INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

IFPRI

RESEARCH PROGRAM ON Policies, Institutions, and Markets

CGIAR

Led by IFPRI

IFPRI Discussion Paper 02064

December 2021

Public-Sector Maize Research Locations and Spatial Heterogeneity in Maize Productivity

Insights from Four African Countries on the Roles of Agroclimatic Similarity

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Notices

Abstract

Agricultural research and development (R&D) is one component of public investments in the agricultural sector toward food system transformation. Enhancing the effectiveness of agricultural R&D remains critical, given increasingly scarce public resources. Exploring spatial spillover potentials has been one way to enhance the effectiveness of agricultural R&D. Geographical locations of National Agricultural Research Systems (NARS) research activities are recognized as an important factor affecting such spatial spillover potentials. However, evidence is generally limited in Africa south of Sahara (SSA) as to the spillover potentials of NARS-developed technologies. This paper partly aims to fill this knowledge gap by obtaining insights for maize, one of the most commonly grown crops in SSA, using nationally representative farm household data for Ethiopia, Ghana, Nigeria, and Uganda, and spatial agroclimatic data. Building on recent literature, this study proxies spillover potentials by "agroclimatic similarity" (AS) indicators between locations where agricultural R&D for maize is conducted by NARS (research locations) and where each farm household is located (farm locations). Results of the analyses suggest that an indicator of the total factor productivity of maize growing farm households, the land productivity of maize, and the use of improved maize varieties are generally higher in farm locations that share similar agroclimatic conditions with maize research locations of NARS. These patterns hold for all four countries studied, even after controlling for the physical proximity to maize research stations and other farm household characteristics. The findings contribute to better understanding of how geographic locations of public investments affect their overall effectiveness as well as returns in maize production and the agricultural sector in general.

Keywords: agricultural R&D, agroclimatic similarity, productivity, maize, Africa

Acknowledgments

We would like to thank the CGIAR Research Program on Policies, Institutions, and Markets (PIM), which is led by the International Food Policy Research Institute (IFPRI) and carried out with support from the CGIAR Trust Fund, for providing financial support to conduct this study. The author is responsible for any remaining errors.

1 Background

Agricultural research and development (R&D) is one of the critical components of public investments in the agricultural sector toward food system transformation. The public-sector remains a crucial provider of agricultural R&D, particularly in developing countries, given the public-goods nature of research products, significant risks, and long-gestation periods required before the returns materialize (Byerlee 1996; Evenson & Gollin 2003, 2007; Walker & Alwang 2015; Lynam et al. 2016).

Globally, net returns to agricultural R&D report positively, and the same is true in developing countries (Evenson & Gollin 2007; Alene et al. 2009; Renkow & Byerlee 2010; Alston et al. 2011; Rao et al. 2019). However, enhancing the effectiveness of agricultural R&D remains critical, given the increasingly scarce public resources available as the development challenges of food systems become more and more complex. Exploring the spatial spillover potentials of agricultural R&D has been one way to enhance its effectiveness (Maredia & Byerlee 2000; Maredia et al. 1996; Traxler & Byerlee 2001; Alston 2002; You & Johnson 2010; Islam & Madsen 2017).

Spatial locations of National Agricultural Research Systems (NARS) research activities are recognized as an important dimension of the spatial spillover potentials of agricultural R&D (e.g., Evenson & Gollin 2007; Takeshima 2019; Takeshima & Liu 2020). In African countries south of Sahara and globally, NARS have been the primary implementer of adaptive research to transform imported technologies into locally suitable ones, including in the areas of plant breeding, which may not always be provided by international agricultural research systems (IARS) like CGIAR (Herdt 2012). However, evidence about the spillover potentials of NARS-developed technologies is generally limited in SSA. Because SSA exhibits substantial agroclimatic and productivity heterogeneity (Gollin & Udry 2021), evidence is especially necessary so that the spillover potentials and the location of NARS research activities can have significant overall returns to public-sector agricultural R&D (Pardey et al. 2007).

In part, this paper aims to fill this knowledge gap by obtaining relevant insights from selected SSA countries: Ethiopia, Ghana, Nigeria, and Uganda. This paper specifically focuses on maize, one of the primary commodities in SSA, and provides some evidence on how the productivity of maize in different parts of these countries depends on an indicator of spillover potential of NARS developed technologies. This is done by using maize R&D location information, spatial agroclimatic data, and nationally representative household data. Following the recent literature (Alston 2002; Bazzi et al. 2016; Takeshima 2019; Takeshima & Liu 2020), we proxy spillover potentials by “agroclimatic similarity” between locations where agricultural R&D for maize is conducted by NARS (research locations) and where each farm household is located (farm locations), which account for the multi-dimensional nature of agroclimatic conditions. Exploiting the panel data nature of the farm household data also allows us to focus on an indicator of total factor productivity (TFP) of maize-growing farm households, for which public-sector R&D like plant breeding has some of the greatest effects (e.g., Evenson & Gollin 2003). We focus on maize because it is the most widely grown commodity in SSA[1] and is used both as a basic staple crop and as key fodder for growing livestock, which contributes to nutrition security by providing animal protein. Public R&D contributed to the productivity growth of maize in the 20th century in SSA (Byerlee & Eicher 1997; Morris 1998; Smale et al. 2011), but we have also seen an emergence of private-sector participation in R&D (including

[1]In 2019, maize was the mostly widely cultivated area in Africa, planted over 40.7 million ha, accounting for approximately 1/7 of total cultivated areas (FAO 2021).

hybrid or genetically engineered varieties) and the seed sector development in various developing countries (Morris et al. 1998; Pray & Nagarajan 2014).

The remainder of this paper is structured as follows: section 2 describes empirical methods; section 3 discusses data and descriptive statistics; section 4 presents the main empirical results; and, finally, section 5 concludes our findings.

2 Empirical methods

Our empirical approach proceeds in the following way. For countries with panel data (Ethiopia, Nigeria and Uganda), we first estimate the Cobb-Douglas production function

$$\ln y_{it} = \alpha + \sum_j \beta_j \ln x_{ijt} + \beta_z w_{it} + c_i + \varepsilon_{it} \quad (1)$$

in which production outputs for farm household i at year t (y_{it}), is regressed on a vector of inputs j used by i in t (x_{ijt}), as well as other time-variant weather factors w_{it} (rainfall, temperature and drought). Parameters α, β, and ε_{it} are estimated coefficients or error terms. Unobserved farm household fixed effects c_i can be interpreted as a component associated with the variations in TFP across farm households (Takeshima 2019).

We then estimate a productivity regression,

$$\pi_i = \gamma + \delta_M \cdot \sigma_{i,k,M} + \delta_N \cdot \sigma_{i,k,N} + \delta_z \cdot z_i + u_i \quad (2)$$

where π_i denotes proxies for maize productivity, $\sigma_{i,k,M}$ and $\sigma_{i,k,N}$ are agroclimatic similarity indicators with maize research locations and non-maize research locations (with notations k, M and N defined in the next sub-section), z_i is a set of household characteristics variables, and γ, δ's and u are estimated coefficients or error terms.

Note that $\hat{c}_i$ and σ_{ik} (as is described below) are time-invariant. Therefore, we estimate productivity regression (2) as a cross-sectional regression, using observations including z_i from the first year in which household i appears in the panel data, which can vary across household i.

We use two proxies for productivity π_i. The first proxy is $\hat{c}_i$, which is an estimated value of c_i, which proxies TFP variations across households. The second proxy is land productivity of maize, averaged across all panel rounds for each farm household i.

When using the first proxy $\hat{c}_i$ as an outcome variable in (2), we estimate equation (2) separately for maize growing farm households, and all farm households including non-maize growing households. The more significantly positive coefficients for δ_M than δ_N among maize-growing farm households, and the opposite for all farm-households, would serve as indirect evidence that maize productivity is higher in areas with greater spillover potentials of maize research.

2.1 Agroclimatic similarity indicators

One of the variables of our interest is agroclimatic similarity (AS) with maize research locations within the country, which measures the similarity between farm location and the research locations in terms of soil and climate conditions. AS is considered an important indicator of spillover potentials of agricultural technologies, which significantly affect the spatial variations in agricultural productivity (Alston 2002; Evenson & Gollin, 2003; Walker & Alwang 2015; Lynam et al. 2016; Takeshima 2019).

An indicator of AS in earlier studies (Bazzi et al. 2016; Takeshima 2019) was based on the sum of absolute differences in standardized values of each agroclimatic variable between research locations and farm locations. Takeshima & Liu (2020) expanded this indicator of AS by taking into account the multi-dimensional nature of agroclimatic conditions.

