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Issue Brief

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I. INTRODUCTION

Research scientists at North Carolina State University are exploring ways to harness plant fungal synbionts – specifically foliar fungal endophytes – to improve crop resistant to stressors such as drought, pests, and pathogens. Although this project is in an exploratory, basic research phase, the investigators recognized the importance of engaging stakeholders about their perspectives on the potential utility of fungal manipulations on crops.

Scholarship that explores the public understanding of and engagement with science and technology highlights the importance of engaging with stakeholders early and often as critical to socially responsible innovation pathways. Within that context, for the purpose of this project, we sought to interview potential stakeholders from a variety of sectors to understand the broad implications of potential products derived from modified foliar fungal endophytes (hereafter FFEs). With the constraints of COVID, we were able to interview (via Zoom) a total of eleven respondents. We interviewed five extension agents, three industry stakeholders, one stakeholder whose role includes both extension and trade organization representative, one policy expert (formally), and one consumer advocacy stakeholder.

Our respondents put forth a range of important ideas, which we have organized below in sections focused on potential benefits, potential challenges, and recommendations to mitigate those challenges. We aim to present the range of perspectives and ideas we heard, often in the words of the stakeholders themselves. To be clear, these data do not allow us to make claims about majority opinions across or within stakeholder groups. These stakeholder interview data are rich and nuanced, and they represent a starting point for ongoing dialogue with stakeholders throughout the innovation and product development processes. Results below can inform future engagement efforts—whether additional stakeholder interviews or more formal surveys—and also provide insight to the FUNCROPS

innovation team about the diversity of perspectives held by stakeholders surrounding the potential development of modified FFEs.

II. POTENTIAL BENEFITS

Respondents described a range of potential benefits from potential microbial interventions in agricultural systems. Enthusiasm was most pronounced from industry stakeholders, one of whom stated that "there's tremendous upside" to potentially using microbes like FFEs. Because we are so far upstream from the development of FFEs as readily available tools on farm, we asked open-ended questions about what kind of benefits they could envision coming from microbial products more broadly. Benefits range from pest management and potentially offsetting resistance to pesticides and herbicides, resilience to uncertain weather patterns, nutrient uptake, to market benefits, as well as other benefits that do not fit neatly into those categories.

1.a. Improved response to biotic stressors

To begin, a number of respondents envision FFEs supporting crops' responses to biotic stressors. Some stakeholders spoke generally about "some kind of pest management" or, "disease management." Other stakeholders talked about the potential for being able to manage pests and pathogens while reducing "the amount of pesticides applied or the number of times," or "alternative products that are not considered synthetic." Multiple stakeholders acknowledged this potential but cautioned that FFEs and other potential emerging technologies "to be considered as part of their toolkit and part of an integrated approach." Still other stakeholders talked explicitly about the role FFEs could play in countering pesticide resistance: "the classical example is all these weeds that we now have that are resistant to Roundup... but now we have some diseases that are resistant to fungicide."

1.b. Improved tolerance to abiotic stressors

Stakeholders noted the range of abiotic stressors that North Carolina growers face, particularly as weather conditions change, and where they see greatest potential benefit for FFE products. One extension agent noted that in eastern North Carolina, approximately "67% of the variation you get [in yields] could be explained by the weather." One specific condition that FFEs could address is drought tolerance, or "making crops more resilient during drought conditions." Soybean, for example, "has limited irrigation capacity which makes them particularly susceptible to drought which is particularly problematic during reproductive development." Other stakeholders noted that a product that helped crops improve their heat tolerance, "upgrading or upregulating their defense mechanism related to heat stress." Soy, again, is particularly vulnerable to heat stress: "once you get above... 92 degrees, the plant essentially shuts down. And it's nighttime temperatures that are an issue and so nighttime temperatures above 80 degrees are really detrimental and we get that consistently," and the stakeholder goes on to say that they would look for a "way to combat that." Stakeholders also noted that in some places, excessive moisture is at least as problematic, particularly during certain parts of the growth cycle. Some stakeholders noted that because of the potential specificity of microbial products, FFEs could be developed specifically for managing different conditions for different regions: drought for one, moisture for another, or even saltwater intrusion. Still other stakeholders talked about the interconnections between abiotic and biotic stressors, noting that wet conditions may increase fungal pathogens, and that FFEs could help manage those issues.

