Can results-based prizes to private sector incentivize technology adoption by farmers?

Evidence from AgResults Nigeria pilot that uses prizes to incentivize adoption of Aflasafe™

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Selected Paper prepared for presentation at the 2018 Agricultural & Applied Economics Association Annual Meeting, Washington, D.C., August 5-August 7

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Evidence from AgResults Nigeria pilot that uses prizes to incentivize adoption of Aflasafe^{TM}.

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Abstract: Donors are increasingly interested in assessing the efficacy of attracting private sector innovation and creativity to achieve agriculture development goals through results-based prizes. The AgResults, a multi-donor funded, initiative is testing the efficacy of these results based incentives or "pull mechanisms" to drive agricultural technology adoption by smallholders. In Nigeria, the pilot is addressing the problem of aflatoxin contamination, which causes liver cancer and is associated with stunting. The pilot announced a $18.75/ton incentive for any private sector actor who aggregates maize from smallholders that is treated by Aflasafe—a biocontrol that addresses aflatoxin contamination—which is paid out only if an independent verification confirms that the maize is indeed Aflasafe treated. This paper presents the results of the external evaluation which assessed if private sector engagement led to smallholder adoption of Aflasafe, and if smallholder farmers became more aware of aflatoxin as a problem, and Aflasafe as a solution. The paper also evaluates if the smallholders, independently or through the maize aggregators, accessed premium markets for Aflasafe-treated maize with consequent increase in smallholder incomes. Importantly it assesses if the smallholders consumed more Aflasafe-treated maize, especially in the face of premium prices for Aflasafe maize, choosing instead to sell it for higher prices. Using a quasi-experimental evaluation design, the paper finds that smallholders did learn about Aflasafe, but they learnt much less about aflatoxins and their adverse impacts. On average the farmers received a price premium on the maize sold, and earned a 4 percent premium on maize prices. The smallholder farmers earned $315 more in maize revenues, which is a 24 percent increase over the comparison group. The pilot did lead to an increase in consumption of Aflasafe-treated maize though by less than expected—farmers in the treatment group consumed 13 percent more of Aflasafe-treated maize implying only modest health benefits. Overall the evidence suggests that pull mechanisms have the potential to increase technology adoption, but complimentary push efforts may be needed to generate general awareness about the technologies being promoted. Insofar as this approach achieves the objectives in a way that private sector actors and the smallholders realize profits, it may be more sustainable, and therefore ultimately be more cost-effective. However, we need more time to assess this potential.

Keywords: agriculture technology adoption, quasi-experimental design, evaluation, pull mechanisms, results

JEL: Q1, D1, C1

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Acknowledgements. We would like to thank Emily Crawford for her fearless efforts in managing data collection in Northern Nigeria and Mikal Davis for his research support in developing the initial survey instruments. We are also indebted to the AgResults Secretariat and pilot management team and Ranajit Bandyopadhyay for their comments on our paper. This evaluation was possible because of funding from UK Department of for International Development (DFID). The authors would also like to thank the AgResults steering committee for their comments that comprise of members from AgResults donors—UK DFID, Department of Foreign and Affairs and Trade, Australian Government, U.S. Agency for International Development, The Bill and Melinda Gates Foundation, and Canada and the World Bank which is the trustee for the program.

I. Introduction.

After the food crises of 2007-2008, there was a growing realization that donor resources were not nearly adequate to meet agricultural development challenges. The AgResults initiative was launched at the June 2012 G20 Summit in Los Cabos, Mexico as an innovation to boost private sector engagement in meeting these challenges. With funding of several governments—Australia, the Bill & Melinda Gates Foundation, Canada, United Kingdom, and United States—and the World Bank as its trustee, the AgResults initiative uses results based incentives or "pull mechanisms" to harness the resources and creativity of the private sector to drive agricultural innovation, research, and delivery for smallholder farmers in developing countries. AgResults is now a $122 million initiative comprised of seven pilot projects that incentivize the private sector to develop and deliver innovative products to smallholder farmers in settings where markets for agricultural inputs, services, and outputs are underdeveloped or nonexistent. Each pilot provides financial incentives to multiple private sector actors only after they achieve predefined results. The ultimate objective of the pull mechanisms is to encourage private sector investments in addressing the constraints that have limited the development of a market for beneficial agricultural technologies, and creating sustainable markets for these technologies when the incentives end.

The AgResults Nigeria pilot focuses on the problem of contamination of maize by a naturally occurring toxin called aflatoxins, which is produced by fungi commonly found in African soils—*Aspergillus Flavus and Aspergillus parasiticus*. Aflatoxins cause liver cancer with chronic exposure and liver edema and death with acute exposure (Williams et al, 2004). Chronic exposure to aflatoxins is also associated with stunting (Gong et al, 2002). Aflasafe, a biocontrol which can effectively control aflatoxins, has been developed for Nigeria (Bandyopadhya et al, 2016). However, smallholder farmers in Nigeria are not aware of Aflasafe or aflatoxins, which are invisible to the naked eye. Even if smallholders were made aware of aflatoxins as a problem and Aflasafe as its solution, Aflasafe is not economically viable for smallholders to adopt without a price premium on aflatoxin-free maize or an increase in yield. However, it is hard for smallholder farmers to access these premium markets which include export markets, grocery chains and the poultry feed market. The AgResults Nigeria pilot aims to innovatively address these constraints that have led to a missing market for Aflasafe and Aflasafe-treated maize (AT maize). Specifically, it provides a price incentive to private sector actors of $18.75 per ton for AT maize aggregated from smallholders. Motivated by the prize, diverse private sector actors—seed producers, poultry-feed producers, maize aggregators, and social enterprises—participated in the competition, and worked with smallholders to produce AT maize over the four years of the pilot from 2014 to 2017.[1]

The external evaluation of this pilot was designed to understand if the pull mechanism in Nigeria led to the development of a functioning market for Aflasafe by creating awareness about Aflasafe and aflatoxins and improving smallholder outcomes as measured by increased maize revenue and consumption of AT maize. This paper presents the results of the evaluation focusing on the smallholder outcomes.

[1] The pilot end in 2018 but the evaluation concluded one year before the pilot to allow the program to expand to evaluation's comparison areas.

