ETH zürich

Agricultural Intensification: Balancing production, environment and livelihoods

Public Lecture

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The Earth Institute at Columbia University

World Food System Center

Image by Benjamin Drummond / Sarah Joy Steele for Vital Signs

Presentation #1
Pedro Sanchez

Tropical Agricultural Intensification:
Balancing Production, Environments and Livelihoods

Public Lecture

Swiss Federal Institute of Technology ETH Zurich

10 March 2014

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Agriculture and Food Security Center

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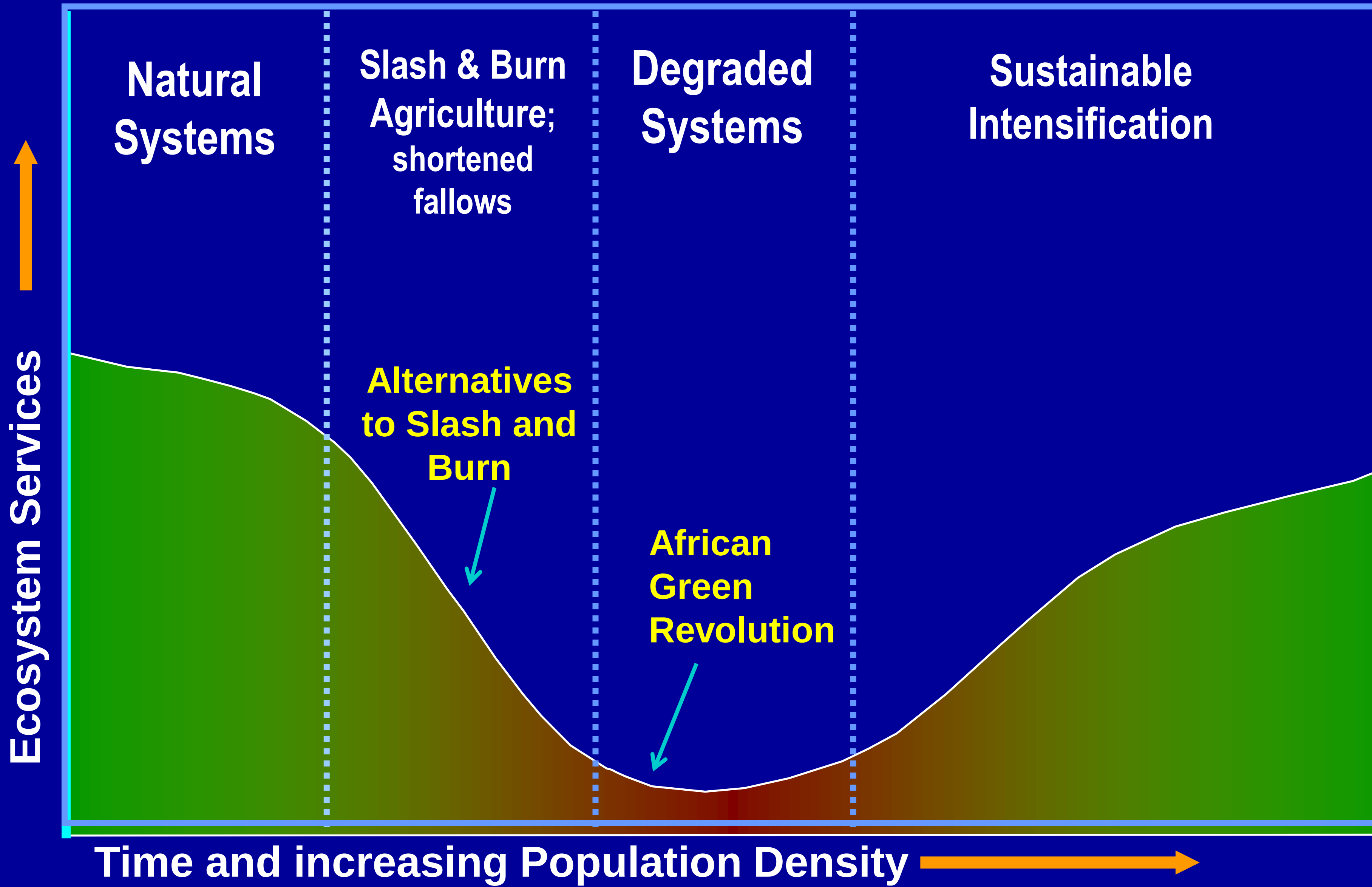


Natural Systems
Slash & Burn Agriculture; shortened fallows
Degraded Systems
Sustainable Intensification
Alternatives to Slash and Burn
African Green Revolution
Ecosystem Services
Time and increasing Population Density

Sustainable Agricultural Intensification

- A conceptual framework for achieving balanced outcomes among the intensification of agricultural production, environment and livelihoods.

- Does not promote a particular set of practices or philosophies.

- There can be alternative intensification pathways, which will vary depending on agro-ecological zone, farming system, cultural preferences, institutions and policies.

- Each intensification pathway will have different tradeoffs and/or synergies between production, environment and livelihoods.
- Make decisions that balance these tradeoffs according to thresholds or critical levels at a specific time frame.

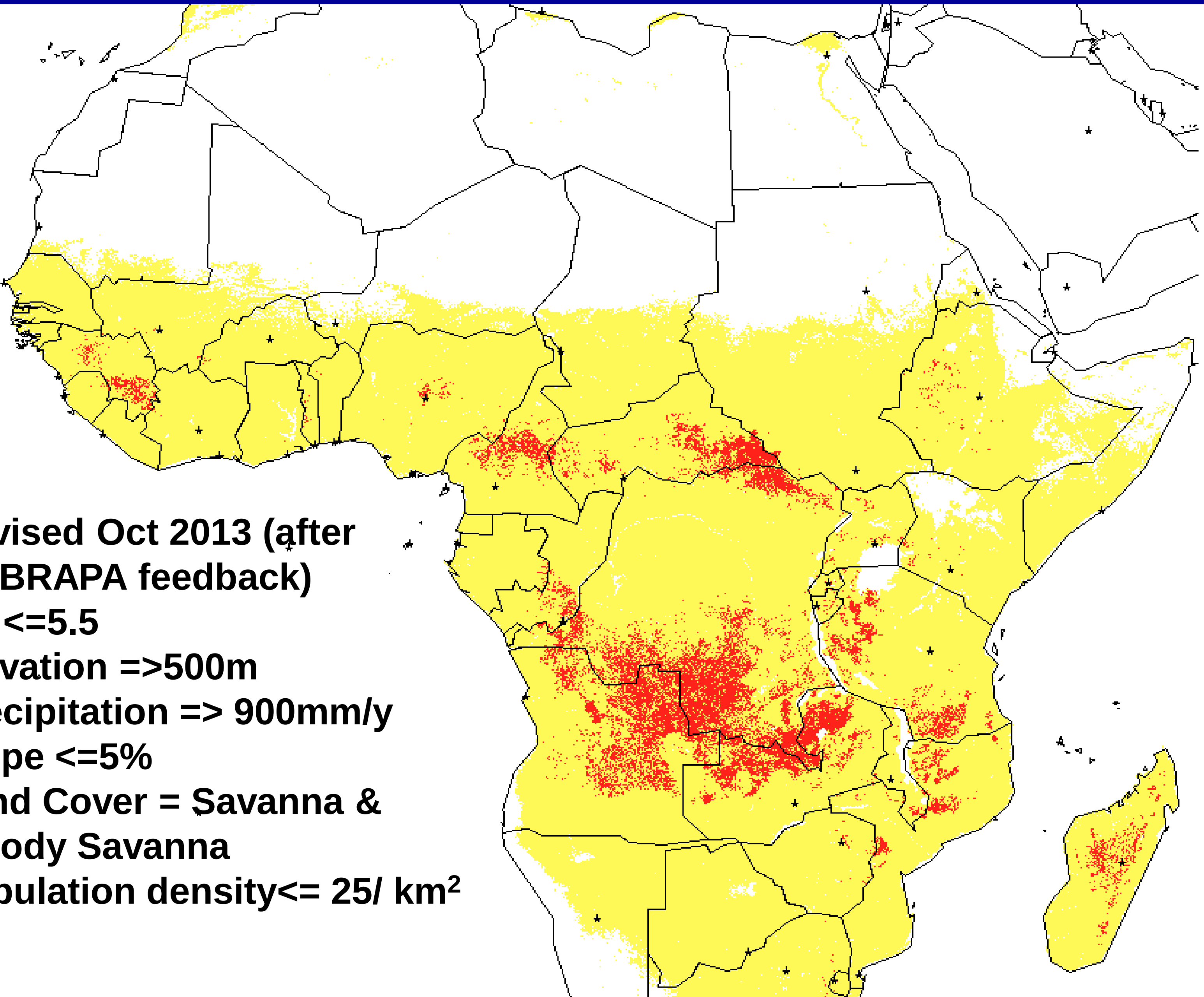
The 2050 Challenges

- Increase food production by 100 – 125% to meet the more complex diets of 9+ billion people.
- More meat and processed foods.
- 90% of additional food demand will be in Asia and Africa.
- High food prices (30%) is the new normal.
- Food demand growth is unavoidable.
- Soils, water, germplasm, policies and energy are the critical issues.

How to Meet the Challenge

- **Sustainable intensification,** in currently cultivated land will produce **the bulk of food** production increases.
- **Additional:**
  - Pre- and post- harvest **food waste could be** reduced from 40 to 20%.
  - **Extensification:** Expand agriculture in landscapes that are less environmentally sensitive in the Far North, Tropical Africa, Tropical South America, Eastern Europe. Extent not quantified.
  - Sustainable development of new large **aquifers** like in Northern Kenya to expand irrigated agriculture.
  - There is **idle** land in most farms

African Cerrado?



