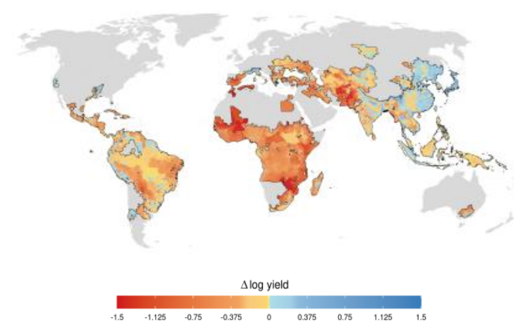
THE UNIVERSITY OF CHICAGO
MARKET SHAPING ACCELERATOR

The Return to Investing in Climate-Resilient Crops[1]

Executive Summary

Figure ES - 1: Change in log rice yields from climate change by 2100 (Hultgren et al., 2022)



The increase in high heat days resulting from climate change will cause yield collapses for crops critical to the nutrition and livelihoods of millions in Sub-Saharan Africa. The development and widespread adoption of crops with 1-degree greater heat tolerance would save billions of dollars of production. But crops with hidden traits do not always command a premium until well established. This cuts private R&D investment and delays uptake. Subsidies to develop and distribute key crops could generate $138 in benefits for every $1 spent.[2]

We identify the crops and regions in Sub-Saharan Africa with high social return to investment (most vulnerable to projected climate change, feed the most people and have seen fewer new local varieties) and calculate the net social return to each investment. To do this we combine data from climate projections, crop heat tolerance, household consumption by location and crop, data on new varietal releases by crop/location, and the costs of spurring innovation.

Where the private sector has expertise, Advance Market Commitments can crowd in private sector investment to develop and, critically, disseminate climate-resilient crops. For sorghum and rice in some parts of West Africa as well as soybean and maize in Southern Africa[3] there are firms that could respond to targeted incentives. These crop priorities align relatively well with previous research.[4] The benefits of heat resilient sorghum alone would be between $2.0 billion to $4.6 billion depending on the extent of take up of the new variety.

Where the private sector has little expertise, public investment through the CGIAR and national agriculture research institutions is needed. Potatoes and sweet potatoes in East and Southern Africa as well as groundnuts in Southern Africa have seen much less innovation per hectare compared to Asia and there is relatively stronger public sector presence.[5]

Table ES - 1: Costs and benefits of investments in innovation gaps[6]

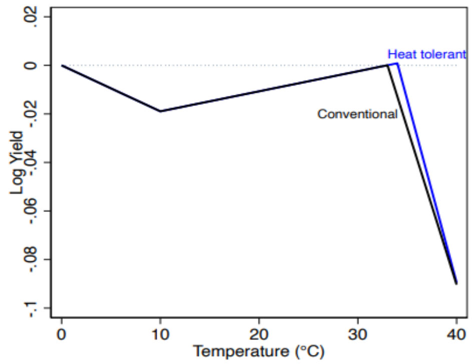
Crop	Region	Old to new temperature threshold	Push or pull?	Costs (US$, millions)	Benefits: Conservative scenario (US$, millions)	Benefits: Aggressive scenario (US$, millions)	Benefit/ cost ratio (cons.)
Maize	Southern Africa	29 to 30°C	Pull	15	535	1,337	35
Soybean	Southern Africa	29 to 30°C	Pull	8	66	168	8
Groundnut	Southern Africa	30 to 31°C	Push	N/A	34	87	N/A
Sorghum	West Africa	33 to 34°C	Pull	14	1,979	4,613	138
Rice	West Africa	32 to 33°C	Both	10	273	695	28

The Return to Investing in Climate-resilient Crops

Rachel Glennerster, Kyle Emerick, Anne Krahn, Sarrin Chethik, and Siddhartha Haria

