See It Grow: Monitoring the use of stress-tolerant varieties and seed performance

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Introduction

Picture-based analyses of drought-tolerant seed use and performance in a Kenyan crop insurance project

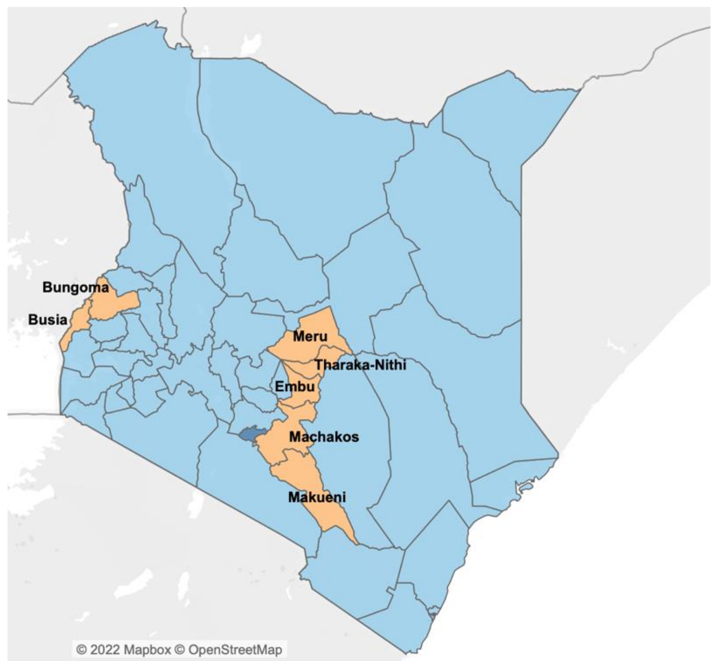
Farming is an inherently high-risk activity, and farmers' livelihoods depend on a set of interlinked environmental factors including weather, soil conditions, disease, pests, and more. Unfortunately, globally, many of the risks in agricultural production have been exacerbated by increasingly erratic and extreme weather patterns (Porter et al. 2014). One way to mitigate such climate risk is the use of seed varieties that are bred to be resilient to the types of extreme weather that crops regularly suffer, such as drought (Cacho et al. 2020). Use of such seeds can potentially help reduce insurance premiums to more sustainable levels, as drought-tolerant varieties could help mitigate losses from moderate droughts and thus insurance would only be required to cover farmers for losses associated with more severe droughts.

In this project note, we examine to what extent the use of drought-tolerant varieties is associated with improved performance in the context of a crop insurance project in Kenya. We hypothesize that crops grown from drought-tolerant varieties sustain less damage than other varieties. We test this hypothesis and extend our analysis to ask if there are phenological differences between stress-tolerant varieties (STVs) and non-STVs that would affect the period during which insurance coverage is needed. Finally, since both reduced risk exposure and phenological differences could affect insurance payouts, and thereby insurance premiums in the longer run, we examine differences in farmers' yields and insurance payouts between the two groups.

Background and experimental design

This analysis uses data collected during the implementation of a "picture-based crop insurance" (PBI) program across seven Kenyan counties. PBI settles claims using smartphone images of crops collected throughout the season, from planting to harvest (Ceballos, Kramer, and Robles 2019). ACRE Africa and KALRO, two organizations implementing this approach in Kenya, were interested in bundling such insurance with seeds of drought-tolerant varieties to address farmers' agricultural risk more holistically. To that end, they worked with champion farmers (local opinion shapers who can influence agricultural practices and promote inclusion in their communities) to promote new STVs of maize, sorghum, and green gram (Cecchi et al. 2021).[1] Initially, trial packs of the STVs were provided to all study farmers for free, while for subsequent seasons, farmers in randomly selected villages were given the opportunity purchase these seeds through their champion farmers (Kramer et al. 2021).[2]

Figure 1: Project counties



The promotion of drought-tolerant seed varieties in the context of the PBI program that monitored fields every two weeks through smartphone images, offered a unique opportunity to compare the outcomes of regular versus drought-tolerant varieties. These data (Waithaka et al., 2022) allowed us to (1) track which farmers were using which seed varieties and (2) monitor crop development through

[1] The specific varieties were SAWA for maize, Advanta for sorghum, and Karembo for green gram. In terms of randomization, "We cross-randomize whether a champion is marketing only seeds of improved but not stress-tolerant varieties, or also seeds of stress-tolerant varieties" (Cecchi et al. 2021).