Following Takeshima & Liu (2020), we generate AS indices, $\sigma_{i.R}$, for household i with respect to specific research locations, R as,

$$\sigma_{i.R,k} = -\left|\theta_i^k - \theta_R^k\right| \tag{3}$$

where θ_i^k and θ_R^k are the k-th principal component (PC) of agroclimatic parameters θ in areas where household i and R are located, respectively. $\left|\theta_i^k - \theta_R^k\right|$ are absolute deviations. An increase in $\sigma_{i.R,k}$ indicates the increase in AS in terms of k-th PC, with the negative sign in front. An AS index for household i with respect to k-th PC (σ_{ik}) is,

$$\sigma_{i,k.M} = \max_{M} \sigma_{i,M,k}, \text{ or } \sigma_{i,M} = \text{average of } \sigma_{i,k.M} \text{ across all } M \tag{4}$$

for maize research locations, and

$$\sigma_{i,k,N} = \max_{N} \sigma_{i,N,k}, \text{ or } \sigma_{i,N} = \text{average of } \sigma_{i,k.N} \text{ across all } N \tag{5}$$

for non-maize research locations. M denotes maize research locations, while N denotes non-maize research locations. Thus, $R = \{M, N\}$ means that research locations R belong to either M or N. Therefore, σ_{ik} in (2) consist of $\sigma_{i,k,M}$ and $\sigma_{i,k,N}$.

As is described in the descriptive statistics section, we use 6 PCs (therefore 6 different $\sigma_{i,k.M}$ variables and 6 different $\sigma_{i,k.N}$ variables), since 6 PCs explain a sufficiently large share of the overall variations in agroclimatic conditions.

For both maize and non-maize research locations, the first σ_{ik} is the AS with the most similar research location for i, in terms of k-th PC of agroclimatic variables. The second σ_{ik} is the average of similarity indicators across all research stations. We estimate the models separately using both measurements of σ_{ik} to check the robustness of the results.

2.2 Set of other variables

Outcome variables

The outcome variable in production function (1) is the total production revenue, including the imputed value of products consumed by the household. This includes the value of all crops produced, as well as livestock products (values of animals sold alive, or values of meat, milk, and eggs).

The primary outcome variable in productivity equation (2) is the farm household fixed effects (c_i). The variable also includes the land productivity of maize, which is the value of maize produced divided by the area of maize planted, and whether the maize-growing households used improved varieties of maize (only for Ethiopia and Uganda due to data availability).

Explanatory variables

Explanatory variables in production function

Explanatory variables for production function (1) include labor provided by family members, land, expenses on all the other inputs (seed, fertilizer, agrochemicals, rental of machines, hired labor, and expenses on livestock production, including the purchase of animals, fodder, and payment for veterinary services), the total value of agricultural capital owned, and the total value of livestock owned. Explanatory variables here also include key agroclimatic variables of each survey year, including annual rainfall, average annual temperature, and average annual drought index of that year. These agroclimatic variables are different from the historical averages used to compute agroclimatic similarity variables.

Explanatory variables associated with productivity

Explanatory variables for productivity equation (2) include AS indicators described in the previous section, as well as household demographics, wealth and capital, access to infrastructure, and agroclimatic variables.

Household demographics include the number of household members by gender and age group (children aged 19 years or younger, working-age members aged between 20 and 60, and elderly aged 61 years or older), as well as age and gender of the household head.

Wealth and capital include human capital (years of education completed by the household head), household asset values, and exogenous farmland endowment (which include farmland owned or distributed by the chiefs of the community or village).

Access to infrastructure includes the physical distance to the nearest road, nearest population center, nearest market, nearest administrative center, and nearest border post. For Ghana, due to the lack of available data, we only included the distance to the road, market, and administrative center. Due to a similar lack of data for Uganda, we used the physical distance to the nearest town with a population of 20,000.

To distinguish the effects of agroclimatic similarity with the effects of simple physical proximity to research locations, we also include a variable proxying the proximity to nearest maize research locations, measured by the Euclidean distance.

Agroclimatic variables include the same set of variables used in computing the agroclimatic similarity indicators.

Lastly, we included year dummies to control for year-specific effects.

3 Data and descriptive statistics

3.1 Data

Our primary data consist of Living Standard Measurement Study – Integrated Surveys on Agriculture (LSMS-ISA) data for Ethiopia (from 2011, 2013, and 2015), Nigeria (2010/11, 2012/13, and 2015/16), Uganda (2005, 2009, 2010, 2011, 2013, 2015, and 2018), and Ghana Living Standard Survey (GLSS) (2006, 2013, and 2017). Ethiopia, Nigeria, and Uganda data are panel data, while Ghana data is repeated cross-sectional data.

Our primary samples from these data consist of farm households without missing information on relevant variables described in the previous section. We also focus on farm households without missing information for at least two survey rounds so that panel fixed-effects equation (1) identifies household fixed effects (c_i) for all farm households. After dropping observations with missing data, our primary samples consist of 9,631 observations for Ethiopia, 8,649 observations for Nigeria, 15,108 observations for Uganda (panel households times survey rounds), and 16,504 observations for Ghana data.

Agroclimatic data and other spatial data

In addition to household data, this study also uses various spatial agroclimatic data: historical and current rainfall data are taken from The Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) by Funk et al. (2015); temperature data are from NOAA (2021); soil data come from FAO et al. (2012); terrain ruggedness is computed following Riley et al. (2008) using USGS (1996); and drought data are from the Standardized Precipitation Evapotranspiration Index (SPEI) from Vicente-Serrano et al. (2010). The SPEI quantifies drought severity in ways that are comparable across time and space The SPEI is correlated with water balance, and more negative values indicate greater drought severity.

For Uganda analysis, the distance to the nearest town with a 20,000 population was obtained from IFPRI (2021).

Research locations

Research locations for maize, and for other crops, are compiled from ASTI (2021), as well as the author's compilations based on the list of released maize varieties in each country. These are locations where the headquarters of agricultural research institutes and their outstations are located (separated by whether they have mandates in maize research or not). Figure 5 illustrates these locations for the four countries studied. While it is likely that some maize-related research and other agricultural research may also take place outside these locations, the intensity of such research is likely to be relatively marginal.

3.2 Descriptive statistics

Agroclimatic similarity indicators

Figure 1 through Figure 4 illustrate the distribution of AS indicators based on 6 principal components (PCs) as described above, for each country (further discussion on the related statistics for AS indicators can be found in the Appendix). For simplicity, these figures only show AS indicators with respective to maize research locations ($\sigma_{i,k.M}$). As was described above, values of AS indicators closer to 0 indicate greater similarity, while more negative values indicate less similarity. While the values of AS indicators cannot be compared across different AS indicators based on different PCs, generally they have left-skewed distributions.

PC-analyses suggest that 6 PCs can explain approximately 75 to 90 percent of overall variations in agroclimatic conditions in all four countries (Table A1 and Table A2 in Appendix). Therefore, we use 6 AS indicators with respect to maize research locations ($\sigma_{i,k.M}$) and 6 AS indicators with non-maize research locations ($\sigma_{i,k.N}$) in our analyses in equation (2). Using 6 AS indicators is also a common practice in related studies (e.g., Takeshima & Liu 2020).

These 6 AS indicators are also generally uncorrelated with each other (Table A3 in Appendix). Thus, including these AS indicators in our analyses allows us to take into account the multi-dimensional nature of agroclimatic conditions in assessing the roles of agroclimatic similarity in maize productivity.

Other household variables

Table 1 presents the descriptive statistics of outcome variables, inputs variables, current and historical climate variables, as well as other household characteristics variables described in the previous sections, for all four countries studied. For simplicity, descriptive statistics are shown by combining all survey rounds. Descriptive statistics for production revenues and inputs are shown for Ethiopia, Nigeria and Uganda panel data, for which production function (1) is estimated, while these are omitted for Ghana data for which (1) is not estimated.

Descriptive statistics in Table 1 generally suggest that sample farm households are typically smallholders with production revenues equivalent to about USD1,000 to USD1,500 annually (crop and livestock production combined), out of which about USD65 to USD500 is derived from maize production. These farm households are also asset-poor, using household labor extensively, while using a modest amount of purchased inputs and hired labor. A majority of households are male-headed, aged around 45 to 50 years old, with about 2 to 5 years of formal education completed. These households are also mostly rural-based, located remotely from the nearest roads, population centers, or administrative centers. Agroclimatically, these households are typically located in areas with 1,000 mm rainfall and average temperatures of around 20 to 28 degrees Centigrade, historically experiencing some level of drought on average.

