

Appendix

Data cleaning

In the raw data, a small number of plots have suspiciously large values for plot size. To ensure that implausibly large plots are not driving the results, outliers in the size of single plots were removed based on the 1.5 interquartile range (IQR). Since all sample households are smallholder farmers, the risk of removing true values via this method appears low.

For income, a visual inspection of boxplots showed a considerable number of outliers in income when considering the 1.5 IQR as cut-off value. Cleaning was done at the lowest possible unit, for each individual income component, based on the 1.5 IQR. Outliers detected were winsorized, i.e., adjusted to the 0.01% and the 0.99% threshold. For instance, the crop income component was cleaned by detecting and winsorizing outliers in the amount harvested and the price per kg for each individual crop. All data cleaning differentiated between Dodoma and Morogoro region to account for differences across the two regions.

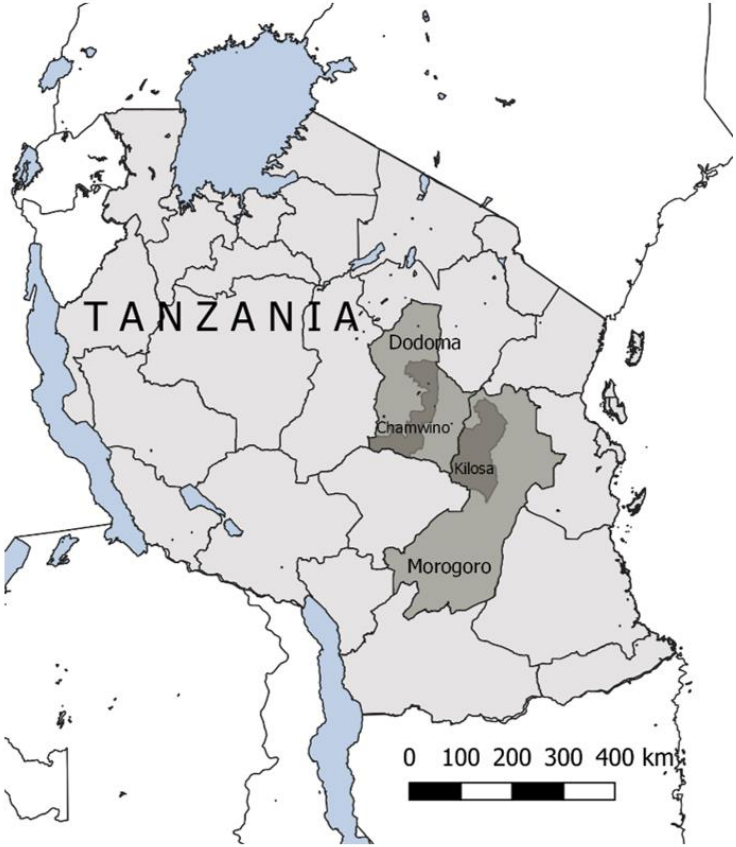


Fig. A1: Map showing the study area in Tanzania, with the dark areas indicating the study regions and districts (administrative boundaries as of 2020).

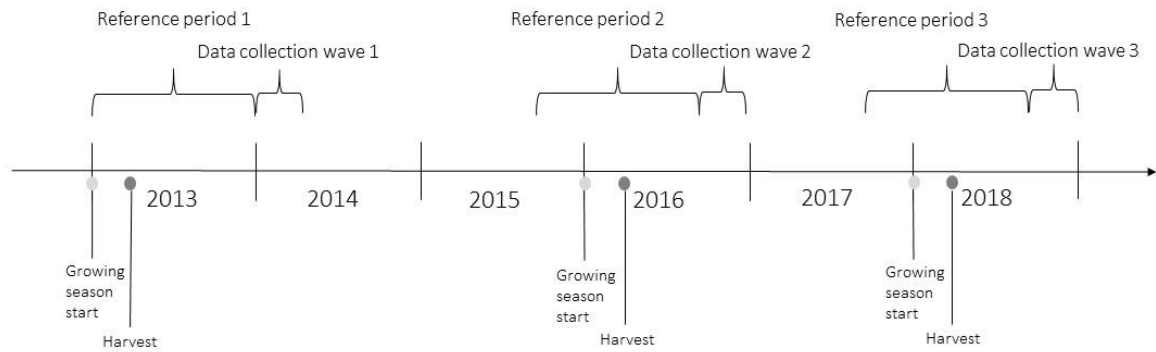


Fig. A2: Timeline showing data collection, reference periods for agricultural production, and start and end date of the main growing season.

Table A1: Unconditional t-tests on the equality of means between dropped households and households that remained in the panel.