1.c. Nutrients

A number of stakeholders knew about the soil microbiome, so when asked about potential benefits of new microbial products, their understanding of the benefits extended to nutrient uptake. One stakeholder thought it would be useful to "fix nitrogen from the atmosphere." Yet another stakeholder said they had heard about a "phosphorus enhancing product that makes phosphorus already in the soil more available to the plant." These potential benefits around nutrient utilization, some stakeholders reasoned, "are interesting in that they could reduce the amount of fertilizer we're applying." Another stakeholder echoed this potential benefit, describing their interest in "reduc[ing] our overall footprint from using nonrenewable fertilizer sources."

1.d. Market benefits

While many stakeholders were concerned about on-farm marginal costs and benefits (described below), some stakeholders noted the potential economic benefit that could arise from FFE products. Two stakeholders specifically mentioned "reducing dependency" on "some of these materials that are coming from other (or "foreign") countries." Other market benefits could support North Carolina's extensive animal agriculture economy: stakeholders noted that "North Carolina is a grain deficit state" and anything that supports grain production in NC seems to be important to broader health of the agricultural markets in the state.

III. CHALLENGES AND RECOMMENDATIONS

Respondents described four broad categories of challenges that will likely shape the development of FFE agricultural products: potential grower hesitancy, lab to farm transition, policy and regulatory issues, as well as public and consumer acceptance particularly as it relates to GMO histories.

CHALLENGE 1. GROWERS MAY BE HESITANT ABOUT THE ADOPTION OF FFE PRODUCTS.

Because of a complicated history with microbial products, the opportunity costs of transitioning to FFE products, and the politics of messaging and language, grower hesitancy may be one of the key barriers to FFE product adoption and success. Each of these issues, paired with recommendations also pulled from stakeholder responses, is outlined in greater detail below.

Challenge 1.1

Previous microbial products did not deliver on promises of dramatically improved yields and growers may be skeptical about new microbial products. Early in the development of microbial products, there were "a lot of snake oil products that had a lot of big claims and didn't deliver and I think growers have strong memories of that and so we're now fighting to get over that." In fact, nearly half of all interview respondents used the phrase "snake oil" unprompted. Similarly, "the skepticism comes from some of these biologicals not having worked in the past... the skepticism is from a lack of efficacy versus skepticism from being scared of the technology."

This skepticism also comes from a mistrust of industry research claims. One stakeholder pointed out the importance of what kind of evidence is backing up claims because "a lot of times with these [microbial] products it's all testimonial evidence instead of research evidence" and that raises some suspicions among extension agents and growers alike. That mistrust also broadens out: according

to another stakeholder, "there are still people that are going to be very skeptical, very suspicious about government and big business." Even industry stakeholders acknowledge that, "producers have taken those and tried them out and they just don't see those results and so they're a little bit more skeptical now."

Recommendations 1.1

1.1.a. Growers should be consulted about their extensive knowledge of on-farm challenges and needs, and this information should be treated as expertise. Stakeholders described two distinct roles for consulting with growers, who should not be "treated like a monolith." To begin, one stakeholder noted that growers "have a lot of experience… [and] a lot of observational data about how to deal with one region or another." This is an important theme in stakeholder engagement: considering a wide range of expertise including local or community expertise. One of the challenges for successful FFE products is developers' ability to match products with local environmental conditions, and growers have an abundance of this knowledge.

Secondly, another stakeholder noted that growers should be consulted about "what data [they] would need to see to be convinced to want to buy this." On the one hand, this latter point is distinctly related to product adoption, but for potential FFEs to be successful as agricultural tools, then a variety of growers should be consulted about what data may be important across crops and conditions.

