Evaluating the Effects of Alternative Management Strategies on Rwandan Agriculture

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Background

- Agriculture plays a very important role in Rwanda's economy, accounting for about 3/4 of employment and contributing almost 1/3 of the nation's GDP (Niyitanga, Kabayiza, and Niyonzima, 2015)
- The average household farms less than 1 hectare (Ayalew Ali and Deininger, 2014), generally in rainfed conditions and with few inputs
- Lack of information about the potential impacts of increased use of inputs and improved management practices on crop yields
- This study estimates the response of major crop yields to changes in management practices, on a national scale and by climatic region
  - Provides important information to help inform policymakers and stakeholders

National Institute of Statistics of Rwanda

Data

- The National Institute of Statistics of Rwanda (NISR) has conducted seasonal surveys to estimate and characterize agricultural production in Rwanda since 2013
- 2017 was the first year NISR collected survey data using sampling representative at the district level
- Collects data on crop yields nationally, including major staple crops
- Covers farmer management decisions, including use of traditional or improved seeds, pesticides, organic or inorganic fertilizer, irrigation, and anti-erosion activities such as cover crops

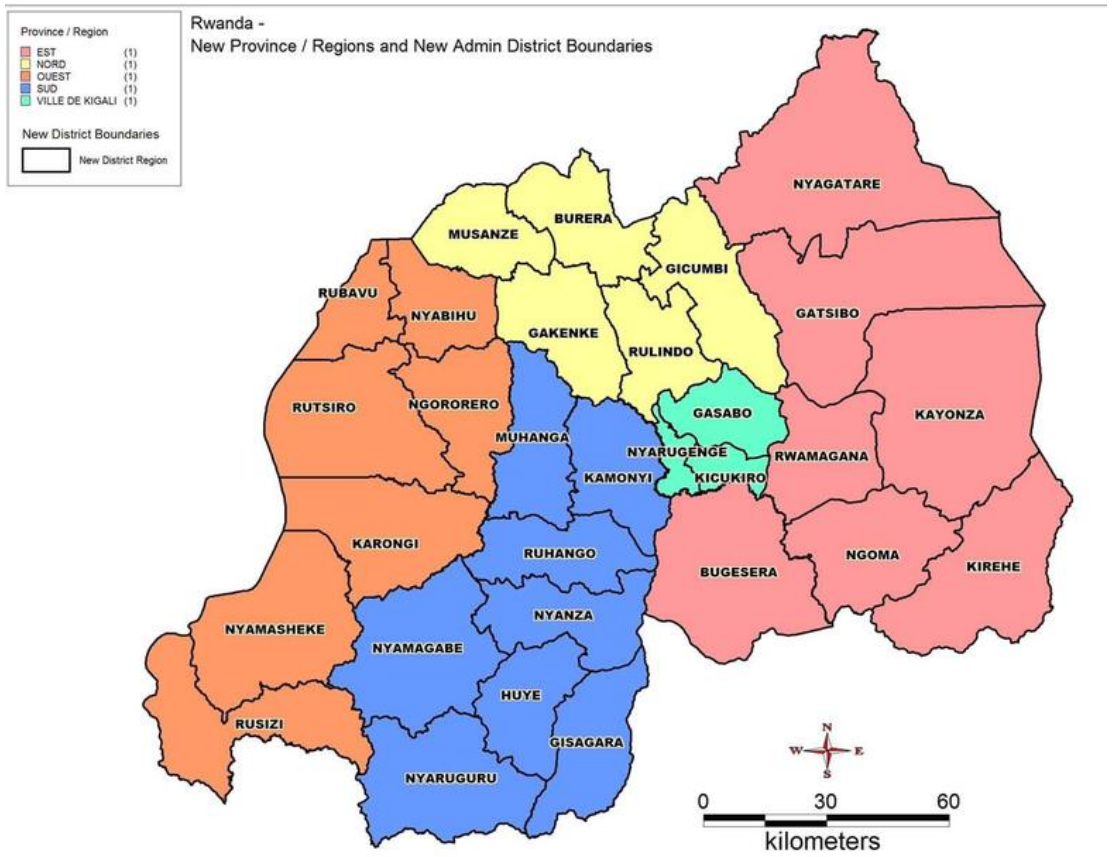
Data Collection Methods

- SAS utilizes multiple-frame sampling: surveys in which two or more frames are used and samples are taken from each frame
- Benefits include desired level of precision and estimating with greater coverage to lower risk of coverage bias (Rao and Wu, 2010)
- Samples from each frame are extrapolated to represent the stratum level characteristics, with results reported at the district level
- Observations collected across more than **14,000 villages**

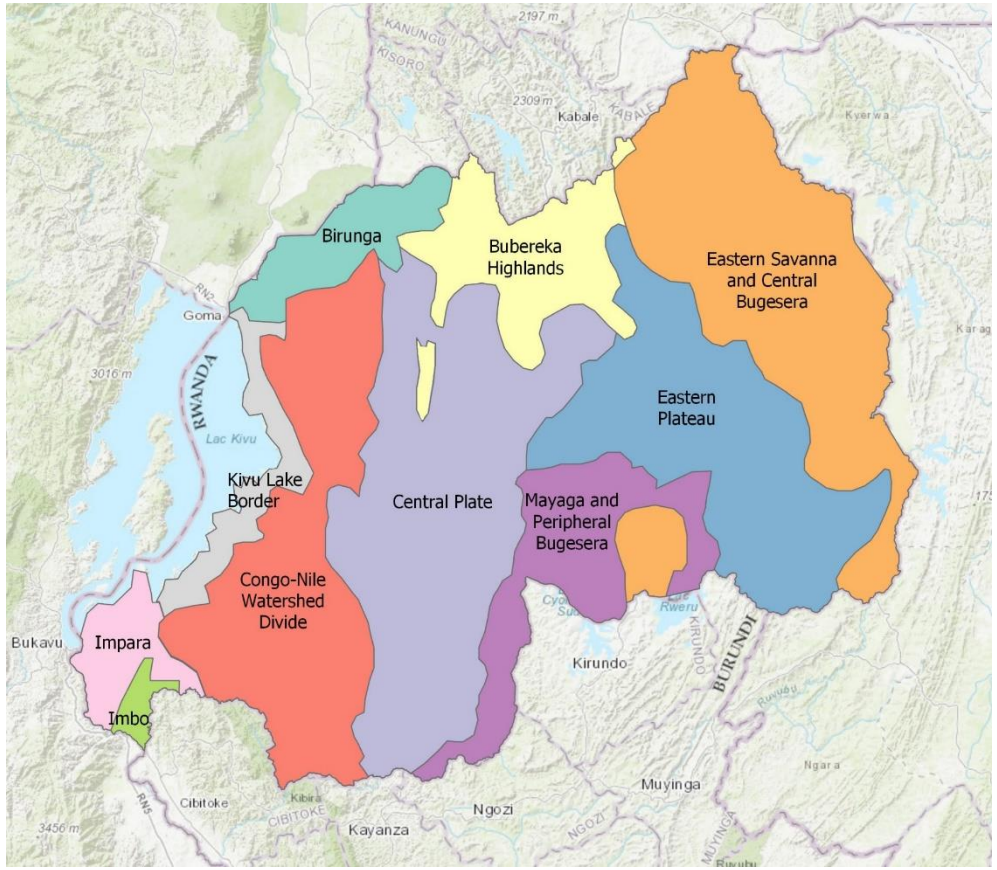
Management Practices Analysis

- We use a pooled dataset at the crop-plot combination level
- We estimate a linear regression using Ordinary Least Squares (OLS)
- Data:
  - Total number of observations is 85,573
  - Data cover seasons A, B & C for years 2017 and 2018
- The number of observations in each regression is determined by the number of observations with no missing values for any of the included variables
- For each regression, some variables are dropped if only very few observations are non-missing

