The Possibility of a Maize Green Revolution in the Highlands of Kenya: An Assessment of Emerging Farming Systems

（ケニア高地におけるトウモロコシの緑の革命の可能性 :新農業システムのアセスメント）

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Motivation

- Sub-Saharan Africa faces
  - High rate of population growth
  - Decline of per capita arable lands
  - Rise of global food prices
  - ➢ Improvement of agricultural productivity is imperative.

- As population pressure on land grows rapidly in Kenya, farmers started to intensify land use.
  - ➢ The emergence of a **new maize farming system**

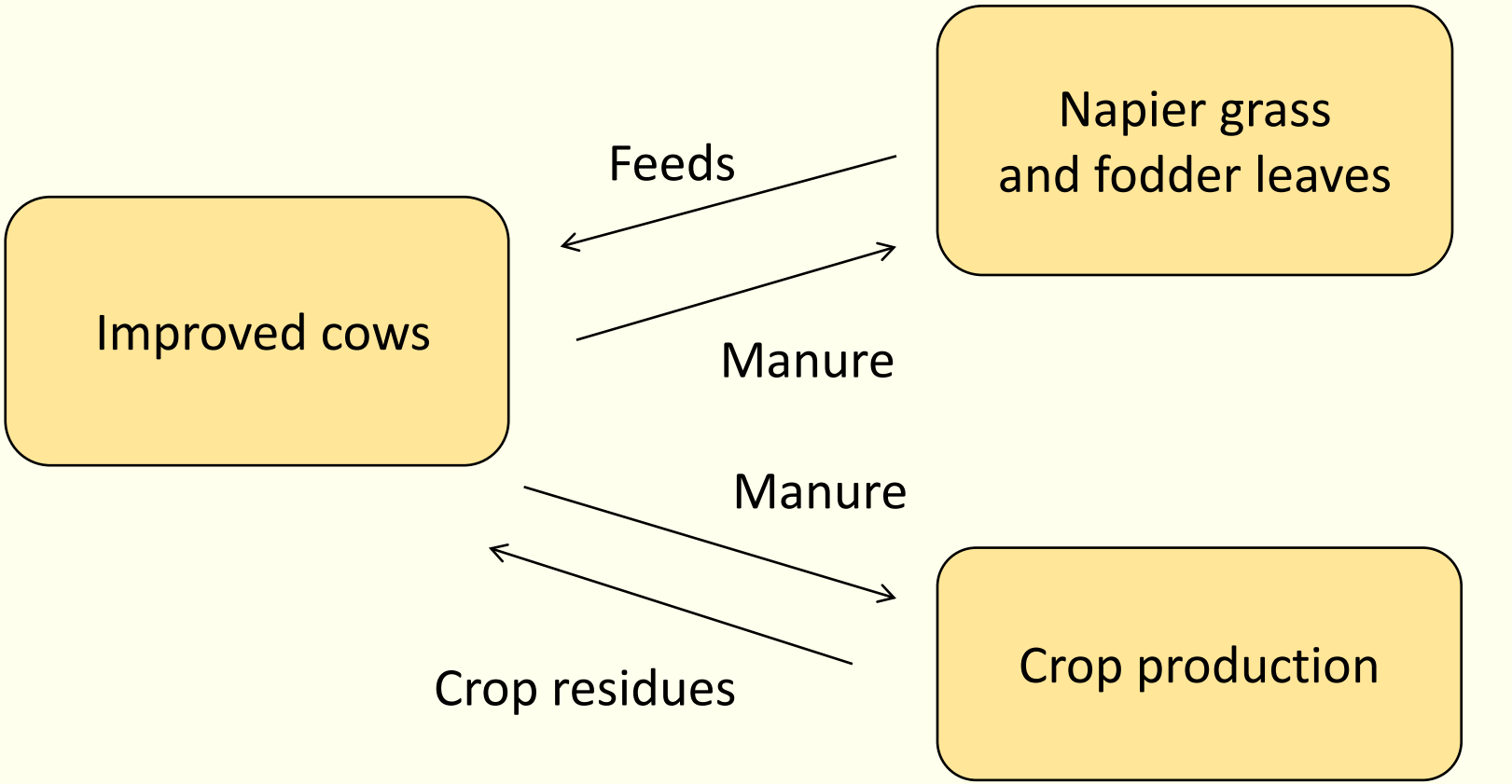
Agricultural revolutions

- Agricultural revolution in England in the 18th century
  - Crop rotation
  - Introduction of turnip
  - Stall-feeding of cattle
  - Application of manure