Revised Oct 2013 (after EMBRAPA feedback)
pH <=5.5
Elevation =>500m
Precipitation => 900mm/y
Slope <=5%
Land Cover = Savanna & Woody Savanna
Population density<= 25/ km²

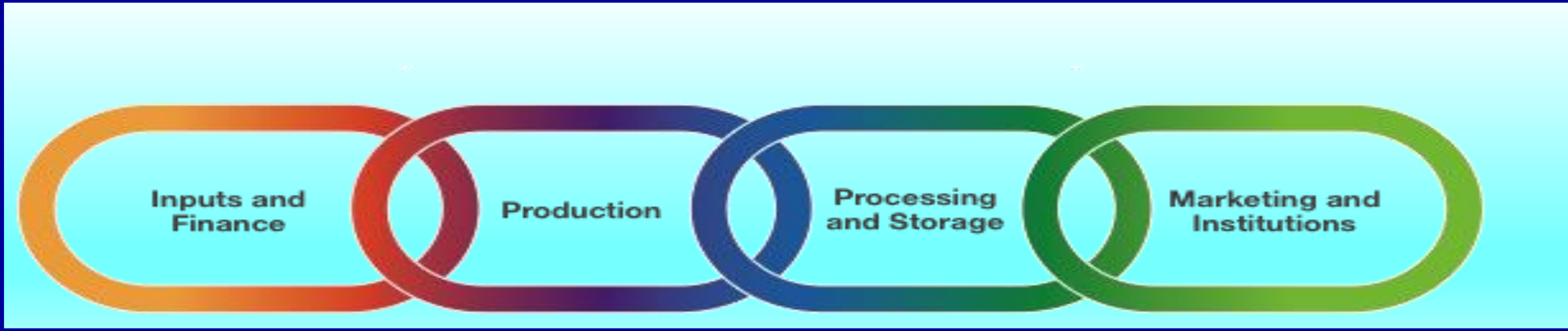
Cereal yields	Current (tons/ha)
SS Africa	1
Latin America	3
South & Southeast Asia	3
China	5
N. America, Europe, Japan	10

Why 1 ton/ ha?

There is a Major Biophysical Reason and a Major Economic Reason

1. Soil fertility depletion is extreme in smallholder farms in Africa; the key entry point is not improved varieties or water but replenishing soil nutrients. Known this for decades*.

2. A broken or nonexistent value chain:



*See new study by Folberth et al, 2013. *Agricultural Systems* 119: 22-34.

Malawi—The First African Green Revolution September 2005

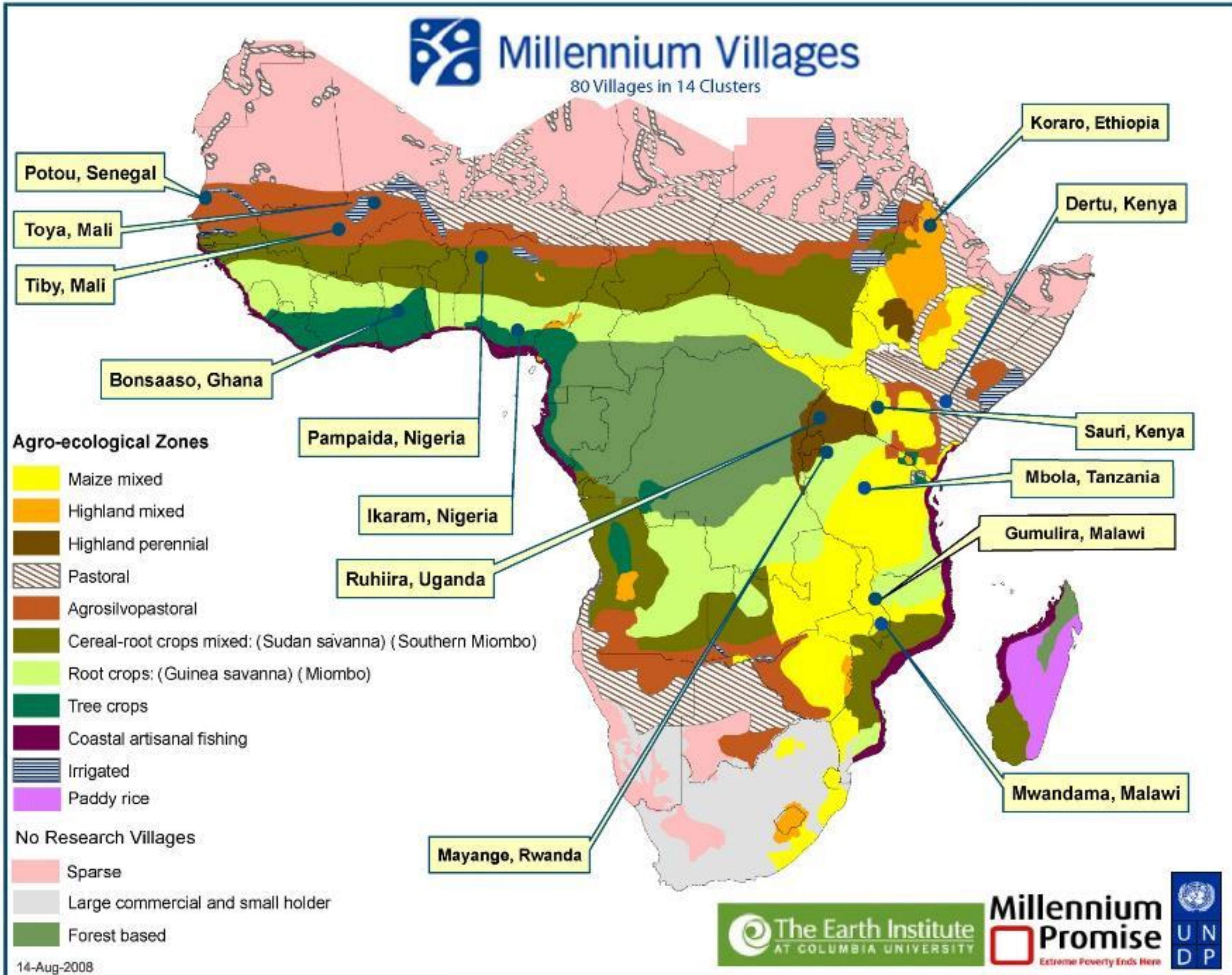
Smart subsidies

RESULTS: Malawi Input Subsidy Program 8 years.
1 bag of 23-20-4S and 1 bag of urea: 64 kg N/ha

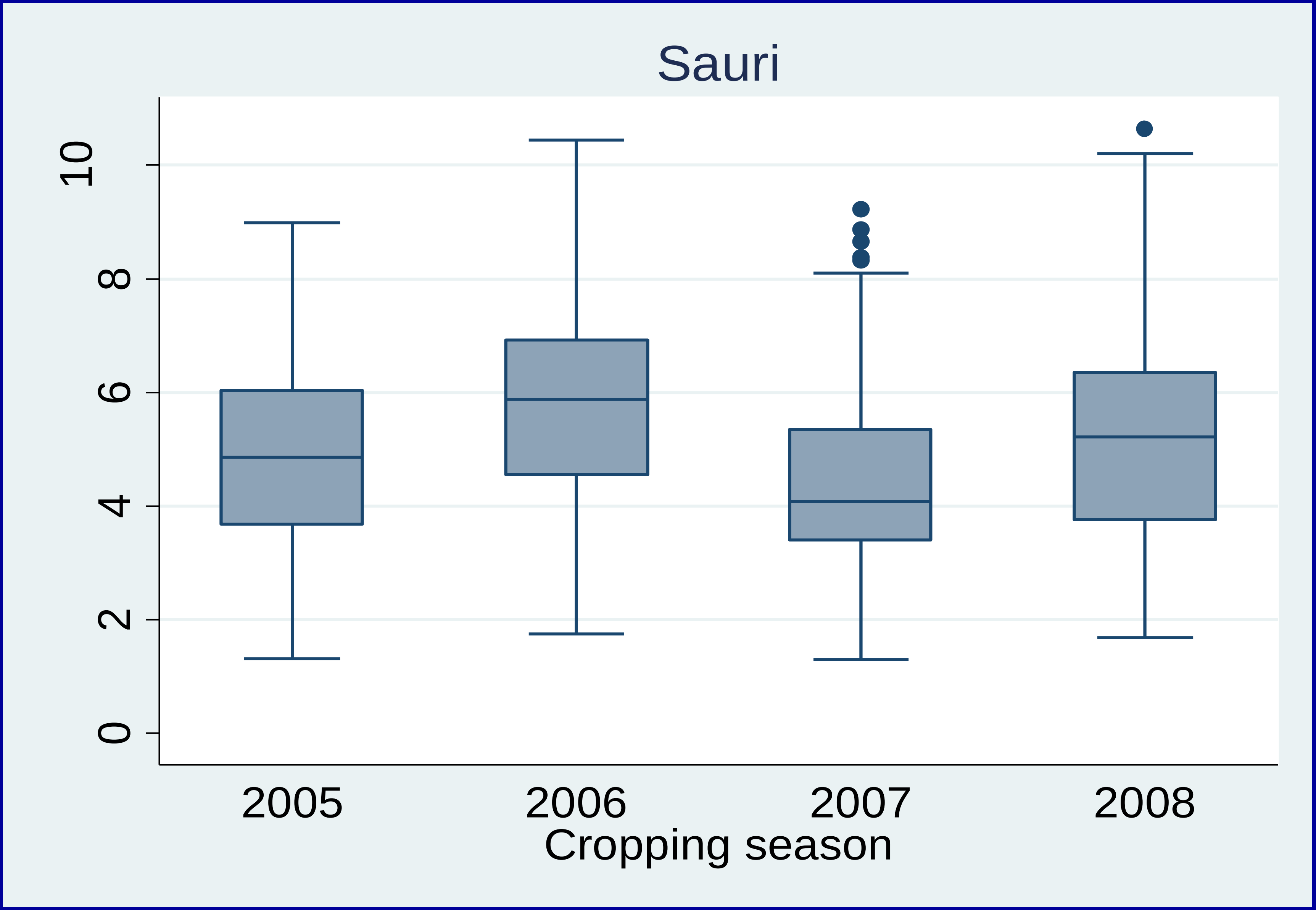
Harvest Year	Million tons	Food requirement	Yield (tons/ha)	Officially
2005	1.3	- 43%	0.8	drought
2006	2.4	+ 18%	1.5	good
2007	3.3	+ 57%	2.7	good
2008	2.8	+32%	1.6	good
2009	3.6	+58%	2.2	good
2010	2.9	+33%	1.9	drought
2011	3.3	+56%	2.2	drought
2012	2.9	+32%	1.7	good
2013	3.0	+32%	2.1	good
Mean 2006-13	3.2	+40%	2.0 (Δ2.5x)	Sustainable?