Description of analysis

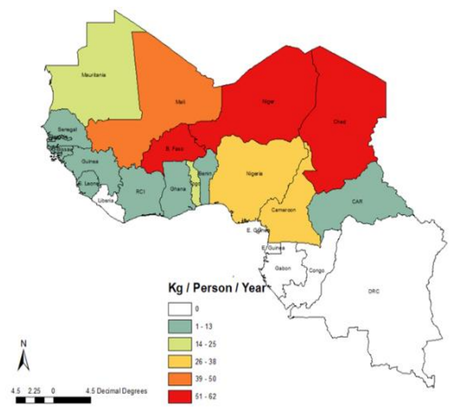
Figure 1: Sorghum yield by temperature



Notes: The linear yield function is shown for a conventional crop variety and for the proposed heat tolerant variety. The turning point occurs at the temperature in which yield decreases, and is one degree higher for the heat tolerant variety. We assume the two functions converge at extreme temperatures.

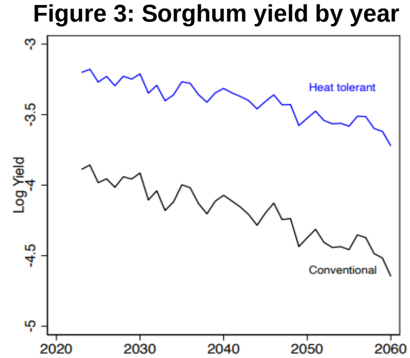
Increased heat will reduce crop yields. Crop yields are a function of temperature. Figure 1 shows the change in log sorghum yields from an additional day at a given temperature relative to a day at 0ºC. Beyond a turning point, higher temperatures reduce yields. End of century global yield losses are estimated to be 45 percent in the absence of adaptation and economic development. Even factoring in current projections of climate adaptation and development, end of century losses are still estimated to be 24 percent.[7]

Figure 2: Annual per capita consumption of sorghum, 2019 Source: [Kane et al. 2022]



Key staple crops in Sub-Saharan Africa are highly vulnerable. Crops whose yields will fall sharply as the number of high heat days increase include key staples like maize, soybeans, groundnuts, rice, and sorghum (see Figure 2 for a map of annual per capita consumption of sorghum, a staple crop in Western Africa).[8] Degree days above 29°C are harmful for maize and soybeans.[9] Degree days above 30°C are harmful for groundnuts[10] and degree days above 32°C are harmful for rice.[11] Degree days above 33°C are harmful for sorghum.[12] Up to 60% of the land where sorghum is grown in sub-Saharan Africa is vulnerable to persistent drought.[13] This comes on top of stagnating staple yields in Africa over the last 60 years making households more vulnerable to shocks.[14]

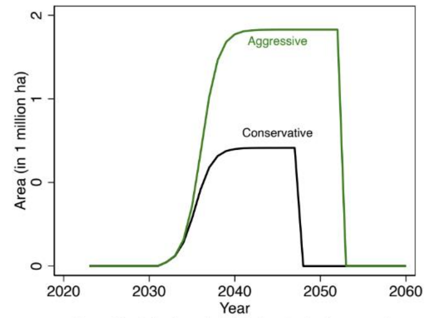
Figure 3: Sorghum yield by year



Notes: This figure graphs the expected impact of climate change on crop yields between 2023-2060. The black line represents expected yields for conventional varieties and the blue line represents yields for heat tolerant varieties.

Increasing the heat-tolerance of crops by just 1 degree could dramatically reduce the yield losses caused by climate change. Using yield-temperature functions from the literature and modeling the impact of increasing their threshold turning points combined with forecasts from climate models shows the impact of increasing the heat turning point for a crop. However, there will also be benefits much earlier as high heat is already reducing yields (see Figure 3, which depicts the relative yields associated with a climate-resilient and conventional variety, respectively). The gap between heat tolerant and conventional varieties increases over time as high heat days increase.

Figure 4: Assumed area of improved sorghum adopted by year



Notes: After following an initial S-shaped adoption curve, the aggressive scenario assumes that between 2042-2052 adoption is near constant at 10% per year and then ceases in 2053. After following an initial S-shaped adoption curve, the conservative scenario assumes that between 2042-2047 adoption is near constant at 5% per year and then ceases in 2048.