4 Results

Our primary focus is the associations between maize-growing households' TFP or the land productivity for maize, with indicators of agroclimatic similarity, $\sigma_{i,k,M}$ and $\sigma_{i,k,N}$, in productivity equation (2). The estimated coefficients in (1) other than c_i, or other coefficients in (2) are of secondary importance. We, therefore, present those results in the Appendix, and discuss them briefly later in this section.

Table 2 through Table 4 present estimated coefficients for $\sigma_{i,k,M}$ and $\sigma_{i,k,N}$, from equation (2). Table 2 and Table 3 present the results for maize farm households and all farm households, respectively, for which the outcome variable is farm household fixed effects c_i. Table 4 presents the results for which the outcome variable is the land productivity of maize. For ease of interpretation, these tables show the standardized associations (associations with one standard deviation change in each AS indicator). In each of these tables, we also show results based on two AS indicators, one based on the maximum AS, and the other based on the average AS, across all maize research locations.

Table 2 suggests that various AS indicators with maize research locations associated with different PC of agroclimatic variables, are positively associated with higher TFP among maize producing farm households. These results generally hold for Ethiopia, Nigeria, and Uganda. Importantly, while not all AS indicators are statistically significantly positive, none of the coefficients for AS indicators are statistically significantly negative. In contrast, signs and statistical significance are weaker and relatively more inconsistent for the coefficients for AS indicators for both maize and non-maize research locations. These results are also relatively robust whether we focus on the maximum AS, or average AS, across all maize research locations. Note that positive effects of AS hold after controlling for the physical proximity to maize research locations. Therefore, the observed effects of AS indicators are not necessarily because farm households are located near the maize research locations. Even if farm households are located far away from the nearest maize research locations, their productivity is higher if their farm locations have similar agroclimatic conditions as the maize research locations.

These results altogether serve as evidence that maize-growing farm household productivity is higher in areas where maize production technologies developed through public-sector agricultural research, which have greater spillover potentials.

Similarly, Table 3 suggests that when all farm households are considered (including not only maize-growing farm households but also non-growing farm households), the associations with AS with regard to maize research locations become less consistently positive, while the associations with AS with regard to all research locations become more consistently positive with statistical significance. These results are again relatively consistent depending on whether we focus on the maximum or the average AS, and across countries. Thus, these results further strengthen the argument that spillover potentials of technologies developed in maize research locations have greater effects for productivity among maize-growing farm households than for other farm households, while spillover potentials for more general technologies (not necessarily related to maize) have greater effects for a broader set of farm households including those not growing maize.

Table 4 presents the results when the outcome variable for equation (2) is the land productivity of maize. For all four countries, AS with maize research locations are relatively more consistently positively associated with the land productivity of maize, while AS with other research locations are less consistently associated. These results are also consistent regardless of whether we focus on the maximum or the average AS across research stations.

Table 5 presents the results when the outcome variable for equation (2) is the use of improved varieties in maize production. Results are shown only for Ethiopia and Uganda, where data for the use of improved varieties are available. Results suggest that maize-producing households are more likely to adopt improved varieties in areas with greater agroclimatic similarity, and thus indicate spillover potentials for varieties developed at maize research locations. These results suggest that greater adoption of improved maize varieties in areas with greater spillover potentials is one of the drivers for higher TFP among maize-growing households and maize land productivity.

Coefficients for other variables

As was described above, other coefficients for production function (1) or productivity regression (2) are of secondary importance. Table A4 summarizes the Cobb-Douglas production function coefficients in equation (1). Table A5 and Table A6 summarize the statistically significant signs of these coefficients for TFP (c_i), and for maize land productivity. Table A5 and Table A6 suggest that other variables are often jointly significant, indicating that including them minimizes biases due to omitted variables. Some variables are relatively consistently associated with greater TFP among maize-growing households or maize land productivity, including household labor endowment of adult members in working age, gender of household head, household assets, and farmland endowments, which are consistent with the hypotheses that higher productivity is associated with greater availability of family labor (which requires less monitoring compared to hired labor), that male household heads tend to be better connected with providers of inputs or extension services who also tend to be male, and that a greater household asset enables the purchase of more modern agricultural inputs. Coefficients of other variables vary in statistically significant ways across countries, indicating the heterogeneity across countries. Our models appropriately account for such cross-country differences through the inclusion of these other control variables.

Potential endogeneity of R&D research locations

There is a potential endogeneity issue associated with the R&D research locations, if these locations had been partly determined with agroclimatic similarity in mind. Certain factors suggest that such endogeneity may be relatively limited. First, some R&D research locations had been determined based on more political factors, such as granting of farmland by local authority for use as experiment station (e.g., Takeshima 2019; Takeshima & Liu 2020), which may not necessarily reflect the resulting agroclimatic similarity with production locations. Second, maize is a relatively newer crop in many parts of SSA, compared to more traditional crops, for which production areas have spread more substantially in the recent decades (for example, maize area in SSA doubled between 1985 and 2019 (FAO 2021)), while a substantial share of R&D locations had been selected before the significant expansion of maize areas in studied countries. However, more formal investigations need to be conducted in future studies.

5 Conclusions

Spatial spillover potentials have been recognized as an important determinant of the effectiveness of public-sector R&D in agriculture, which has important implications for designing public investment strategies in agriculture. However, evidence remains scarce in developing regions like Africa south of the Sahara, as to whether such spatial spillovers are significant given the research capacity levels of NARS, varied physical and institutional infrastructure, and characteristics of farm households who are end-users of agricultural research outputs.

This paper aimed to partly fill this knowledge gap by estimating the impact of spatial locations of maize research stations on maize productivity across locations in four African countries (Ethiopia, Ghana, Nigeria, and Uganda) using nationally representative household surveys and various spatial data on agroclimatic conditions in these countries. Specifically, the study finds that an indicator of the total factor productivity of maize-growing farm households, and the land productivity of maize, is generally higher in areas that share similar agroclimatic conditions with areas where maize research has been conducted. These patterns hold for all four countries studied, even after controlling for the physical proximity to maize research stations, and other farm household characteristics.

The findings of this study inform the effort toward enhancing the effectiveness of public investments in agriculture, including public-sector R&D for maize. Our findings are consistent with the arguments that enhancing the capacity of NARS to conduct adaptive research suitable for the local agroclimatic conditions remains critical, and one potential approach is to allocate more resources to research locations that share similar agroclimatic conditions with the majority of production areas in the country. These spatial considerations are particularly important in regions like SSA where spatial heterogeneity in agroclimatic conditions is substantial and, furthermore, where spillover potentials continue to change in the long-term due to climate change that affects agroclimatic conditions in both research locations and production locations.

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Table 1. Descriptive statistics