Rwanda Agroecological Zones (AEZ)

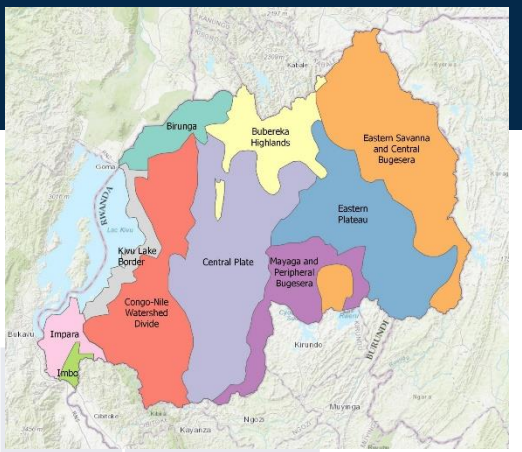


Political boundaries



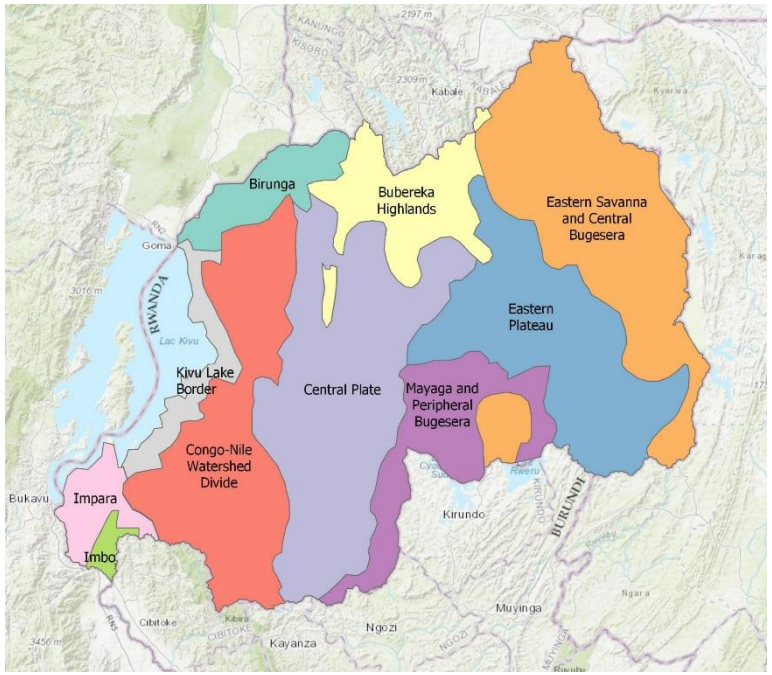
10 zones, grouped by similar climatic conditions

AEZ Biophysical Characteristics



ZONE	Average Temperature	Average Precipitation	Elevation	Slope (degrees)	Calcium	C:N	Magnesium	Organic Carbon	pH	Potassium
Bubereka Highlands	19.3	79.9	1978.6	41.0	2.8	13.5	1.1	4.5	4.8	0.3
Birunga	15.4	77.9	2295.8	18.3	15.9	11.5	3.7	7.8	5.9	1.4
Kivu Lake Border	19.6	99.5	1683.1	32.8	3.0	12.4	1.4	3.9	4.7	0.3
Congo-Nile Watershed Divide	18.1	112.0	2197.6	37.3	3.0	13.5	1.2	5.4	4.8	0.4
Central Plate	20.2	77.8	1691.8	29.8	3.0	13.5	1.1	3.7	5.0	0.3
Eastern Plateau	21.7	56.0	1528.0	20.7	4.6	13.5	1.9	3.0	5.2	0.4
Mayaga and Peripheral Bugesera	22.0	63.1	1422.0	12.7	4.2	12.2	1.5	2.2	5.0	0.4
Imbo	21.2	116.2	1176.7	27.7	9.1	12.6	4.9	3.6	5.6	0.5
Eastern Savanna and Central Bugesera	21.9	59.0	1390.0	8.6	4.7	12.2	1.8	2.7	5.0	0.4

All Crops at the National Level



Mixed Crop System	Pesticides Applied	Fertilizer Applied[e]		
		Organic	Inorganic DAP	Inorganic NPK17.17.17
-0.087***	0.097***	0.085***	0.015***	0.032***

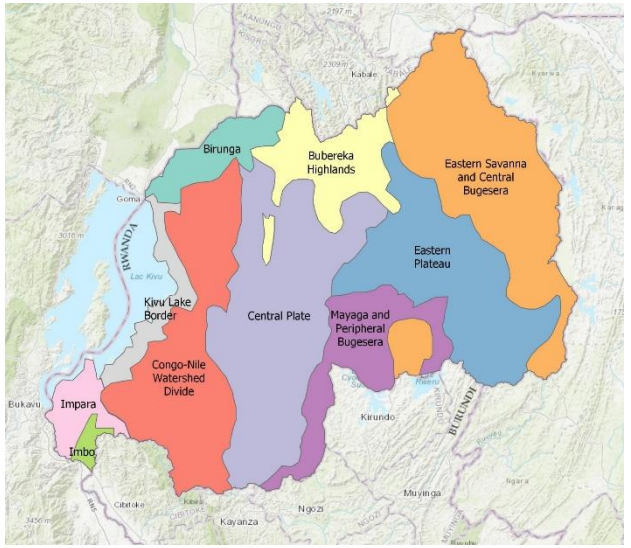
Plot Area		Paid Labor[e]
Small	Large	
0.221***	-0.177***	0.002***

Anti-Erosion Practices				
Bed Ridges	Bench Terrace w/ Cover Plants	Cover Plants and Mulching	Water Drainage	None
0.084**	-0.105**	0.305***	0.175***	-0.051**

- On average, farmers who utilize **mixed cropping systems** have almost **9% lower yields** than those who use pure cropping
  - Note, this yield result is on a plot basis
- On average, **small plots** result in **higher yields** than large plots
  - Perhaps due to more concentrated resources