Newspaper Reports

- Subsidy program was cut back drastically because of donor shortfall and corruption.
- 2014 crop is still in the ground. Harvest will be in April.
- Malawi is requesting food aid for the first time since 2006.


Millennium Villages
80 Villages in 14 Clusters
Koraro, Ethiopia
Potou, Senegal
Dertu, Kenya
Toya, Mali
Tiby, Mali
Bonsaaso, Ghana
Pampaida, Nigeria
Sauri, Kenya
Mbola, Tanzania
Ikaram, Nigeria
Gumulira, Malawi
Ruhiira, Uganda
Mwandama, Malawi
Mayange, Rwanda
Agro-ecological Zones
Maize mixed
Highland mixed
Highland perennial
Pastoral
Agrosilvopastoral
Cereal-root crops mixed: (Sudan savanna) (Southern Miombo)
Root crops: (Guinea savanna) (Miombo)
Tree crops
Coastal artisanal fishing
Irrigated
Paddy rice
No Research Villages
Sparse
Large commercial and small holder
Forest based
14-Aug-2008
The Earth Institute
AT COLUMBIA UNIVERSITY
Millennium
Promise
Extreme Poverty Ends Here
UN
DP

High Yields, Variable

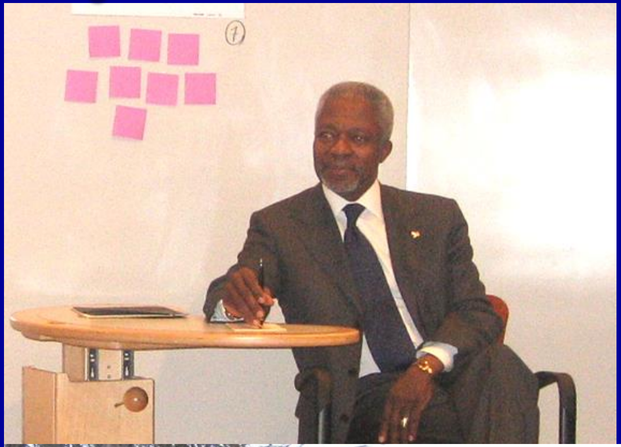


Nziguheba et al 2010. Advances in Agronomy

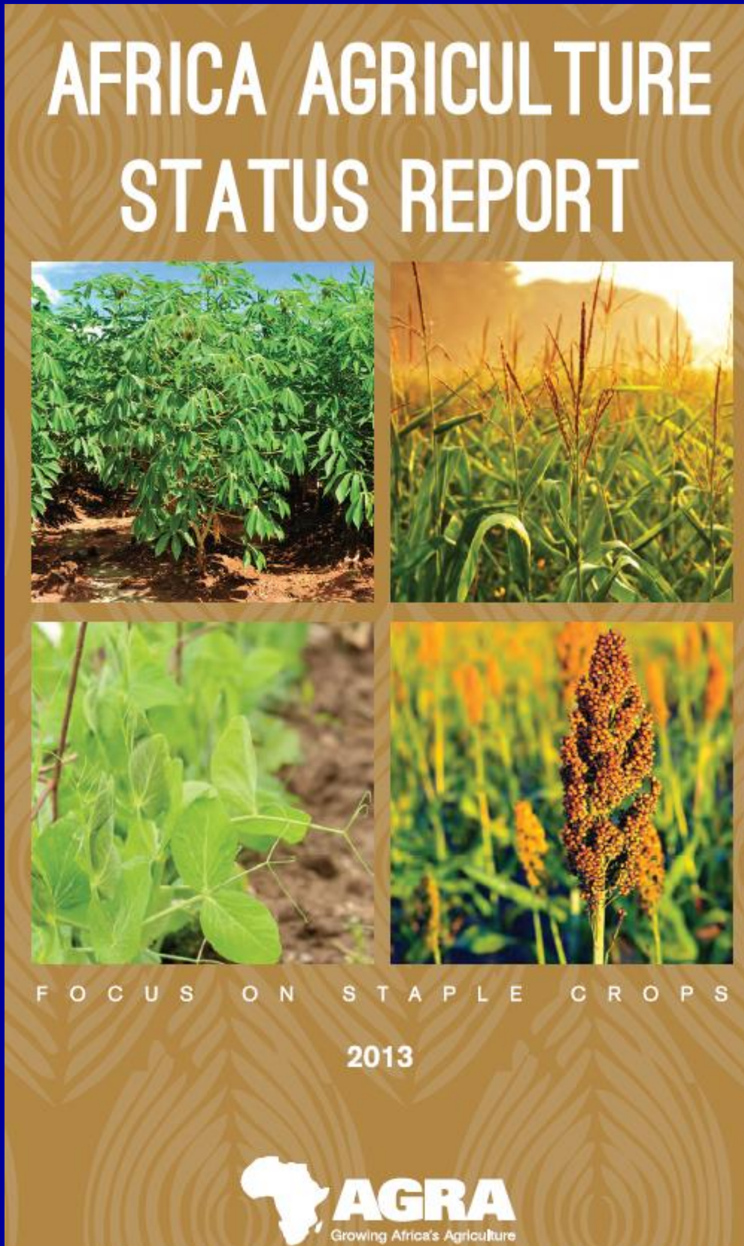
2006 Tipping Point 1: Political Will

- Ethiopia:14%
- Malawi: 18%
- Nigeria: $4b investment from private sector, $3b from Gates, World Bank, etc
- Ghana: 14%
- Tanzania > 10%; doubled maize and rice yields in Southern Corridor 2013
- Burkina Faso: 14%. Sorghum yields increased by 250% last decade.
- Kenya, Uganda: 5%

Tipping Point 2: Private Sector gets Involved. Davos, January 2006



Tipping Point 3:A Movement
AGRA –Yara Forum, Sept 2012



Maize Yields (tons/ha)	2005	Mean 3 yrs 2009-2011	% increase 2009-2011/ 2005
Malawi	0.81	2.21	173%
Rwanda	0.89	2.12	138%
Ethiopia	2.01	2.49	24%
Nigeria	1.66	1.85	12%
Kenya	1.64	1.53	-7%
AGRA 12	1.34	1.73	29%

Emerging Africa:A Hopeful Continent (The Economist March 2, 2013)

GDP growth (2002-12)	%/yr
Ethiopia	8.9
Mozambique	7.6
Nigeria	7.5
Ghana	7.2
Rwanda	7.2
Uganda	7.0
Tanzania	6.0
Malawi	5.7
Kenya	4.6
Zimbabwe	-2.8
Africa	6.0

- **Agricultural GDP: 0.7% (´00) → 4.0%(´12)**
- **FDI: $15B (´02) → 46B (´12)**
- **Mobile phones: 75% of people**
- **Households with TV: 30%**
- **Democracies: 3 (´90)→ 25 (´12)**
- **Since 2000:**
  - **High School enrollment up by 48% Deaths by malaria down by 30%**
  - **HIV infections down by 70%**
  - **Life expectancy up by 10 years**
  - **Real income per person up by >30%**

2013

- Unprecedented political will to increase yields and market access.
- Surge in agricultural investments in Africa.
- Africa has 200m people in the middle class.
- Its the market that does the scaling-up.
- No hunger call for the Sahel last year. WFP anticipated it, but it was avoided.
- PxP ,1000 days, Feed the Future, NEPAD, CAADEP etc. campaigns effective.
- No longer managing hunger and poverty----- forging ahead?
- Lets take advantage of it

Step 2: Going from 3 to 5 tons/ha

- Completing the value chain: a robust credit system, cereal banks, food diversification, small-scale water management, increase water use efficiency, crop insurance
- Using science for better decision making: Bringing information to the field.
- How to reduce risks and increase adoption.