The benefits of climate-resilient crop innovation are large. The gains of adopting improved varieties with greater heat tolerance are large but depend crucially on the extent of uptake: after following an initial S-shaped adoption curve, the aggressive scenario assumes that between 2042-2052 adoption of the heat tolerant variety is near constant at 10% of sorghum growing area per year and then ceases in 2053 (see Figure 4). After following an initial S-shaped adoption curve, the conservative scenario assumes that between 2042-2047 adoption is near constant at 5% of the sorghum growing area per year and then ceases in 2048 (see Figure 4). Even in the conservative case, the benefits of increased heat tolerance of sorghum in West Africa is $2.0 billion, rising to $4.6 billion if uptake is high (see Table 1).

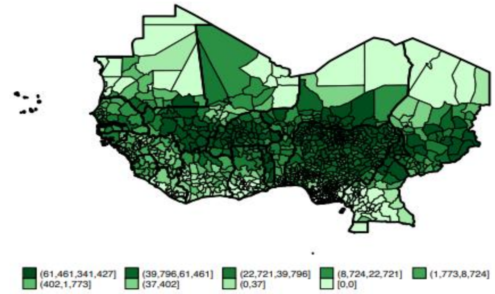
Table 1: Benefits of 1-degree increase in heat tolerance by crop/region

			Benefits (US$, millions)	
Crop	**Region**	**Old to new temperature threshold**	**Conservative scenario (US$, millions)**	**Aggressive scenario (US$, millions)**
Maize	Southern Africa	29 to 30°C	535	1,337
Soybean	Southern Africa	29 to 30°C	66	168
Groundnut	Southern Africa	30 to 31°C	34	87
Sorghum	West Africa	33 to 34°C	1,979	4,613
Rice	West Africa	32 to 33°C	273	695

Note: All cost and benefit estimates are discounted using a 3% discount rate. All cost and benefit estimates are rounded to the nearest million. Benefit/cost ratio values are calculated using non-rounded numbers. Benefit/cost ratio values are calculated for the conservative scenario only. We include cost estimates for pull incentives only.

Some of the poorest parts of West Africa would benefit the most from heat tolerant sorghum. Figure 5 (on the next page) illustrates the aggregate area assumed to be covered by the improved heat tolerant variety of sorghum under an aggressive scenario. The darker shade corresponds with a greater area covered by the improved variety. The area covered by the improved heat tolerant variety is determined by the area allocated to sorghum within each sub-national polygon in 2020.[15]

Figure 5: Aggregate area of improved sorghum adoption (in hectares)



Notes: The aggregate improved crop area within each sub-national polygon reflects the aggressive take-up assumption outlined in Figure 4.

Commercial markets underinvest in climate-resilient crop innovation in low-income countries despite these crops offering large social benefits. This is because firms would be unable to command high enough prices to recoup their R&D and distribution costs in low-income country markets made up of poor farmers[16] who are often reluctant to pay for climate-resilient traits that are hidden. Weak commercial incentives are exacerbated by limited intellectual property right protection, as was the case for maize hybrids in Nigeria.[17] High prices designed to cover fixed costs would reduce the benefits of the innovation by filtering out the poorest farmers.

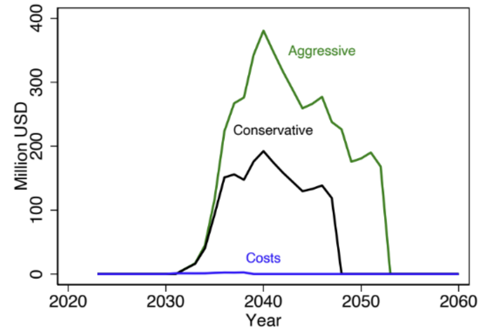
Realizing the potential of climate-resilient crops calls for a combination of push and pull funding. This includes "push" funding for the CGIAR system and national agriculture research institutions. Meta-analysis suggests the past CGIAR research portfolio generated a benefit-cost ratio on the order of 10:1.[18] However, public sector breeders are often not responsible for seed production and marketing, resulting in slower progress in seed sectors throughout many African countries.[19] The large number of adaptions (heat, drought, flood, and saline tolerance) that are needed for multiple crops means it is important to crowd in expertise from both private and public funders. Increased push funding should therefore be combined with stronger "pull" incentives which tie incentives to outputs including high uptake of new crops which encourages investment in distribution as well as the development of crops that are adapted to the needs of farmers. [20] This will help ensure faster uptake of new crops and leverage in private sector investment and know-how. A temporary subsidy from a pull incentive would enable farmers to learn about benefits and profitability of the crop.[21]