- Green revolution in Asia since 1960s
  - Application of chemical fertilizer
  - High-yielding modern rice variety
  - Development of irrigation

- Some farmers choose to adapt a new maize farming system in Highlands of Kenya
  - Adoption of hybrid maize variety
  - Application of organic fertilizer
  - Stall-fed improved dairy cows
  - Intercropping with maize and legumes

New maize farming system



Intercrop with legumes
Chemical fertilizers
Hybrid seeds

Effects of population pressure on input intensification

- Boserupian hypothesis (1965)
  - Rise in population density
  - ➢ Changes relative prices of land and labor
  - ➢ Increases input use per area
- Induced innovation hypothesis (Hayami & Rutan, 1970)
  - Population pressure
  - ➢ Decreases wage rate relative to land price
  - ➢ Increases the demand for labor and non-land input use
  - ➢ Could enhance productivity
- Confirmed by empirical studies (Josephson, Ricker-Gillbert, and Florax, 2014; Muyanga and Jayne, 2014; Ricker-Gillbert, Humbe, and Chamberlin, 2014).

Objectives

- To explore the determinants of the new maize farming system

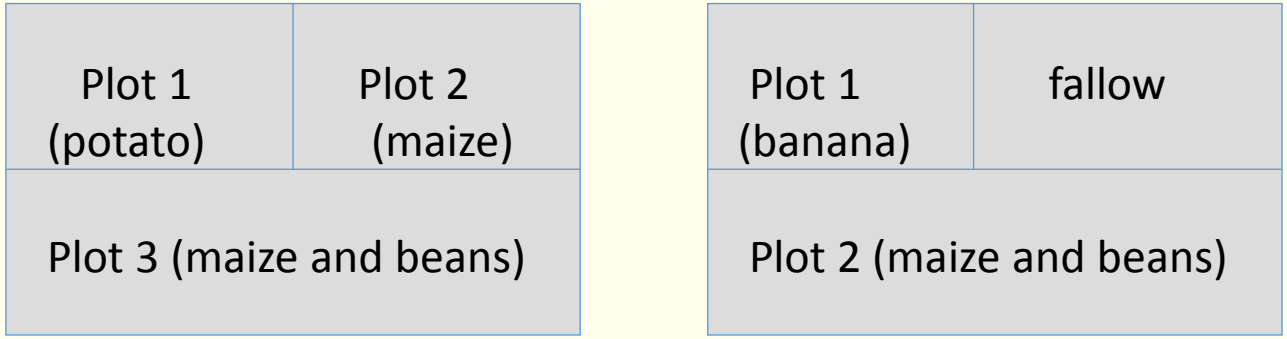
- To estimate the impact of the new maize farming system on productivity in two ways
  - By examining the impacts of individual inputs separately
  - By measuring the impacts of the entire new maize farming system by the agricultural intensification index.

Data

- Two rounds of panel household surveys were implemented jointly by GRIPS and Egerton University - Tegemeo Institute in 2004 and 2012.
- Limit samples to HH who grow maize on at least 20% of their farm land.
- Panel sample size: 622 households.
- Standard multi-purpose household surveys supplemented with detailed agricultural production data.

Data (cont.)