II. Background: pilot's theory of change

The Aflasafe AgResults pilot design focused primarily on developing the supply of AT maize by incentivizing maize aggregates to aggregate AT maize. Through their efforts to aggregate maize, it was expected that smallholders would become more aware, and other value chain actors would become more engaged in the production of Aflasafe-treated maize. The pilot did not focus on generating awareness more broadly amongst Nigerian consumers because there are ethical and pragmatic concerns with generating awareness about the health impacts of consuming aflatoxin-contaminated maize without ensuring the availability of AT maize to meet the demand. It was expected that once the AgResults pilot ensures a steady supply of AT maize—in excess of the demand by exporters and poultry feed markets—government-driven efforts will be well-positioned to generate broader aflatoxin awareness and enforce existing aflatoxin-regulations to support quality verification of AT maize.

The pilot uses a "pull" mechanism—ex-ante incentives—for aggregating AT maize that encourage private sector entities —referred to throughout as "implementers"—to increase availability of AT maize by organizing smallholder farmers as suppliers of AT maize that the implementers will then purchase and sell to downstream buyers of maize—preferably buyers who are willing to pay a premium for maize with reduced aflatoxin levels. Conceptually, the pilot seeks to de-risk the private sector's investment in the supply of AT maize by temporarily offsetting the underlying conditions—particularly uncertain demand—with greater financial compensation for successfully taking on the supply side risks of aggregating and selling more Aflasafe-treated maize. Specifically, the pilot rewards participating maize intermediaries, or maize aggregators that procure AT maize from smallholder farmers by paying the aggregators a premium of US$18.75 per MT of AT maize aggregated. To qualify for the incentive payment, the maize should have more than 70 percent Aflasafe recovery (or Aflasafe concentration) based on tests by a third-party verifier. In addition, the pilot required, but did not verify, that the implementers must purchase maize from smallholders.[2]

The pull mechanism expected implementers to innovate on approaches to encourage adoption of Aflasafe by smallholders. Therefore the prizes are paid out regardless of the strategies that implementer used to engage smallholders, such as by providing access to credit and other inputs with a promise for better quality maize and better maize yields, access to premium markets or output sale guarantees. Implementers may also motivate smallholders to adopt Aflasafe by raising their awareness about the health benefits to their families, causing them to grow more AT maize for both consumption and sale. However, there is also a countervailing incentive for implementers to not raise awareness among smallholders so they sell the AT maize to the implementer rather than saving it for consumption. Therefore, it is an important empirical question whether smallholder awareness was raised as a result of the pilot.

The pilot did not reward implementers for targeting specific consumers for the final sale of the aggregated maize, particularly the final consumers of maize who are generally not aware of aflatoxins or Aflasafe-treated maize. Instead there was natural incentive for implementers to pursue transactions with market actors who are willing to pay a premium for aflatoxin-safe

[2] AgResults steering committee decision taken at the April 2014 steering committee meeting. However, this requirement was not part of pilot's verification protocol.

maize—the export market, large supermarkets and the poultry feed industry since chickens respond adversely to aflatoxins immediately. Implicit in the pilot's theory of change was that as the supply of AT maize grows—particularly beyond the needs of poultry feed and export—concurrent public activities to raise awareness of aflatoxins in Nigeria will help activate latent demand for AT maize, helping to maintain an attractive output market for AT maize and expanding the distribution of aflatoxin-safe maize to these markets. At the same time, given the preponderance of smallholder maize farmers in the Nigerian population, and their high exposure to aflatoxins in the maize they consume, there is also a trade-off between farmers' responding to market incentives by selling all of their AT maize for premium prices and retention of that maize for home consumption; the outcomes of that trade-off therefore, is an important determinant of the pilot's impact on both smallholder incomes and their consumption of aflatoxin-safe maize.

The evaluation assesses the assumptions in the AgResults theory of change. In this paper, we assess if AT maize created smallholder awareness about Aflasafe, led to its adoption and consequent increase in smallholder incomes. It also assess if AgResults created awareness about aflatoxin health impacts among farmers and those responsible for cooking (typically the wives if the farmer is male), and whether it impacted on-farm decisions to consume aflatoxin-safe maize.

III. Method

We used a quasi-experimental design to assess the impact of the AgResults Nigeria pilot on the smallholder outcomes—adoption of Aflasafe, smallholder income from maize and consumption of Aflasafe-treated maize.[3] Specifically we compared a treatment group—which comprised farmers from villages identified by the AgResults implementers as farmers they worked with—with farmers in the comparison group—which comprised farmers from villages where the implementers did not work.[4] We address the potential selection bias by assigning analysis weights to farmers in the comparison group weighing more heavily households that look like households in the treatment group on observable characteristics by assigning analysis weights using a propensity score model.

In addition, we control for factors other than treatment that could influence the key outcomes—Aflasafe adoption, maize yield and returns. First, we include household characteristics (age and education of the household head, religion, household size, whether the main economic activity is maize farming, type of house, fuel, toilet and water access), and farm characteristics (size of land owned, average maize harvest in a typical year, ownership of farm equipment and

[3] The evaluation started out with a step-wedge cluster-randomized control trial (RCT) that leveraged the implementers to engage with villages in phases. The villages that were randomly assigned to last year of treatment were the control villages. However, the RCT was not successful because in the competitive environment of the AgResults pilots the implementers did not adhere to their treatment plan – the treatment rate was low in in villages assigned to treatment, and there was similar degree of contamination in the control villages. The treatment rate was so low that we had to add treatment villages and farmers to the analysis sample during the endline survey, relying on baseline values gathered by recall focusing on variables that either do not change, can be calculated, or are expected to be sticky and therefore likely to have better recall.

[4] By ex-ante agreement Katsina state was not part of the AgResults program and was set aside as a comparison area for the evaluation. The villages selected in Katsina were located in areas close to the border of Kano and Kaduna state.

animals).[5] Third, we control for environmental and contextual factors such as distance to an urban center (population > 100K), soil carbon content, temperature variability, and rainfall for which we had baseline values from secondary data sources.

We use linear regression models to estimate the average impact of AgResults on farmers' outcomes. Household survey responses are clustered in villages, and we do not view these responses as independent across farmers because AgResults was implemented at the *village* level instead of the household level. Thus, the primary sampling unit is a village and statistical precision is more a function of the number of villages in the treatment and comparison groups than of the number of households in the treatment and comparison groups. This design precludes selection of comparison group farmers who live in the same village as one or more treatment group farmers—a circumstance that might result in agricultural practices induced by the AgResults intervention spilling over into the comparison group.