Comparing Management Practice Results Across Zones

ZONE	Plot Area		Mixed Crop System	Improved Seeds	Pesticides Applied	Irrigation Used	Organic Fertilizer Applied[e]	No Anti-Erosion Practices
	Small	Large						
Bubereka Highlands	0.229***	-0.217***	-0.196***	0.348***	0.275***	n/a	0.138***	0.089
Birunga	0.076	-0.250***	-0.027	0.562***	0.268***	n/a	0.053*	0.058
Kivu Lake Border	0.097	0.044	-0.001	0.096	0.263*	0.652**	0.043	0.012
Congo-Nile Watershed Divide	0.180***	-0.102	-0.135***	0.373***	0.160***	n/a	0.072***	-0.119**
Central Plate	0.295***	-0.114***	-0.092***	0.496***	0.184***	0.122*	0.096***	-0.054
Impara	0.129	-0.209	-0.057	0.338*	0.371**	-0.073	0.032*	-0.052
Eastern Plateau	0.320***	-0.166***	-0.154***	0.272***	0.126**	0.084	0.119***	-0.100**
Mayaga and Peripheral Bugesera	0.139	-0.120	0.127	0.302**	-0.073	0.573*	0.075**	-0.239*
Imbo[†]	0.624	0.239	0.602	0.906**	-0.223	-3.784***	-0.140*	0.151
Eastern Savanna and Central Bugesera	0.125	-0.203***	-0.027	0.293**	0.258**	0.415	0.051***	-0.152**
ALL	**0.221*** **	**-0.177*** **	**-0.087*** **	**0.290*** **	**0.097*** **	**0.123*** **	**0.085*** **	**-0.051*** **



[†]Results should be interpreted with caution, Imbo has relatively few observations (185)

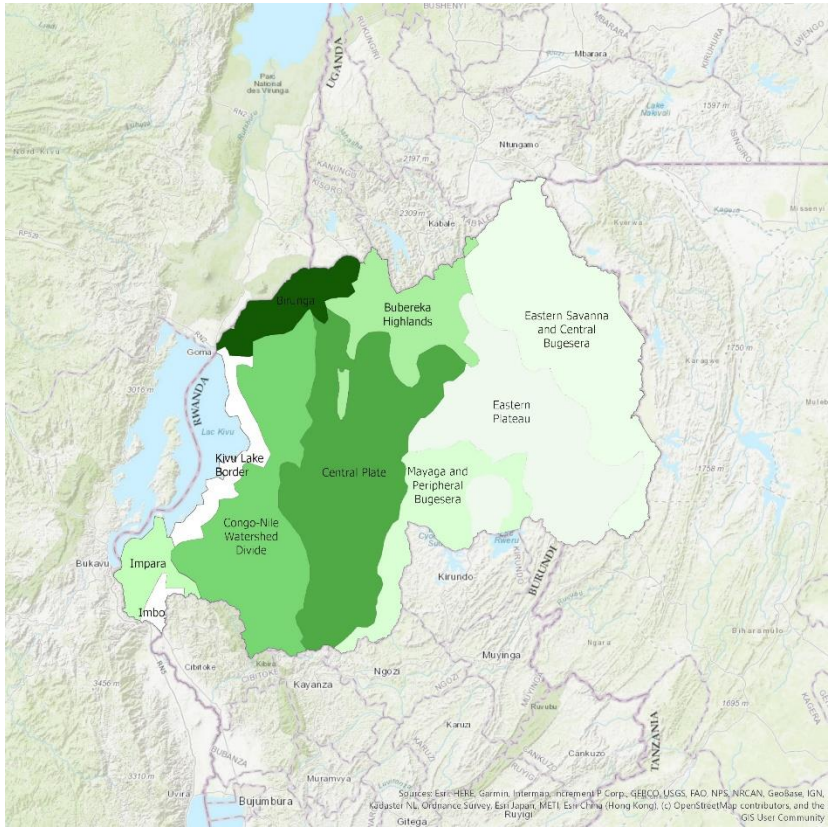
All crops, main only

AEZ Comparisons

Improved Seeds

- Of all the management practices analyzed, improved seeds have the largest and most universal impact on yields (significant in 9/10 AEZs)
- At the minimum, farmers in the Eastern Plateau AEZ who use improved seeds have an average of 27.2% higher yields than those who do not
- At the maximum,† farmers in the Birunga AEZ who use improved seeds have an average of 56.2% higher yields than those who do not

National: +29%



Birunga includes parts of Rubavu, Nyabihu, Musanze, and Burera

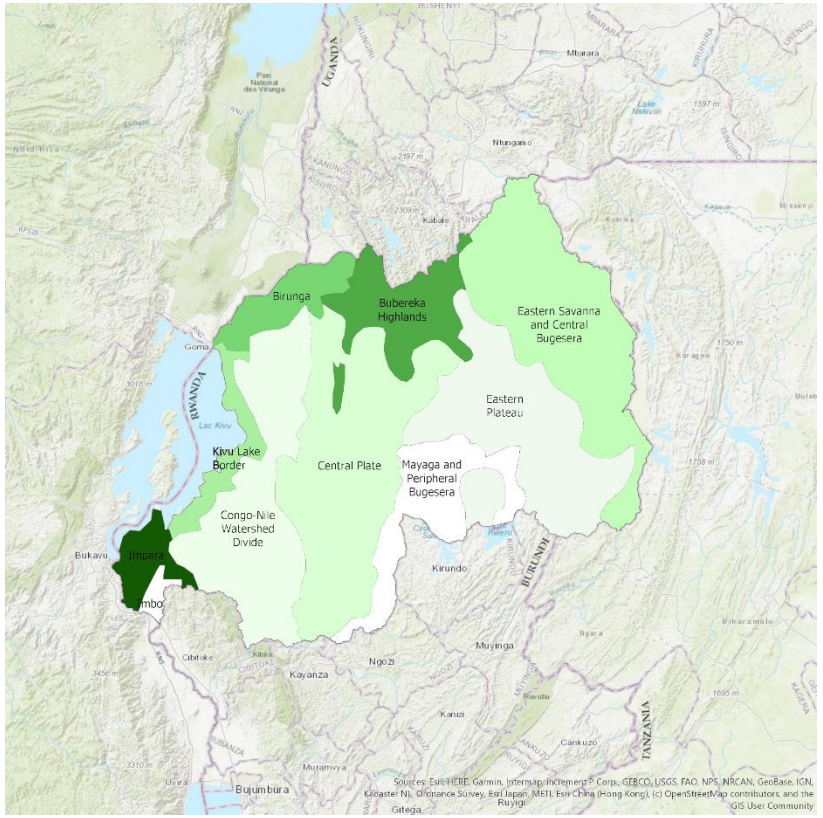
† Not including Imbo, with a 90.6%** result. Interpreted with caution since this AEZ has relatively few observations (185).

AEZ Comparisons

Pesticides

- Applying pesticides also has significant positive effects on yields (8/10 AEZs)
- At the minimum, farmers in the Eastern Plateau AEZ who apply pesticides have an average of 12.6% higher yields than those who do not
- At the maximum, farmers in the Impala AEZ who apply pesticides have an average of 37.1% higher yields than those who do not