[2] Trial packs were provided to farmers in the Upper Eastern counties (including Embu) for the short rains 2019/20 season, to farmers in Western and Lower Eastern countries for the short rains 2020/21 season, and in Embu again for the short rains 2020/2021 season. STVs were offered for purchase to all farmers in randomly selected villages starting in short rains 2021 season in Upper Eastern countries, and to farmers in randomly selected villages in all counties from long rains 2021 onward.

the series of crop photographs taken over the course of the season. These images were reviewed by agricultural experts for crop damage as well as processed through a machine learning algorithm. While experts made determinations on the type and extent of damage to all crops, the machine learning algorithm labeled each maize image with its respective probability of sustaining types of damage, as well as the likelihood of the crop in the image to be in a particular phenological growth stage (Cecchi et al. 2021).[3] Both sources of damage labeling are used in the subsequent analysis of differences in outcomes between STVs and non-STVs.

Table 1 presents the data sources used in our analysis, along with the variables of interest and level of observation.

Table 2: Data Sources

Data	Level of Observation	Variables of Interest
Damage labeled images	Site-level data (LR2020, SR2020, LR2021)	Damage types and probabilities
Site registration	Site-level data (LR2020, SR2020, LR2021, SR2021)	Seed varieties
Crop-cutting experiment yield	Site-level data (LR2021)	Yields, environmental characteristics, farming characteristics
Self-reported crop yield	Farmer-level data (LR2020, SR2020, LR2021)	Planting date, harvest date
Demand bookings	Farmer-level data (LR2020, SR2020, LR2021, SR2021)	Socioeconomic indicators: age, gender, and level of education
Champion treatment assignments	Farmer-level data via champions (continuously updated dataset for active champions)	Insurance and seed treatment assignments for champions
Damage payouts by insurance	Farmer-level data (LR2020, SR2020, LR2021)	Damage payout amount

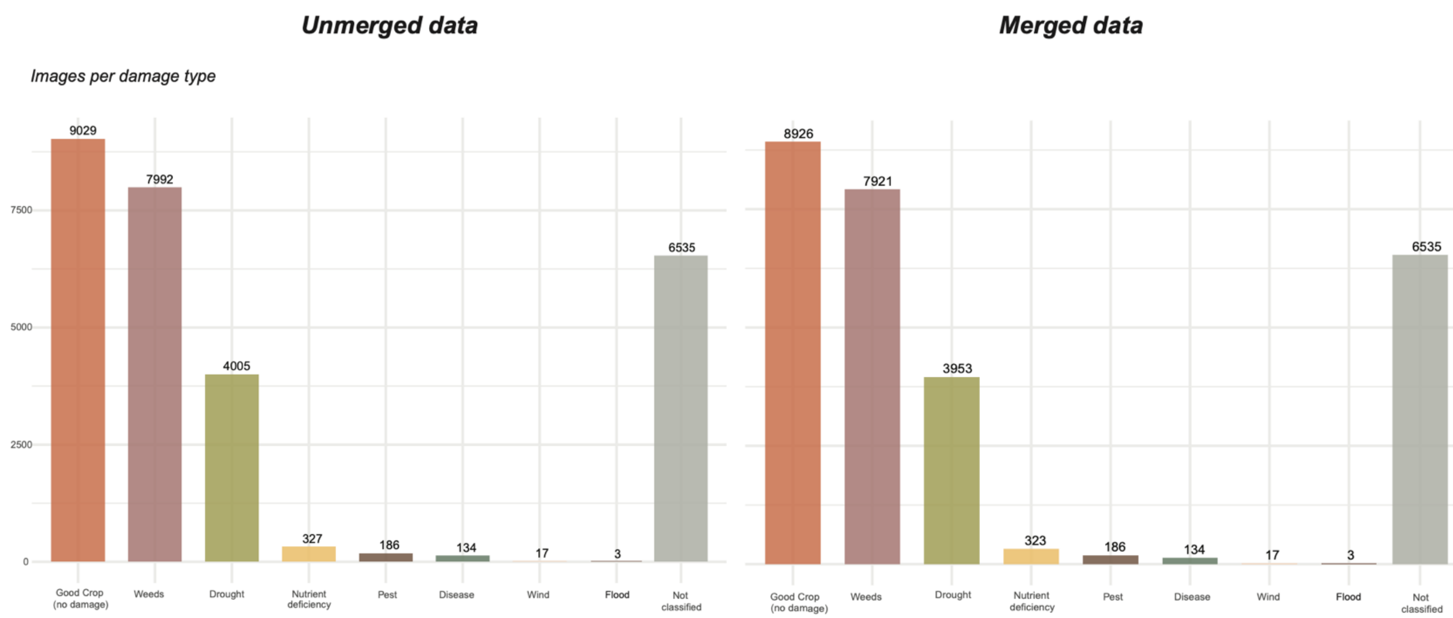
Note: LR represents the long rains season in Kenya, which lasts from March to May. SR represents the short rains season in Kenya, which lasts from October to December.