To estimate the average impact of AgResults on farmers' outcomes we use linear regression models (see equation 1). The estimation recognizes that survey respondents are clustered in villages, and their survey responses are not independent.

$$y_{ij} = \alpha + D_j\delta + X_i\beta + Z_j\gamma + \varepsilon_{ij} \qquad \text{[Equation 1]}$$

In regression equation above, y_{ij} reflects the outcome for respondent *i* in village *j*; D_j, the treatment indicator, is equal to one if the individual's village *j* is a treated village, and 0 if a comparison village; the coefficient, δ, represents the average treatment effect; X_i represents the household level covariates specified above for person *i* and Z_j represents the village level covariates such as temperature or soil composition for village *j*; and the individual idiosyncratic error term ε_{ij} is cluster robust at the village level.

The regression allows us to answer research questions about the effect of AgResults on farmers implementers said they worked with or reached out to—as measured by coefficient δ on T. Of the treatment group the farmers reached by implementers, 57 percent had used Aflasafe. Therefore, in addition to estimating the effect of the pilot on the farmers reached by implementers, we also estimate the effect of the program among the subset of farmers who used Aflasafe. For each outcome, this is the "treatment on the treated" impact estimate, which is equal to the impact estimate for the whole group (δ) divided by 0.57[6], the share of treatment smallholders that adopted Aflasafe.

[5] We also include whether a farmer belonged to a cooperative, whether he or she had access to credit, and whether he or she knew any of the implementers at baseline. The majority of the treatment group was not interviewed at baseline because the treatment rate was much lower than anticipated at the time of baseline. Therefore we had to include treatment households in the sample for whom we did not have baseline data. Therefore, we rely on recall on these variables. Several of these variables do not change over time or can be easily back-calculated (e.g. gender, age, religion, education, ownership of farm equipment and animals) several are relatively static over the short-range of the pilot (type of house, fuel, toilet and water access), and we assessed their stickiness within the observations for which we had both baseline and endline data.

[6] This procedure assumes that AgResults had no effect on the outcome under study for farmers reached by implementers who did NOT use Aflasafe. With that assumption, the initial finding for the average effect on all farmers is a weighted average a 0 impact on a .43 share of the treatment group farmers and a potentially non-0 impact on the remaining .57 share of the treatment. To get an overall impact of M with this weighted average formula, the non-0 impact on the farmers who applied Aflasafe must have been L = M/.57, so that .57L + .43(0) comes out to equal M.

IV. Data

The study sample for the evaluation comprised smallholders that were in the zone of influence of six implementers in Northern Nigeria states of Kano and Kaduna that joined the program the pilot's first year[7]. The comparison group includes farmers from villages in Kano and Kaduna where no AgResults implementer worked until the end of pilot's year 3 and villages in Katsina state, which by agreement, was not part of the AgResults program and was set aside as a comparison area for the evaluation until the of pilot's year 3[8]. The treatment group consists of farmers in Kano and Kaduna identified by the six focal implementers as farmers with whom they worked until the pilot's year 3.[9] The total sample size was 1823 smallholders, with 944 smallholders in 112 treatment villages and 879 smallholders in 109 comparison villages (see Table 1 in Appendix).

From this sampling frame we used two-stage sampling, by village and then smallholder, to select treatment cases for interviewing based on several criteria. In selecting villages, we first included all villages that were also part of the baseline survey sample. Second, in adding further villages from among the roster of villages that met our criteria of selection (bordering Kano and Kaduna) we purposively sampled villages to achieve geographical diversity across the different states and local government authorities (LGAs) in Northern Nigeria, the latter being the lowest administrative unit within a state. Within villages, we sampled farmers such that the ratio of farmers by the six implementers in our sample was proportional to the number of farmers in the sampling frame provided by each implementer. In total, we had completed interviews with 944 treatment farmers in 112 villages.

In Kano and Kaduna the comparison group farmers came from the list of farmers that the implementers identified as the group they expected to work with but did not end up working with, implying that these farmers met the conditions they used to identify farmers they expected to work with. In Katsina, the comparison group farmers come from villages along the border with Kano and Kaduna, to make them as comparable as possible to the treatment group farmers in Kano and Kaduna. In these villages we selected comparison group farmers based on the criteria that the implementers themselves used to identify farmers to work with in Kano and Kaduna. For a subset of villages, we selected farmers from lists provided by maize production cooperatives in the villages and skipped farmers who did not state that maize production was their main occupation, a primary selection criteria for most implementers. For another subset of Katsina villages, we selected farmers from village farmer lists and skipped farmers if they stated that they had greater than 1 hectare land and if they did not state maize production as their main

[7] These implementers remained the focus of pilot operations over the first three years, accounting for 76% of the smallholders that engaged in the pilot, and 76% of the total AT maize aggregated by the pilot by the end of pilot's year 3.

[8] We confirmed non-participation of comparison group villages in Kano and Kaduna using AgResults monitoring data, which we further validated in the field with villages leaders during endline data collection. The pilot expanded to Katsina in its fifth year of operation.

[9] We conducted the evaluation one year before the pilot's end in 2017 to allow the program to expand to the comparison areas.

occupation. This selection process reflected the selection criteria for one of the implementers who had the largest share of farmers in the program.

The validity of a quasi-experimental evaluation rests on the quality of the comparison group: in particular, in assuring that the comparison group does not differ systematically from the treatment group on factors that influence outcomes, other than exposure to the treatment under study. Any systematic differences on other factors could lead to selection bias in the impact estimates—and will do so in instances where those factors exert an influence on outcomes. For example, farmers who choose to work with AgResults implementers may be (i) more likely to have means of procuring production inputs, (ii) more averse to aflatoxins, or (iii) less averse to investment risk. These elements could lead those farmers to achieve higher incomes than comparison group farmers, for example; if so the AgResults treatment would not be the reason—but would be mistaken as the reason. Selection bias could also be driven by the AgResults implementers themselves: the implementers may choose to initiate their AgResults efforts in villages that are close to road networks or have more tightly integrated farmer cooperatives, factors that also could drive better smallholder outcomes independent of the pilot treatment.

There are several facets of the impact analysis design that protect against selection bias. The Kano and Kaduna comparison villages and their associated farmers were identified *a priori* by the implementers as villages and farmers with whom they planned to work in the future, though in fact the implementers did not end up working with them. This choice reduces selection bias because villages and farmers initially selected but then not pursued by implementers may have similar unobservable attributes to villages and farmers initially selected and then engaged in later years.