National: +9.7%



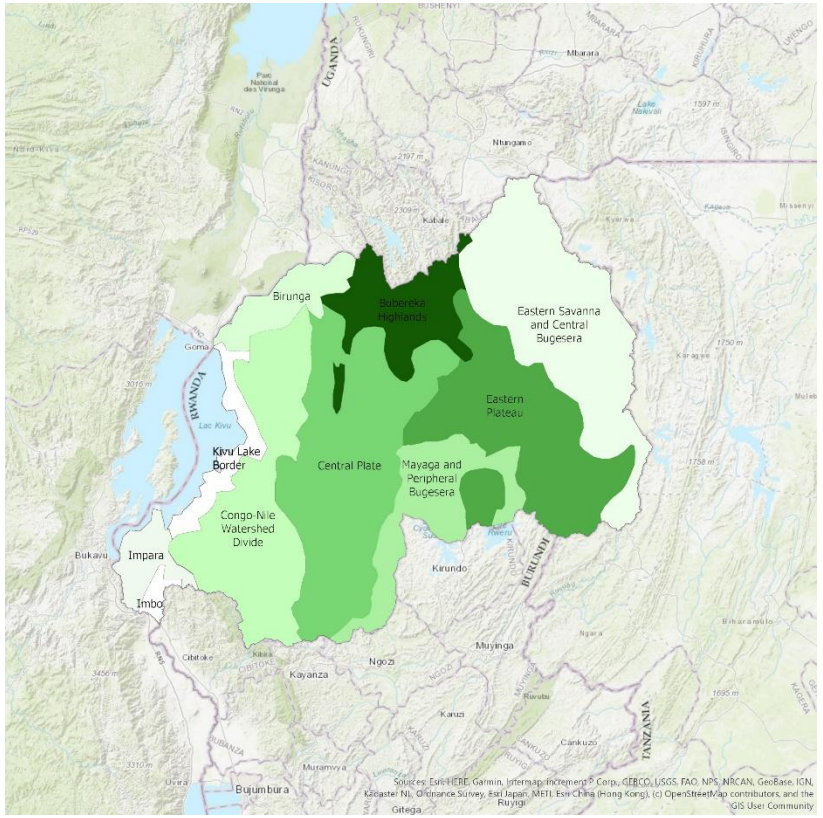
Impala includes parts of Nyamasheke and Rusizi

AEZ Comparisons

National: +0.085% for every 1% increase in fertilizer

Organic Fertilizer

- Organic fertilizer has a significant positive effect in 8/10 AEZs
- In the Bubereka Highlands, each 1% increase in organic fertilizer application results in an average 0.138% increase in yields
- The least significant effect is in Impala, where each 1% increase in organic fertilizer application results in a 0.032% increase in yields, on average



Bubereka Highlands includes parts of Burera, Gicumbi, and Nyagatare

Comparing Management Practice Results Across Crops, Season A

Season A

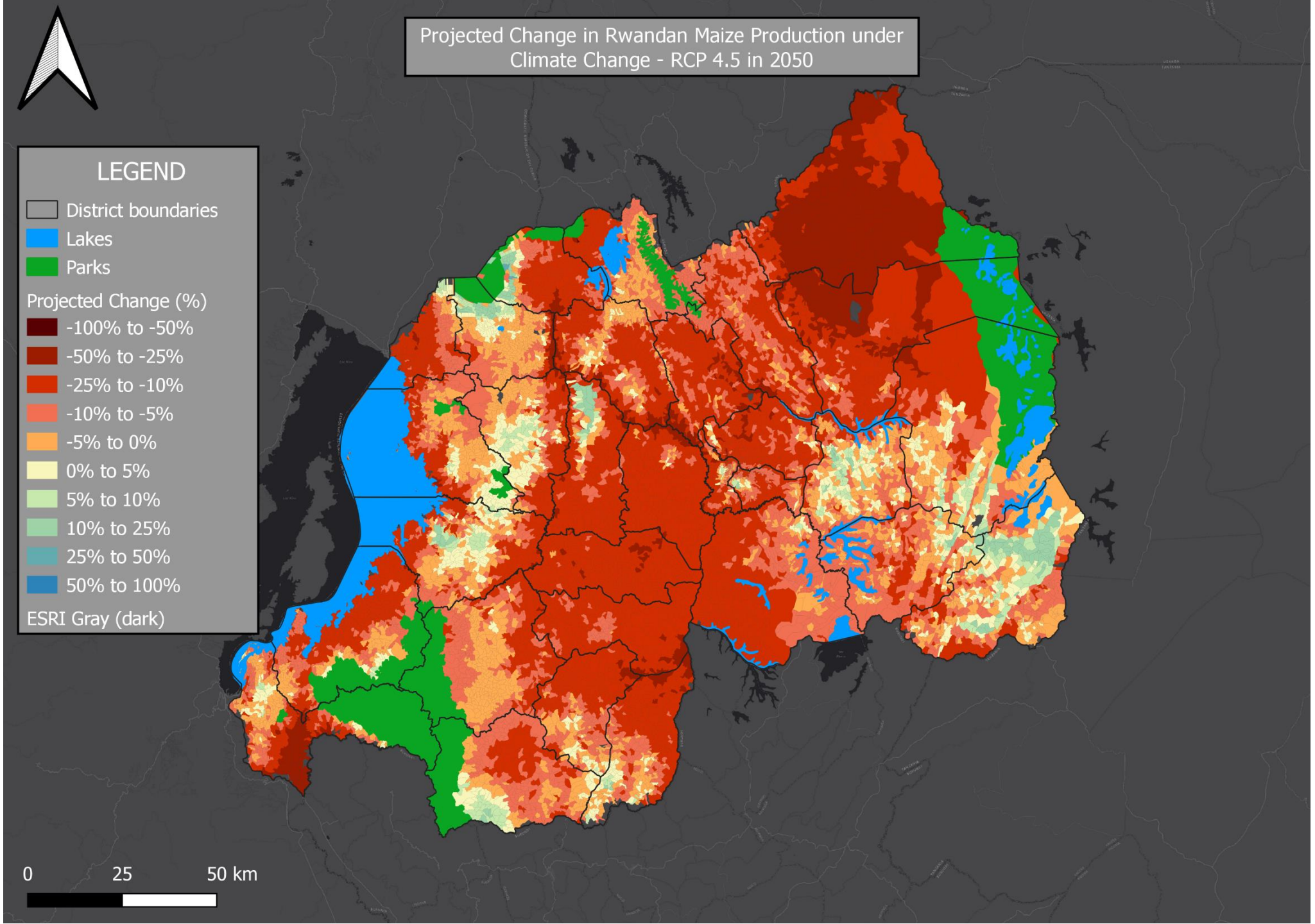
CROP	Maize	Bush Bean	Cassava	Climbing Bean	Irish Potato	Pea	Sorghum	Soybean	Sweet Potato	Beer Banana	Cooking Banana	Dessert Banana	ALL
Plot Area[e]	-0.101***	-0.215***	-0.323***	-0.182***	-0.267***	-0.304***	-0.044	-0.300***	-0.298***	-0.142***	-0.140***	-0.305***	**-0.187*** **
Mixed Crop System	-0.06	0.297***	-0.449*	0.046	0.150***	0.762***	0.031	0.291***	-0.213***	-0.19	-0.427**	-0.16	**-0.067*** **
Improved Seeds	0.144***	n/a	n/a	n/a	0.419***	n/a	n/a	n/a	n/a	n/a	n/a	0.634***	**0.262*** **
Pesticides Applied	-0.073	0.278***	0.267	0.117	0.176***	0.107	n/a	0.11	0.203*	0.299	0.087	0.26	**0.116*** **
Organic Fertilizer Applied[e]	0.086***	0.132***	0.009	0.089***	0.128***	0.102	0.061**	0.097**	0.099***	0.064**	0.106***	0.170***	**0.103*** **
No Anti-Erosion Practices	0.025	-0.052	-0.162	-0.001	-0.082	-0.146	-0.119	0.230**	0.135	-0.185	-0.261*	-0.02	**-0.065*** **