Push funding is particularly important for crops and regions where the private sector is relatively absent. Initial analysis of private breeders suggests important gaps in private sector know-how and the need for greater push funding for rice, groundnuts, sweet potatoes, and potatoes in Sub-Saharan Africa where there has been much less private innovation per hectare compared to some countries in Asia. CGIAR and other public research institutions have a stronger presence compared to private sector breeders in these crops and locations.[22]

Regional economic communities provide an opportunity for wider scale-up. The initial prioritization analysis was based on country-level data about variety releases and measures of caloric output. We present the analysis at a regional level as new varieties may also be suited to other areas in the region with similar agro-ecological conditions. In addition, seed regulations are harmonized through regional economics communities such as COMESA, ECOWAS, and SADC. This provides an opportunity for regional scale-up.

Estimated aggregate costs of developing and incentivizing the distribution and uptake of heat-resilient varieties through pull incentives range from ~$11 million to ~$22 million (~$8 million to ~$15 million discounted).[23] These estimates include the costs of testing, monitoring, and providing incentives tied to uptake in the first years (i.e., the incentives are intended to help cover firm costs including R&D and distribution). Benefit-cost ratios under a conservative scenario range from 8 to 138 with sorghum in West Africa showing the highest returns. Figure 6 shows the annual benefits in the aggressive scenario (green), the benefits in the conservative scenario (black), and the costs (blue). Table 2 shows the total benefits in the aggressive and conservative scenarios as well as the costs. The variation in benefits between crops is primarily driven by differences in each crop's baseline area of production and yield for each crop, vulnerability to forecasted temperature increases in the region, and selling price. The much larger benefits under an aggressive scenario illustrate the importance of uptake and scale. The benefits could be even larger in worse climate change scenarios with higher temperatures.

Figure 6: Annual sorghum benefits and costs (US$, millions)



Notes: This figure uses the improved area assumptions outlined in Figure 4 for an aggressive and conservative scenario. We calculate the yield gain for the improved hectares and multiply by the per ton price of sorghum, incorporating a 3% discount factor. Estimated aggregate benefits for sorghum under the aggressive assumption are 4.6 billion USD. Estimated aggregate benefits for sorghum under the conservative assumption are 2.0 billion USD. Estimated aggregate costs are 14 million USD. The conservative benefits-cost ratio is 138.

Table 2: Costs and benefits of investments to fill innovation gaps

					Benefits		
Crop	**Region**	**Old to new temperature threshold**	**Push or pull?**	**Costs (US$, millions)**	**Conservative scenario (US$, millions)**	**Aggressive scenario (US$, millions)**	**Benefit/ cost ratio (cons.)**
Maize	Southern Africa	29 to 30°C	Pull	15	535	1,337	35
Soybean	Southern Africa	29 to 30°C	Pull	8	66	168	8
Groundnut	Southern Africa	30 to 31°C	Push	N/A	34	87	N/A
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Note: All cost and benefit estimates are discounted using a 3% discount rate. All cost and benefit estimates are rounded to the nearest million. Benefit/cost ratio values are calculated using non-rounded numbers. Benefit/cost ratio values are calculated for the conservative scenario only. We include cost estimates for pull incentives only.