1.1.b. Mutual learning needs to take place about conditions, potential products, and what barriers might exist. A number of extension respondents talked about the importance of improving their own education about these issues as critical to serving their growers effectively. They talked about learning more about both the biological and technical dimensions of FFEs and related organisms, as well as social dimensions. One respondent noted that "we as agents need to be better versed on this; we need to be knowledgeable in the technology. We need to know what is currently known about it." Another respondent agreed: "we should be brought up to speed... what is currently known about this technology. You know, we as agents, we get bits and pieces from popular press or research from various people…." but want more systematic education on the topics. They pointed out that there was opportunity especially "in winter months, when we as agents can get trained by specialists and they're doing a better job now, especially with us being able to use zoom."

Extension agents could in turn use their new understanding of the product to educate growers. One agent noted that they had not "historically emphasized educational efforts about [the microbiome] from an extension perspective" and that seems to be an important (and we anticipate imminent) opportunity for engagement across NC State extension faculty and staff and the field agents.

More broadly, another stakeholder put it quite well: "I think you know a lot of times very basic scientists forget the complete pipeline. And in order for this technology to be successful, they will need acceptance from growers. And so, keeping that in mind from the get go and having these conversations from the very beginning like what our growers need and how do we, how can we ensure the success of these products and meet some of these more global and larger goals but also understand how it's going to impact a grower and what's feasible for a grower."

1.1.c. After focusing on mutual learning, growers and extension agents will need to see clear evidence of demonstrated efficacy of products from sources that they trust. First and foremost, product developers are going to "have to show some sort of a positive benefit that makes it worth that extra trip over the field... for my growers if they find things that are beneficial—truly beneficial—and not one year out of five" then this extension agent thinks his growers would be interested in FFE products. For their part, extension agents are trained to say, "show me the data. And if the

science is good and the methodology is good and it produces the results that it says it does then, hey, we're for it." They think about evidence of management practices and they think about how to best communicate that evidence: agents "want to see that [a management strategy or technology] shows that it's truly effective to see if I want to make that recommendation to my growers."

The source of the evidence matters, too: "most extension agents, if they see data from a company... they feel a lot more confident if they see third party work that gets similar results." One stakeholder talked about how "the university is seen as an unbiased source of information, or at least should be. You should be [an[unbiased source of information," and extension in turn communicates that information. Further, another stakeholder communicated that "it's an important role that a land grant institution that conducts unbiased research plays when new products are coming onto the market so that we can provide these stakeholders with data about the value versus that being provided by industry." This trust seems even more critical given the history of ineffective microbial products and the potential costliness of changes in management strategies on farms with such tight margins.

Another one of the biggest conditions for product adoption and commercial success would be getting the right data from the right conditions. Like other stakeholders mentioned, growers and extension agents "need data to show value." But getting data from the field (e.g. a working farm) is risky to growers.

Challenge 1.2

The opportunity costs of transitioning to FFEs from existing management strategies may be too high for growers. In this context, it is important to know that "for the most part [an FFE product] isn't going to be easy to implement partially because these items are still a lot more expensive than chemicals. And so the producers that are more eager to shift over to this kind of a practice are the ones that are, to be honest, have a little bit of wiggle room to do that. Unfortunately, there are a lot of producers that say if I don't hit this yield I'm going under this year, so I can't take a risk of going with something that is a little bit more sustainable over something that's chemical and reliable….there's just a razor thin margin about what a lot of these producers are facing." Put simply, for "a lot of cases chemicals are—at least as far as yield and as far as probably price—still the best option for the grower as long as they're not considering sustainability."

As such, integrating a new set of management practices would likely be more expensive than and initially less effective than current strategies, and most growers' margins may be too thin to experiment. Extension agents across the board noted something like "I think my growers are willing to try those things, and I think they're willing to use them on a regular basis, but they are going to have to be cost effective." But cost effectiveness means different things on different farms. For most growers, "margins are so tight... you're just trying to survive another year." Even as growers do think about transitioning to new management tools to support the long-term viability of their farms, "there isn't always the margin to think long term."