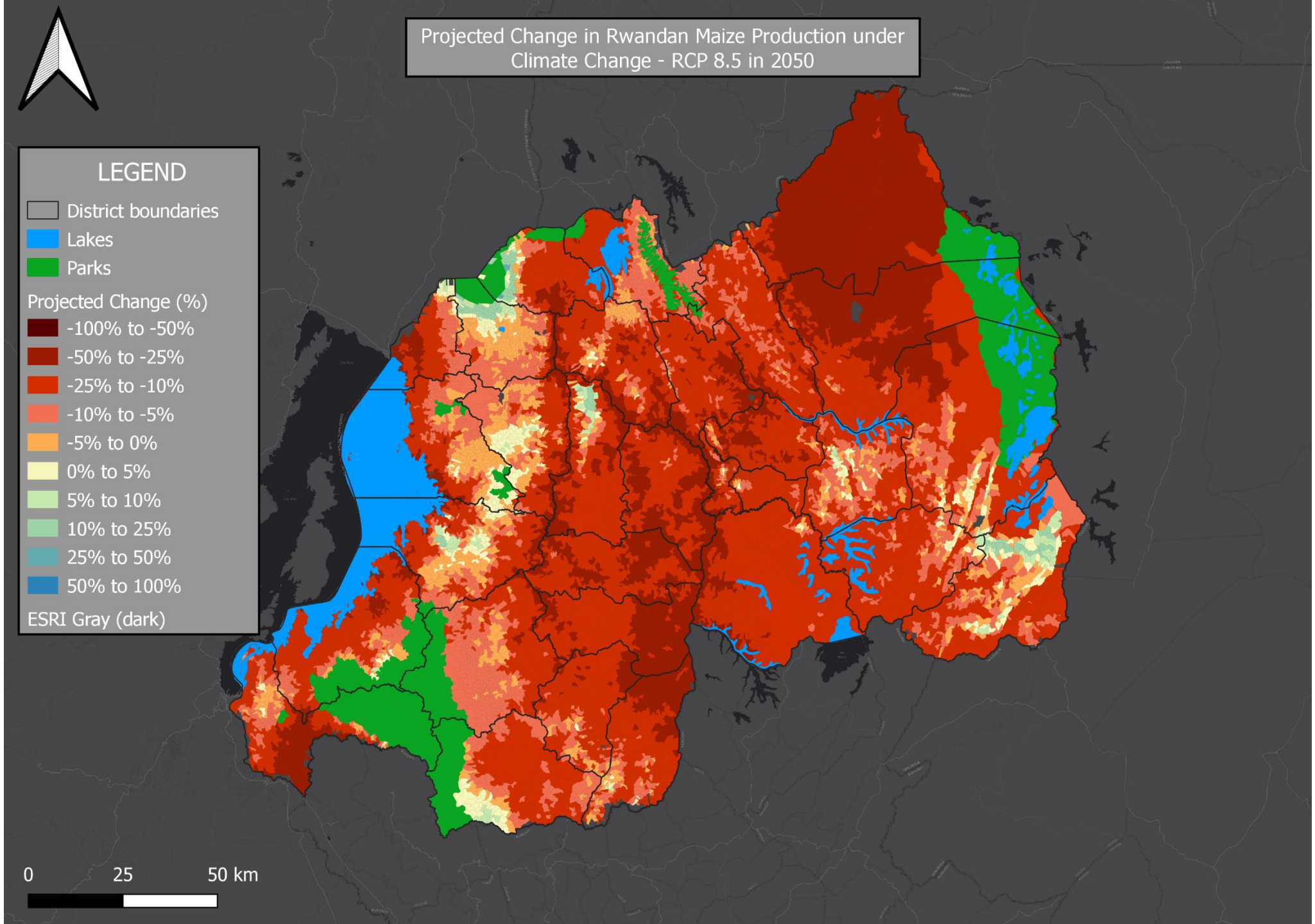
All crops, including niche, for both seasons

Climate Change Projections

Climate project results by crop and RCP

	Maize RCP 4.5	Maize RCP 8.5	Sorghum RCP 4.5	Sorghum RCP 8.5
Village average yield reference (kg/m²)	0.074	0.074	0.090	0.090
Village average projected yield (kg/m²)	0.065	0.062	0.086	0.083
Village average minimum projected yield (kg/m²)	0.034	0.032	0.027	0.025
Village average maximum projected yield (kg/m²)	0.103	0.098	0.287	0.281
Village average difference from reference (kg/m²)	-0.009	-0.012	-0.004	-0.006
Village average difference from reference (%)	-11.1%	-16.3%	-4.4%	-7.3%


Projected Change in Rwandan Maize Production under Climate Change - RCP 4.5 in 2050
LEGEND
District boundaries
Lakes
Parks
Projected Change (%)
-100% to -50%
-50% to -25%
-25% to -10%
-10% to -5%
-5% to 0%
0% to 5%
5% to 10%
10% to 25%
25% to 50%
50% to 100%
ESRI Gray (dark)
0
25
50 km