Variables	Ethiopia	Ghana	Nigeria	Uganda
Production revenue (current USD)	1129.669	N / A	1561.656	1436.170
Land cultivated (ha / year)	1.025	N / A	1.497	2.404
Family labor use in farming (adult male)	6.432 hour / 7 days	N / A	135.285 person-days / year	123.937 person-days / year
(adult female)	3.911 hour / 7 days	N / A	99.027 person-days / year	160.680 person-days / year
(children)	6.826 hour / 7 days	N / A	56.733 person-days / year	36.127 person-days / year
Expenses on other inputs (including hired labor) (current USD)	386.763	N / A	586.410	80.142
Agricultural capital (current USD)	15.086	104.081	53.043	22.89
Livestock value (current USD)	623.747	850.153	908.691	385.455
Irrigation (yes = 1)	0.097	0.009	0.035	0.017
Rainfall (mm, annual total)	1095.577	1093.344	684.711	1295.128
Temperature (°C, annual average for the survey year)	20.985	27.824	27.356	22.892
Maize outputs (current USD / year)	65.071	481.466	172.41	313.589
Maize planted area (ha / year)	0.138	0.802	0.167	0.292
Using improved varieties (yes = 1)	0.225	N / A	N / A	0.107
Euclidean distance to the nearest maize research location (decimal coordinates)	1.833	0.577	2.275	0.440
Age of household head (year)	46.488	48.059	51.994	47.119
Gender of household head (female = 1)	0.219	0.196	0.133	0.300
Education of household head (years)	1.757	4.110	4.641	5.486
Household size (male, 0 – 14 years old)	1.175	1.153	1.425	1.306
Household size (female, 0 – 14 years old)	1.105	1.071	1.289	1.314
Household size (male, 15 – 60)	1.284	1.254	1.345	1.340
Household size (female, 15 – 60)	0.912	1.360	1.576	1.412
Household size (male, 61 or above)	0.152	0.171	0.231	0.143
Household size (female, 61 or above)	0.091	0.177	0.158	0.153
Household asset (current USD)	PC	453.427	562.728	863.502
Farm-land owned (ha)	1.029	3.214	0.632	0.826
Distance to road (km)	16.652	11.190	10.549	N / A
Distance to population center (km)	39.587	N / A	25.288	N / A
Distance to market (km)	67.645	83.211	71.077	N / A
Distance to administrative center (km)	168.324	105.894	75.183	N / A
Distance to border post (km)	251.616	N / A	324.497	N / A
Distance to 20,000 town (hour)	N / A	N / A	N / A	1.859
Rainfall (mm, historical average)	1090.061	1108.368	1055.658	1260.817
Temperature (°C, historical average)	20.465	27.600	27.117	22.779
Drought index (SPEI)	-0.066	-0.245	-0.144	-0.100
Soil alkalinity (ph)	6.452	6.097	6.011	5.793
Soil organic content (g / kg of soil)	1.137	0.872	0.872	1.249
Soil texture (% medium)	0.657	0.742	0.591	0.668
Soil texture (% coarse)	0.004	0.192	0.361	0.033
Soil salinity (deciSiemens per metre)	0.227	0.108	0.228	0.076
Soil sodicity (% of soil)	1.506	1.869	3.082	1.639
Soil with poor drainage (%)	0.146	0.193	0.227	0.195
Soil with excess drainage (%)	0.004	0.013	0.123	0.013
Terrain ruggedness (index)	230.118	1.489	26.287	97.284
Samples (Panel sample only)	9631	16504	8649	15108

Source: Authors. PC = estimated by Principal component. N / A = Not Available. USD = United States Dollars based on the official exchange rates of corresponding years.

Table 2. Associations between TFP and agroclimatic similarity (among maize growing farm households; associations with one standard deviation increase in each AS indicator)

AS variables	Ethiopia		Nigeria		Uganda	
	Maximum AS	Average AS	Maximum AS	Average AS	Maximum AS	Average AS
ASM 1	0.693***	0.733	0.154	–0.609	0.047	2.559***
	(0.251)	(1.599)	(0.103)	(0.669)	(0.092)	(0.931)
ASM 2	–4.848	–4.189	0.074	–0.826	0.454***	1.590*
	(4.128)	(10.260)	(0.145)	(0.546)	(0.108)	(0.800)
ASM 3	1.835**	–2.212	1.415***	3.761**	–0.196	–1.203
	(0.802)	(4.247)	(0.345)	(1.678)	(0.170)	(1.520)
ASM 4	–0.130	0.748	–0.035	0.251	0.288***	–0.269
	(0.268)	(1.535)	(0.071)	(0.499)	(0.046)	(0.518)
ASM 5	0.046	–0.140	–0.275	0.782*	0.074	0.335
	(0.373)	(1.111)	(0.294)	(0.406)	(0.062)	(0.269)
ASM 6	2.003***	4.362**	0.058	–0.622	–0.052	0.727
	(0.547)	(1.752)	(0.074)	(0.405)	(0.049)	(0.633)
ASN 1	–0.789	–0.317	0.128	–0.519	0.028	–2.407***
	(0.534)	(1.440)	(0.091)	(0.662)	(0.074)	(0.922)
ASN 2	4.731	2.463	–0.174	0.389**	–0.511***	–1.472*
	(2.791)	(11.990)	(0.126)	(0.151)	(0.127)	(0.808)
ASN 3	0.475	2.989	1.032**	–3.107	0.124	1.136
	(0.683)	(3.832)	(0.624)	(1.912)	(0.078)	(1.462)
ASN 4	–1.156	–1.033	0.177**	–0.088	–0.184**	0.436
	(0.790)	(1.820)	(0.081)	(0.507)	(0.049)	(0.459)
ASN 5	–0.144	0.324	0.169**	–0.475**	–0.121	–0.244
	(0.363)	(1.310)	(0.085)	(0.331)	(0.072)	(0.259)
ASN 6	–1.889**	–3.575**	–0.100	0.678	0.116	–0.701
	(0.948)	(1.527)	(0.072)	(0.498)	(0.085)	(0.635)
p-value based on F-test (H_0: AS jointly insignificant)	.000	.000	.000	.000	.000	.000
Sample size (number of panel households)	2112		1956		3284	

Source: Authors. Asterisks indicate the statistical significance *** 1% ** 5% * 10%

Note: Numbers in parentheses are robust standard errors.
AS = Agroclimatic Similarity:
ASM = Agroclimatic similarity with maize R&D locations.
ASN = Agroclimatic similarity with non-maize R&D locations
Maximum AS = Results based on maximum AS indicators across all research locations.
Average AS = Results based on average AS indicators across all research locations.

Table 3. Associations between TFP and agroclimatic similarity (among all farm households; associations with one standard deviation increase in each AS indicator)

AS variables	Ethiopia		Nigeria		Uganda	
	Maximum AS	Average AS	Maximum AS	Average AS	Maximum AS	Average AS
ASM 1	0.061	–1.776	0.195***	0.562	0.037	2.723***
	(0.193)	(1.201)	(0.073)	(0.500)	(0.082)	(0.866)
ASM 2	–5.435*	–7.519	0.072	–0.347	0.520***	2.377***
	(2.972)	(6.034)	(0.117)	(0.217)	(0.094)	(0.737)
ASM 3	0.708	2.329	0.690*	0.172	–0.162	–1.575
	(0.580)	(2.817)	(0.272)	(0.876)	(0.157)	(1.452)
ASM 4	–0.018	–0.166	–0.060	0.649	0.231***	0.233
	(0.215)	(1.093)	(0.062)	(0.403)	(0.042)	(0.487)
ASM 5	–0.099	–1.616*	0.180	0.844***	0.030	0.277
	(0.228)	(0.865)	(0.121)	(0.318)	(.0.056)	(0.250)
ASM 6	1.290***	4.845***	0.013	–0.167	–0.085	0.315
	(0.435)	(1.347)	(0.062)	(0.420)	(0.090)	(0.570)
ASN 1	–0.105	1.834	–0.195	–0.557	0.040	–2.502
	(0.164)	(1.162)	(0.210)	(0.488)	(0.067)	(1.722)
ASN 2	7.000*	7.578	–0.138	0.119	–0.600	–2.298
	(3.596)	(6.923)	(0.090)	(0.116)	(0.609)	(1.484)
ASN 3	–1.462	–2.251	0.500*	0.014	0.088	1.434
	(0.934)	(2.527)	(0.278)	(0.975)	(0.072)	(1.396)
ASN 4	–0.130	0.323	0.285**	–0.500	–0.124	0.025
	(0.323)	(1.289)	(0.142)	(0.413)	(0.089)	(0.431)
ASN 5	0.254	1.564	–0.008	–0.331	–0.074	–0.181
	(0.274)	(0.968)	(0.073)	(0.216)	(0.065)	(0.240)
ASN 6	–1.152	–3.906	–0.061	0.196	0.179**	–0.291
	(0.752)	(2.380)	(0.060)	(0.433)	(0.078)	(0.569)
p-value based on F-test (H_0: AS jointly insignificant)	.000	.000	.000	.000	.000	.000
Sample size (number of panel households)	4993		2906		3851	

Source: Authors. Asterisks indicate the statistical significance *** 1% ** 5% * 10%

Note: Numbers in parentheses are robust standard errors.
AS = Agroclimatic Similarity:
ASM = Agroclimatic similarity with maize R&D locations.
ASN = Agroclimatic similarity with non-maize R&D locations
Maximum AS = Results based on maximum AS indicators across all research locations.
Average AS = Results based on average AS indicators across all research locations.