- Typical HH have land parcels each of which is subdivided into multiple land plots to grow multiple crops.
- Parcel ID is traceable over time, but plot ID is not.
- Example: Parcel 1 in main season in year t Parcel 1 in short season in year t



- Number of parcels & plots in the sample

	2004	2012
Number of parcels	958	880
Total number of plots	1,552	1,356
Total number of plots in main season	991	877
Total number of plots in short season	561	479

Sample household & sub-location characteristics

	2004		2012		Testing difference in means
	Mean	S.D.	Mean	S.D.	
Household characteristics					
Number of households	622		622		
Female-headed households (%)	22%	(41)	29%	(46)	***
Head completed primary education (%)	35%	(48)	41%	(49)	**
Age of the head (years)	55.89	(13.9)	61.01	(14.2)	***
Value of productive asset (KSh)	49,394	(184,421)	35,050	(155,685)	
Value of asset (KSh)	80,829	(201,970)	65,933	(169,348)	
Household size	6.6	(2.9)	7.1	(3.2)	***
Household members between 15 & 64	3.6	(2.0)	4.4	(2.4)	***
Number of dependents	2.8	(1.9)	2.6	(1.7)	**
Owned land size (ha)	1.7	(2.4)	1.5	(1.8)	**
Owned land size per household members between 15 & 64 (ha)	0.6	(0.9)	0.4	(0.7)	***
Sub-location characteristics					
Number of sub-locations	96		96		
Sub-location population density (persons/km^2)	744	(1,123)	1,101	(1,616)	***
Time to the nearest big town (min by car)	98	(48)	79	(37)	***

Crop production of the maize plots in the main cropping season

	2004		2012		Testing difference in means
	Mean	S.D.	Mean	S.D.	
Number of plots	1,552		1,356		
Maize plot size (ha)	0.38	(0.42)	0.34	(0.31)	***
Hybrid maize seeds (%)	49%	(50)	72%	(45)	***
Intercrop with legumes (%)	78%	(42)	72%	(45)	***
Manure applied (%)	39%	(49)	48%	(50)	***
Chemical fertilizer applied (%)	70%	(46)	71%	(45)	
Intercropped legumes seeds (kg/ha)	20	(25)	25	(25)	***
Quantity of manure (kg/ha)	970	(2,554)	1385	(2,729)	***
Quantity of chemical fertilizer (kg/ha)	46	(62)	44	(50)	
Cost of other chemical inputs (KSh/ha)	88	(376)	176	(506)	***
Cost of hired labor (KSh/ha)	2,941	(5,625)	3,973	(5,684)	***
Quantity of maize yield (kg/ha)	1,363	(1,452)	1,909	(1,446)	***
Value of crop production (KSh/ha)	41,733	(43,285)	50,701	(43,652)	***
Net crop income (KSh/ha)	32,101	(39,441)	38,918	(39,589)	***

Milk production per household in a year

	2004		2012		Testing difference in means
	Mean	S.D.	Mean	S.D.	
Number of households	662		662		
Number of local cows	1.3	(4.8)	1.3	(4.5)	
Number of improved cows	1.9	(2.9)	1.8	(2.5)	
Number of total cows	3.2	(5.2)	3.1	(4.8)	
HH with improved cows (%)	0.57	(0.5)	0.56	(0.5)	
Quantity of milk produced per cow for HH owning only local cows (liter/cow)	154	(222)	182	(211)	
Quantity of milk produced per cow for HH owning only improved cows (liter/cow)	695	(619)	841	(665)	***
Quantity of milk produced per cow for HH owning local & improved cows (liter/cow)	336	(307)	396	(296)	
Quantity of milk produced per cow for all HH (liter/cow)	511	(570)	624	(627)	***
Value of milk produced (KSh/cow)	29,268	(35,912)	27,683	(35,729)	
Net milk income (KSh/cow)	20,922	(29,498)	22,127	(30,916)	

Maize production intensification index

- Principal component analysis is used to construct an index of maize production intensification.
- **Household level agricultural intensification index**

$$HI_{it} = \sum_{k=1}^{5} F_k \left[\frac{(x_{itk} - X_k)}{S_k} \right]$$

where

- HI_{it} : agricultural intensification index of household *i* in year *t*
- $k \in \{1,2,3,4,5\}$ corresponds to each of the factors constructing the agricultural intensification index;
  - A dummy for hybrid maize seed adoption
  - Quantity of intercropped legume seeds
  - Quantity of manure
  - Quantity of chemical fertilizer.
  - Number of improved cows per hectare
- F_k: factor score for the variable *k* which consists of the farming system
- x_{itk}: variable k
- X_k and S_k are the mean and standard deviation of the variable k

Maize production intensification index(cont.)