The Katsina comparison villages came from a region that implementers would have like to work in but agreed not to engage in until 2017 planting season after the endline evaluation was complete (in coordination with the evaluation team). The Katsina comparison villages were also in regions along the borders of Kano and Kaduna states and were drawn from regions that our stakeholders suggested were similar to villages in Kano and Kaduna states.

Regressions used to estimate impacts include covariates that control for factors other than treatment that could influence the outcome—maize yield and returns. First, we include household characteristics (age and education of the household head, religion, household size, whether the main economic activity is maize farming, type of house, fuel, toilet and water access), and farm characteristics (size of land owned, average maize harvest in a typical year, ownership of farm equipment and animals).[10]Third, we control for environmental and contextual factors such as distance to an urban center (population > 100K), soil carbon content, temperature variability, and rainfall for which we had baseline values from secondary data sources.

[10] We also include whether a farmer belonged to a cooperative, whether he or she had access to credit, and whether he or she knew any of the implementers at baseline. The majority of the treatment group was not interviewed at baseline because the treatment rate was much lower than anticipated at the time of baseline. Therefore, we rely on recall on these variables. We do not use baseline data. Several of these variables do not change over time or can be easily back-calculated (e.g. gender, age, religion, education, ownership of farm equipment and animals) several are relatively static (type of house, fuel, toilet and water access). To assess the stickiness of the variables we gathered as recall in the endline data we conducted an analysis on the sub-sample of households for whom we had the baseline data and endline data (see Table 2, in appendix).

Finally, we assign analysis weights to farmers (observations) in the comparison group, weighing more heavily the households that ‘look like’ households in the treatment group on observable characteristics. We assigned inverse propensity score weights to the comparison group—creating larger weights for observations that “looked more like” the treatment sample. Without sample weights, the comparison and treatment groups have statistically significant differences in 19 mean characteristics including schooling, religion, number of household members, amount of maize harvested in a ‘typical’ year, whether or not they owned chickens in 2015; whether they had improved walls, toilet facilities, or lighting in 2015; and whether or not they owned a wheelbarrow in 2015. Using weights, we were able to balance on majority of these 19 mean characteristics, but not all because balance in one characteristic can upset balance in another. In addition, the data are clustered in villages, which makes the effort to balance more difficult.[11]

We estimated the propensity model using a simple linear probability regression, with treatment as the dependent variable. The explanatory variables were household size, hectares owned, improved toilet in 2015, improved lighting in 2015, ownership of a draft animal in 2015, and ownership of a ridger in 2015. The propensity model is estimated while ignoring the clustering of individuals in villages. The predicted propensity scores from this regression p were then used to assign a weight of $p/(1-p)$ to the comparison group (each household in the treatment group receives a weight of 1). These weights are treated as sampling weights (“pweight” in Stata) in the impact analyses.

After weighting, we find that the comparison group is fairly similar to the treatment group on most observable demographic characteristics, environmental characteristics, and relatively time-invariant wealth and farm characteristics that can affect key outcomes (see Table 3 in appendix). Out of 20 hypothesis tests for non-equivalence, only three involve treatment-comparison differences in background characteristics with effect sizes greater than 0.15 and only one is statistically significantly different from 0.00 ($p < .01$ level). Regardless of significant differences, we include all of these variables as covariates in all impact regressions.

Next, we discuss the variables with larger effect sizes. More farmers in the comparison group identify themselves as Islamic than do farmers in the treatment group. This is likely because Katsina is a predominantly Muslim state while Kano and Kaduna have populations of more mixed religions. However, we do not expect large differences in farming practices based on religion (other than the role of women on farms), and we believe including this variable in impact regressions will neutralize any small effects this factor may have on key outcomes and impact estimates. Further, farmers in the treatment group were more likely to have known an AgResults implementer before their engagement in the pilot, than were farmers in the comparison group. The farmers in Katsina are less likely to have heard of an implementer because the implementers had agreed to not yet work in the state. We believe including this variable in the impact regressions counters any bias this initial difference creates. Finally, the comparison group lives in areas with greater temperature variation within the year. It is not clear how this fact might alter maize productivity and other outcomes, especially in light of the fact that the comparison group has lower maximum temperatures in the dry season. As with above, including this variable in the impact regressions counters any bias this initial difference creates.

[11] See Standing et al (2008) for a discussion of balance in clustered designs.

As Table 3 in the appendix shows, after weighting the comparison and treatment sample is balanced on key factors that we believe most affect key outcomes.

V. Results.

Pilot's impact on awareness and adoption. The pilot's theory of change posits that the underlying constraint limiting the demand for Aflasafe, and AT maize is the lack of awareness among smallholders of Aflasafe as a technology that can address aflatoxin contamination. Therefore, to examine the pilot's impact on smallholder uptake of Aflasafe, we first assess smallholders' knowledge about Aflasafe, how to use it, as well as their awareness of aflatoxins and their health impact and how Aflasafe works to address aflatoxins. Moving along the theory of change, we also assess the pilot's impact on uptake, the extent to which they applied Aflasafe whether they applied Aflasafe in the prescribed quantity to achieve aflatoxin reduction.[12]

Since uptake of Aflasafe was also intended to influence smallholder's decision to consume AT maize once made aware of the health benefits, we also assessed the extent of intra-household sharing of knowledge. Specifically, we assess if the pilot had an impact on raising awareness about Aflasafe and aflatoxin health impact among the person in the household who is responsible for cooking meals (the cook, here after), typically a female household member.

For each of these outcomes, we present the impact of the program among smallholders in villages engaged by AgResults implementers, or the full treatment group defined for the study and on the subset of smallholders in the treatment group that applied Aflasafe to one or more of their maize plots in the 2017 maize planting season—the "adopters."

Overall, we find that about 73 percent of smallholders in the treatment group had heard of Aflasafe, compared to only 6 percent of smallholders in the comparison group implying that there was a 67 percentage point impact on knowledge from the pilot (see Table 4 in the appendix). However only 25 percent of the smallholders in the treatment group knew how Aflasafe works, and far fewer—only 10 percent—knew how to use Aflasafe. While our estimates of impacts for those who adopted Aflasafe by definition indicate a higher level of knowledge of Aflasafe, we see that the pilot causes only a 39 percentage point impact on knowledge of how Aflasafe works than the comparison group, and only a 16.3 percentage point impact on knowledge of how to use Aflasafe. These findings were reinforced in our qualitative inquiries, which showed that farmers who were linked to AgResults implementers tended to be familiar with Aflasafe as part of the technology packages they used in producing for those implementers, but they were frequently unable to specify what Aflasafe was used for, reporting for example that it helped to increase maize productivity or quality, but not directly linking it to prevalence of aflatoxins in the maize. This suggests that the information flow from the implementer to the smallholder was not perfect with regard to how the technology works, and how it should be applied.