Margins are consistently tight but some farmers have more room to experiment: "Most of the farmers that have started looking at some more sustainable practices like crop rotations and, you know, no till in some places, things like that, generally they take a year or two of the hits so the first couple of years, their yields are a little bit down, but if they can survive those couple of years, then they start to see those yields going back up. So those are the ones that have the confidence to say yeah doing this really does work once they're on the other side of that kind of barrier." But even farmers that are willing to experiment with new techniques in the name of sustainability are "expecting that the decision that they make is going to increase the stability or the profitability of their company. So even

if they're planning for the long term, the plan is that it will pay off at some point. I think, ultimately, yes it always comes down to: is this an economically viable move because if it's not, your company goes out of business, and then what's the point of that move?" In other words, growers "are mostly interested in, right now, if it's going to provide at least a positive return on investment."

Moreover, the infrastructure that would be required for all of these dimensions to fall into place—those that would ensure an FFE could become a commercially successful product—are not yet in place and would be expensive to put into place. Even taking an effective product and "get[ting] in in the farmers' hand and into the field within three days" would require new and expensive infrastructure. Moreover, each biological is different and may require different systems in place.

Recommendations 1.2

1.2.a. Working with policy makers to develop clear incentive structures may support growers' willingness to adopt FFE products. Stakeholders saw national policy change as being critical for widespread adoption and commercial success of microbial products. Currently, these products are more expensive than pesticides year to year, so one stakeholder noted that the only way to make these products cost effective is regulatory changes that "phase out these pesticides or these chemical fertilizers... because chemicals are very cheap and they're very effective." While this respondent did not necessarily see those kinds of policy changes as likely, they did note that it would be effective: "I can either take a huge hit by not treating with anything, or else I can take less of a hit with microbes since chemicals are no longer going to be an option." Another stakeholder also noted the importance of "financial incentives" to motivate growers to adopt new products that may be more sustainable and to support the implementation of new infrastructure to support new tools.

1.2.b. Developers may do well to think about using FFEs as one tool in growers' management toolkit rather than as full replacements for existing management strategies. Clouds of hope and hype often surround the development of emerging biotechnologies. Broadly, harnessing the power of the microbiome has brought some of that hype as a powerful potential tool for replacing synthetic inputs that have broad-spectrum environmental effects. While this kind of hype may capture the attention of funders of research proposals, the reality of replacement will likely be much more mixed especially given the high upfront costs of new infrastructure to make FFE products useful on-farm.

One example of how envisioning how FFEs may become useful to growers requires looking at growers as a heterogeneous groups: some growers already work in Integrated Pest Management systems (IPM) and some stakeholders see possible value for "work[ing] several different microbial products into an IPM routine for biopesticide activity, there's potential for replacement."

However, "if they're [just] replacing conventional pesticides it's just going to be really tough." The more likely scenario is that "for a long time we'll be looking at just partnering conventional plus biological and reducing those conventional pesticides." In other words, FFE products may support or even just complement the reduction of certain conventional synthetic inputs rather than replace them altogether.

Challenge 1.3

While academic grants and publications draw on motivations such as climate resilience and sustainability for exploring the development of FFE products, those terms may create problematic perception rifts between academic and agricultural stakeholders. While academic publications that describe the potential value of harnessing the power of the microbiome tend to draw on sustainability, resilience, or adapting to climate change as motivation for their work, some of our respondents noted

that in order for these potential products to gain traction with most growers, language will have to be chosen carefully. One stakeholder described "skepticism when it comes to climate change." And, she continued, "sustainability has just become really almost a buzz like it almost has no meaning because it gets thrown around so often. Resiliency I feel like it's replacing sustainability….I think our growers tend to think in terms of the mindset of like, hey, we've been doing these things to protect the ground for many, many years and now all of a sudden you're trying to put a word on it."

Another stakeholder noted that "our growers, you know, they may not like changing climate terminology [but] they are for sure concerned about the volatility of the weather in North Carolina lately." One more stakeholder offered more detail: "[growers] know that our weather patterns are changing. They understand that we have more periods of wet weather, we have longer periods of dry weather, we have these crazy spells of an extreme rain event. So they see that and they understand that... but the word climate change and they're like, nah, we don't want to change."