	Household dropped from the panel		Household remained in the panel		p-value from t-test
	Mean	N	Mean	N	
Tenure security	0.34	104	0.35	737	0.78
Land conflict	0.11	104	0.10	737	0.77

Data source: Trans-SEC household panel survey (waves 1 and 3). Column 5 reports results from unconditional t-tests on the equality of means between households that dropped from the panel and those that remained, with * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A2: Determinants of remaining in the panel survey over time (Probit).

Dependent variable:	Household was surveyed in all three waves	
	(1)	(2)
Tenure security	-0.01 (0.01)	0.00 (0.01)
Land conflict	0.01 (0.03)	0.03 (0.03)
Household size		-0.01 *** (0.00)
Farm size		-0.01 (0.01)
Number of plots		-0.02 (0.03)
Owns livestock		-0.03 *** (0.01)
AIC	635.17	624.01
N	841	841

Note: Standard errors are clustered at the level of the precipitation data points with * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Displayed are average marginal effects. All control variables are constructed from wave 1 data. Data sources: Trans-SEC household panel survey (waves 1-3) and CHIRPS (precipitation).

Table A3: Added regressor test (Probit).

Dependent variable:	Land conflict		Tenure security	
	(1)	(2)	(3)	(4)
Household size	0.01 (0.00)	0.01 (0.00)	0.02 *** (0.00)	0.02 *** (0.00)
Farm size	0.02 *** (0.00)	0.01 *** (0.00)	0.01 * (0.01)	0.00 (0.01)
Number of plots	0.00 (0.01)	0.00 (0.01)	0.06 *** (0.01)	0.06 *** (0.01)
Owns livestock	-0.05 *** (0.01)		-0.11 *** (0.03)	
Attrition dummy (=1 if household dropped out of survey after wave 1)	-0.05 (0.05)	-0.02 (0.07)	0.08 (0.08)	0.06 (0.09)
Household size * attrition dummy	-0.01 (0.01)	-0.00 (0.01)	-0.02 (0.01)	-0.02 (0.01)
Farm size * attrition dummy	0.02 (0.02)	0.03 (0.03)	-0.01 (0.04)	0.00 (0.05)
Number of plots * attrition dummy	0.00 (0.02)	0.00 (0.02)	0.04 (0.03)	0.04 (0.03)
Owns livestock * attrition dummy	0.14 ** (0.07)		-0.10 * (0.06)	
Number of livestock		0.00 *** (0.00)		0.00 (0.00)
Number of livestock * attrition dummy		0.00 (0.00)		-0.01 *** (0.00)
AIC	542.78	547.89	1064.41	1075.32
N	841	841	841	841

Note: Standard errors are clustered at the level of the precipitation data points with * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Displayed are average marginal effects. All control variables are constructed from wave 1 data. Data sources: Trans-SEC household panel survey (waves 1-3).

Table A4: Unconditional t-tests on the equality of means between matched and unmatched plots.

Statistic	Plot matched		Plot not matched		p-value from t-test
	Mean	N	Mean	N	
Plot size	0.53	3,397	0.71	2,499	0.00 ***
Land conflict	0.06	3,397	0.06	2,499	0.67
Land certificate	0.10	3,397	0.07	2,499	0.00 ***
Tenure security (very secure)	0.50	3,397	0.49	2,499	0.17

Data source: Trans-SEC household panel survey (waves 1 - 3). Column 5 reports results from unconditional t-tests on the equality of means between the plots that could be matched and those that could not be matched, with * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A5: Determinants of plots matching over time (Probit).

Dependent variable:	Plot was matched across all three waves	
	(1)	(2)
Tenure security	-0.00 (0.02)	-0.00 (0.03)
Land conflict	0.03 (0.02)	0.04 (0.02)
Land certificate	0.02 (0.01)	0.02 ** (0.01)
Household size		-0.00 (0.01)
Owns livestock		-0.02 *** (0.00)
Plot size		-0.07 *** (0.02)
AIC	1634.50	1619.21
N	1,853	1,853

Note: Standard errors are clustered at the level of the precipitation data points with * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Displayed are average marginal effects. All control variables are constructed from wave 1 data. Data sources: Trans-SEC household panel survey (waves 1-3) and CHIRPS (precipitation).

Table A6: Added regressor test for plot-level attrition (Probit).

Dependent variable:	Land conflict (1)	Tenure security (2)	Land certificate (3)
Attrition dummy (=1 if plot could not be matched across waves)	-0.01 (0.01)	0.12 *** (0.02)	0.02 (0.01)
Household size	-0.00 *** (0.00)	0.04 * (0.02)	-0.01 (0.00)
Plot size	-0.01 (0.02)	0.01 (0.06)	0.06 *** (0.02)
Owns livestock	0.02 (0.02)	-0.00 (0.04)	0.02 *** (0.01)
Household size * attrition dummy	0.01 *** (0.00)	-0.02 (0.02)	0.01 (0.01)
Plot size * attrition dummy	0.03 (0.03)	-0.03 (0.03)	-0.09 *** (0.03)
Owns livestock * attrition dummy	-0.04 (0.04)	-0.06 *** (0.02)	0.02 (0.02)
AIC	860.44	2575.18	1202.46
N	1,885	1,998	2,015

Note: Standard errors are clustered at the level of the precipitation data points with * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Displayed are average marginal effects. All control variables are constructed from wave 1 data. Data sources: Trans-SEC household panel survey (waves 1-3).