Table 4. Associations between maize land productivity and agroclimatic similarity (associations with one standard deviation increase in each AS indicator)

AS variables	Ethiopia		Ghana		Nigeria		Uganda	
	Maximum AS	Average AS	Maximum AS	Average AS	Maximum AS	Average AS	Maximum AS	Average AS
ASM 1	0.379***	2.373***	0.005	–0.161	0.241**	–1.131	0.518	1.545
	(0.057)	(0.397)	(0.062)	(0.276)	(0.071)	(1.094)	(0.351)	(1.439)
ASM 2	0.223	6.690***	0.015	0.196	0.274***	–0.508	0.198	0.266
	(0.486)	(2.314)	(0.043)	(0.389)	(0.105)	(0.486)	(0.357)	(1.104)
ASM 3	–0.057	–2.321	0.056**	–0.044	–0.096	–0.176	–0.793	–0.259
	(0.183)	(2.222)	(0.028)	(0.240)	(0.257)	(1.532)	(0.834)	(2.081)
ASM 4	0.127**	–0.622	0.070	0.117	–0.163	0.967***	0.528**	–0.059
	(0.064)	(0.434)	(0.043)	(0.450)	(0.166)	(0.337)	(0.251)	(0.875)
ASM 5	–0.093	–0.322	0.013	–0.190	–0.488	–0.377	0.297	–0.113
	(0.086)	(0.259)	(0.026)	(0.166)	(0.476)	(0.360)	(0.552)	(0.368)
ASM 6	0.114	–0.219	0.028	0.906***	–0.073	–0.352	–0.354	0.683
	(0.134)	(0.467)	(0.027)	(0.250)	(0.051)	(0.389)	(0.566)	(0.937)
ASN 1	–0.098	–2.050***	–0.031	0.168	0.226***	1.227**	–0.134	–1.343
	(0.068)	(0.376)	(0.033)	(0.165)	(0.061)	(0.551)	(0.257)	(1.419)
ASN 2	0.551	–7.139***	–0.002	–0.174	–0.011	0.459***	–0.213	–0.095
	(0.712)	(2.671)	(0.043)	(0.425)	(0.061)	(0.149)	(0.294)	(1.138)
ASN 3	0.310**	2.128	0.030	–0.081	0.686***	0.032	0.530	0.170
	(0.154)	(0.976)	(0.028)	(0.223)	(0.184)	(1.750)	(0.367)	(2.002)
ASN 4	0.057	0.864*	–0.024	–0.066	0.065*	–1.059***	–0.584	0.084
	(0.086)	(0.498)	(0.035)	(0.444)	(0.039)	(0.331)	(0.522)	(0.765)
ASN 5	–0.058	0.327	–0.032	0.094	0.213***	0.496**	–0.286	0.131
	(0.087)	(0.307)	(0.025)	(0.084)	(0.049)	(0.235)	(0.495)	(0.354)
ASN 6	–0.102	0.265	0.008	–0.837***	–0.086	0.248	0.648	–0.498
	(0.122)	(0.409)	(0.030)	(0.249)	(0.087)	(0.396)	(0.553)	(0.943)
p-value based on F-test (H_0: AS jointly insignificant)	.000	.000	.299	.000	.000	.000	.098	.598
Sample size	2112		10271		1956		3284	

Source: Authors. Asterisks indicate the statistical significance *** 1% ** 5% * 10%

Note: Numbers in parentheses are robust standard errors.
AS = Agroclimatic Similarity:
ASM = Agroclimatic similarity with maize R&D locations.
ASN = Agroclimatic similarity with non-maize R&D locations
Maximum AS = Results based on maximum AS indicators across all research locations.
Average AS = Results based on average AS indicators across all research locations.

Table 5. Associations between decision to use improved maize varieties and agroclimatic similarity (associations with one standard deviation increase in each AS indicator)

AS variables	Ethiopia		Uganda	
	Maximum AS	Average AS	Maximum AS	Average AS
ASM 1	–0.0245	–0.288	0.020	–0.347
	(0.0262)	(0.179)	(0.031)	(0.306)
ASM 2	0.629***	0.620	–0.031	0.405***
	(0.101)	(1.044)	(0.024)	(0.132)
ASM 3	0.164***	–1.660	0.020	0.939***
	(0.047)	(1.096)	(0.021)	(0.276)
ASM 4	0.131***	0.195	–0.031	0.372***
	(0.013)	(0.169)	(0.028)	(0.097)
ASM 5	–0.038	0.230*	–0.008	–0.163
	(0.039)	(0.129)	(.019)	(0.100)
ASM 6	0.018	–0.333	0.045***	0.384***
	(0.029)	(0.222)	(0.015)	(0.096)
ASN 1	–0.023	0.264	–0.002	0.377**
	(0.012)	(0.178)	(0.030)	(0.152)
ASN 2	–0.868***	–0.695	0.014	–0.422***
	(0.274)	(1.213)	(0.026)	(0.131)
ASN 3	–0.054	1.567***	0.007	–0.892
	(0.036)	(0.482)	(0.016)	(0.530)
ASN 4	–0.049	–0.108	0.018	–0.351*
	(0.043)	(0.198)	(0.015)	(0.168)
ASN 5	0.014	–0.256*	0.011	0.153***
	(0.0123)	(0.139)	(0.019)	(0.047)
ASN 6	0.018	0.286	–0.075**	–0.372*
	(0.024)	(0.191)	(0.026)	(0.188)
p-value based on F-test (H_0: AS jointly insignificant)	.000	.000	.000	.000
Other exogenous variables	Included	Included	Included	Included
Sample size	2112		3284	

Source: Authors. Asterisks indicate the statistical significance *** 1% ** 5% * 10%

Note: Numbers in parentheses are robust standard errors.
AS = Agroclimatic Similarity:
ASM = Agroclimatic similarity with maize R&D locations.
ASN = Agroclimatic similarity with non-maize R&D locations
Maximum AS = Results based on maximum AS indicators across all research locations.
Average AS = Results based on average AS indicators across all research locations.

Appendix: Additional results

Table A1. Principal components coefficients for each agroclimatic variable by country