Recommendation 1.3

Work with extension agents to think about the politics of language and the messaging around the motivation for adopting FFE products. As product developers think about communicating the potential value of these products, they will need to understand their audience in order for growers to be interested in the products. We described above the potential tensions between how academic researchers frame issues in research proposals and publications and how growers perceive issues. Extension is well-positioned to serve as a 'boundary' or 'translational' organization, serving as interpreters between researchers and growers, particularly about partisan issues like climate change or buzzwords like sustainability and resilience.

CHALLENGE 2. THE TRANSITION FROM LABORATORY SUCCESS TO ON-FARM USABILITY WILL LIKELY BE COMPLEX.

One stakeholder noted that "going from a controlled environment—greenhouse or growth chamber—to field, it's extremely difficult to reproduce, to bridge that gap to get reproducible results in the field." This transition will likely be complicated by a number of factors including biological requirements and environmental conditions, as well as logistical and infrastructure needs, which respondents describe in greater detail below.

Challenge 2.1

Microbial biological requirements can be very specific and may not respond well to stressed or even variable environmental conditions. Finding the right microbes has been described as "like a needle in a haystack." In fact, one stakeholder mused, "it doesn't seem to me that in the next two years they're going to come up with anything even close to Bt." And even if useful species are found and characterized, "microbes are notoriously finicky about staying alive especially under adverse conditions."

Moreover, it can be notoriously difficult to get microbes to do what you want them to do, and there are a number of different steps and conditions in which the FFEs would have to survive and thrive throughout. Stakeholders talked about the technical challenges of perfecting "a formulation that will keep that stuff alive and stable…" and "surviv[ing] on a leaf," and then "the right surfactant to help you get into the leaf." Another stakeholder similarly noted, "and then there's the application... colonization of the plant," and then being able to withstand environmental conditions to successfully preserve or increase yields

Building off of lab to farm challenges, these finicky microbes as products would be, "In a farmer's barn where it's not necessarily climate controlled... you need to make sure it stays alive for at least a year and in a lot of cases two years," about which some stakeholders are skeptical.

Relatedly, microbial products would have to withstand stressful environmental conditions once on the plant. One stakeholder noted that the FFEs would be "getting hit with UV rays. Other microbes may be attacking it. There's humidity, heat, moisture fluctuations." Or, if you're talking about seed coating: transport, farmer treatments of seeds which are often designed to eliminate microbial activity.

Different geographies present a challenge to stakeholders envisioning product success, too: "maybe you could get something that would work in acidic soils on the east coast" but under different conditions in the West, the microbes don't perform the same. One stakeholder described their own experiments in attempting to "tak[e] a microbe out of its native soil and putting it in a different soil and getting it colonized on a plant" as relative failures. In general, microbes live in very specific micro-environments and products may therefore only work in very specific niches.

Recommendation 2.1

Genetic manipulation may play a greater role in the logistics of turning helpful microbes into helpful tools rather than modifying what microbes do for the plant. While one potential role of genetic engineering is to accelerate or amplify the symbiotic relationship between plant and microbe, one stakeholder noted that manipulation may play a greater role in helping cultivate "shelf stability" or other characteristics that could help turn a useful microbe into an effective agricultural product.

Challenge 2.2

Moving from lab to farm: even in experimental farms, there are control variables that simply do not translate to working farms. As one stakeholder put it, "One thing that is really important in industry is to see academic research that moves from academic farmers, the university farms, into the field. Because oftentimes what we find even with our own experimental farms is that something that looks great in a really controlled environment kind of falls apart in the field or is just less predictable." Being able to collect data from working farms will be critical for product success.

Recommendations 2.2

2.2.a. Working with extension to recruit growers who would be willing to participate in on-farm research. One extension agent noted specifically that he would be interested in getting his growers to participate in on-farm research projects to help generate the kind of data necessary to know if FFEs would be effective products. Additionally, as noted above, microbial products would be much more specific than broad spectrum treatments currently used, so working with growers across a range of environments and geographic conditions would be critical for data collection.