Table A7: Summary statistics for walking time from homestead to plots.

Variable name	Mean	Median	St. Dev.	Min	Max	N
Walking time (in minutes) (wave 1)	6.49	0.00	11.67	0	45	1,019
Walking time (in minutes) (wave 2)	5.30	0.00	11.06	0	45	1,058
Walking time (in minutes) (wave 3)	6.55	0.00	11.86	0	45	1,034

Data sources: Trans-SEC household panel survey (waves 1-3). Values outside the 1.5 IQR were considered outliers and removed. For households with more than one plot, the mean walking time is displayed.

Table A8: Summary statistics for alternative measures of tenure security.

Variable name	Mean	St. Dev.	Min	Max	N
Share of owned land that is perceived as ‘very tenure secure’ (wave 1)	0.31	0.45	0	1	762
Share of owned land that is perceived as ‘very tenure secure’ (wave 2)	0.44	0.47	0	1	760
Share of owned land that is perceived as ‘very tenure secure’ (wave 3)	0.61	0.43	0	1	777
Share of owned land that is perceived as ‘almost’ or ‘very tenure secure’ (wave 1)	0.54	0.48	0	1	762
Share of owned land that is perceived as ‘almost’ or ‘very tenure secure’ (wave 2)	0.62	0.46	0	1	760
Share of owned land that is perceived as ‘almost’ or ‘very tenure secure’ (wave 3)	0.87	0.30	0	1	777
Household owns at least one plot that it perceives as ‘almost’ or ‘very tenure secure’ (wave 1)	0.61	0.49	0	1	763
Household owns at least one plot that it perceives as ‘almost’ or ‘very tenure secure’ (wave 2)	0.72	0.45	0	1	760
Household owns at least one plot that it perceives as ‘almost’ or ‘very tenure secure’ (wave 3)	0.97	0.17	0	1	777

Data sources: Trans-SEC household panel survey (waves 1-3). The balanced sample comprises 778 households surveyed in all three waves. For some households, information is missing for some variables.

Table A9: Effects of weather on perceived tenure security with alternative outcome variable (OLS).

Dependent variable:	Share of land perceived as ‘very tenure secure’			
	(1)	(2)	(3)	(4)
Dry spell	-0.04 *** (0.01)	-0.03 *** (0.01)		
Dry spell (lag 1)		0.05 *** (0.01)		
Precipitation CV			-0.19 *** (0.02)	-0.19 *** (0.01)
Precipitation CV (lag 1)				0.03 (0.07)
Median temperature	-0.09 (0.17)	-0.07 (0.17)	0.03 (0.13)	0.05 (0.12)
Household controls	No	Yes	No	Yes
Household fixed effects	Yes	Yes	Yes	Yes
Enumerator fixed effects	Yes	Yes	Yes	Yes
Wave fixed effects	Yes	Yes	Yes	Yes
R ²	0.74	0.75	0.74	0.75
N	2,287	2,287	2,287	2,287

Note: Standard errors are clustered at the level of the precipitation data points with * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Data sources: Trans-SEC household panel survey (waves 1-3), CHIRPS (precipitation) and ERA5 (temperature).

Table A10: Effects of weather on perceived tenure security with alternative outcome variables (OLS).

Dependent variable:	Share of land perceived as ‘almost’ or ‘very tenure secure’				At least one plot perceived as ‘almost’ or ‘very tenure secure’			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dry spell	-0.03 ** (0.01)	-0.03 ** (0.02)			0.00 (0.02)	0.00 (0.02)		
Precipitation CV			-0.18 *** (0.05)	-0.18 *** (0.05)			-0.11 (0.07)	-0.11 (0.07)
Median temperature	-0.11 (0.13)	-0.10 (0.12)	-0.01 (0.08)	0.00 (0.08)	-0.08 (0.14)	-0.08 (0.14)	-0.06 (0.09)	-0.05 (0.08)
Household controls	No	Yes	No	Yes	No	Yes	No	Yes
Household fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Enumerator fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wave fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R ²	0.71	0.71	0.71	0.71	0.74	0.74	0.74	0.74
N	2,287	2,287	2,287	2,287	2,288	2,288	2,288	2,288

Note: Standard errors are clustered at the level of the precipitation data points with * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Data sources: Trans-SEC household panel survey (waves 1-3), CHIRPS (precipitation) and ERA5 (temperature).