Annex: Proposed model for pull funding program

Proposed program timeline

A multi-stage pull incentive mechanism could incentivize the development and large-scale adoption of climate-resilient crops. We envisage the following stages and timelines:

Figure A - 1: Gantt chart

	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052
R&D and field trials			1	2	3	4	5																							
Approval period								1	2																					
RCT									1	2	3																			
Reward payments												1	2	3	4	5														
Monitoring												1	2	3	4	5														
Benefits incurred										1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21

Key
Conservative and aggressive
Aggressive only

1. **R&D and agronomic field trials (five years)**. Firms would engage in R&D and demonstrate their crops had the desired properties (e.g., increased heat-tolerance) in agronomic field trials.
2. **Approval period (two years)**: We set aside two years for firms to seek regulatory approval in the relevant regions and countries.
3. **Randomized controlled trials ("RCTs") (three years):**[24] Firms will be expected to demonstrate the impact of their crops through RCTs operating over 3 years, overlapping with the approval period for one year. The funder will be responsible for contracting out these evaluations to avoid conflicts of interest.[25]
4. **Reward payments (five years)**: Firms will be rewarded based on their crop variety's adoption rate over a five-year period. The reward payments are intended to cover the costs of developing the crop variety and for the risk that they take by participating (i.e., there's some chance that they do not successfully develop a new variety). Reward payments begin after crop varieties have demonstrated their benefits in RCTs. Payments could also be given as firms meet various milestones (pass agronomic field trials, achieve regulatory approval, demonstrate impact in an RCT).[26] This may be useful if firms face financing constraints.
5. **Monitoring (5 years):** To reward adoption, adoption must be measured. Measuring adoption will require surveying farmers and DNA fingerprinting of crops. We envisage this taking place concurrently with reward payments.
6. **Benefits (16-21 years):** While the funding program will only last five years, we envisage the benefits lasting longer. Firms will still sell the seed as their fixed costs have been covered and farmers will have had time to learn about the heat tolerance. In our

conservative estimate, we expect the improved variety to continue to be used and, therefore, provide benefits for 16 years. In our aggressive estimate, we estimate these benefits last 21 years.

Breakdown of proposed funder costs

Below are estimates of key cost drivers for an example crop variety program (sorghum in West Africa). In total, the undiscounted funder costs are ~$21 million (~$14 million discounted) and the undiscounted firm costs are ~$5 million (~$4 million discounted):

The cost of a pull mechanism for sorghum has three components:

1. **The pull fund**: The pull fund is used to reward firms for developing new crops that are widely adopted. The fund must be large enough to compensate for firms' direct costs and for the risk associated with participating. In this example, firms' costs of R&D and agronomic field trials are estimated at ~$1 million per year, for five years. These are approximations based on available sources and conversations with relevant experts.[27] Firms will also have marketing and distribution costs to reach farmers so the reward is structured as a premium over standard seed prices. We calculate a fifty percent markup over status quo prices would be sufficient to cover both R&D and marketing costs and thus calculate total cost of the pull fund as 50% of existing seed prices multiplied by adoption under the conservative adoption trajectory.[28] We envisage the funder rewarding firms only for adoption in the early years until the benefits of the seeds are known and development costs have been covered. The total, undiscounted reward payments are estimated to be ~$15 million (~$10 million discounted).
2. **Monitoring**: Firms will make reward claims based on their estimate of adoption in different locations which will be independently verified. Monitoring will entail a survey of farmers and DNA sampling of crops. DNA sampling is especially necessary since previous research suggests that farmers are not always aware of the exact variety they are using. These costs are estimated at ~$225 thousand per year, for each year that reward payments are paid.
3. **RCT**: Funders will directly cover RCT costs. Note that in other industries that require RCTs for regulatory approval – such as the pharmaceutical industry – the firm bears these costs directly and, therefore, future profits would justify each firms' expenditure. This is not the case here – the funder will directly cover costs to ensure the trial is independent and of high quality. These costs are estimated at ~$1.5 million per year covering three countries based on previous agriculture RCTs. This would be for a period for three years.

Such a pull financing model offers value for money. We estimate a benefit-cost ratio for sorghum of 138. Firms would only be rewarded for achieving higher adoption among farmers and meeting milestones. See Table A - 1 for a detailed list of proposed incentives for climate-resilient crops.