Projected Change in Rwandan Maize Production under Climate Change - RCP 8.5 in 2050
LEGEND
District boundaries
Lakes
Parks
Projected Change (%)
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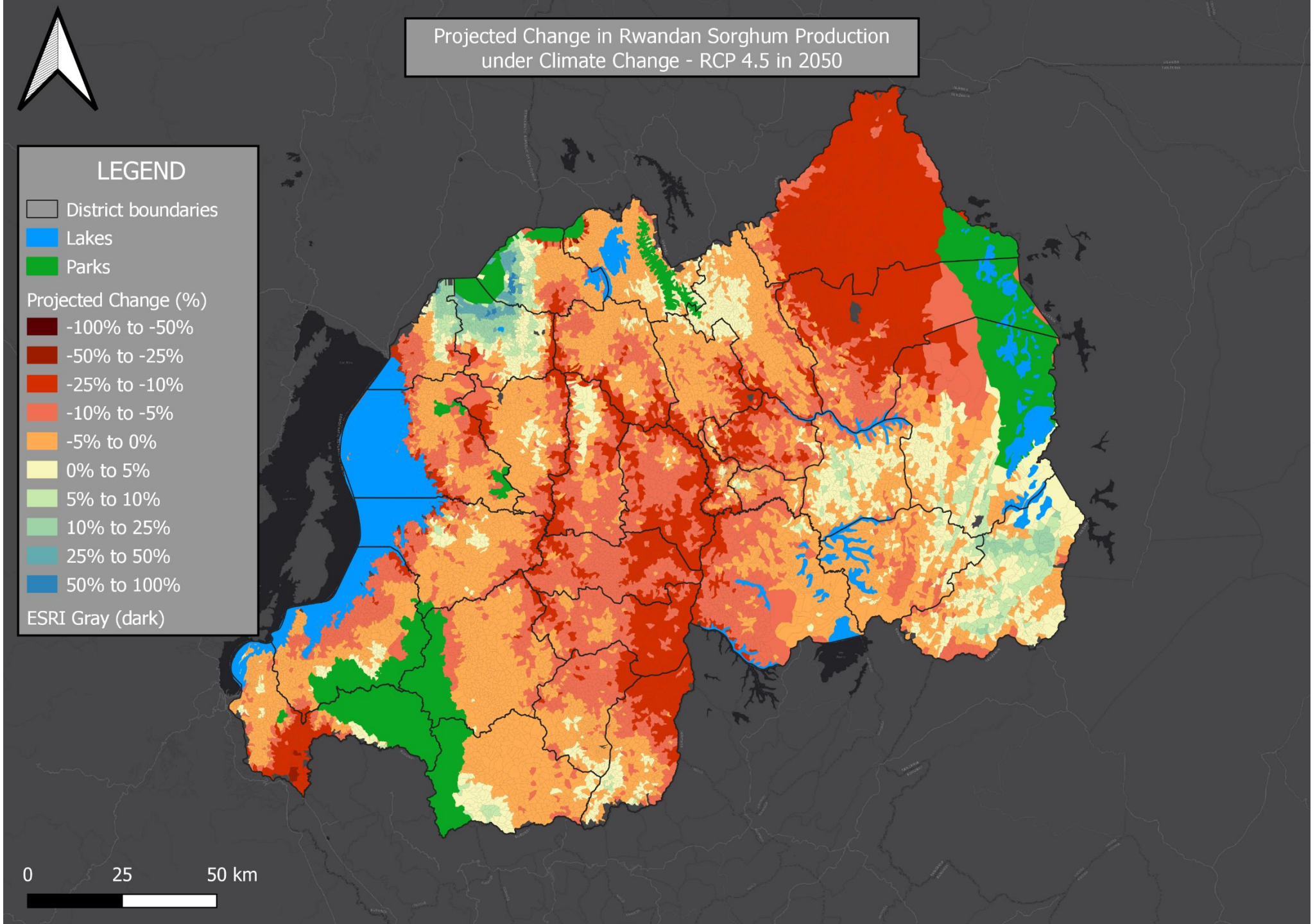
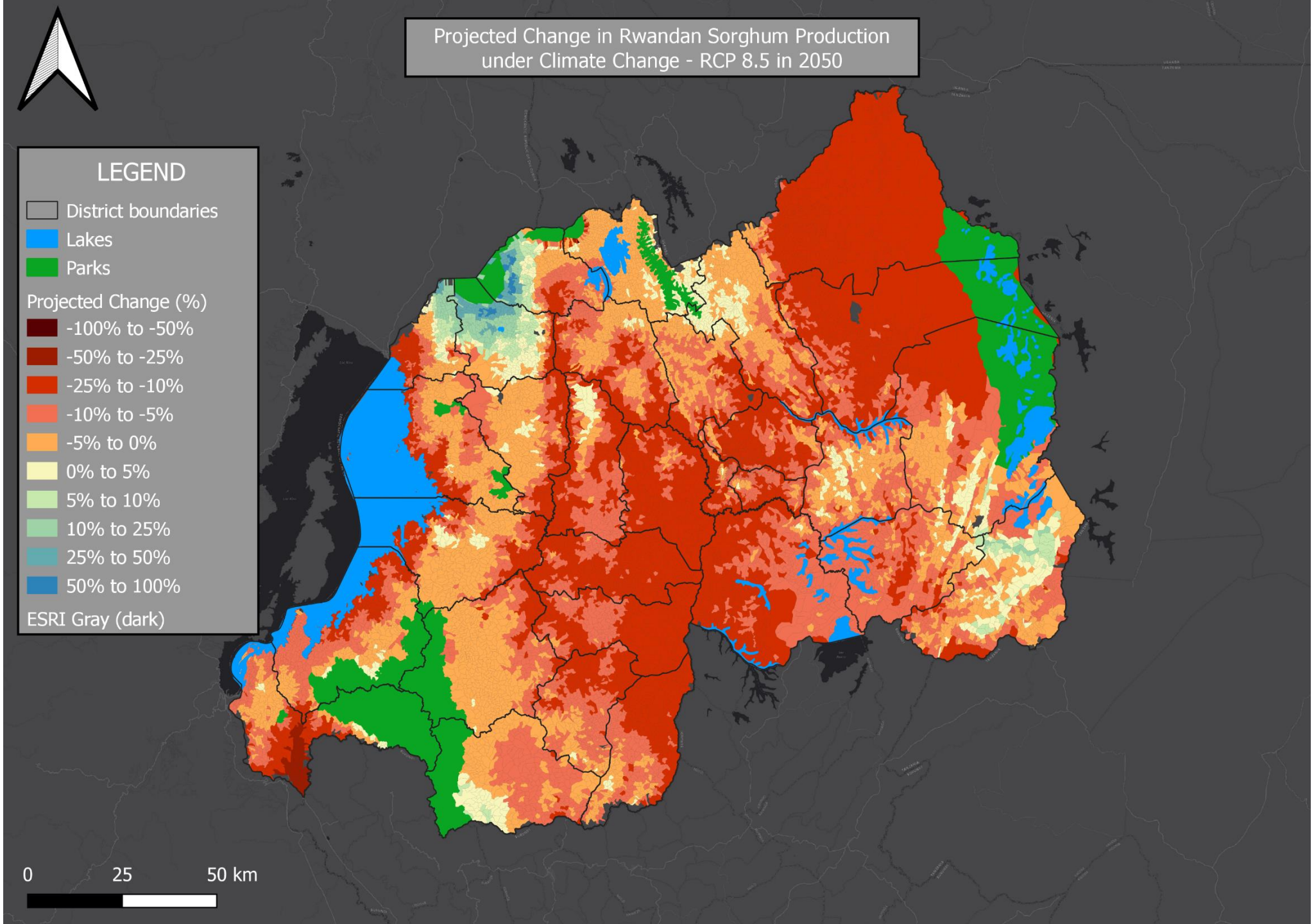
-50% to -25%
-25% to -10%
-10% to -5%
-5% to 0%
0% to 5%
5% to 10%
10% to 25%
25% to 50%
50% to 100%
ESRI Gray (dark)
0
25
50 km


Projected Change in Rwandan Sorghum Production
under Climate Change - RCP 4.5 in 2050
LEGEND
District boundaries
Lakes
Parks
Projected Change (%)
-100% to -50%
-50% to -25%
-25% to -10%
-10% to -5%
-5% to 0%
0% to 5%
5% to 10%
10% to 25%
25% to 50%
50% to 100%
ESRI Gray (dark)
0
25
50 km


Projected Change in Rwandan Sorghum Production under Climate Change - RCP 8.5 in 2050
LEGEND
District boundaries
Lakes
Parks
Projected Change (%)
-100% to -50%
-50% to -25%
-25% to -10%
-10% to -5%
-5% to 0%
0% to 5%
5% to 10%
10% to 25%
25% to 50%
50% to 100%
ESRI Gray (dark)
0
25
50 km

Next Steps

- Model enhancements
  - Continue to explore impacts across alternative specifications
- Incorporate 2019 seasons A, B, and C data
- Simulate potential impacts of alternative scenarios
  - Adoption of improved management practices
  - Climate adaptation