- **Plot level agricultural intensification index**

$$PI_{ipst} = \sum_{l=1}^{4} G_l \left[\frac{(z_{ipstl} - Z_l)}{T_l} \right]$$

where

- PI_{ipst} : agricultural intensification index of household *i* in plot *p* in season *s* in year *t*
- *l*∈{1,2,3,4} corresponds to each of the factors constructing the agricultural intensification index;
  - A dummy for hybrid maize seed adoption
  - Quantity of intercropped legume seeds
  - Quantity of manure
  - Quantity of chemical fertilizer.
- G_l: factor score for the variable *l* which consists of the farming system
- z_{ipstl}: variable *l*
- Z_l and T_l are the mean and standard deviation of the variable l

Maize production intensification index (PCA)

	Pooled years	2004	2012
Household level		**Factor loadings**	
Hybrid maize seeds (=1)	0.46	0.48	0.41
Quantity of intercropped legume seed (kg/ha)	0.09	0.03	0.10
Quantity of manure (kg/ha)	0.41	0.38	0.45
Quantity of chemical fertilizer (kg/ha)	0.59	0.60	0.59
Number of improved cows (numbers/ha)	0.51	0.51	0.52
Mean of index generated from pooled data	0.00	-0.126	0.124
SD of index	1.24	1.32	1.14
Plot level		**Factor loadings**	
Hybrid maize seeds (=1)	0.56	0.56	0.57
Quantity of intercropped legume seed (kg/ha)	0.43	0.38	0.45
Quantity of manure (kg/ha)	0.34	0.27	0.36
Quantity of chemical fertilizer (kg/ha)	0.62	0.69	0.59
Mean of index generated from pooled data	0.00	-0.181	0.204
SD of index	1.19	1.22	1.12

Crop production by quartile of the agriculture intensification index in the maize plots in 2012

	Quartile of agriculture intensification index			
	1st	*2nd*	*3rd*	*4th*
Hybrid maize seeds (%)	11%	85%	95%	96%
Intercrop with legumes (%)	50%	66%	79%	91%
Manure applied (%)	39%	44%	46%	60%
Chemical fertilizer applied (%)	32%	69%	87%	96%
Intercropped legumes seeds (kg/ha)	11	17	26	45
Quantity of manure (kg/ha)	528	762	1042	3134
Quantity of chemical fertilizer (kg/ha)	9	23	49	94
Cost of other chemical inputs (KSh/ha)	54	118	189	334
Cost of hired labor (KSh/ha)	2,083	3,458	4,709	5,213
Quantity of maize yield (kg/ha)	1,247	1,664	2,064	2,606
Value of harvest from all crops (KSh/ha)	27,503	40,384	52,122	79,475
Crop income from all crops (KSh/ha)	23,901	32,076	38,142	58,648
Maize plot size (ha)	0.32	0.38	0.37	0.28

Empirical models

A plot level regression model to estimate determinants of intensification adoption:

$$I_{iphvdst} = \alpha_0 + \alpha_1 Pop_{vdt} + \alpha_2 LL_{hvdt} + \alpha_3 PL_{iphvdst} + \alpha_4 Pr_{vdt} + \alpha_5 X_{hvdt} + \alpha_6 Dist_{vdt} + \alpha_7 Div_d + \alpha_8 D_t + \alpha_9 Div_d * D_t + SS_s + \beta_{phvd} + \varepsilon_{iphvdst}$$

- $I_{iphvdst}$: input variables of interest or agricultural intensification index for plot *i* in parcel *p* of HH *h* in sub-location *v* in in division *d* in season *s* in year *t*
- Pop_{vdt}: sub-location population density
- LL_{hvdt}: land-labor ratio

← Population pressure to the lands

- $PL_{iphvdst}$: plot land size
- Pr_{vdt}: a vector of sub-location level input prices
- X_{hvdt}: a vector of HH level control variables
- $Dist_{vdt}$: a time distance from the sub-location center to the nearest big town
- SS_s: a short season dummy
- Div_d: division dummies
- D_t: a year 2012 dummy
- β_{phvd}: parcel fixed effect

- Parcel fixed effect estimation is used to purge β_{phv}.