Value Chain

Cereal Banks: doubling prices

Price ksh/90 kg bag:
At farm gate (August): 700
Cereal bank sold (April): 1450

Diversification of High-Value Products and Agro business Development

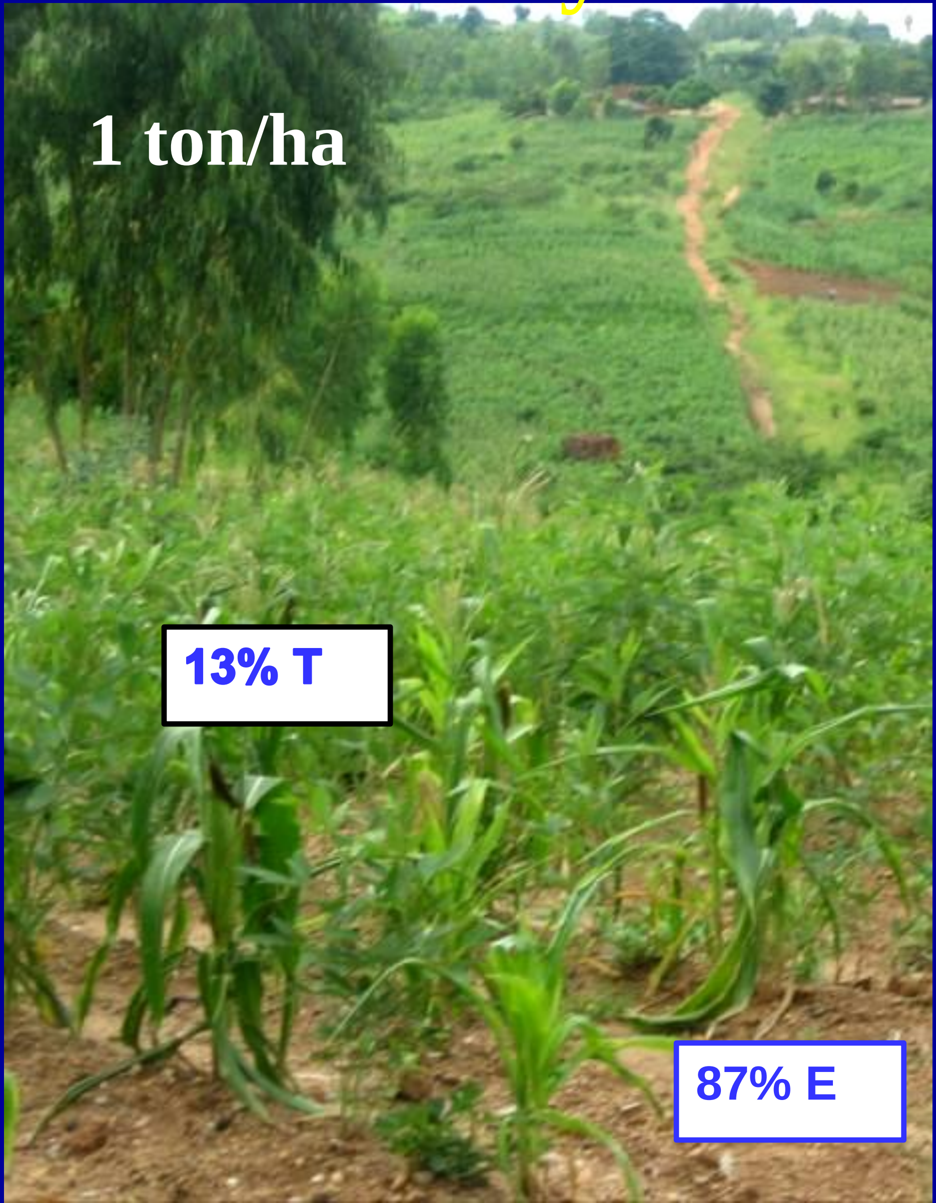
Subsoil: Best place to store rainfall

Capture it in percolation ponds

Pump it out from shallow wells

Koraro MV, Ethiopia

Increasing Yields in Africa Improve Water Use Efficiency



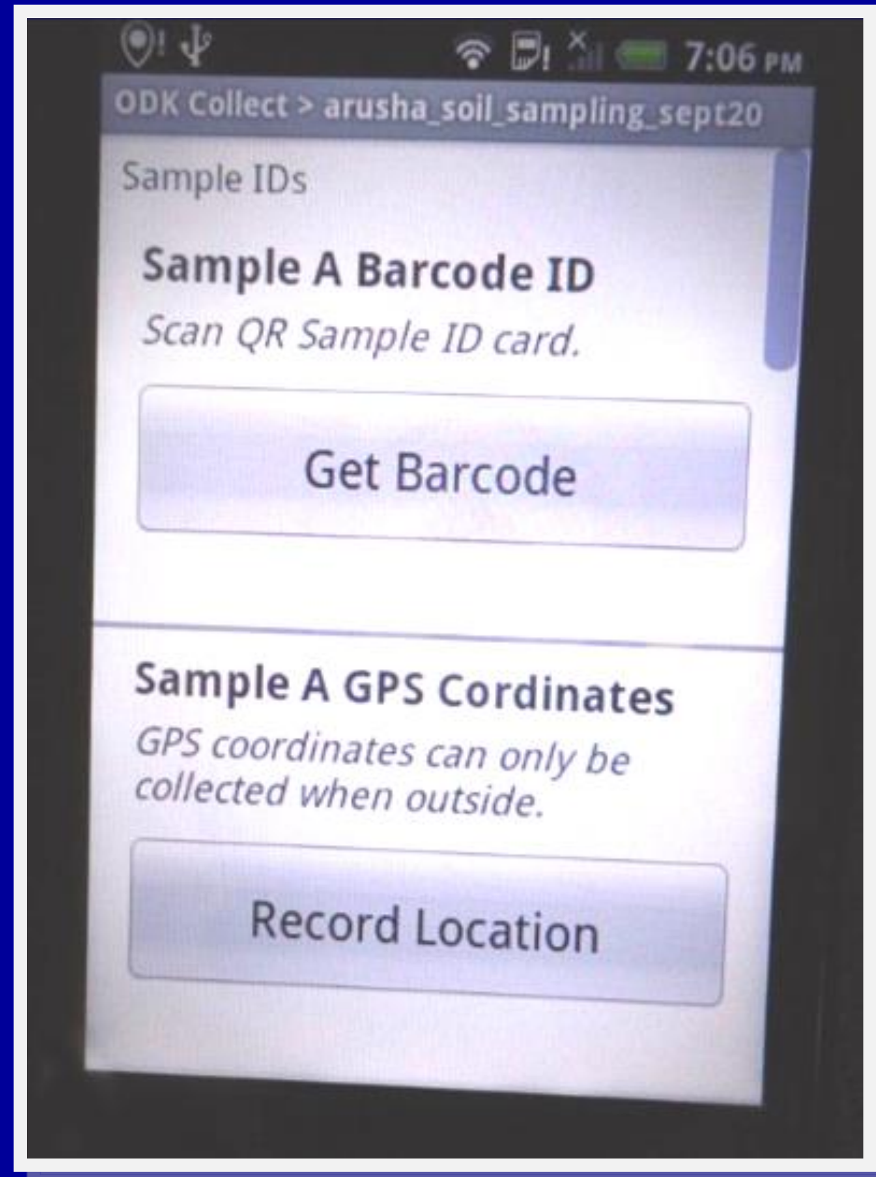
Bringing the Lab to the Field

SoilDoc: The Lab in a Box

Replacing the Shakers

Uploading Data with Android


SoilDoc
Sample B / NG-7PvKoD-2
Collected on
Sept. 17, 2012, 8 p.m.
Location
12.665, -7.969
Famer Name
Albakaye Ousmane Kounta
Famer ID
n/a
Sampling Reason
Planned extension
Soil Texture
Medium
Soil Moisture
Field Capacity
Soil Main Crop
Papaya watermelon


7:06 PM
ODK Collect > arusha_soil_sampling_sept20
Sample IDs
Sample A Barcode ID
Scan QR Sample ID card.
Get Barcode
Sample A GPS Cordinates
GPS coordinates can only be collected when outside.
Record Location

Field Level, Real Time Recommendations

pH Salt	5.91	OPTIMAL
Δ pH	0.78	
Soil Bulk Density mg/cm³	1.20	
Soil Moisture at Sampling	0.16	
Soil Nitrate mg/kg	87.92	MEDIUM/HIGH
Soil Potassium mg/kg	102.18	HIGH
Soil Phosphorus mg/kg	0	
Soil Sulfate mg/kg	3.10	VERY LOW

How About?

Adding intra-seasonal climate forecasting relevant to rainfed agriculture to Soil Doc tablet. Timing of planting rains? Dry spells during rainy season?

Training a new generation of African scientists and extension specialists

For Soil Scientists

- Rethink timing of N applications.
- Increase Agronomic Use Efficiency of N fertilizers for 15 to 30 kg maize grain/ kg N applied.
- Combine mineral and organic sources for higher efficiencies.
- Figure out how to tap the pool of about 50% of the P applied that stays in the soil in long-term residual experiments

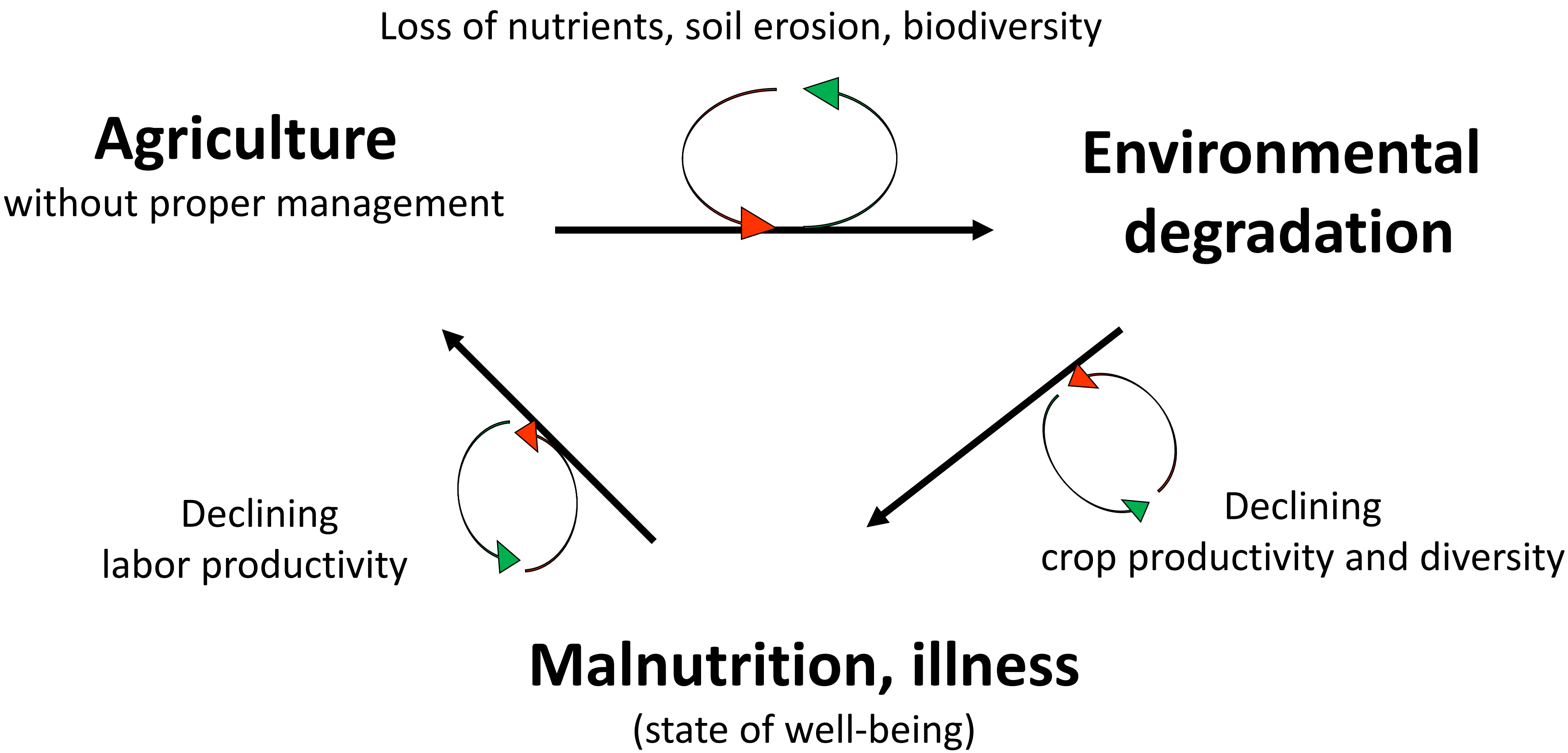
AE_N = kg maize grain/ kg N applied	
Blanket recommendation in Malawi: 14	
N fertilizer + hybrid maize: 26	
+Full INMR (with organic N): 32	
Global average:	37
US average:	57