Variable	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8	PC 9	PC 10	Unexplained
Ethiopia											
Rainfall	-0.36	0.11	-0.22	0.23	0.12	0.23	-0.48	-0.15	0.21	0.60	0.01
Temperature	0.12	-0.23	0.16	0.26	-0.68	0.13	0.41	-0.16	0.22	0.32	0.00
Drought index	0.29	0.02	0.05	-0.36	0.41	-0.39	0.31	-0.33	0.23	0.43	0.00
Alkalinity	0.38	-0.08	0.15	-0.30	-0.10	0.08	-0.24	0.72	0.02	0.31	0.01
Organic contents	-0.39	-0.01	-0.08	0.24	0.19	-0.25	0.33	0.46	0.47	-0.19	0.02
Medium texture	0.40	0.03	-0.36	0.14	-0.06	-0.06	-0.22	0.04	0.30	-0.15	0.00
Coarse texture	0.07	0.60	0.32	0.14	-0.08	-0.10	-0.03	0.01	0.03	0.01	0.00
Salinity	0.16	-0.25	0.39	0.40	0.36	0.14	-0.02	0.11	0.30	0.09	0.05
Sodicity	0.25	-0.24	0.30	0.41	0.28	0.04	-0.12	-0.15	-0.32	-0.14	0.05
Poor drainage	-0.16	-0.12	0.45	-0.44	-0.06	0.25	-0.27	-0.23	0.48	-0.32	0.01
Excess drainage	0.07	0.60	0.32	0.14	-0.08	-0.10	-0.03	0.01	0.03	0.01	0.00
Ruggedness	0.17	0.28	-0.18	-0.08	0.27	0.77	0.41	0.03	0.03	-0.04	0.00
Ghana											
Rainfall	-0.43	-0.01	0.14	0.06	0.17	-0.22	0.26	0.24	0.42	0.47	0.04
Temperature	0.08	0.42	-0.31	0.04	0.55	-0.14	-0.46	0.41	0.05	-0.08	0.00
Drought index	0.34	0.28	-0.06	-0.01	-0.24	0.53	-0.22	-0.16	0.46	0.09	0.03
Alkalinity	0.33	0.19	-0.11	0.17	0.35	-0.31	0.18	-0.65	-0.10	0.26	0.01
Organic contents	-0.34	0.30	0.41	0.03	0.07	0.06	-0.18	-0.26	0.40	-0.10	0.06
Medium texture	0.26	0.44	0.35	-0.04	-0.20	0.02	0.11	0.28	-0.27	0.55	0.02
Coarse texture	0.25	-0.31	-0.21	-0.46	0.32	0.31	0.24	0.17	0.19	0.23	0.03
Salinity	0.25	-0.34	0.44	0.24	0.05	0.00	-0.41	0.20	-0.18	0.07	0.03
Sodicity	0.33	-0.34	0.36	0.17	0.32	-0.07	-0.01	-0.05	0.34	-0.04	0.04
Poor drainage	0.36	0.26	0.18	-0.02	-0.07	-0.24	0.49	0.28	0.20	-0.53	0.01
Excess drainage	-0.14	0.14	0.42	-0.55	0.38	0.23	0.03	-0.15	-0.31	-0.18	0.03
Ruggedness	-0.14	0.08	-0.01	0.61	0.30	0.58	0.35	0.09	-0.20	-0.08	0.00
Nigeria											
Rainfall	0.34	-0.42	-0.10	-0.22	0.06	0.00	-0.06	0.07	0.16	0.75	0.01
Temperature	-0.01	-0.22	0.18	0.63	-0.29	0.40	0.46	0.23	0.11	0.09	0.00
Drought index	-0.22	0.48	0.01	0.15	0.04	-0.29	-0.02	0.19	0.72	0.21	0.00
Alkalinity	-0.13	0.49	0.22	0.07	0.00	0.22	-0.26	0.32	-0.52	0.40	0.01
Organic contents	0.40	-0.02	0.11	0.00	0.54	-0.14	0.17	0.65	-0.04	-0.26	0.00
Medium texture	0.43	0.32	-0.03	0.07	-0.20	-0.19	0.21	-0.15	-0.16	0.22	0.08
Coarse texture	-0.46	-0.29	0.10	-0.10	0.13	0.16	-0.23	0.19	0.03	0.00	0.05
Salinity	0.10	0.00	0.65	-0.09	-0.07	-0.26	0.18	-0.27	-0.06	-0.11	0.06
Sodicity	-0.03	-0.19	0.63	-0.11	-0.18	-0.15	-0.22	0.13	0.13	0.09	0.06
Poor drainage	0.31	0.08	0.20	0.34	0.46	0.40	-0.39	-0.41	0.21	-0.02	0.00
Excess drainage	-0.40	-0.05	0.08	0.10	0.56	-0.19	0.46	-0.27	-0.18	0.31	0.01
Ruggedness	0.01	0.26	0.13	-0.61	0.04	0.58	0.39	-0.01	0.23	-0.01	0.00
Uganda											
Rainfall	0.11	-0.18	-0.42	-0.27	-0.03	-0.18	0.70	0.32	-0.22	-0.14	0.00
Temperature	0.39	0.09	-0.41	0.30	-0.04	-0.24	-0.09	0.03	0.01	0.69	0.01
Drought index	-0.03	0.05	-0.02	-0.09	0.86	0.30	0.20	-0.01	0.21	0.17	0.01
Alkalinity	0.25	0.51	0.22	0.10	-0.15	0.06	0.11	0.17	0.01	-0.13	0.23
Organic contents	-0.32	-0.23	-0.01	0.19	-0.30	0.57	0.07	0.52	0.21	0.28	0.00
Medium texture	0.15	0.39	-0.02	-0.49	-0.26	0.28	0.23	-0.30	0.32	0.28	0.03
Coarse texture	0.45	-0.37	0.29	-0.01	0.16	0.07	-0.12	0.12	-0.16	0.17	0.09
Salinity	0.15	0.48	0.23	0.25	0.16	-0.05	0.10	0.48	-0.10	-0.10	0.14
Sodicity	0.49	-0.16	0.10	-0.24	-0.10	0.46	-0.11	-0.01	-0.35	-0.11	0.06
Poor drainage	0.17	-0.04	-0.20	0.64	-0.04	0.34	0.32	-0.44	0.00	-0.27	0.01
Excess drainage	0.31	-0.32	0.35	0.07	-0.09	-0.28	0.23	0.04	0.67	-0.11	0.02
Ruggedness	-0.24	-0.06	0.55	0.10	-0.07	-0.11	0.45	-0.24	-0.39	0.42	0.00

Source: Author's estimations. PC = principal component.

Table A2. Proportion of variations in agroclimatic variables explained by principal components

Principal component	Ethiopia	Ghana	Nigeria	Uganda
Principal Component 1	0.318	0.299	0.249	0.180
Principal Component 2	0.481	0.444	0.451	0.340
Principal Component 3	0.619	0.574	0.607	0.469
Principal Component 4	0.743	0.678	0.708	0.572
Principal Component 5	0.830	0.748	0.778	0.664
Principal Component 6	0.890	0.817	0.839	0.739
Principal Component 7	0.937	0.875	0.890	0.807
Principal Component 8	0.957	0.923	0.931	0.864
Principal Component 9	0.974	0.950	0.959	0.912
Principal Component 10	0.989	0.975	0.977	0.950

Source: Author's estimations.

Table A3. Correlation coefficients among agroclimatic similarity indicators based on different principal components

	ASM based on PC 1	ASM based on PC 2	ASM based on PC 3	ASM based on PC 4	ASM based on PC 5	ASM based on PC 6
Ethiopia						
ASM based on PC 1	1.000					
ASM based on PC 2	0.448	1.000				
ASM based on PC 3	0.441	0.745	1.000			
ASM based on PC 4	0.543	0.438	0.725	1.000		
ASM based on PC 5	0.369	0.307	0.413	0.362	1.000	
ASM based on PC 6	0.103	0.121	0.181	0.085	0.121	1.000
Ghana						
ASM based on PC 1	1.000					
ASM based on PC 2	0.313	1.000				
ASM based on PC 3	-0.145	0.042	1.000			
ASM based on PC 4	0.111	0.185	0.081	1.000		
ASM based on PC 5	0.234	0.075	-0.195	0.068	1.000	
ASM based on PC 6	0.092	0.237	0.107	0.524	0.085	1.000
Nigeria						
ASM based on PC 1	1.000					
ASM based on PC 2	0.236	1.000				
ASM based on PC 3	0.248	0.007	1.000			
ASM based on PC 4	0.052	-0.144	0.063	1.000		
ASM based on PC 5	0.099	-0.152	0.129	0.444	1.000	
ASM based on PC 6	-0.060	-0.007	0.097	0.084	0.250	1.000
Uganda						
ASM based on PC 1	1.000					
ASM based on PC 2	0.695	1.000				
ASM based on PC 3	0.593	0.731	1.000			
ASM based on PC 4	0.162	0.230	0.179	1.000		
ASM based on PC 5	0.368	0.380	0.121	0.170	1.000	
ASM based on PC 6	0.515	0.628	0.552	0.094	0.438	1.000

Source: Authors. ASM = Agroclimatic Similarity indicator with maize research locations. PC = principal component.

Table A4. Cobb-Douglas production function coefficients

Variables	Ethiopia	Nigeria	Uganda
Land	0.146**	0.037**	0.489**
	(0.009)	(0.011)	(0.029)
Labor	-0.019	0.073**	0.159**
	(0.018)	(0.019)	(0.013)
Expense other than family labor	0.522**	0.148**	0.033**
	(0.020)	(0.015)	(0.004)
Agricultural capital	0.043*	0.139**	0.046**
	(0.024)	(0.029)	(0.013)
Livestock value	0.001**	0.014*	0.057**
	(0.0002)	(0.008)	(0.003)
Irrigation	0.043	0.857**	0.050
	(0.066)	(0.204)	(0.090)
Rainfall (1000 mm)	-0.155	0.103	0.543**
	(0.120)	(0.242)	(0.123)
Temperature	0.085*	-0.543**	-0.083*
	(0.043)	(0.264)	(0.047)
Wave dummy	Included	Included	Included
Intercept	Included	Included	Included
Sample size	9,631	8,649	15,108

Source: Authors. Asterisks indicate the statistical significance *** 1% ** 5% * 10%
Note: Numbers in parentheses are robust standard errors.

Table A5. Statistically significant coefficients and signs for other variables associated with maize producing households' total factor productivity

Variables	Ethiopia	Nigeria	Uganda
Euclidean distance to the nearest maize research location (decimal coordinates)	+	–	
Age of household head (year)		–	
Gender of household head (female = 1)	–	–	–
Education of household head (years)	–	–	+
Household size (male, 0 – 14 years old)	+		+
Household size (female, 0 – 14 years old)	+		+
Household size (male, 15 – 60)	+		+
Household size (female, 15 – 60)		+	
Household size (male, 61 or above)			
Household size (female, 61 or above)			
Household asset (current USD)			+
Farm-land owned (ha)	+	+	+
Distance to road (km)		–	
Distance to population center (km)	+	+	
Distance to market (km)		+	
Distance to administrative center (km)	+		
Distance to border post (km)			
Distance to 20,000 town (hour)			
Rainfall (mm, historical average)	+	–	–
Temperature (℃, historical average)		+	
Drought index (SPEI)	+	–	
Soil alkalinity (ph)	+		–
Soil organic content (g / kg of soil)	+	–	+
Soil texture (% medium)	–	–	+
Soil texture (% coarse)		–	
Soil salinity (deciSiemens per metre)		+	+
Soil sodicity (% of soil)		+	+
Soil with poor drainage (%)	+		
Soil with excess drainage (%)			+
Terrain ruggedness (index)			
Survey wave dummy	Yes	Yes	Yes
Sample	2112	1969	3284

Source: Author's estimations.