Table A11: Effects of weather on perceived tenure security with maximum temperature as control variable (OLS).

Dependent variable:	Perceived tenure security			
	(1)	(2)	(3)	(4)
Dry spell	-0.01 *** (0.00)	-0.01 *** (0.00)		
Precipitation CV			-0.13 (0.08)	-0.13 (0.08)
Maximum temperature	-0.23 *** (0.02)	-0.23 *** (0.02)	-0.18 *** (0.01)	-0.18 *** (0.02)
Household controls	No	Yes	No	Yes
Household fixed effects	Yes	Yes	Yes	Yes
Enumerator fixed effects	Yes	Yes	Yes	Yes
Wave fixed effects	Yes	Yes	Yes	Yes
R ²	0.79	0.79	0.79	0.79
N	2,288	2,288	2,288	2,288

Note: Standard errors are clustered at the level of the precipitation data points with * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Data sources: Trans-SEC household panel survey (waves 1-3), CHIRPS (precipitation) and ERA5 (temperature).

Table A12: Effects of weather on land conflict with maximum temperature as control variable (OLS).

Dependent variable:	Any land conflict				Conflicts with pastoralists		Other land conflicts	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dry spell	0.07 *** (0.01)	0.07 *** (0.01)			0.04 ** (0.02)		0.03 *** (0.01)	
Precipitation CV			0.19 *** (0.05)	0.19 *** (0.05)		0.14 *** (0.05)		0.05 *** (0.01)
Maximum temperature	-0.09 *** (0.03)	-0.09 *** (0.03)	-0.12 *** (0.04)	-0.13 *** (0.04)	-0.09 ** (0.04)	-0.12 ** (0.05)	-0.01 (0.02)	-0.00 (0.02)
Household controls	No	Yes	No	Yes	Yes	Yes	Yes	Yes
Household fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Enumerator fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wave fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R ²	0.52	0.52	0.52	0.52	0.55	0.55	0.46	0.45
N	2,266	2,266	2,266	2,266	2,266	2,266	2,266	2,266

Note: Standard errors are clustered at the level of the precipitation data points with * p < 0.10, ** p < 0.05, *** p < 0.01. Data sources: Trans-SEC household panel survey (waves 1-3), CHIRPS (precipitation) and ERA5 (temperature).

Table A13: Effects of weather on the acquisition of land certificates with maximum temperature as control variable (OLS).

Dependent variable:	New land certificate			
	(1)	(2)	(3)	(4)
Dry spell (lag 1)	0.03 (0.02)	0.03 * (0.02)		
Dry spell		-0.02 * (0.01)		
Precipitation CV (lag 1)			-0.14 *** (0.03)	-0.16 *** (0.05)
Precipitation CV				-0.14 (0.09)
Maximum temperature	-0.07 (0.11)	0.03 (0.13)	-0.30 *** (0.07)	-0.15 ** (0.06)
Household controls	No	Yes	No	Yes
Household fixed effects	Yes	Yes	Yes	Yes
Enumerator fixed effects	Yes	Yes	Yes	Yes
Wave fixed effects	Yes	Yes	Yes	Yes
R ²	0.66	0.68	0.67	0.68
N	1,521	1,516	1,521	1,516

Note: Standard errors are clustered at the level of the precipitation data points with * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Data sources: Trans-SEC household panel survey (waves 1-3), CHIRPS (precipitation) and ERA5 (temperature).

Table A14: Main analyses repeated at plot-level (OLS).

Dependent variable:	Very tenure secure plot				Land conflict on the plot				New certificate on the plot	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Dry spell	-0.01 (0.01)	-0.02 *** (0.01)			0.05 *** (0.01)	0.04 *** (0.01)			0.00 (0.09)	
Dry spell (lag 1)									0.07 ** (0.03)	
Precipitation CV			-0.17 *** (0.04)	-0.17 *** (0.03)			0.11 ** (0.05)	0.14 ** (0.05)		-0.28 (0.22)
Precipitation CV (lag 1)										-0.21 (0.14)
Median temperature		-0.12 (0.11)		-0.04 (0.08)		-0.07 (0.04)		-0.17 ** (0.06)	0.46 (0.29)	0.34 (0.21)
Plot FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Household FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Enumerator FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wave FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R ²	0.71	0.71	0.72	0.72	0.49	0.49	0.49	0.49	0.44	0.44
N	3,424	3,424	3,424	3,424	3,383	3,383	3,383	3,383	2,293	2,293

Note: Standard errors are clustered at the level of the precipitation data points with * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Data sources: Trans-SEC household panel survey (waves 1-3), CHIRPS (precipitation) and ERA5 (temperature).