a wet year there can be a lag time because of ground conditions unless the farmer has a way to apply the fertilizer themselves most will still do a weed and feed app because of application cost.
Snow cover prevented a reading, drought years provided misleading data, plan to graze some years and N-Strips not really designed for grazing.
The response is too late to be able to correct the issue.
Don't apply much N in the fall.
Useful but they slow us down so that is a drawback.
We have a lot to do, and they slow us down so less valuable the more they slow us down.

Many times, the strips did not become visible until after cattle were removed and top dress N applications had already occurred.
We do not use N-Rich Strips since it is not feasible for our application.
There are times that no response is observed, or response is late for adequate top dress application.
Too much trouble
Depends [on] if the farmer believes in them or not. There ha[ve] been Springs where the ground has been too wet to get on and by the time able to get it applied it has been late when able to finally get it done, and some felt they ha[d] lost yield. [At one time,] not enough sensors around [but] now with sensors getting cheaper and easier to use the "shiny" has worn off for some to come back to table to buy a new sensor. [With] wheat being double cropped back late not able to get strips put out in a timely fashion.
It seems to be very late to apply N by the time I can see a difference.
I'm trying to utilize grid sampling and rate applied fertilizer.
I do soil samples.
Getting urea into topsoil during dry weather periods
Late applied N [was] ineffective without rain; [this] clobbered me in [a] dry year.[a]
Producers' Perceptions of Complexity *N* = 11
[I am] not sure how to use them in a pasture setting or the benefit they would have when not trying to maximize production.
Remembering to write down where I did the test. And remembering where I wrote it down.
Got on the wrong software page.
Hard to find, hard to interpret
[A] hassle to put them out and more of a hassle to read and determine correct rate.
Just the commitment to getting them done. Sometimes I hire nitrogen application and it's difficult to get them to do them.
Maybe I don't have a good understanding of N rich strips? Wouldn't it be the same as making another pass across the end of the field or for that matter just noticing when the manure patches show up?
Most fields were grazed and many times the strip was hard to see.
One issue was when taking the first reading after spring green up the recommendation called for 0 lbs. of N to be applied. A few weeks after spring green up, the N-Rich strip could be seen for a 1/2 mile in the field and the sensor then called for 100 lbs. This makes organizing spring top dress with N on wheat very difficult.
To many numbers to mess with
If it was eas[ier][a]
Producer's Perception of the Lack of Complexity *N* = 1
Not really, just the time it takes. No real difficulties

Note. [a] Producers' responses regarding the SBNRC. Other responses related to the N-Rich Strips.

Conclusions, Discussion, and Recommendations

Change agents for these technologies should continue to stress the related attributes during trainings by using demonstrations and other promotional efforts to increase the likelihood of adoption. However, more work appears to be needed to avert producers' negative reevaluations of the technologies, i.e., after having initially adopted but later rejecting such. Rogers (2003) described two types of discontinuance or later rejection of innovations as either disenchantment or replacement discontinuance. Disenchantment discontinuance can be characterized as an adopter's decision to reject an innovation after growing dissatisfied with its performance. While replacement discontinuance is when an adopter discontinues using an innovation due their having adopted an alternative in its place (Rogers, 2003).

Although we did not explicitly measure the attribute *compatibility* with an anchored response scale, 34 of the producers' 73 written responses described the PA technologies as either lacking or having compatibility with their farming practices, but the former was indicated overwhelmingly (see Table 2), which implied *disenchantment* with the technologies. For instance, some producers noted the need for rainfall soon after applying N, but that it did not always rain, nor did they irrigate. Issues also arose if their wheat was grazed by cattle for a time, which is a common practice in the producers' states. So, the technologies were not as compatible with their farming systems as the producers may have thought when they adopted use of the strips and calculator. This perceived lack of compatibility warrants additional investigation of producers' views on the attribute. In addition, those who described using soil testing or soil grid sampling as alternative methods for managing N use efficiency (see Table 2) could be interpreted as *replacement discontinuance*. However, more in-depth content analysis for emergent themes in the producers' written comments as well as personal and focus group interviews may assist in more fully understanding producers' perceptions and related behaviors during the confirmation stage (Rogers, 2003) of the innovation-decision process for these PA technologies.

Moreover, the views of key informants (Rogers, 2003) should be sought out to understand what may have precipitated the spike in adoption of the N-Rich Strips that occurred around 2005 and again from about 2010 to 2012 (see Figure 1). If any behaviors of change agents are identified as unique to those time periods of increased adoption; such should be considered for use in the future. In addition, more effective ways are needed to increase survey questionnaire response rates with the targeted group, e.g., paper instruments completed during in-person meetings or instantaneous access to online questionnaires via QR codes (Hill et al., 2013) may lead to higher response rates. Further, randomly selecting producers' locations from which to query fertilizer suppliers and crop service providers about trends in the purchase of N-fertilizer over time could assist in mitigating the recall problem (Rogers, 2003) confounding many ex post facto survey research studies. Rogers (2003) supported the use of archival data to address this threat to the veracity of findings and thereby avoid drawing spurious conclusions.

The *elephant in the room* that frequently permeates and may confound or even obscure a clear-eyed understanding of an innovation's introduction, diffusion, adoption, continuance, or rejection is the phenomenon of *pro-innovation bias*, which Rogers (2003) indicted as a criticism of diffusion research. As such, Rogers (2003) asserted: "Perhaps owing to the pro-innovation bias that pervades much diffusion inquiry (see Chapter 3), investigation of rejection behavior has not received much scholarly attention" (p. 178). Pro-innovation bias is the view often held by many change agencies, with agricultural scientists or cooperative extension services personnel no exception, that *all members* of a targeted social system, i.e., potential adopters, a) should adopt an innovation and do so rapidly and b) no reinvention of the innovation is needed or should occur (Rogers, 2003). In other words, the potential adopters' less than positive, skeptical, or hesitant perceptions of an innovation's attributes coupled with preexisting socio-cultural norms also likely to influence their adoption decisions are frequently overlooked, underappreciated, misinterpreted, or even summarily dismissed by the actors fomenting change. An assessment of the potential for pro-innovation bias regarding the PA technologies studied may better inform and even modify the behaviors of change agents promoting these innovations and increase the likelihood of producers continuing to implement such in the future.

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