Pull incentives are more attractive for varieties of crops that already have a higher uptake among farmers. For such crops, a subsidy linked to uptake is much more likely to cover firm costs.

Table A - 1: Details of proposed incentives for climate-resilient crops

Crop	Region	Total area harvested in 2021 (million hectares)	Total no. of farmers in region (million farmers)	Old to new heat turning point	Push or pull?	Costs (US$, million)	Benefits (US$, million)	Benefits -Cost Ratio
Maize[29]	Southern Africa	19.7	19.7	29°C to 30+°C	Pull	15	535	35
Soybean	Southern Africa	1.5	3.0	29°C to 30+°C	Pull	8	66	8
Groundnut	Southern Africa	3.2	1.6	30°C to 31+°C	Push	N/A	34	N/A
Sorghum	West Africa	15.5	6.2	33°C to 34+°C	Pull	14	1,979	138
Rice	West Africa	10.6	6.0	32°C to 33+°C	Both	10	273	28

Note: All cost and benefit estimates are discounted using a 3% discount rate. All cost and benefit estimates are rounded to the nearest million. Benefit/cost ratio values are calculated using non-rounded numbers. Benefit/cost ratio values are calculated for the conservative scenario only. We include cost estimates for pull incentives only.

References

[1] This is a draft document for comment which MSA will update periodically.
[2] All dollar amounts are U.S. dollars unless otherwise indicated.
[3] Access to Seed Index, 2023. Specifically, this is based on private sector presence for sorghum and rice in Nigeria ECOWAS would provide an opportunity for regional scale-up. Soybean was selected as an opportunity to attract the private sector in Zambia and Zimbabwe with scale up through COMESA and SADC. Maize was identified as an opportunity for scaling up climate-resilient varieties in DRC.
[4] Hultgren et al., 2022. See supplementary Figure S15
[5] This is based on a tentative review of the Access to Seed Index and Africa CG presence.
[6] All cost and benefit estimates are discounted using a 3% discount rate. All cost and benefit estimates are rounded to the nearest million. Benefit/cost ratio values are calculated using non-rounded numbers. Benefit/cost ratio values are calculated for the conservative scenario only. We include cost estimates for pull incentives only.
[7] Hultgren et al. 2022. See Table 1
[8] Hultgren et al., 2022. Fig 3 covers the global impact of climate change on staple crops. Supplementary Figure S. 14 provides regional impacts including for sub-Saharan Africa.
[9] Burke and Emerick, 2016
[10] Schlenker and Lobell, 2010
[11] Deng, Xie, and Wang 2023
[12] Tack, 2017
[13] Hadebe et al., 2017
[14] Suri et al., 2022, Ritchie 2022, Tian et al. 2019
[15] Tang et al., 2023
[16] Bird et al., 2022
[17] Kuhlmann et al., 2018
[18] Alston et al., 2021
[19] Kuhlmann and Zhou, 2016
[20] Glennerster and Suri, 2015
[21] Suri 2011, Carter et al. 2014, Dar et al. forthcoming
[22] This is based on a tentative review of variety releases, the Access to Seed Index and Africa CG presence.
[23] This is based on pull incentive cost estimates for maize, soybean, sorghum, and rice.
[24] The current timetable assumes a one-year overlap between the approval period and the RCT period.
[25] We envisage the funder only covering RCT costs for the initial candidates that meet the relevant criteria.
[26] For our benefit-cost analysis we assume funders only make reward payments linked to farmer adoption, but this is just a simplification for modeling costs.
[27] CGIAR System 3-Year Business Plan Companion Document, 2018. Page 29.
[28] This involves combining the conservative adoption trajectory and estimates of seeding intervals for various crops. Costs and BCRs in this document refer to the conservative scenario.
[29] Initial analysis identified maize as priority for scaling existing climate-resilient varieties. In this case firms may not have R&D costs. However, we use the same approach of multiplying an estimate of required crop sales by fifty percent of the price to calculate the size of the reward fund to incentivize firm participation.