Chinsanga (2008); Vanlauwe et al (2010); Cassman et al (2003)

Half of the fertilizer P stays in the topsoil. **Sanchez (in preparation)**	**P reten-tion**	**Yrs**	**% applied P remai-ning**
Alfisol, clayey, Rothamsted, UK	low	145	59
Sandy, calcareous, Ludhiana, India	low	25	58
Typic Paleudult, sandy, Yurimaguas, Peru	low	18	47
Typic Haplustox,clayey, Planaltina, Brazil	high	13	35
Oxic Paleustult, Sandy, Maravilhas, PE, Brazil	low	10	59
Typic Palehumult, clayey, Hawaii	high	7	47

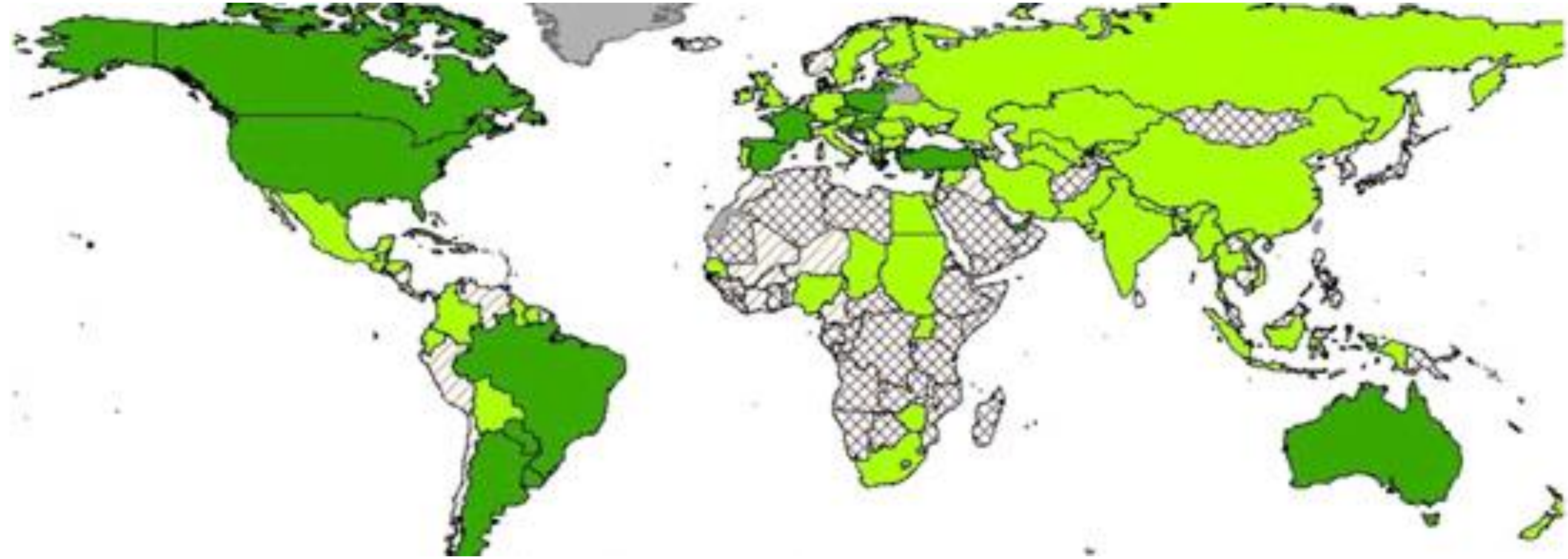
Presentation #2
Cheryl Palm

From Unhealthy Soils and Unhealthy People to Healthy Soils and Healthy People

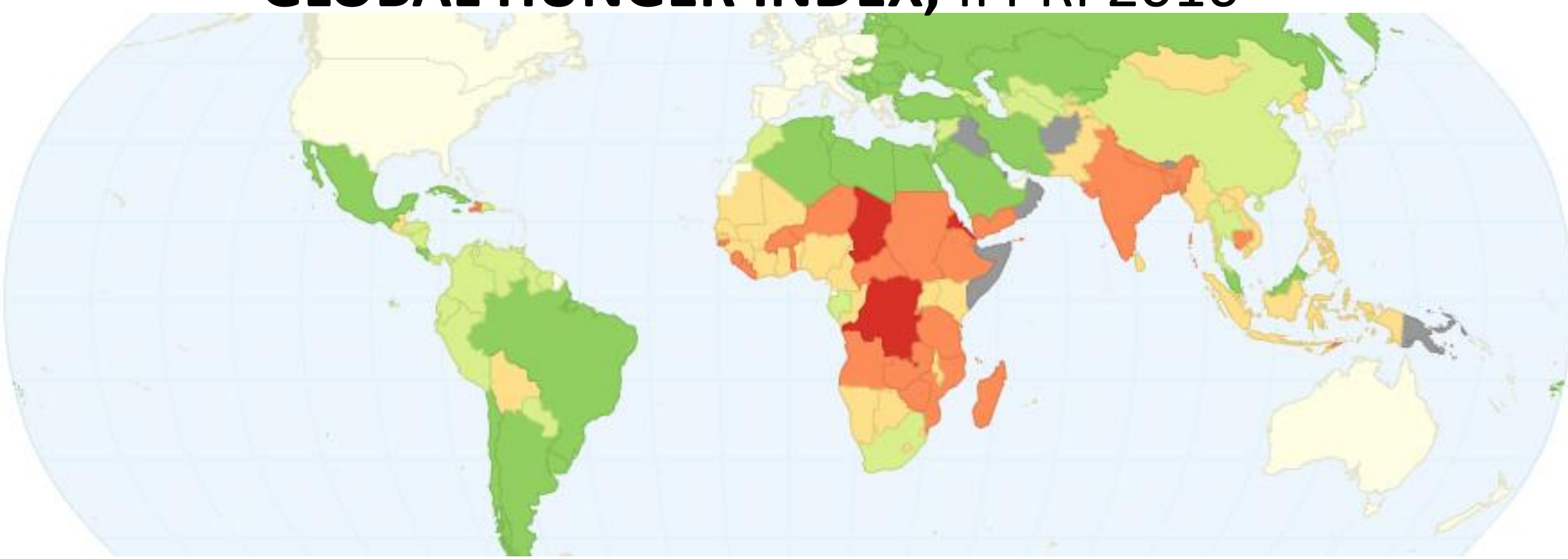


Deckelbaum et al., 2006

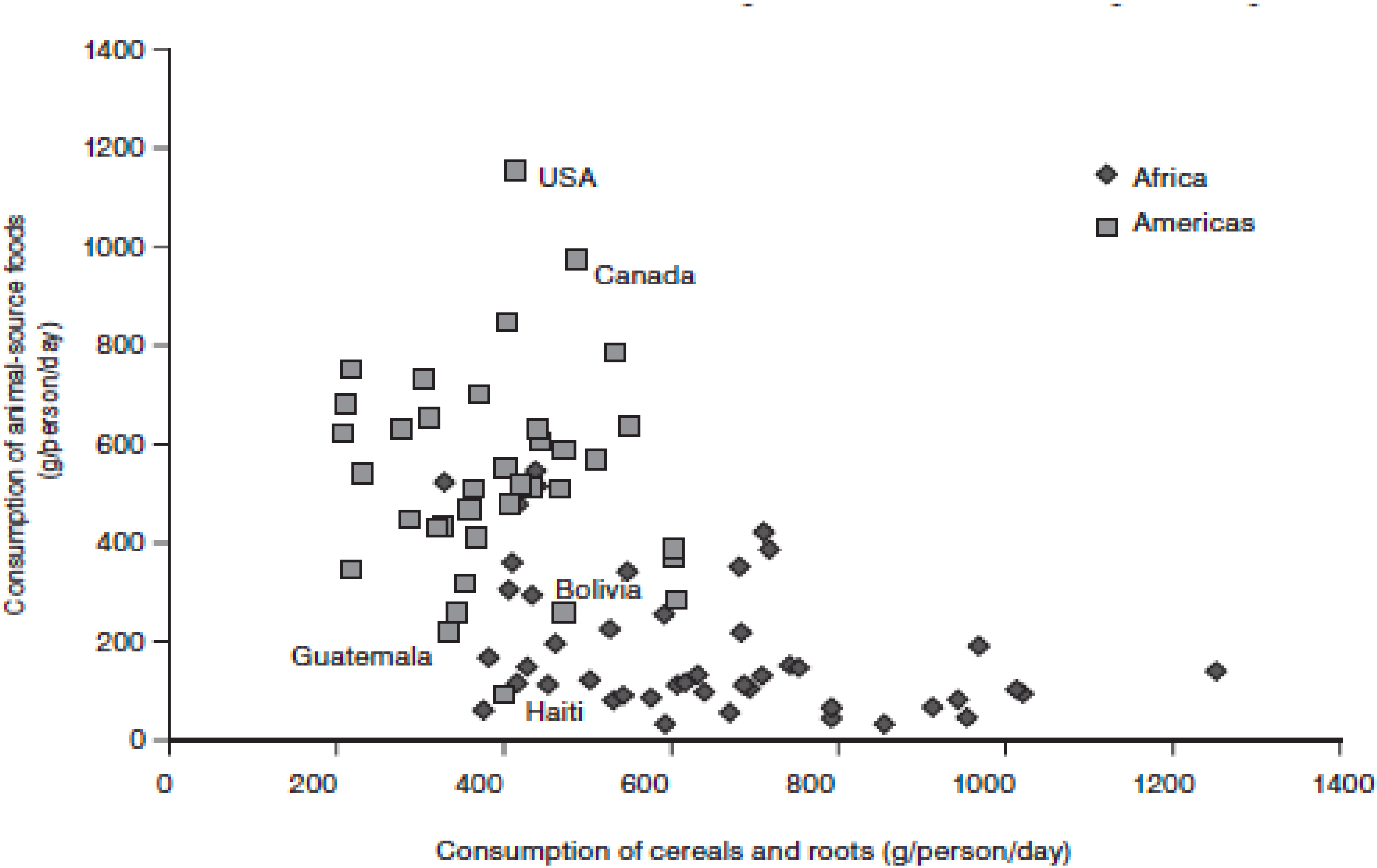
GLOBAL CROP NITROGEN (and people) STRESS Liu et al, 2010



GLOBAL HUNGER INDEX, IFPRI 2010



Comparison of Protein Consumption
Africa and Americas

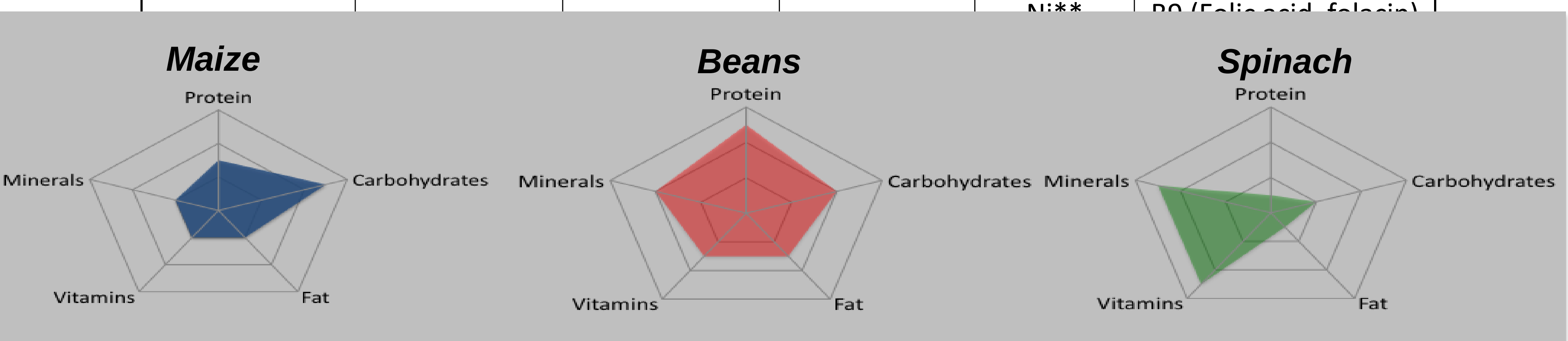


Berti and Jones 2012

Human Nutrition : 51 Essential Nutrients

Food-based approach

Air, water and energy	**Protein (amino acids)**	**Lipids-Fat (fatty acids)**	**Macrominerals**	**Trace elements**	**Vitamins**
Oxygen	Histidine	Linoleic acid	Na	Fe	A
Water	Isoleucine	Linolenic acid	K	Zn	D
Carbohydrates	Leucine		Ca	Cu	E