[12] The recommended application rate for Aflasafe is 10kg/ha although no field trials have been conducted for application rates less than 10kg/ha to determine if a lower application rate can be efficacious (Bandyopadhyay, 2016).

Similarly, the farmers did not display strong knowledge about aflatoxins or its health risks. Only 23 percent of the smallholders in the treatment group knew what aflatoxins are and what their health risks, as compared to 0.8 percent of the smallholders in the comparison group. Those that used Aflasafe were about 22 percentage points more likely than the comparison group to know about aflatoxins and their health risks. While this shows a large impact, nearly two thirds of the smallholders that used Aflasafe did not know the health benefits it was providing (see Table 4, Appendix). Our qualitative inquiries reinforce these findings. We found that farmers who were linked to AgResults implementers tended to be familiar with Aflasafe only as a part of a larger technology package they used in producing for those implementers. Interviews with implementers do suggest that they conducted training on Aflasafe. However, the topics that received most emphasis were recommended agricultural practices with a promise to increase yields. As a result, farmers typically associated Aflasafe as part of the package of inputs that they received but they did not always associate Aflasafe with aflatoxins. These findings suggest that some of the impacts in Exhibit 6 could have arisen among smallholders who did not adopt Aflasafe but benefited from other inputs and information provided by the implementers. If this were the case, the estimated impacts on the adopters may be overstated because in calculating impacts on adopters, we assume that non-adopters did not benefit at all from AgResults.

We also examined the effect of the pilot on cooks' knowledge—typically a female member of the household—of Aflasafe and aflatoxins. We hypothesized that if cooks are knowledgeable about aflatoxins they may make important decisions related to the use of Aflasafe-treated maize compared to maize that is not treated. They may also influence the decision to consume rather than sell Aflasafe-treated maize. The evaluation found that the pilot did have an impact on the cook's knowledge about Aflasafe and aflatoxins but the magnitude of impact was small. Only 29 percent of cooks had heard of Aflasafe in the treatment group compared to less than 1 percent of cooks in the comparison group. Only 9.7 percent of cooks in the treatment group knew how Aflasafe works, compared to 0.3 percent of cooks in the comparison group. Far fewer cooks in the treatment group—7.7 percent—knew what aflatoxins are, and only 5.8 percent understood the health risks of aflatoxins, while no cooks in the comparison group knew about aflatoxins are their health risks. Given that farmers themselves tended to have relatively low awareness of aflatoxins and their health implications, as well as the specific role that Aflasafe plays in reducing aflatoxins, it is unsurprising that the intra-household knowledge transfer to cooks of the household was low.

In summary, the pilot had an impact on knowledge about Aflasafe (67 percentage point increase in knowledge about Aflasafe among smallholders), but a much smaller impact on smallholder's knowledge about how it works (22 percentage point increase), and even smaller impact on how to use Aflasafe according to prescription (9 percentage point increase). Pilot's impact on the knowledge of aflatoxins and its health risks was similar to the pilot's impact on how Aflasafe works (22 percentage point increase).

Even among the subset of smallholder those that used Aflasafe, the impacts of the program on their knowledge of the use of Aflasafe and dangers of aflatoxins was less than would be expected. This is not surprising given our qualitative findings that the implementers focused more on the economic motivation for farmers to use Aflasafe. We had hypothesized that the implementers could have countervailing incentive to not share knowledge about the health benefits so that they sell more maize to them, increasing their incentives, but we did not see evidence of that. The implementers reported sharing this information but it was not their focus, and it simply reflects the reduced effort in sharing information that is not germane to their business model.

Evaluation results suggest the pilot did have an impact on uptake of Aflasafe—57 percent of smallholders in the treatment group applied Aflasafe on at least on plot, compared to only 1 percent in the comparison group, implying an increase in uptake by 56 percentage points as a result of the pilot (see Table 5 in Appendix). However, smallholders did not apply Aflasafe to all their maize plots: smallholders in the treatment group applied Aflasafe to only 44 percent of the maize area compared to 0.7 percent of the maize in the comparison group, implying that the pilot increased the maize area under Aflasafe by 43 percentage points. This translated to the pilot increasing the application of Aflasafe on 1.2 hectares on average per smallholder. However, the results indicate that the pilot's impact on increasing the maize area on which Aflasafe was applied based on prescription increased only by 6.5 percentage points. The prescribed application rate of Aflasafe is 10kg/ha approximately 40 days after planting. However, smallholders in the treatment group had a lower application rate (6kh/ha). These results were reinforced in our qualitative inquiries which found that most farmers did not describe the prescribed time for application or the prescribed application rates.

Focusing on the subset of smallholders in the treatment group who applied Aflasafe, the pilot led to an increase in maize area under Aflasafe by roughly 75 percentage points, and an increase in maize area where Aflasafe was applied correctly by 11 percentage points.

Smallholder returns

The pilot's theory of change expected to affect smallholder incomes from maize in three ways:

- Through direct or indirect pass down of financial incentives by implementers to encourage smallholders' uptake of Aflasafe in maize production (e.g. pass down of AgResults premiums or interest-free credit on inputs or free inputs or output buy-back guarantee);
- Through increase in maize yields by improving access to or information about inputs and agricultural practices from implementers, and/or
- Through price premiums on AT maize over and above AgResults premiums.

The pilot business plan estimated at average maize of yield of 2MT/ha, farmers would break even, implying that the total cost of production equal the returns from production, after adopting Aflasafe which costs $10.75/kg or $100.75/ha, assuming that smallholders set aside on average 1MT consumption needs. Without yields greater than 2MT/ha and/or price premiums on maize sold, the farmers would not have the financial incentive to adopt[13]. Conversely, farmers would need a price premium of 1- 4 percent depending on their maize yields to break-even (Bandyopadhyay et al, 2016).