Determinants of input intensification (Parcel FE estimation, plot panel data)

	Manure (t/ha)	Chemical fertilizer (10kg/ha)	Hybrid maize seeds (=1)	Intercropping legume seeds (kg/ha)	Intensification index
Log of sub-location population density (ppl/km^2)	0.470	0.340	0.152*	5.227	0.328*
	(0.722)	(0.907)	(0.0782)	(4.364)	(0.194)
Log of owned land size per working adult (ha)	0.0688	-0.370**	-0.00952	-1.056	-0.0681*
	(0.118)	(0.177)	(0.0167)	(0.973)	(0.0387)
Log of cultivated plot size (ha)	-0.544***	-0.985***	0.0172	-4.513***	-0.231***
	(0.104)	(0.198)	(0.0159)	(0.923)	(0.0425)
Log of maize price (KSh/kg)	0.205	0.0141	0.0421*	-0.397	0.0570
	(0.209)	(0.290)	(0.0221)	(1.491)	(0.0605)
Log of DAP price (KSh/kg)	1.087*	-2.450**	-0.0203	1.971	-0.150
	(0.604)	(1.032)	(0.104)	(5.492)	(0.232)
Log of hybrid maize seed price (KSh/kg)	0.0197	0.550	-0.0834	-1.316	-0.0460
	(0.466)	(0.940)	(0.103)	(4.556)	(0.213)
Log of farm wage rate (KSh/day)	-0.0932	-1.785	-0.0497	2.083	-0.201
	(0.466)	(1.193)	(0.0853)	(5.167)	(0.216)
HH & sub-location covariates	YES	YES	YES	YES	YES
Constant	0.147	30.34**	0.487	-19.76	1.011
	(8.946)	(12.02)	(1.344)	(85.02)	(3.022)
Observations	2,879	2,884	2,908	2,883	2,831
R-squared	0.068	0.164	0.189	0.106	0.155
Number of parcels	1,118	1,119	1,122	1,120	1,113

Empirical models

A plot level regression model to estimate effect of intensification:

$$Q_{iphvdst} = \delta_0 + \delta_1 I_{iphvdst} + \delta_2 PL_{iphvdst} + \delta_3 X_{hvdt} + \delta_4 Dist_{vdt} + \delta_5 Div_d + \delta_6 D_t + \delta_7 Div_d * D_t + SS_s + \theta_{phvd} + \mu_{phvdt} + \varepsilon_{iphvdst}$$

- $Q_{iphvdst}$: outcome variables for plot *i* in parcel *p* of HH *h* in sub-location *v* in in division *d* in season *s* in year *t*
- $I_{iphvdst}$: a vector of input use or the intensification index
  - Hybrid maize seed adoption
  - Quantity of intercropping legume seeds
  - Quantity of manure
  - Quantity of chemical fertilizer

  or

  Intensification index
- θ_{ph}: parcel fixed effect
- μ_{pht}: parcel-year fixed effect

- Parcel fixed effects estimation is used to purge θ_{phvd} & parcel-year fixed effects estimation is used to purge μ_{phvdt}.

Effects of intensification on crop production (HH FE estimation, plot panel data)