Table A6. Statistically significant coefficients and signs for other variables associated with maize land productivity

Variables	Ethiopia	Ghana	Nigeria	Uganda
Euclidean distance to the nearest maize research location (decimal coordinates)	+	–		
Age of household head (year)		–	–	
Gender of household head (female = 1)		–	–	–
Education of household head (years)	+	+		+
Household size (male, 0 – 14 years old)			+	
Household size (female, 0 – 14 years old)			+	
Household size (male, 15 – 60)		+	+	+
Household size (female, 15 – 60)	–		+	
Household size (male, 61 or above)				
Household size (female, 61 or above)		–		
Household asset (current USD)	+	+	+	+
Farm-land owned (ha)	–		+	
Distance to road (km)				
Distance to population center (km)	–			
Distance to market (km)	–			
Distance to administrative center (km)	–	–	+	
Distance to border post (km)			–	
Distance to 20,000 town (hour)				
Rainfall (mm, historical average)	+		+	
Temperature (℃, historical average)			–	+
Drought index (SPEI)			+	+
Soil alkalinity (ph)	–	+	–	–
Soil organic content (g / kg of soil)	+	+	–	
Soil texture (% medium)	–		+	
Soil texture (% coarse)	+	+	+	
Soil salinity (deciSiemens per metre)	+		+	
Soil sodicity (% of soil)	+	–		
Soil with poor drainage (%)		+		–
Soil with excess drainage (%)		+	+	
Terrain ruggedness (index)	+		–	
Survey wave dummy	Yes	Yes	Yes	Yes
Sample	4526	10271	3243	4090

Source: Author's estimations.

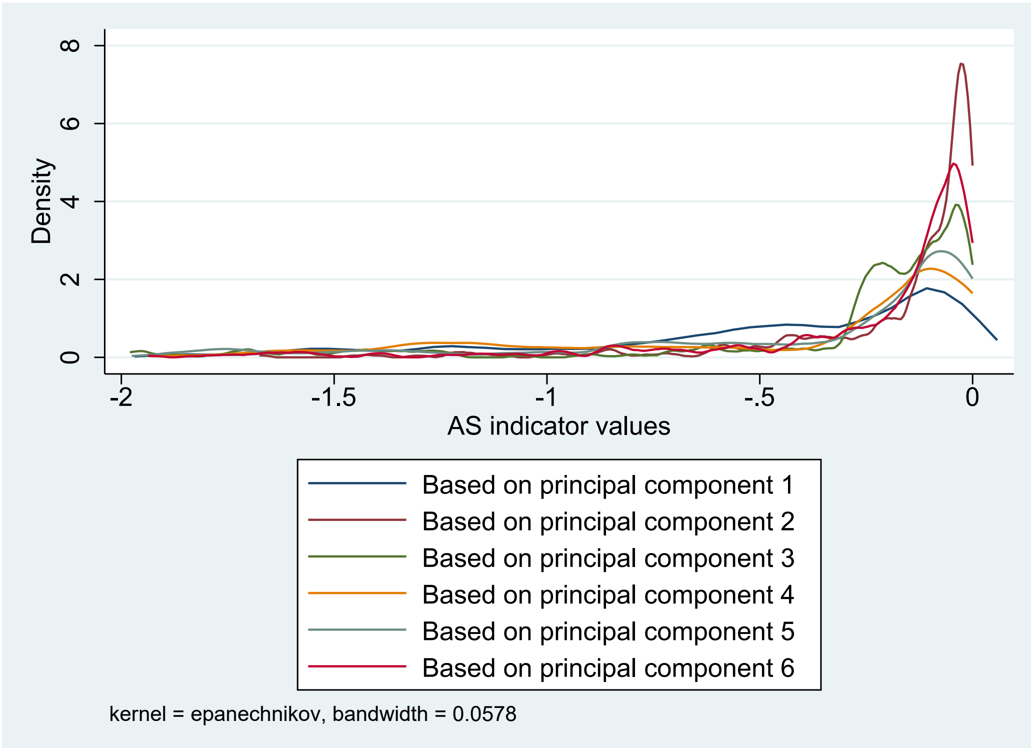

Figure 1. Kernel density estimates of the distribution of agroclimatic similarity indicators based on 6 principal components (Ethiopia)
Source: Author.

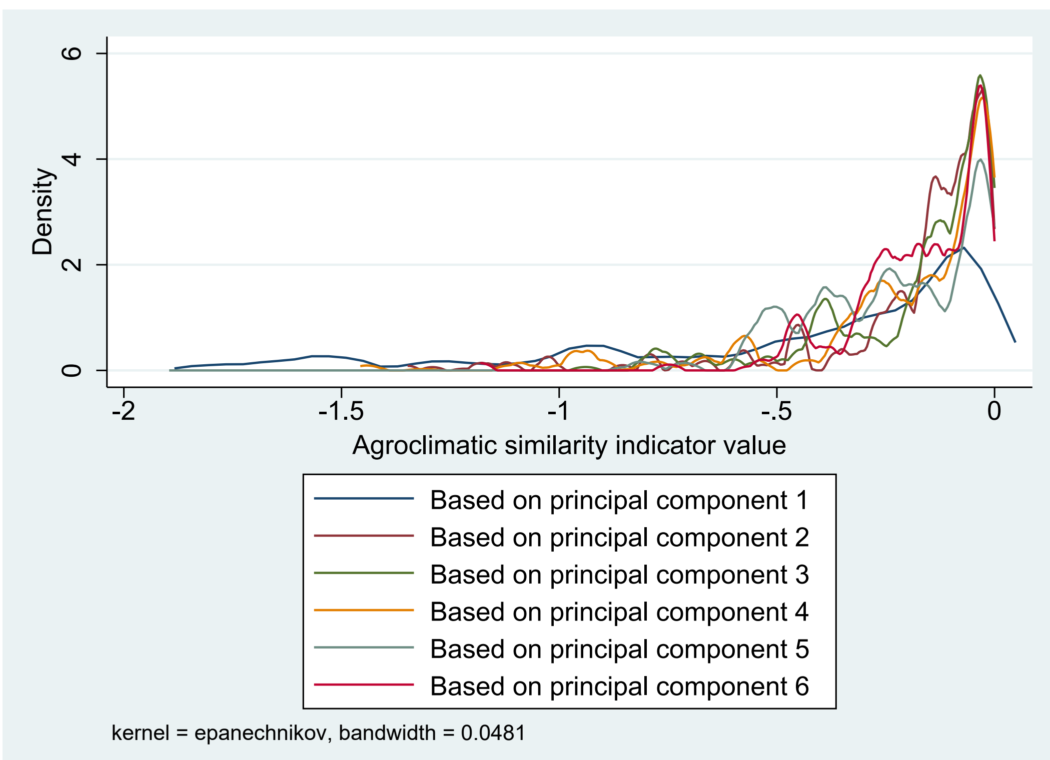

Figure 2. Ghana
Source: Author.