	Lysine		Mg	Mn	K
	Methionine		S	I	C (Absorbic acid)
	Phenylalanine		P	Fe	B1 (Thiamine)
	Threonine		Cl	Se	B2 (Riboflavin)
	Tryptophan			Si	B3 (Niacin)
	Valine			Mo	B5 (Pantothenic acid)
				Co (in B12)	B6 (Pyroxidine)
				B**	B7/H (Biotin)
				Ni**	B9 (Folic acid, folacin)



Food-based, nutrition-sensitive agriculture

- Agriculture sector is best placed to influence food production and the consumption of nutritious foods
- Aims to maximize the impact of nutrition outcomes, while minimizing the unintended negative nutritional consequences of agricultural interventions and policies.

STRATEGY 1: To restore or maintain high levels of local diversity

STRATEGY 2: To facilitate the adaptation of new varieties and crops

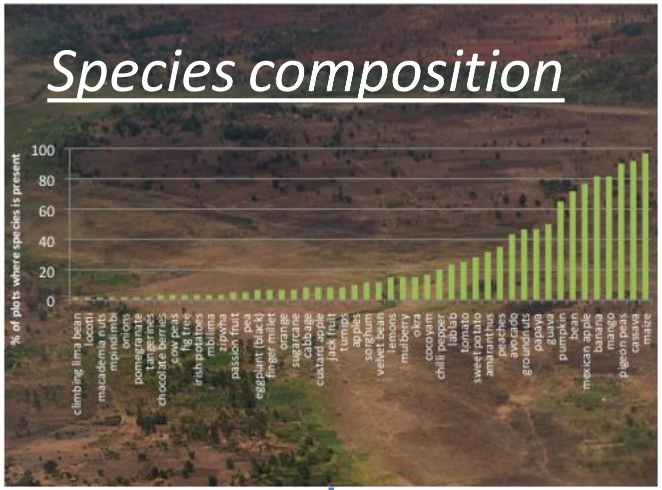
Agricultural Species Diversity – 3 sites in Africa
What does it mean for nutrition?

	Ruhiira	Sauri	Mwandama
# edible plant species in the community:	55	49	42
Average # edible plant species/ farm:	18	15	11
Average # livestock species/ farm:	2	2	0.5

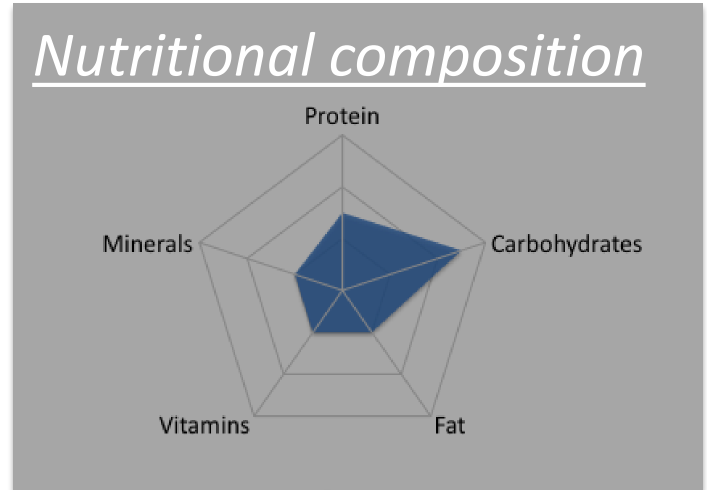
BANANA-BASED SYSTEM
RUHIIRA, UGANDA

MAIZED -BASED SYSTEMS
SAURI, KENYA and MWANDAMA, MALAWI

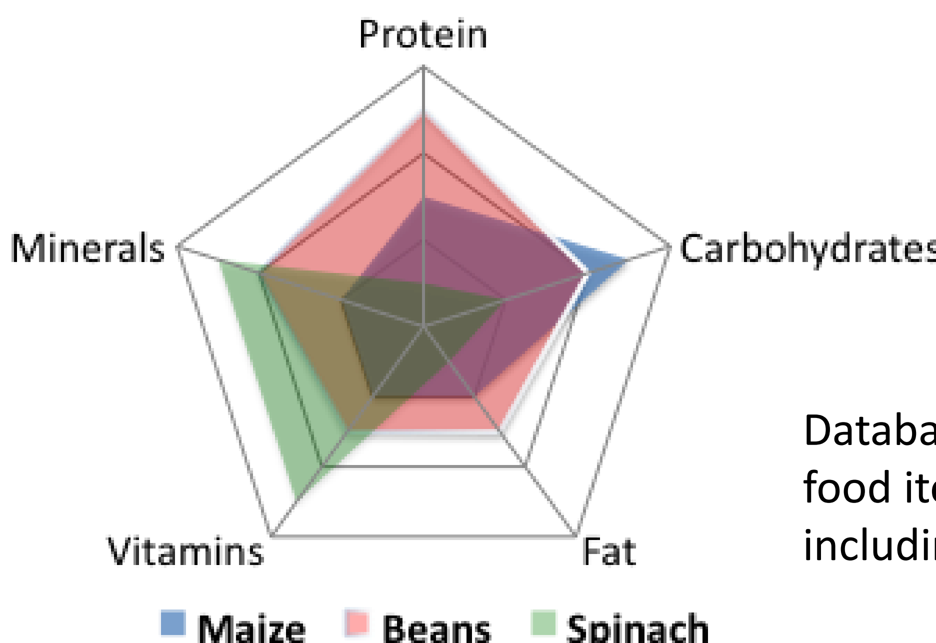
Nutritional Functional Diversity (FD)