More Information

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Appendix

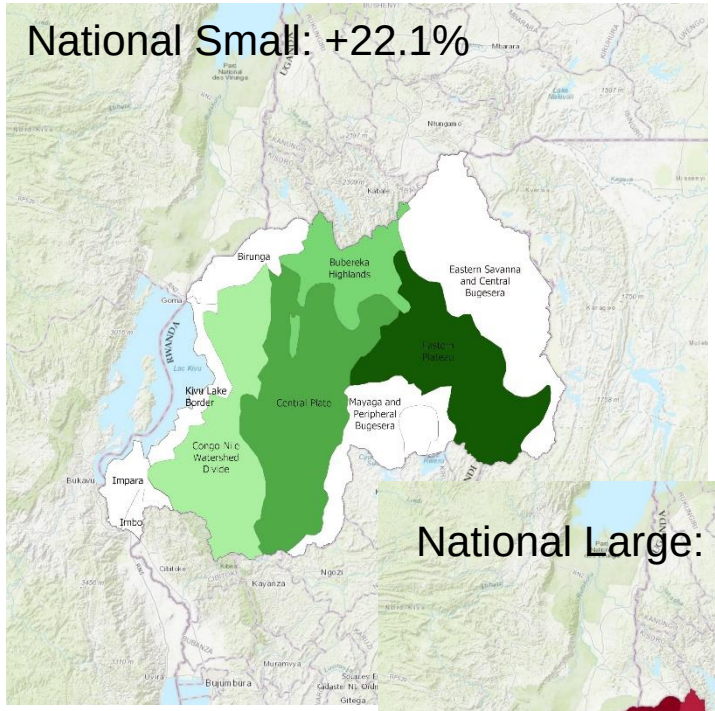
Interpreting the Regression Results

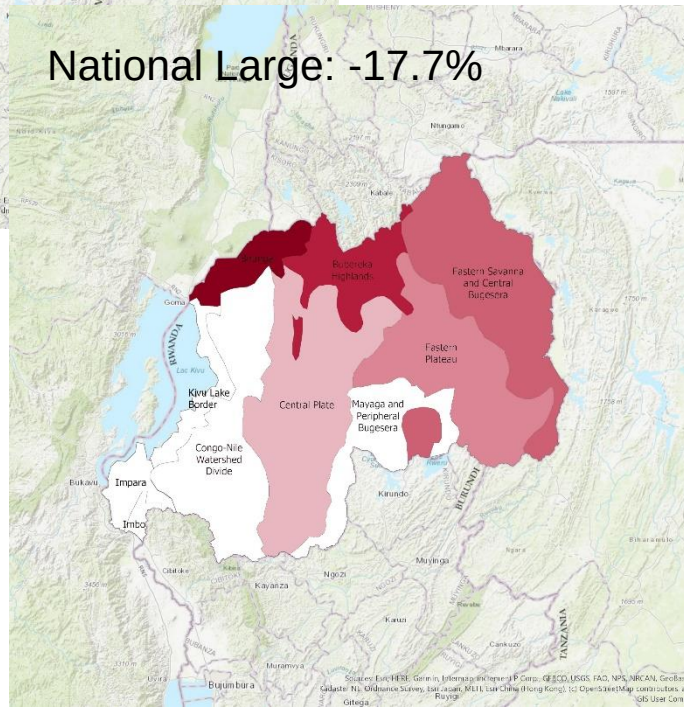
- **Coefficients may be marked with one, two, or three asterisks (*), which indicates significance.**
  - Three asterisks (***) indicates the coefficients estimated with the highest possible confidence, 99%.
  - Two (**) indicates the coefficients estimated with a high confidence, 95%.
  - One (*) indicates the coefficients estimated with confidence, 90%.
  - If there is no asterisk, we are less confident in the estimation and should be wary of considering that coefficient.
- **All coefficients, unless otherwise noted, should be interpreted as the percent change in yield when a management practice is applied as opposed to not applied.**
  - For example, if the coefficient for “water drainage” is 0.169***, then on average, farmers that use this practice have yields 16.9% higher than those who do not.
  - Because “water drainage” has three asterisks (***), we can say with 99% certainty that the greater yield example above will prove to be true in practice.
- **Coefficients denoted with “e” are elasticities and should be interpreted as a 1% increase of use in a management practice will result in some percent change in yield.**
  - For example, a 1% increase in “plot area,” like increasing plot area from 1 ha to 1.01 ha, leads to a -0.175% decrease in yields, on average.

AEZ Comparisons

Small Plots vs Large Plots

- Bottom and top 20% of plots by size
  - Small observations: min of 0.0006 hectares to max of 0.026
  - Large observations: min of 0.1481 hectares to max of 10.35
- All 10 AEZs show, on average, higher yields in small plots (4 highly significant)
- 8 AEZs show, on average, lower yields in large plots (5 highly significant)
- For example, the Eastern Plateau AEZ has the largest sensitivity to plot size
  - On average, small plots in the Eastern Plateau have 32% higher yields, and large plots have 16.6% lower yields





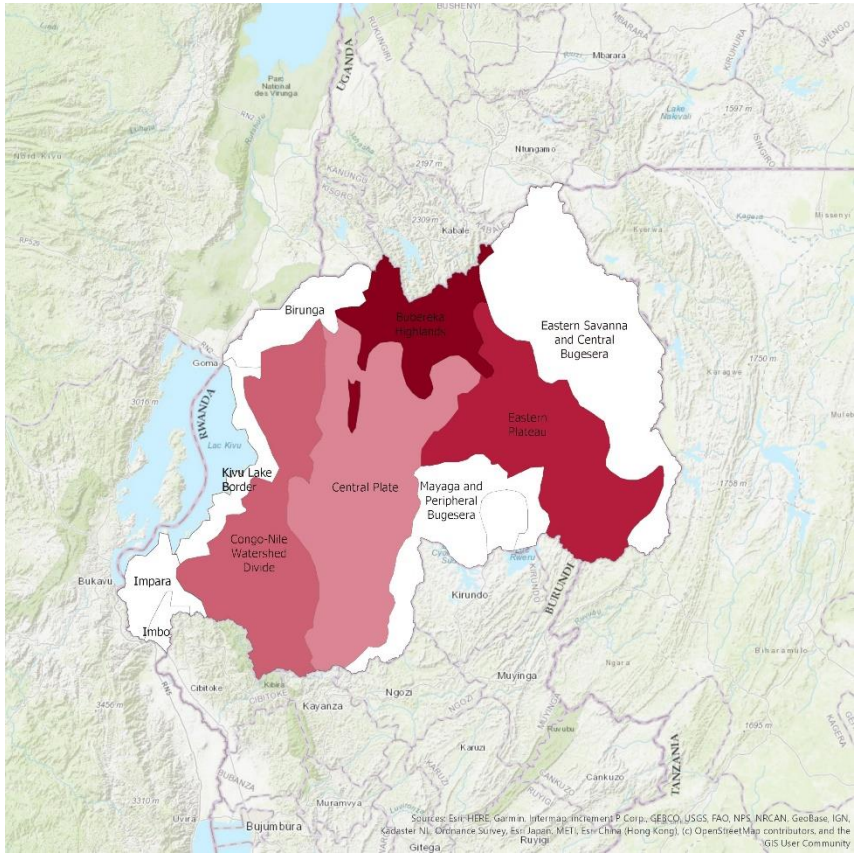
Eastern Plateau includes Rwamagana, Ngoma, Gasabo, and Gicumbi

AEZ Comparisons

Mixed Cropping Systems

- 8 AEZs show, on average, a farmer who uses mixed cropping systems have lower yields than farmers who use pure cropping (4 highly significant)
  - Note, this yield result is on a plot basis
- Farmers in the Bubereka Highlands AEZ who use mixed cropping systems have the greatest decline in yields compared to the farmers in their region who do not (-19.6%)