Recommendation 2.2.b. The tools of precision agriculture may serve to collect the data appropriate to understand microbial biology, environmental conditions, and foster smoother lab to farm transition. Stakeholders noted that the specificity of data needs for effective microbial products would rely heavily on precision agriculture "effectively capturing and managing data." Whereas now, growers can basically say, "we've got some infestation; we're going to have to spray with a broad spectrum pesticide to get rid of everything." With FFE products—and microbial products

more generally, "you'd have to know what the organism is and... know what stage of either insect or pathogen life cycle is best to apply the microbe..."

Microbes also require more detailed environmental data metrics to see whether or not a product is working; information like it was a wet year or a dry year is insufficient. Instead, data requirements are more like: "what was the total moisture, what were the temperature swings, what was the temperature at germination and a few days after germination." And then, taking that more micro level data and scale up, "we didn't see a yield response to this year in these three fields but in these other three fields we did. If we have that data we can put that into an algorithm... and a machine learning algorithm is even better so we can know what data to look for in the future." Stakeholders noted that having these kind of detailed systems have "a long way to go," but point to companies like John Deere who have a similar system in place: they sell equipment, collect data from that equipment, and then share those data back with the grower.

CHALLENGE 3. REGULATING AND GOVERNING EMERGING BIOTECHNOLOGIES IS CHALLENGING AND DYNAMIC ON BOTH THE NATIONAL AND INTERNATIONAL SCALES.

Stakeholders noted the importance of understanding the "regulatory hurdles'' and other policy issues that shape biotechnology development. Although this project focuses on North Carolina crops, the interconnectedness of global markets means that we need to think about both national (see Barnhill-Dilling & Delborne 2021) and international scales of policy-making.

On the international stage, there are a number of active deliberations in the protocols (e.g. Nagoya & Cartagena) that govern biotechnology that may directly or indirectly shape the future of modified microbial products. These debates may have to be settled for these to become commercially successful agricultural tools. For example, while it is well-established that patents are not allowed on individual organisms or genes, there are patents on collections of sequences or understanding groupings that give rise to certain relationships. Here, one stakeholder noted that "the individual organisms within that microbiome are probably useless but when you understand the collection of them together and how they're interacting... that's the value added that you then found and so to me a patent lawyer would love this question: can you patent the collection of those things... as a product?" And then there's the question of how these protocols—that deal with synthetic biology and other biotech tools—will address 'benefits sharing' and open access sequences. While these issues are far removed from the bench and the field, they are broadly relevant to emerging biotechnology governance which in turn may shape commercial success of FFE products.

Recommendation 3

Early and ongoing engagement with policy experts and regulators throughout the innovation process. While detailed knowledge of the U.S. statutes or international conventions may not be critical, having broad understanding of the governance landscape will support socially responsive innovation processes. The agencies that regulate biotechnology have pre-application consultations designed specifically to support developers as they move through the regulatory system in the U.S. As developers grow closer to having a product or products ready to test, engaging with patent and intellectual property experts will also be important, at both the national and global levels.

CHALLENGE 4. THE HISTORY OF PUBLIC AND CONSUMER ACCEPTANCE OF GMOS IS COMPLICATED BY CONTROVERSY AND IT IS UNCLEAR IF FFES WILL FALL UNDER THE SHADOW OF THAT HISTORY.

Stakeholders raised questions about the perennial concern of public and consumer acceptance, the role of opposition, and the shadow of GMO history. Other stakeholders also acknowledge that even though extension agents and conventional growers broadly accept genetic modification tools in agriculture "as long as the science is sound," consumer acceptance "is still the biggest hurdle." Put differently, "it's not necessarily the growers; it's the consumers that are driving that problem." Some stakeholders are concerned that "if some consumer group started to say well you know we're going to start throwing some weird science stuff in there, some kind of propaganda or misinformation about this to scare people away from buying" products that may have been treated with modified FFEs. Consistent with ongoing discussion in emerging biotechnologies, stakeholders know that growers will need to be confident that "consumers have to be accepting of this technology."