X

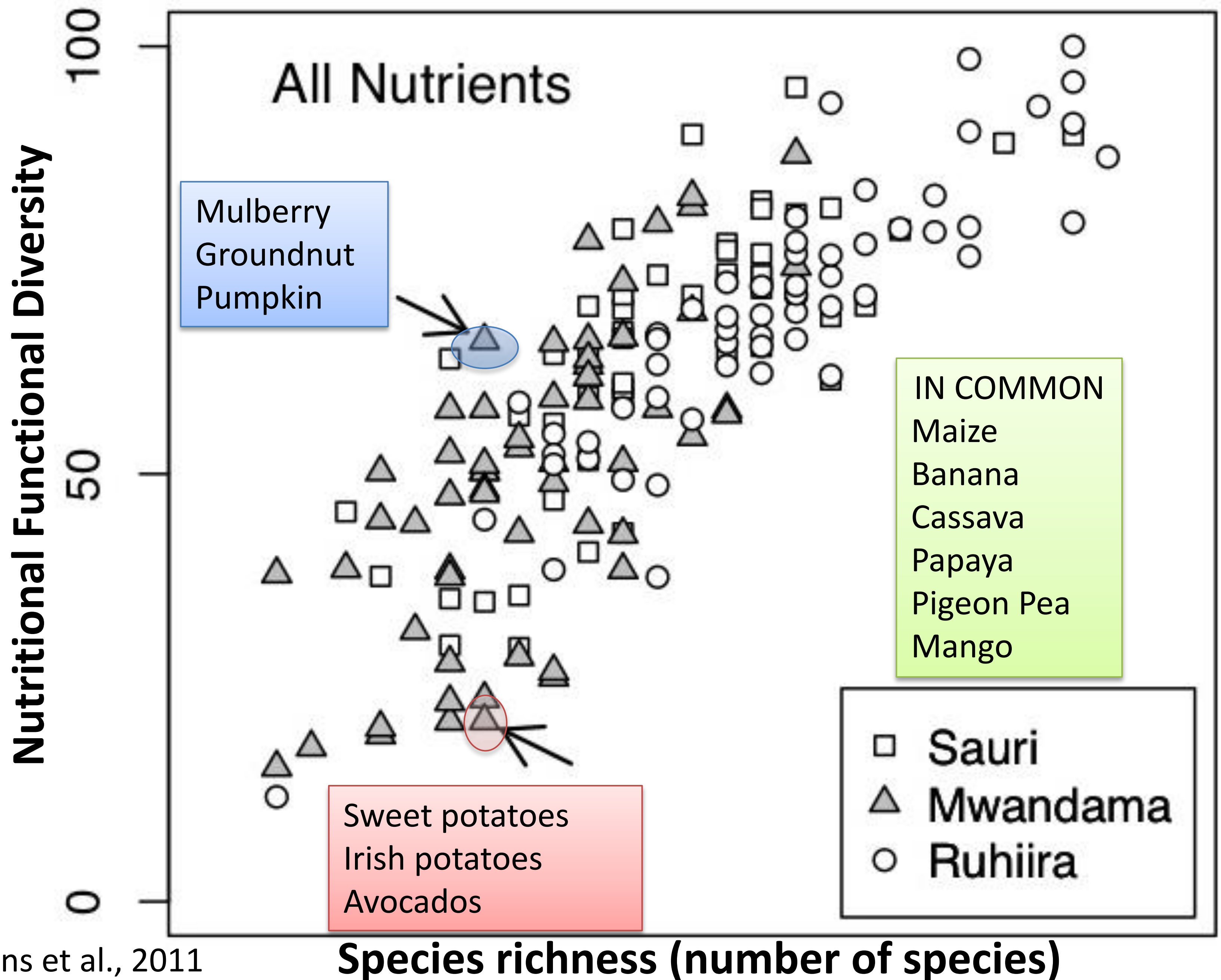


Nutritional functional diversity



Database contains 1000 food items, including many African crops

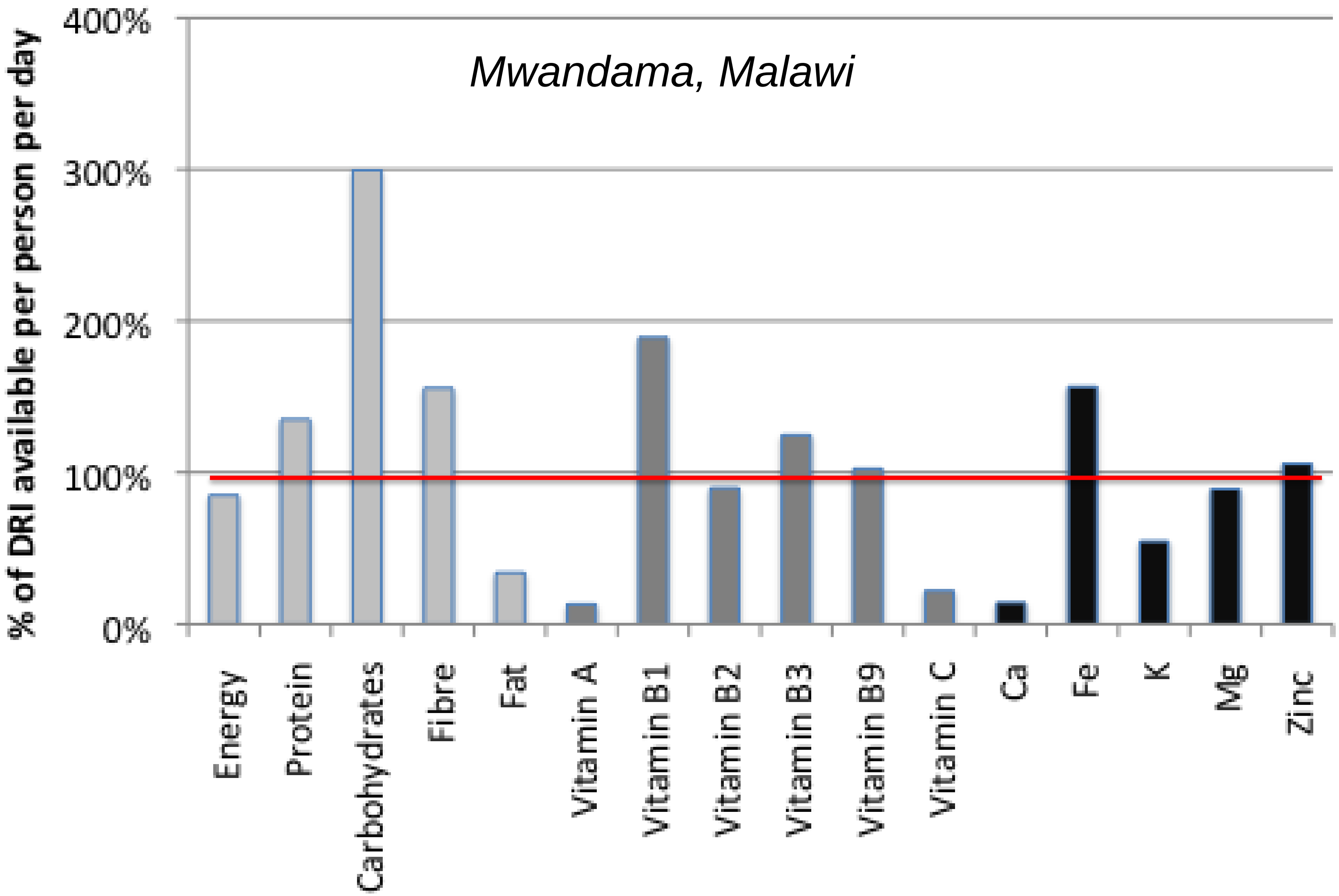
Nutritional Functional Diversity versus Species Richness- on farms