We find as the result of the pilot smallholders got a higher maize price on their maize sales (see Table 6, in appendix). On average, smallholders in the treatment group sold maize at an average price of $406/MT while smallholder in the comparison group sold maize at an average price of $391, implying that farmers in the treatment group got a 4 percent price premium. Focusing on the subgroup of smallholder who used Aflasafe, we find that if all the impacts were driven only by adopters of Aflasafe, then they would have received an increase in price of about $28 and increase in annual maize revenue of $553. However, it is possible that a portion of these measured impacts took place on farmers who did not adopt Aflasafe as access to improved farming practices and improved maize seeds through implementers could have led farmers to have better quality maize (as measured by larger grain, less discoloration etc.) and better prices for maize. Insofar as this is true, our estimates of impact on adopters is an underestimate.

However, the pilot did not have an impact on maize yield. The average maize yield was 2.8 MT/hectare for smallholders in the treatment group and 2.7 for smallholders in the comparison group, and this difference was not significant.[14] This could reflect the fact that implementers exerted effort to identify and engage with smallholder who were serious about maize farming and who thus obtained the maximum yield with or without the implementers' influence.

We find that the pilot had an impact on farmer's annual maize sales revenue. Famers in the treatment group earned on average $315 more in maize revenue per season[15], earning, on average, $1,348 from maize sales compared to $1,033 by smallholders in the comparison group. This implies that smallholders in the treatment group earned 24 percent more in annual maize sales revenue.

Given that there was no impact on maize yield, and there was no impact on area cultivated under maize, the 24 percent higher maize sales revenue is explained by the fact that smallholders in the treatment group were able to complete more maize sales. Farmers in the treatment group sold 24 percent more maize than comparison group smallholders. Smallholders in the treatment group sold 3.33 MT of maize compared to 2.68 MT of maize by smallholders in the comparison group. Conversely, the treatment group set aside a smaller amount for consumption, although the average set aside was what the business plan expected is the amount needed for own consumption (1MT). Given that the implementers were providing output buyback guarantees and linking smallholders to final. Since farmers were able to save adequate quantity of maize for consumption, this suggests that treatment group households were more successful in selling their surplus maize benefitted by implementer's linkages to markets.

[13] IITA research has established that Aflasafe application controls aflatoxins but does not change maize yields.

[14] The average yield reported by pilot manager on AgResults farmers is also 2.8 MT/ha (AgResults, 2018).

[15] Farmers in the north have one maize season in a calendar year.

If we impute the value of maize set aside for consumption by smallholder using the average price received by the farmer, add it to maize sales and deduct the cost incurred for maize production, we get net maize revenue per farmer. The evaluation finds that the pilot increased smallholder's net revenue by $210. When normalized by the maize area we find that the pilot increased smallholder's net revenue per hectare by $30 but this result was not statistically significant. Treatment farmers earned, on average, $1,314 per farmer, while comparison farmers earned an average of $1,104 per hectare. This translated to increase in net revenue per farmer of 19 percent. If this effect on net revenue in the treatment group were driven exclusively by those who adopted Aflasafe, then the program would have an impact of about $369 per farmer. However, to the extent that non-adopters also benefitted from implementers in accessing output markets, it is possible that all impacts do not accrue only to adopters implying that our estimates for those who adopted are an underestimate.

To understand the components of the net maize revenue increase, we explored if the pilot had an impact on the maize production costs. We found that the smallholders incurred $38, or 13 percent, less cost in fertilizer which also comprises a large portion of smallholder input costs. Since fertilizer was one of the largest component of smallholder input costs. The pilot did increase smallholders' cost of maize seeds but seed costs were a small portion of input costs.

Conclusion and policy implications.

Aflatoxins are naturally occurring toxins generated produced by *Aspergillus Flavus* and *Aspergillus parasiticus*, a type of fungus that grows in hot and humid conditions, implying that it affects the entire African continent (Diener et al., 1987; Kurtzman et al., 1987). Drought stress has been found to increase the number of *Aspergillus* spores in the air, increasing the chance of infection in crops (Sanders et al., 1993). Aflatoxins cause liver cancer with chronic exposure, and is also associated with stunting (Gong et al., 2002; 2003; Williams et al., 2004). Aflatoxins are not safe at any levels, and acute exposure can lead to liver edema and death (Williams et al., 2004). Groundnuts and maize are particularly affected with by aflatoxins, and since maize is an important food security crop, controlling aflatoxins in maize can lead large-scale development impact in Africa (Liu & Wu, 2010). In Nigeria, like many other African countries, aflatoxin regulations exist, however enforcing these regulations is difficult, particularly for maize which is often traded unpackaged. Further, own consumption of maize among smallholders is high.

Numerous studies have established the efficacy of Aflasafe in controlling aflatoxins (Bandyopadhyay et al, 2016). It is a biocontrol with natural strain of *Aspergillus flavus* that does not produce aflatoxins, and when applied to crop fields, it controls for aflatoxins. The protection continues even during storage (Bandyopadhyay et al, 2016). Given the efficacy of Aflasafe, and the health burden of aflatoxins, and in the context of an environment where consumer awareness of aflatoxins is low and enforcement of aflatoxins standards is difficult, it is debatable if creating a market for Aflasafe treated maize is viable or if Aflasafe should be treated as a public health good like vaccinations. There are externalities in use of Aflasafe insofar the producers of AT maize do not benefit from any health impact that the end consumers of the product reap, unless they are willing to pay a premium for it. The AgResults Nigeria pilot focused on creating a smallholder inclusive market for AT Maize. It aimed to engage smallholders in consuming and producing AT maize by dangling temporary incentives to maize aggregators that were designed to mimic the premium that the end user market might provide for AT maize. Our results find that this approach engaged multiple private sector in aggregating and supplying AT maize, all of whom invested to organize smallholders, supply Aflasafe, procure AT maize and sell it to premium markets. However, the market penetration relative to the total maize market in Nigeria was small. The smallholders benefited by access to premium markets and being able to sell more maize their annual maize sales revenue increased by $315, or 24 percent, and their annual net maize revenue increased by $210. This increase was driven primarily driven by larger volume of maize sales (24 percent more volume of maize sold), higher prices for maize (4 percent premium) by smallholders in the treatment group and lower fertilizer costs (13 percent less fertilizer cost). Smallholders did learn about the health impact of aflatoxins, or Aflasafe as a solution but there are significant gaps in this understanding. This suggests that a private-sector led approach can work partially to create a market for AT maize; public funds are still important to raise broader awareness about the health impacts of aflatoxins. Overall, while a niche smallholder-inclusive market for AT maize was developed, there are barriers to it going mainstream. To promote continued development of the market for AT maize (and to eventually drive out unsafe maize), it will be important to raise broader consumer awareness, enforce aflatoxin standards, and make aflatoxin testing more easily available.