	Log of maize yield (kg/ha)		Log of value of crop production (KSh/ha)		Log of net crop income (KSh/ha)	
Type of fixed effects model	Parcel	Parcel -year	Parcel	Parcel -year	Parcel	Parcel -year
Hybrid maize seeds (=1)	0.124**	0.0792	0.125**	0.0806	0.0835	0.156*
	(0.0526)	(0.0646)	(0.0582)	(0.0848)	(0.0672)	(0.0924)
Intercropping legume seeds (kg/ha)	0.000314	-0.00100	0.0039***	0.00290**	0.0041***	0.00429***
	(0.0009)	(0.00114)	(0.00100)	(0.00135)	(0.00112)	(0.00149)
Manure (t/ha)	0.0275***	0.0176*	0.0321***	0.0313***	0.0324***	0.0194
	(0.00843)	(0.00949)	(0.00903)	(0.0116)	(0.0107)	(0.0120)
Chemical fertilizer (10kg/ha)	0.0290***	0.0180***	0.0215***	0.0103	0.00533	-0.00974
	(0.00522)	(0.00631)	(0.00614)	(0.00915)	(0.00633)	(0.00868)
Log of cultivated plot size (ha)	-0.457***	-0.530***	-0.387***	-0.450***	-0.333***	-0.435***
	(0.0406)	(0.0447)	(0.0470)	(0.0555)	(0.0434)	(0.0646)
HH & sub-location covariates	YES	NO	YES	NO	YES	NO
Constant	8.721***	6.266***	12.89***	9.680***	10.18***	9.405***
	(2.232)	(0.0777)	(2.129)	(0.0973)	(2.506)	(0.113)
Observations	2,810	2,810	2,810	2,810	2,809	2,809
R-squared	0.732	0.737	0.522	0.532	0.810	0.782
Number of fixed-effects	1,110	1,803	1,113	1,805	1,113	1,805

Effects of intensification on crop production
(HH FE estimation, plot panel data)

	Log of maize yield (kg/ha)		Log of value of crop production (KSh/ha)		Log of net crop income (KSh/ha)	
Type of fixed effects model	Parcel	Parcel -year	Parcel	Parcel -year	Parcel	Parcel -year
Intensification index	0.155***	0.0817***	0.185***	0.126***	0.129***	0.0864**
	(0.0214)	(0.0261)	(0.0248)	(0.0360)	(0.0263)	(0.0366)
Log of cultivated plot size (ha)	-0.463***	-0.534***	-0.397***	-0.457***	-0.342***	-0.430***
	(0.0399)	(0.0441)	(0.0459)	(0.0546)	(0.0426)	(0.0638)
Log of household size	0.137	-	0.115		0.0748	
	(0.0960)		(0.0900)		(0.0826)	
Female-headed (=1)	-0.103		-0.0892		-0.0521	
	(0.113)		(0.109)		(0.102)	
Age of head	0.00138		0.00148		-0.000736	
	(0.00411)		(0.00405)		(0.00370)	
Head completed primary education (=1)	0.102		0.0202		0.180*	
	(0.102)		(0.0868)		(0.102)	
Log of value of productive assets (KSh)	0.0104		-0.0384		-0.00188	
	(0.0245)		(0.0249)		(0.0269)	
Log of carbon	0.0574		-0.0771		0.245	
	(0.171)		(0.153)		(0.200)	
Log of time to big town (min by car)	-0.747		-0.704		-0.219	
	(0.504)		(0.470)		(0.543)	
Constant	9.192***	6.386***	13.23***	9.864***	10.20***	9.580***
	(2.268)	(0.0605)	(2.138)	(0.0755)	(2.476)	(0.0897)
Observations	2,810	2,810	2,810	2,810	2,809	2,809
R-squared	0.730	0.736	0.521	0.530	0.810	0.780
Number of fixed effects	1,110	1,803	1,113	1,805	1,113	1,805

Effects of intensification on net crop income & profit

(Parcel FE models, the largest pure-stand maize plot or intercropped maize plot in main season)

	Log of net crop income (KSh/ha)	Log of crop profit (KSh/ha)
Intensification index	0.0789*	0.101*
	(0.0468)	(0.0539)
Log of cultivated plot size (ha)	-0.441***	-0.433***
	(0.0922)	(0.0988)
Log of household size	0.170	0.107
	(0.107)	(0.115)
Female-headed (=1)	-0.0492	-0.0726
	(0.158)	(0.176)
Age of head	-0.00187	-0.00613
	(0.0256)	(0.0275)
Squared age of head	-0.0000145	0.0000156
	(0.000216)	(0.000230)
Head completed primary education (=1)	0.223	0.347*
	(0.155)	(0.179)
Log of value of productive assets (KSh)	-0.0224	-0.00587
	(0.0386)	(0.0389)
Log of carbon	0.0583	0.00378
	(0.193)	(0.209)
Log of time to big town (min by car)	-0.415	-0.461
	(0.446)	(0.501)
Constant	11.50***	11.75***
	(2.112)	(2.337)
Observations	829	829
R-squared	0.742	0.884
Number of fixed effects	425	425