And stakeholders know their history: one stakeholder noted that "there's a fine line between [these products] and GMOs... but the marketing and the approach behind GMOs was not done the best way and obviously there were a lot of problems with that. So, I think if you get too similar to GMOs then it's not going to be hard for somebody to point that out and really cause some trouble." However, another stakeholder noted: "I think we really messed up [communication about] the first GMOs. There was no public advantage; you know herbicide resistance doesn't help the public in any way. They can't relate to it, it doesn't help them in any way. So, saying that it's going to help farmers combat weevil, that's irrelevant to a consumer in a grocery store." So, while some stakeholders expressed frustration with bad faith advocacy actors, other stakeholders acknowledged that the developers may have dropped the ball in their communication about first generation GMOs.

Interestingly, a consumer advocacy stakeholder had a much more nuanced perspective than perhaps other stakeholders expected. This stakeholder noted the broad concern about emerging technologies and "concern for unintended consequences." However, the same stakeholder went on to equivocate somewhat about the issue: "On some level [a modified FFE] isn't as artificial and therefore doesn't raise the same kind of alarm bells that might otherwise be raised." This stakeholder continued, while "most people in sustainable agriculture would still be necessarily opposed to it but full-throated opposition is not really where their energy would go." But "there's still a group no matter what... they want to stay as natural and not tinkered with as much as possible so no matter what you're trying out they're going to be suspicious of it…any kind of genetic engineering interferes with or blocks progress toward sustainable agriculture worldview." In other words, supporting large scale commodities agriculture was not consistent with this stakeholder's understanding of what is meant by 'sustainable,' but they did not think there would be significant and pointed opposition from consumer or other advocacy groups. In other words, consumer or public attitudes about potential new tools like modified FFEs may not fall along a simple accept/oppose binary. Rather, there may be complex motivations and perspectives.

Recommendation 4

Develop an engagement strategy that moves from stakeholders to wider public audiences in order to understand the full landscape of perspectives. One stakeholder rather astutely observed that "we're looking at a lot of different audiences for a technology like this to be accepted and to be productive," and with different audiences, "communication channels are going to look very different." In short, stakeholders described concerns about communicating and educating public audiences to ensure that consumers would accept products grown with modified FFEs.

Some respondents also acknowledged that they should learn more about different social dimensions of these issues. One extension agent mused, "I think we often get caught up in just the economic part of it. I think it's interesting that more projects involve economists and social scientists and people who are looking at this from all positions because there's a lot to learn from that." The agent continued, noting the importance of "some training on the [social science]... that would be good and maybe we do need to hear a little more [about] the opposing views sometimes so we can do a better job."

To that end, we also recommend continuing to partner with engagement specialists who see engagement as opportunities for mutual learning and careful deliberation, both with stakeholders and with broader public audiences. We noted above that some respondents identified the importance of consulting with growers as part of combatting potential grower hesitancy in FFE product adoption. We want to reiterate that point and take it one step further: we recommend consulting with growers and other central stakeholders early and often throughout the innovation process so that stakeholder input can shape the responsible innovation of FFE products.

And when the time is right, we recommend expanding that work to include broader public audiences. While the methodology and expertise may be different when surveying a nationally representative sample of the general public versus facilitating deliberative stakeholder dialogues, the end goal—we argue—remains the same: finding meaningful ways for these perspectives to shape socially responsible innovation.

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Research scientists at North Carolina State University are exploring ways to harness plant fungal symbionts – specifically foliar fungal endophytes – to improve crop resistance to stressors such as drought, pests, and pathogens. Although this project is in an exploratory, basic research phase, the investigators recognized the importance of engaging stakeholders about their perspectives on the potential utility of fungal manipulations on crops.

For additional information about the project — including other project objectives and personnel — see https://hawkeslab.wordpress.ncsu.edu/funcrops/ or the CALS press release.

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GENETIC ENGINEERING AND SOCIETY CENTER

The GES Center at NC State University serves as an international hub of interdisciplinary research, engaged scholarship and inclusive dialogues surrounding opportunities, and challenges associated with genetic engineering and society. Positioned at the nexus of science and technology, the social sciences and humanities, the GES Center has taken a national and international lead in examining the technical, ethical, and societal dimensions of the products and impacts of biotechnology.

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