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Appendix.

Table 1 Evaluation sample

	Treatment Group	Comparison Group	Total
Farmers	944	879	1823
Villages	112	107	219

Table 2. Assessment of "stickiness" of recall baseline values and their differences between treatment and comparison group

Variable	Comparison Difference	Treatment Difference	Difference in Differences	P-value	Baseline Mean	Endline Mean	Difference	% the Same
Age of household head	-1.025	-0.318	0.707	0.482	46.380	44.741	-1.639	0.133
Gender of household head	-0.022	-0.008	0.014	0.958	0.015	0.017	0.002	0.993
Household's main economic activity is agriculture/maize farming	0.575	0.837	0.262	0.000**	0.191	0.900	0.709	0.419
Household identifies as Islamic	0.001	0.000	-0.001	0.628	0.863	0.868	0.005	0.999
Household size (recall)	0.238	-0.333	-0.571	0.626	10.605	9.864	-0.741	0.092
Number of household members aged 5 years or younger	1.273	2.209	0.936	0.045*	2.852	4.330	1.478	0.146
Completed secondary school or more	0.097	0.054	-0.043	0.662	0.293	0.334	0.041	0.678
Completed primary school or more	0.137	0.023	-0.114	0.371	0.542	0.610	0.068	0.627
Average distance to market from plot (km)	-3.311	-6.167	-2.856	0.147	11.819	6.230	-5.589	0.010
Area of household land owned in hectares	-3.445	-4.345	-0.900	0.515	10.051	5.669	-4.382	0.070
Owned cow(s)	-0.054	-0.202	-0.148	0.022*	0.365	0.277	-0.088	0.633
Owned pig(s)	-0.007	-0.031	-0.024	0.067	0.037	0.008	-0.029	0.982
Owned goat(s)	0.021	-0.062	-0.083	0.364	0.593	0.516	-0.077	0.569
Owned chicken(s)	-0.002	-0.163	-0.161	0.020*	0.643	0.530	-0.113	0.566
Owned ox(en)	0.071	0.109	0.038	0.495	0.018	0.093	0.075	0.875

Owned sheep	0.031	0.147	0.116	0.051	0.374	0.413	0.039	0.578
Owned donkey(s)	-0.003	-0.016	-0.013	0.373	0.009	0.003	-0.006	0.987
Owned camel(s)	0.019	0.000	-0.019	0.234	0.003	0.005	0.002	0.991
Improved roof	-0.017	0.047	0.064	0.178	0.880	0.890	0.010	0.798
Improved wall	0.104	-0.016	-0.120	0.004**	0.275	0.291	0.016	0.681
Improved floor	0.008	-0.023	-0.031	0.166	0.619	0.616	-0.003	0.587
Improved toilet facility	-0.052	-0.047	0.005	0.010**	0.955	0.928	-0.027	0.963
Improved water source	-0.680	-0.814	-0.134	0.004**	0.914	0.225	-0.689	0.258
Improved cooking fuel	-0.007	-0.008	-0.001	0.980	0.027	0.025	-0.002	0.963
Improved lighting	-0.010	0.031	0.041	0.073	0.452	0.479	0.027	0.674
Owned a tractor	-0.017	-0.008	0.009	0.777	0.026	0.009	-0.017	0.968
Owned a harvestor	-0.018	-0.016	0.002	0.585	0.030	0.004	-0.026	0.965
Owned a ridger	-0.168	-0.287	-0.119	0.015*	0.386	0.208	-0.178	0.618
Owned a planter	0.003	0.000	-0.003	0.724	0.033	0.029	-0.004	0.931
Owned a cart	-0.008	0.016	0.024	0.432	0.087	0.070	-0.017	0.882
Owned a wheelbarrow	0.010	0.008	-0.002	0.993	0.217	0.205	-0.012	0.683
Owned a grinder	-0.008	0.000	0.008	0.845	0.045	0.036	-0.009	0.919
Owned a mechanical drier	0.003	0.008	0.005	0.761	0.001	0.005	0.004	0.994
Owned a drying frame/rack	0.160	0.070	-0.090	0.051	0.002	0.095	0.093	0.876

*** denotes significance at the 1% level
** denotes significance at the 5% level
* denotes significance at the 10% level

Table 3 Baseline equivalence on key outcomes.

Baseline equivalence on variables that can affect key outcomes					
Category	**Variable**	**Treatment Mean**	**Comparison Mean**	**Pvalue**	**Effect Size**
Household demographics	Age of household head (years)	44.01	44.97	0.31	-0.09
	HH's main economic activity is agriculture/maize farming (= 1 if yes)	0.87	0.91	0.19	-0.11
	Household head has completed secondary school or more (=1 if yes)	0.30	0.36	0.24	-0.12
	Household identifies as Islamic (=1 if household is Islamic)	**0.78**	**0.89**	**0.26**	**-0.29**
	Number of household members older than 5	6.94	7.43	0.22	-0.11
	In the 2013-2014 maize season, saved money	0.06	0.04	0.21	0.09