[3] This has been found to be a reliable method of labeling, as is found in Hufkens et al. (2019).

For the purpose of analysis, all these datasets were merged into a single master dataset, with some variables being measured at the site level and others at the farmer level. While this merge resulted in a reduction of the sample size,[4] overall, the proportional composition of the data remained, as is demonstrated in Figure 2.

In the final merged dataset, 39 percent of images were of crops grown from STVs, 38 percent of sites used drought-tolerant seed varieties, and 55 percent of farmers overall used a drought-tolerant seed variety. This means that while farmers may not have used drought-tolerant seeds across all their sites, over half of farmers planted an STV at least once across the three seasons analyzed in this report. This represents an opportunity to analyze the performance of such varieties among farmers who already have some familiarity with them. Relatedly, farmers used an average of 1.8 seed varieties across all four seasons, indicating that there is willingness to change the brand or variety of seed they are growing over time.[5]

Figure 2. Image tabulations before and after merging datasets.
The proportional composition of the datasets remained in-tact, despite loss of sites from merging.



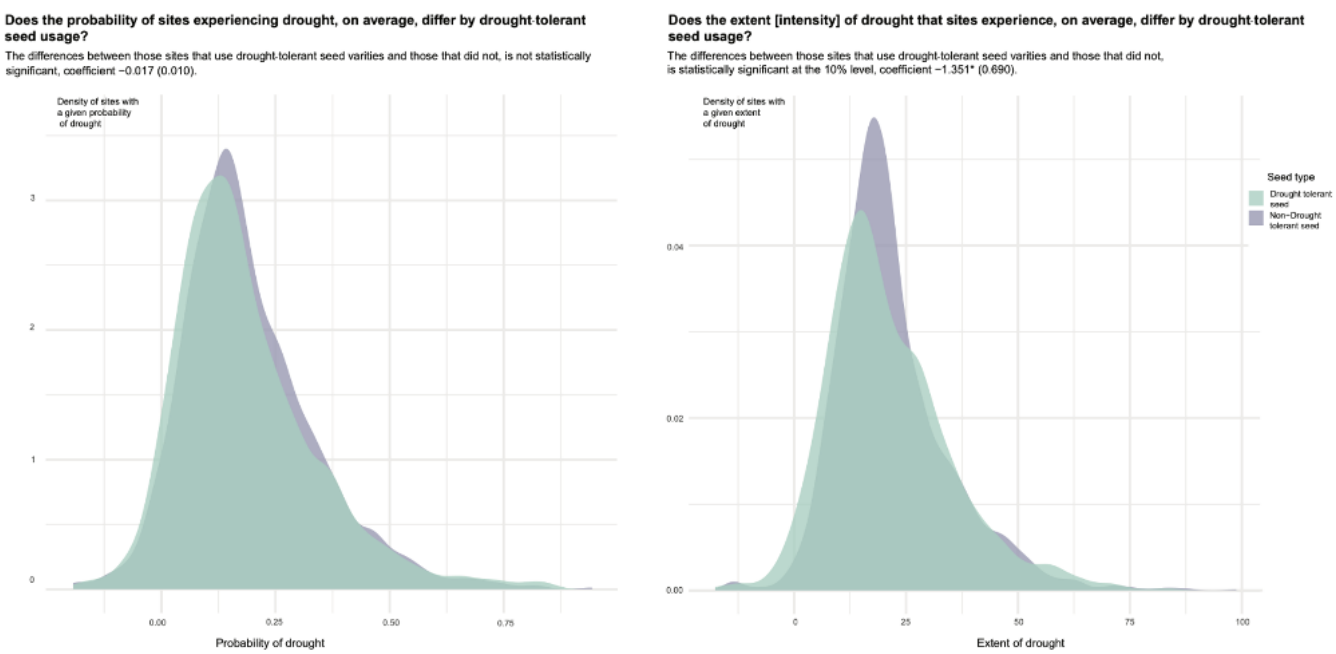
[4] This was mainly due to damage labels not yet having been generated for the short rains 2021 season.
[5] This willingness to switch seed varieties could be influenced in part by the agricultural advisory services provided by champions to farmers. Kenyan farmers in Rutsaert and Donovan (2020) were found to be fairly certain of their seed choices prior to purchase, but when they were not, the input of agro-dealers had significant influence on their seed variety choice. Additional evidence of the impact of the project on changing seed purchasing behavior comes from midline findings that, “The intervention also promoted the use of sorghum as a complementary risk mitigating practice: farmers producing sorghum increased from 14% to over 23%. A similar effect took place for green grams, but only for the PBI treatment arm” (Kramer 2021).