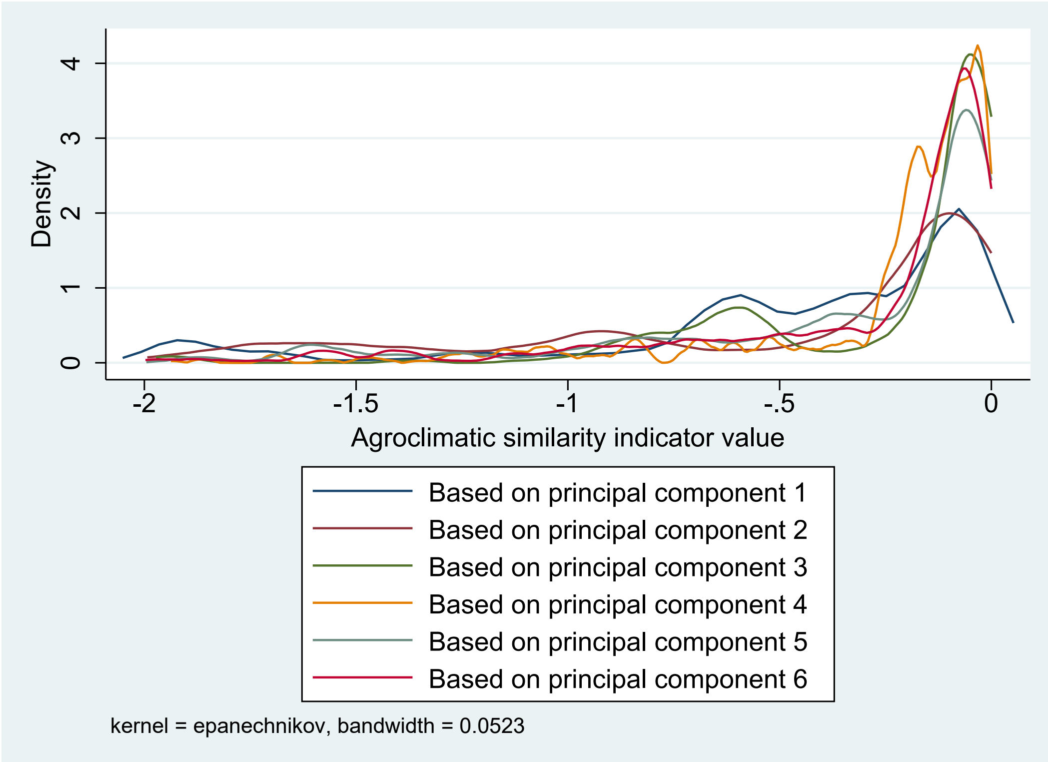

Figure 3. Nigeria
Source: Author.

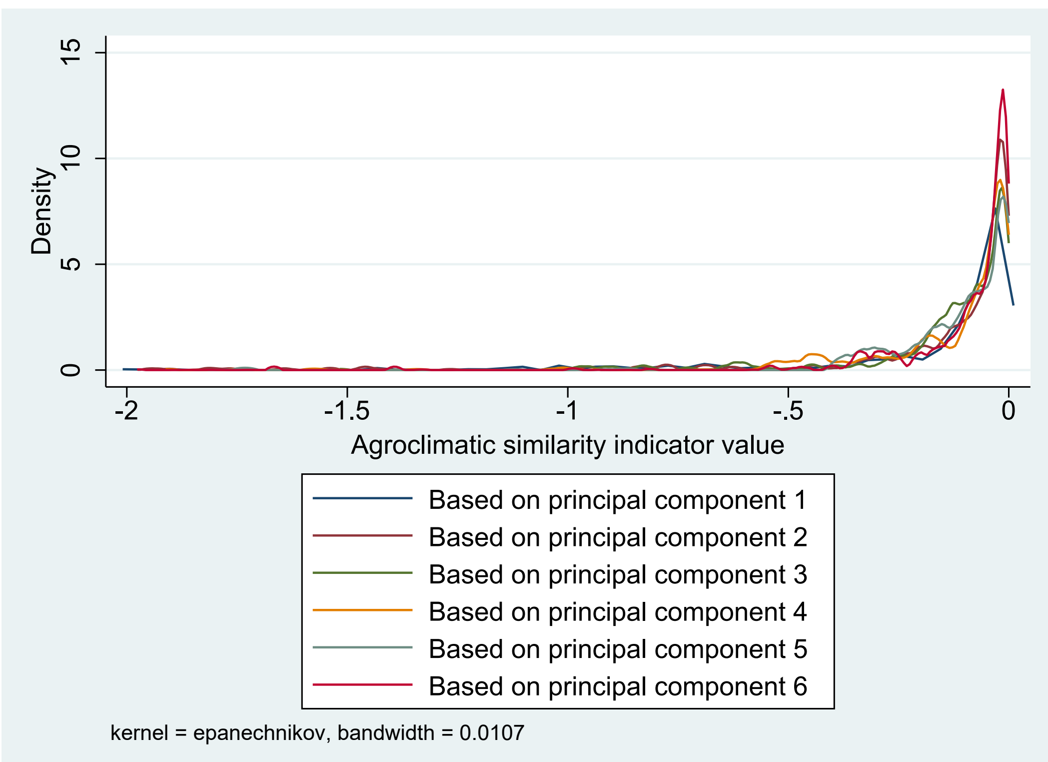

Figure 4. Uganda
Source: Author.

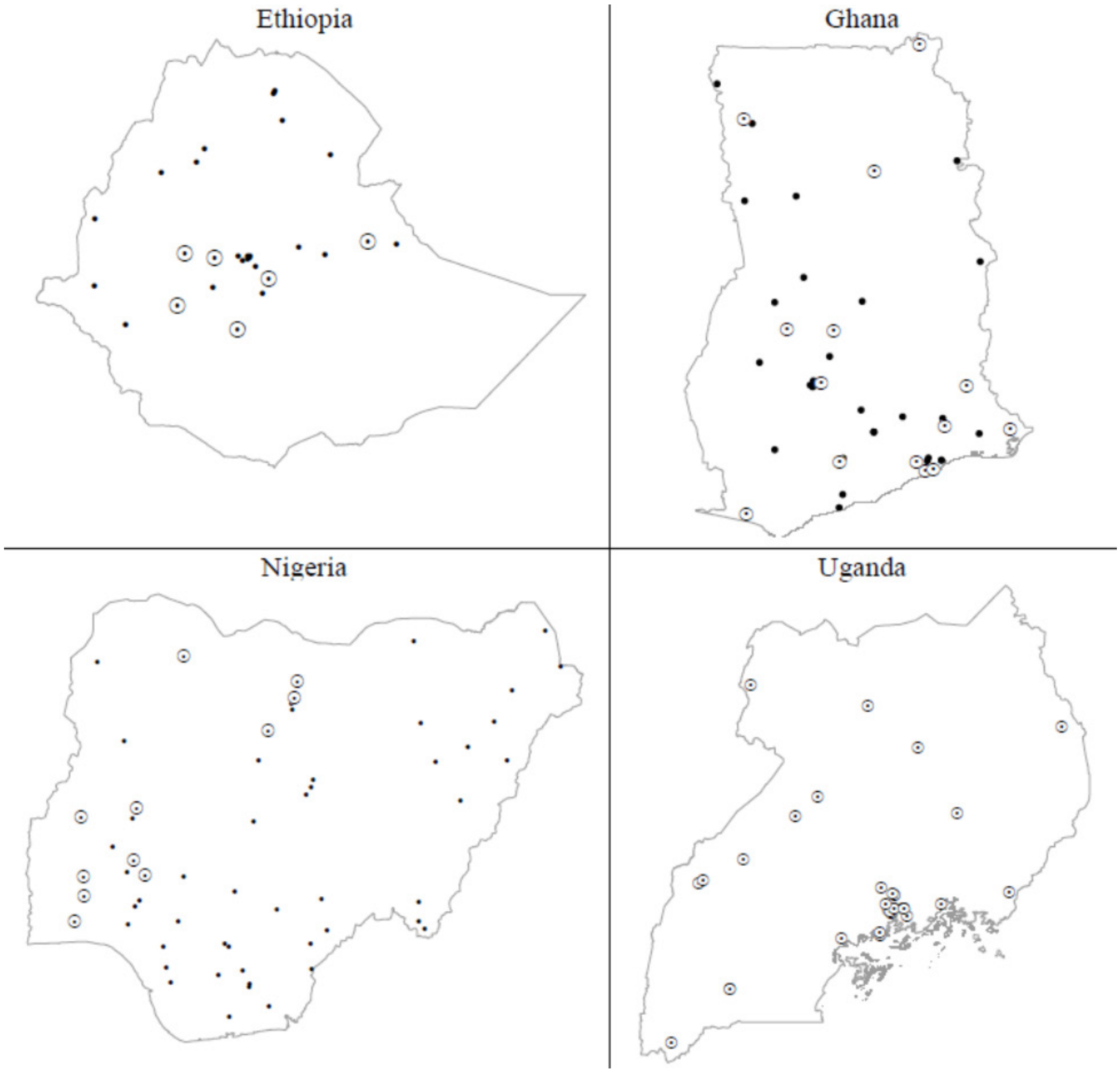

Figure 5. Locations of research institutes and outstations (those with and without mandates on maize) used in the analyses for the four countries

Source: Author.

Note: Circled dots indicate the locations of research institutes and outstations with mandates on maize. Non-circled dots indicate the locations of other types of agricultural research institutes and outstations.

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