	in an informal group (= 1 if yes)				
	Member of Farmer Cooperative (=1 if yes)	0.35	0.43	0.14	-0.17
Household farming characteristics	Area of household land owned (hectares)	5.31	5.52	0.73	-0.03
	Area of household land owned squared	66.20	74.37	0.72	-0.02
	Amt of Dry Maize Harvest in Average Year (kgs)	6013.89	6918.93	0.30	-0.12
	Total large machinery owned by farmer (tractor, mechanical drier, planter, harvester (number of units))	0.13	0.18	0.57	-0.06
	Farmer knew AgResults implementer in 2013-2014 (=1 if yes)	**0.488**	**0.289**	**0.001*****	**0.41**
	At least one plot irrigated (= 1 if household has at least one irrigated plot)	0.15	0.17	0.70	-0.04
Ownership of assets	Improved wall (=1 if wall is made of burnt bricks or cement blocks)	0.24	0.29	0.38	-0.11
	Improved toilet facility (=1 if toilet facility is flush or pit latrine)	0.88	0.92	0.42	-0.15
	Improved lighting (= 1 if lighting source is a generator)	0.36	0.39	0.62	-0.08
	Owned a ridger (= 1 if household owns a ridger)	0.24	0.21	0.40	0.09
	Owned a wheelbarrow (= 1 if household owns a wheelbarrow)	0.18	0.18	0.79	0.02
	Owned a drying frame/rack (= 1 if household owns a wheelbarrow)	0.07	0.08	0.61	-0.04
	Owns cow, ox, donkey, or camel (=1 if owns any one of these)	0.35	0.33	0.53	0.05
	Owns sheep, goat, pig (=1 if owns any one of these)	0.59	0.63	0.37	-0.08
	Owned chicken(s) (=1 if owns chickens)	0.48	0.52	0.32	-0.08
Geographic characteristics	Soil organic carbon content at 60 cm (permilles)	3.12	3.21	0.51	-0.10
	Temperature Seasonality (standard deviation *100)	**2068.06**	**2153.57**	**0.19**	**-0.31**
	Mean Temperature of Driest Quarter (Celsius degree)	230.27	229.80	0.53	0.12
	Annual Precipitation (mm)	1036.45	1047.06	0.73	-0.08
	Travel time to 100K market (hrs)	2.67	2.70	0.90	-0.03

Table 4 Impact of Aflasafe Nigeria pilot on smallholder's Aflasafe and aflatoxin knowledge

Had heard of Aflasafe					
Farmer	72.5%	5.78%	66.7 ***	NA	0.000
Cook[2].	28.9%	0.28%	28.6 ***	NA	0.000
Knew how to use Aflasafe					
Farmer	10.0%	0.71%	9.29 ***	16.3 ***	0.000
Cook	2.31%	0.00%	2.31 ***	4.05 ***	0.000
Knew how Aflasafe works					
Farmer	25.3%	3.10%	22.3 ***	38.9 ***	0.000
Cook	9.71%	0.28%	9.43 ***	16.6 ***	0.000
Knew what aflatoxins are					
Farmer	22.5%	0.76%	21.7 ***	38.1 ***	0.000
Cook	7.56%	0.0%	7.56 ***	13.3 ***	0.000
Knew the health risks of aflatoxins					
Farmer	22.5%	0.76%	21.7 ***	38.1 ***	0.000
Cook	5.75%	0.00%	5.75 ***	10.1 ***	0.000

Notes: [1].This estimate is based on the assumption that all impacts measured in the treatment group were found in smallholders that applied Aflasafe to at least one plot. This is a standard assumption used for estimating "treatment of treated" estimates where in this case the treatment farmers are those who adopted Aflasafe..

[2.] Cooks are typically female household members responsible for cooking food. They were asked if they had heard of Aflasafe, while farmers were asked if they knew what Aflasafe is.

Data: Smallholder survey, March-May 2017.

p<0.1 * p<0.05 ** p<0.01 ***

Table 5 Pilot's impact on technology adoption

Outcome	Treatment Mean (A)	Comparison Mean (B)	Impact on:		Significance (P-Value)
			Smallholders Engaged by Implementers (C= A-B)	Smallholders in Treated Villages who Adopted Aflasafe (D= C / 0.57) [1]	
Percentage of smallholders that applied Aflasafe on at least one maize plot[2]	57.0%	0.96%	56.1 ***	98.4 ***	0.000
Percent of maize area where Aflasafe was applied[2]	43.6%	0.66%	42.9 ***	75.3 ***	0.000
Total area where Aflasafe was applied (Hectares)	1.22	0.02	1.20 ***	2.11 ***	0.000
Percent of maize area where Aflasafe was applied correctly[2]	6.48%	0.27%	6.21 ***	10.9 ***	0.000

Notes: [1]This estimate is based on the assumption that all impacts measured in the treatment group were found in smallholders that applied Aflasafe to at least one plot. This is a standard assumption used for estimating "treatment of treated" estimates where in this case the treatment farmers are those who adopted Aflasafe. However, to the extent that farmers in treatment group who did not adopt Aflasafe also benefited from the intervention because of the implementers broader focus on agricultural practices, the estimated impacts on the adopters may be overstated because in calculating impacts on adopters, we assume that non-adopters did not benefit at all from AgResults.

[2] Impacts in percentage points for outcomes expressed as percentages.

Data: Smallholder survey, March-May 2017.
p<0.1 * p<0.05 ** p<0.01 ***

Table 6 Pilot's impact on smallholder maize yield and returns

Outcome	Treatment Mean (A)	Comparison Mean (B)	Impact on:			Significance (P-Value)
			Smallholders Engaged by Implementers		Smallholders in Treated Villages who Adopted Aflasafe	
			(C= A-B)		(D= C / 0.57)[1]	
Maize price ($/MT)	407	391	16.2*	(4%)	28.4*	0.102
Maize yield (MT/ha)	2.77	2.67	0.10	(4%)	0.2	0.697
Cultivated area under maize (ha)	3.37	3.12	0.25	(8%)	0.4	0.238
Maize sales ($)	1,348	1,033	315**	(31%)	553 **	0.018
Maize sales (MT)	3.33	2.69	0.65***	(24%)	1.14 ***	0.001

Amount set aside for consumption (MT)	1.09	1.43	-0.34***	(-31%)	-0.59***	0.005
Fertilizer Costs ($)[2]	247	285	-38.2**	(-13%)	-67.0**	0.014
Received fertilizer on credit (%) [3]	17%	0.20%	16.8%***	----	0.29***	0.000
Seed costs ($) [2]	19.8	13.2	6.60***	(50%)	11.6***	0.003
Net revenue ($)[3]	1314	1104	210*	(19%)	369*	0.084
Net revenue per hectare ($/ha)[3]	530	501	29.6	6%	51.9	0.585

Notes: [1]This estimate is based on the assumption that all impacts measured in the treatment group were found in smallholders that applied Aflasafe to at least one plot. This is a standard assumption used for estimating "treatment of treated" estimates where in this case the treatment farmers are those who adopted Aflasafe

[2]We tested for differences in other input costs (herbicide/insecticide, land preparation, rental costs, application costs, weeding, harvesting, threshing, land preparation) but none were statistically significant.

[3] Impacts in percentage points for outcomes expressed as percentages.

Data: Smallholder survey, March-May 2017.

p<0.1 * p<0.05 ** p<0.01 ***