Empirical models

A household level model to estimate effect of intensification:

$$Y_{hvdt} = \pi_0 + \pi_1 HI_{hvdt} + \pi_2 L_{hvdt} + \pi_3 X_{hvdt} + \pi_4 Dist_{vdt} + \pi_5 Div_d + \pi_6 D_t + \pi_6 Div_d * D_t + \rho_{hvd} + \varepsilon_{hvdt}$$

- Y_{hvdt}: outcome variables for plot *i* in parcel *p* of HH *h* in season *s* in time *t*
  - Value of harvest of all crops & milk (KSh/ha)
  - Income from all crops & milk (KSh/ha)
  - Non-farm income (KSh/ha)
  - HH total income (KSh/ha)
- HI_{hvdt}: household level agricultural intensification index
- L_{hvdt}: household own land size (ha)
- ρ_{hvd}: household fixed effect

- Household fixed effects estimation is used to purge ρ_{hvd}.

Effects of the intensification index on ag. production
(HH FE estimation, HH panel data)

	Log of value of crop & milk production (KSh/ha)	Log of net crop & milk income (KSh/ha)
Intensification index	0.293***	0.277***
	(0.0302)	(0.0382)
Log of owned land size (ha)	-0.0354	-0.0146
	(0.0446)	(0.0655)
Log of household size	0.0274	-0.0430
	(0.0791)	(0.105)
Female-headed (=1)	-0.0284	-0.161
	(0.0986)	(0.107)
Head's age	-0.00477*	-0.00897***
	(0.00282)	(0.00344)
Head completed primary education (=1)	-0.00583	-0.0262
	(0.0701)	(0.0919)
Log of value of productive assets (KSh)	0.00929	-0.0125
	(0.0218)	(0.0289)
Log of carbon	-0.104	-0.189
	(0.158)	(0.225)
Log of time to big town (min by car)	-0.337	-0.541
	(0.451)	(0.552)
Constant	12.65***	13.89***
	(2.038)	(2.447)
Observations	1,195	1,195
R-squared	0.389	0.524
Number of households	619	619

Effects of the intensification index on HH income
(HH FE estimation, HH panel data)

	Log of net non-farm income per capita (KSh)	Log of net total income per capita (KSh)
Intensification index	0.0787	0.168***
	(0.0820)	(0.0386)
Log of owned land size (ha)	0.231*	0.172***
	(0.118)	(0.0447)
Log of household size	-0.295	-0.545***
	(0.199)	(0.0889)
Female-headed (=1)	-0.496*	-0.305***
	(0.266)	(0.117)
Head's age	-0.0128	-0.00703*
	(0.00873)	(0.00374)
Head completed primary education (=1)	-0.251	-0.117
	(0.223)	(0.0921)
Log of value of productive assets (KSh)	0.0931*	0.0631**
	(0.0538)	(0.0250)
Log of carbon	-0.181	-0.176
	(0.402)	(0.218)
Log of time to big town (min by car)	1.003	-0.490
	(1.132)	(0.640)
Constant	5.095	13.25***
	(5.120)	(2.886)
Observations	1,192	1,192
R-squared	0.170	0.283
Number of households	618	618

Summary and conclusion

- Population pressure on land accelerates farming intensification.
- Adoption of hybrid maize seed, manure application, chemical fertilizer application, and intercropping with legumes have positive and significant effects on land productivity.
- These findings are supported by the significant positive impacts of the agriculture intensification index on land productivity and household income.
- The new maize farming system seems to make it possible for small farmers to improve agricultural production in Kenya.
- Effort for exploring the “optimum” farming systems is encouraged.

Thanks for your attention.