Findings

We began our analysis by focusing on the full sample of data, controlling for farmers' socioeconomic characteristics, season, crop type, and champion fixed effects to capture any omitted variables that could be correlated with a farmer's champion or village.[6] We then restricted our sample to a subset of data collected for the long rains 2021 season, where crop-cutting experiments were able to provide estimated yields for farmers and further environmental controls could be included. Using this approach, our main findings are as follows:

- **For sites that sustained drought, those growing stress-tolerant varieties had, on average, 1.4 percentage points less damage from drought.** Figure 3 supports this finding, demonstrating that while the distribution of sites experiencing drought was not statistically different by seed type (on the left), the percentage of drought-related crop damage within a site was systematically less for STV sites (on the right). This could indicate that STVs have their desired effects but also could reflect selection bias, if for instance, farmers grow STVs on better plots, or if more skilled farmers who regularly sustain less intense drought damage are more likely to use drought-tolerant varieties. However, we did not replicate this finding for the subset of long rains 2021 sites with crop-cutting experiments.

Figure 3: Distributions of drought by stress-tolerant variety
Images display the distributions of experiencing drought and the intensity of drought, using controls for county, season, crop, seed and insurance treatment, socioeconomic indicators and champion. Coefficients are presented in the subtitle of each distribution with standard errors in parenthesis.



[6] We also control for the number of images taken per site, when applicable.

- **There was no statistically significant difference in the probability of drought damage between those sites that grew STVs and those that did not.** Across both the machine-learning generated labels and the labels manually generated by experts, there was no statistically significant difference in the likelihood that crops sustained damage from drought. These findings are contradictory to our main hypothesis and to findings by Boucher et al. (2022) that "drought tolerant maize seeds mitigate the adverse impacts of mid-season drought." Additionally, there was no statistically significant difference between STV and non-STV sites in terms of the likelihood of any type of crop damage, indicating that this finding generalizes beyond drought damage.

- **In the full sample, the flowering date of STV sites was, on average, 4.8 days later than sites growing regular varieties, but in the subsample of sites with crop-cutting experiments, crops grown from STVs reached maturity an average of 6.2 days earlier.** The flowering timing outcome is contradictory to expectations, as a prominent strategy for breeding drought-tolerant seeds is to couple varieties that take less time to reach maturity with those with those that mitigate "soil moisture stress" (Badu-Apraku et al. 2018). At the same time, however, farmers who planted STVs in at least one of their sites planted their seeds (both STVs and regular varieties) on average 4.9 days later, which may explain the later flowering dates of STVs. Further, for the subsample of sites with crop-cutting experiments, we do find earlier maturity dates associated with STVs, suggesting that STVs and regular varieties go through the most critical stages of development during different calendar periods. Adapting insurance coverage periods to reflect such differences in crop phenology has been shown to reduce basis risk across other insurance schemes (Dalhaus, Musshoff, and Finger 2018).