National: -8.7%



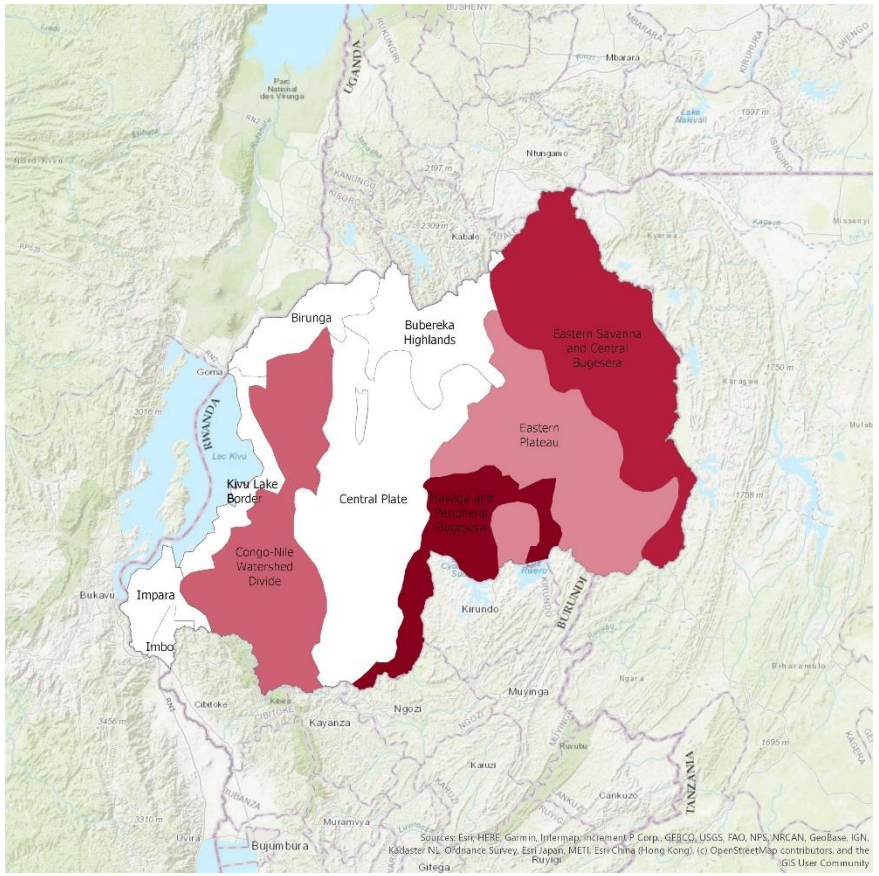
Bubereka Highlands includes parts of Burera, Gicumbi, and Nyagatare

AEZ Comparisons

No Anti-Erosion Practices

- While results by anti-erosion practice by AEZ (cover plants, ditches, etc.) were less clear, not having any anti-erosion practice has a clear negative effect on yields
  - 4/6 AEZs with significant results are negatively correlated
- Mayaga and Peripheral Bugesera AEZ yields are most impacted; farmers that do not employ any anti-erosion practices, on average, have 23.9% lower yields than farmers that do

National: -5.1%



Mayaga and Peripheral Bugesera includes parts of Bugesera, Nyanza, and Gisagara

Comparing Management Practice Results Across Crops, Season B

Season B

CROP	Maize	Bush Bean	Cassava	Climbing Bean	Irish Potato	Pea	Sorghum	Soybean	Sweet Potato	Beer Banana	Cooking Banana	Dessert Banana	ALL
Plot Area[e]	-0.160**	-0.055	-0.283***	-0.156***	-0.090**	-0.258**	-0.171***	-0.396***	-0.230***	-0.144***	-0.103***	-0.130**	**-0.187*** **
Mixed Crop System	-0.195	0.029	-0.008	-0.059	-0.132**	-0.236	-0.012	0.079	-0.071	-0.441***	-0.222*	-0.641**	**-0.067*** **
Improved Seeds	0.751***	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	**0.262*** **
Pesticides Applied	0.552***	-0.142	-0.209	0.045	0.342***	0.445*	0.124	0.293	0.071	-0.065	0.178*	0.086	**0.116*** **
Organic Fertilizer Applied[e]	0.153***	0.056*	0.049	0.099***	0.095***	0.118	0.183***	0.251***	0.119***	0.145***	0.109***	0.139***	**0.103*** **
No Anti-Erosion Practices	-0.302*	0.017	0.148	-0.011	-0.149	-0.151	-0.047	-0.354**	-0.140*	-0.099	-0.196**	0.218	**-0.065*** **

All crops, including niche, for both seasons

Crop Comparisons

Plot Area

- Plot area correlates significantly with lower yields across crops
  - Significant and negative in 11/12 crops in both Seasons A and B
- Plot area has the largest effect on yield for cassava; a 1% increase in plot size leads to
  - in Season A, a 0.32% decrease in cassava yields, on average
  - in Season B, a 0.28% decrease in cassava yields, on average
- Plot area has the smallest effect on yield for maize; a 1% increase in plot size leads to
  - in Season A, a 0.1% decrease in maize yields, on average
  - in Season B, a 0.16% decrease in maize yields, on average

Across All Crops: -18.7%

Crop Comparisons

Mixed Crop System

- Farmers who utilize mixed cropping systems, compared to pure cropping systems, have mixed results depending on the crop, and significance depends on the season
- Cooking banana has most consistently significant and negative results from employing mixed cropping systems
  - In Season A, farmers who use mixed cropping systems, on average, have 42.7% lower cooking banana yields than those who use pure cropping
  - In Season B, 22.2% lower cooking banana yields on average

Across All Crops: -6.7%

Positive	Negative
Bush Bean - B	Cassava - A
Irish Potato - A	Irish Potato - B
Pea - A	Sweet Potato - A
Soybean - A	Beer Banana - B
	Cooking Banana - A&B
	Dessert Banana - B

A/B indicates season when result is significant

Crop Comparisons

Improved Seeds

- Improved seeds are used across few crops, but for those crops, they have significant positive impacts on yields compared to traditional seeds
- Farmers who use improved seeds for maize have 14.4% and 75.1% higher average yields than those who use traditional seeds in Seasons A and B, respectively

	Season A	Season B
Maize	0.144***	0.751***
Irish Potato	0.419***	n/a
Dessert Banana	0.634***	n/a

Crop Comparisons

Pesticides

- Generally, plots with pesticides applied have better yields on average than those that do not
- Irish potatoes with pesticides applied have consistently have higher yields across seasons than those without pesticides
  - In Season A, 17.6% higher on average
  - In Season B, 34.2% higher on average
- Pesticides are important for higher bush bean yields in Season A (+27.8%), but not Season B
- Similarly for maize, pesticides are important in Season B (+55.2%) but not Season A

Across All Crops: +11.6%

Crop Comparisons

Organic Fertilizer

- All 12 crops are positively correlated with organic fertilizer application, and 10/12 are significantly correlated in each season
- In general, organic fertilizer has a slightly larger impact on yields in Season B than in Season A
  - Maize, climbing bean, sorghum, soybean, sweet potato, beer banana
- For every 1% increase in organic fertilizer applied, soybean yields, on average:
  - Increase by 0.097% in Season A
  - Increase by 0.251% in Season B

Across All Crops: +0.103% for every 1% increase in fertilizer