- **Insurance payouts to farmers who grew STVs were not statistically significantly different from payouts to those who did not grow STVs.** This finding aligns with the damage findings for our sample: as the likelihood of damage to crops was, on average, the same between STV and non-STV sites, so too were the insurance payouts based on those damage assessments.

- **Sites growing STVs had, on average, yields that were 239 kg higher than those that did not grow STVs.** This finding provides slight support to the larger body of research on the positive impacts of STV seed adoption on yields (Martey, Etwire, and Kuwornu 2020; Simtowe et al. 2019; Gebre et al. 2021).

Figure 4. Long rains 2021 STV and non-STV sites
Examples of images taken by farmers during the long rains 2021 season.

Stress-tolerant variety crop

Non-stress-tolerant variety crop

Conclusion

In our analysis, we find that growing STVs is not associated with a reduced probability of crops sustaining drought damage and results in only small differences in the extent of damage to sites. Yet, sites growing such varieties experience higher yields than those that do not. This creates an interesting paradox, where crops grown from STVs do not appear to mitigate risk as intended, but the higher yield outcomes that we predict in our hypothesis remain. Given the small differences in the damage outcomes between STVs and regular varieties, the question remains as to how easy it is for farmers to observe the benefits from using more expensive STVs, and therefore, how rapidly these new varieties will be adopted.

One channel that may increase farmers' willingness to adopt STVs is through observing the differences in yields. Cost-effectiveness calculations show that while STV seeds are more expensive than regular varieties, the differences in yields found in the crop-cutting experiment data are large enough to compensate for the higher costs. Sites growing STVs generate an average revenue of 5,708 Kenyan shillings more than non-STV sites.[7] Therefore, while farmers may not be able to visually observe differences in damage to crops, we would expect that they will experience positive revenue impacts.

Our results leave us with opportunities for further analysis. As we did not observe the performance of crops over an extended period, with variation within sites of both drought and non-drought years, one way to test the robustness of our findings would be to use crop simulations to contrast the performance of STVs with regular varieties under a variety of environmental circumstances (Afshar et al. 2021). Using such models, which allow for different weather conditions and management practices to simulate yield data for both regular and STVs, would enable the researcher to test the assumption that these varieties perform better in a drought year.[8] Outside of this approach, an expansion of crop-cutting experiments to verify yields would also increase the robustness of our results across growing seasons, as our yield estimates are restricted to one season. Finally, a third avenue of exploration would be to further investigate environmental conditions at the farmer level, as we were unable to include such controls for our full sample. Ultimately, while we maintain that the integration of drought-tolerant seed varieties into farming practices is a positive step toward risk mitigation, further investigation is needed to better understand the impact on farming outcomes.

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[7] This finding is for our restricted sample from the long rain 2021 crop-cutting experiments. Farmers are charged an average of 32 shillings extra to purchase 1 kg of stress-tolerant seeds and are advised to plant 8 kg of seed per acre. Therefore, while they face an extra cost of 32*8=256 KES per acre, we estimate that STV yields are 238.95 kg per acre greater than regular varieties. Subtracting the additional cost of planting an acre of STV seed, we end up with 5963.75−256 for a net increase in profit of 5,707.75 for STV farmers in comparison to their non-STV-growing peers. These findings also hold across our full sample, with self-reported yields. For the full sample, we find a smaller difference in yields between STVs and non-STVs, of 84.7 kg, but the differences are nonetheless positive and the net gains in profits are of an order of magnitude greater than the price of the seeds themselves.

[8] A caveat is that the crop models are developed under more optimal growing conditions and provide "potential yields" as opposed to the yields that we actually observe under farm conditions or through the crop-cutting experiments.

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