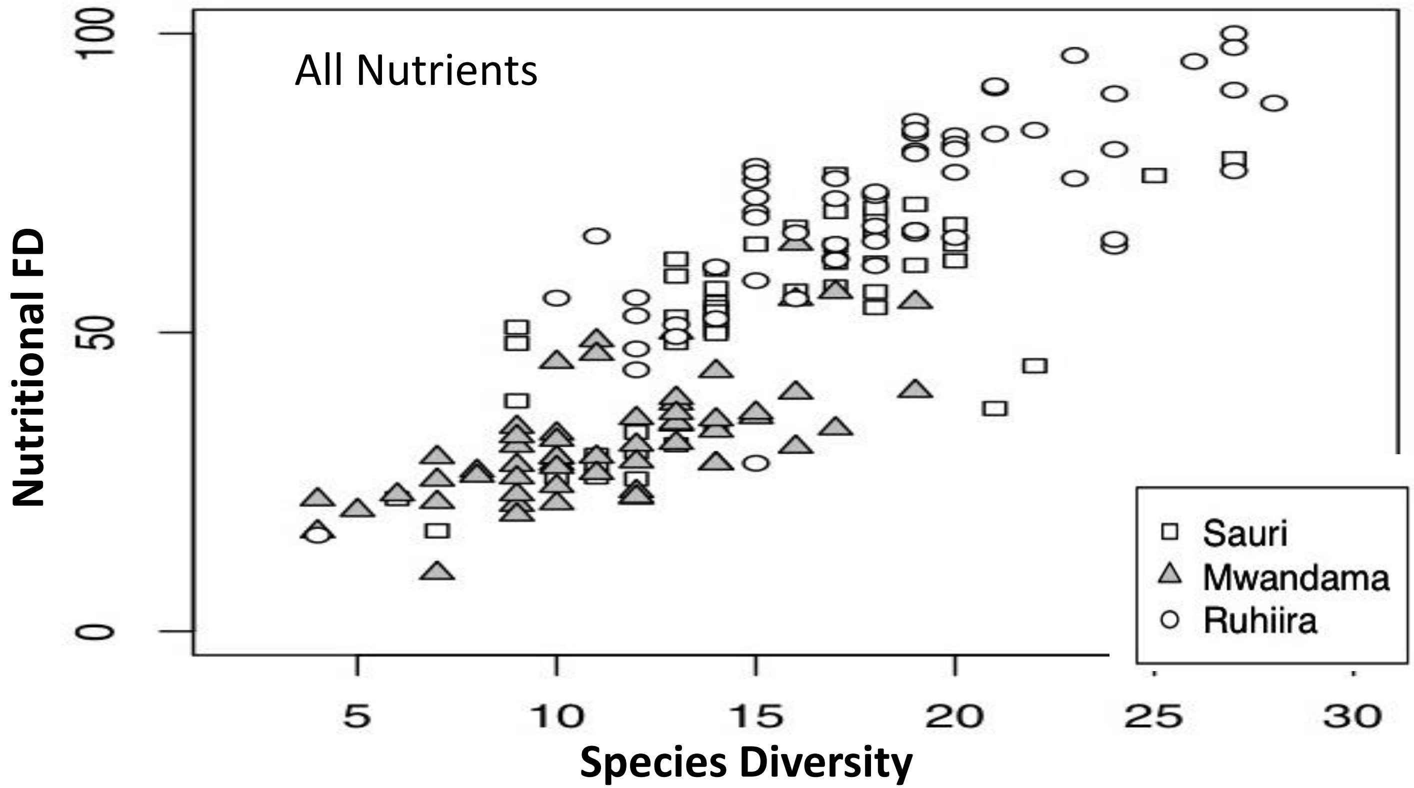
Remans et al., 2011

Nutrient Gap Analysis of Supply

% of Daily Requirement
per person per day produced on farms



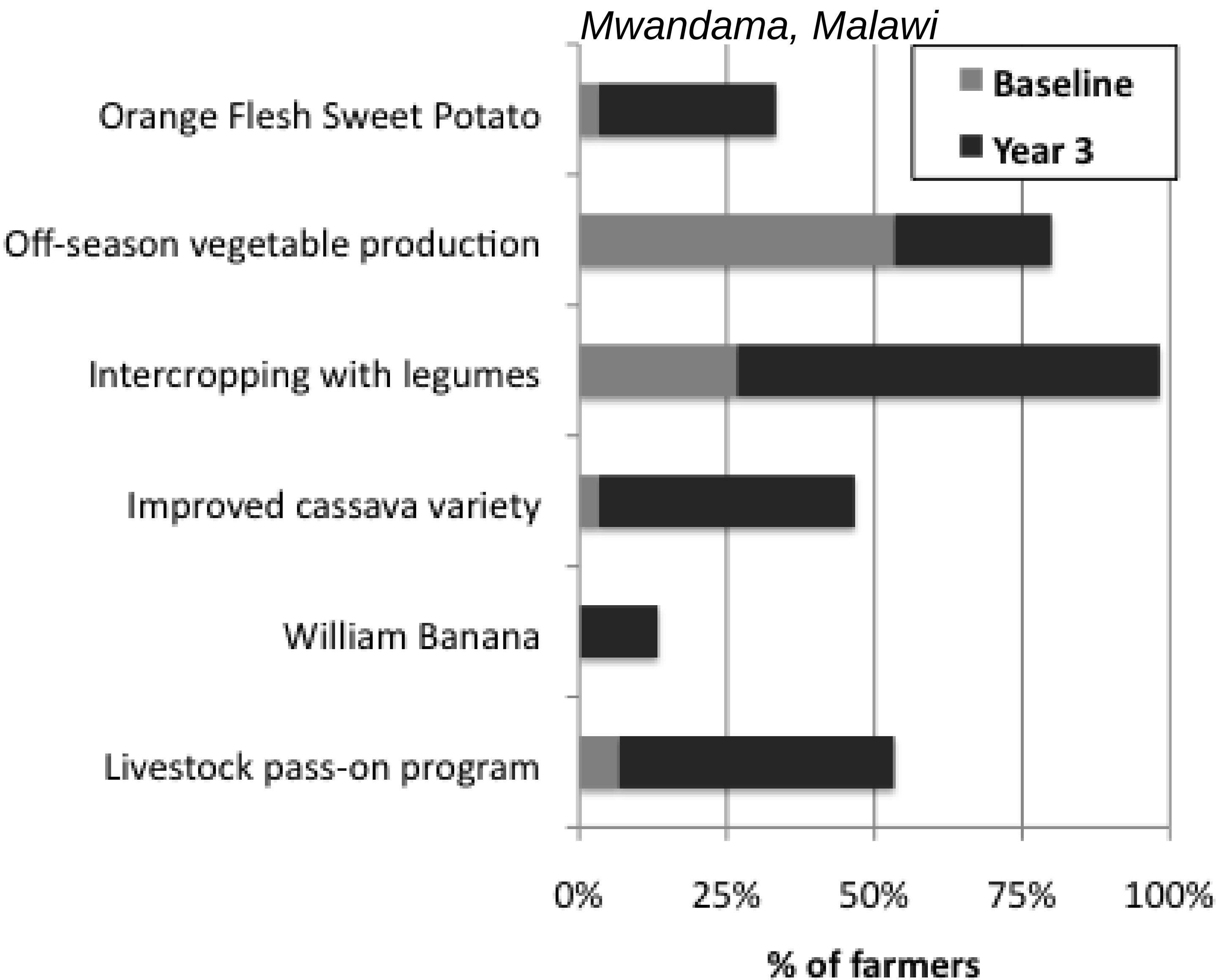
Species and Nutritional Diversity linked to Soil Fertility?



	Malawi, Mwandama	Kenya, Sauri	Uganda, Ruhiira
Soil pH	5.25 (± 0.60)	5.74 (± 0.37)	5.45 (± 0.85)
Soil Effective Cation Exchange Capacity (ECEC)	5.74 (± 2.34)	7.03 (± 1.96)	13.63 (± 4.34)
Soil % Nitrogen (N)	0.079 (± 0.026)	0.121 (±0.031)	0.260 (± 0.066)
Soil % Carbon (C)	1.098 (± 0.415)	1.461 (±0.332)	3.078 (± 0.742)

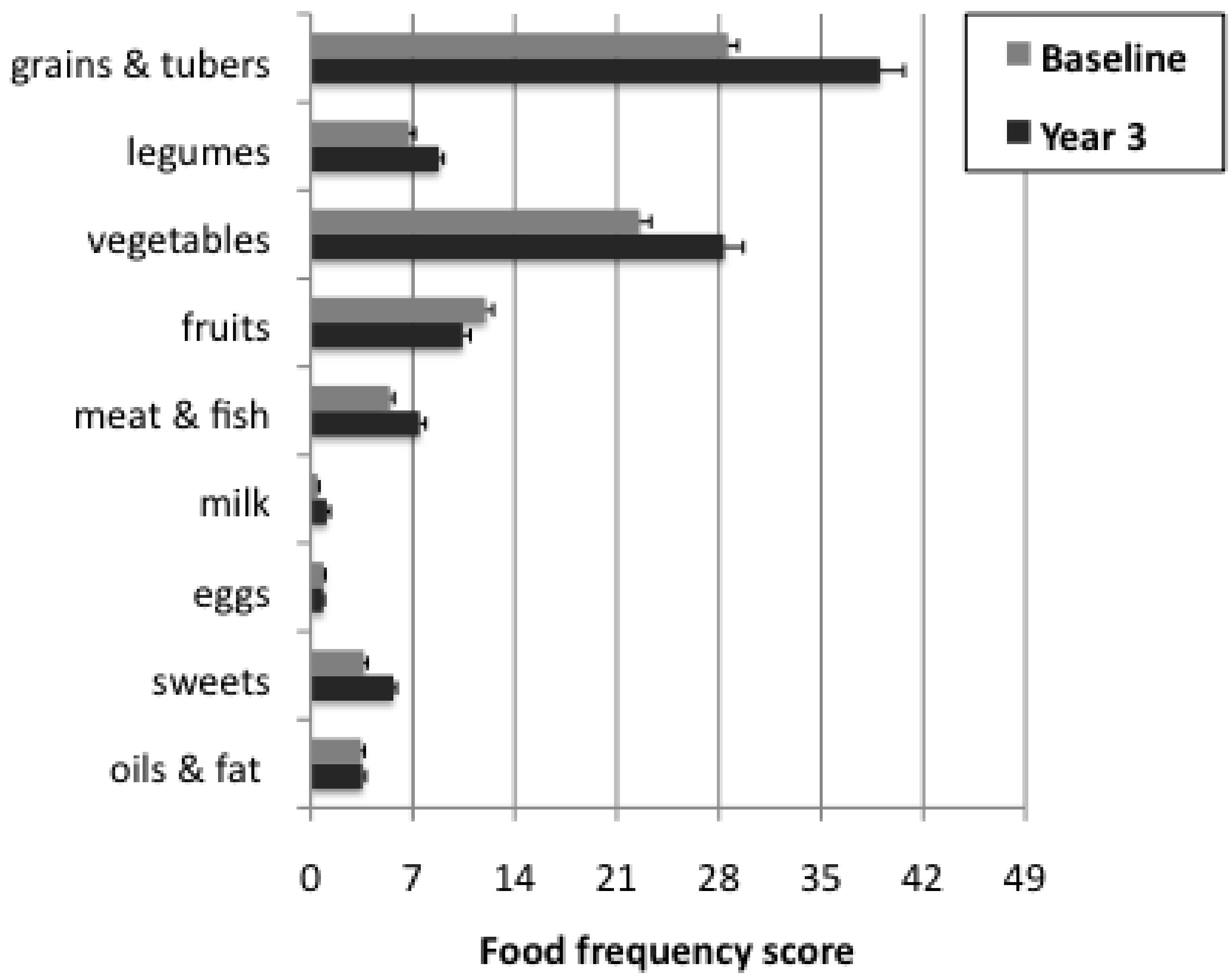
Adoption of Agricultural Diversification Activities

% of farmers diversifying



Analysis of Food Frequency Surveys: Food Consumption Patterns also Change

Mwandama, Malawi

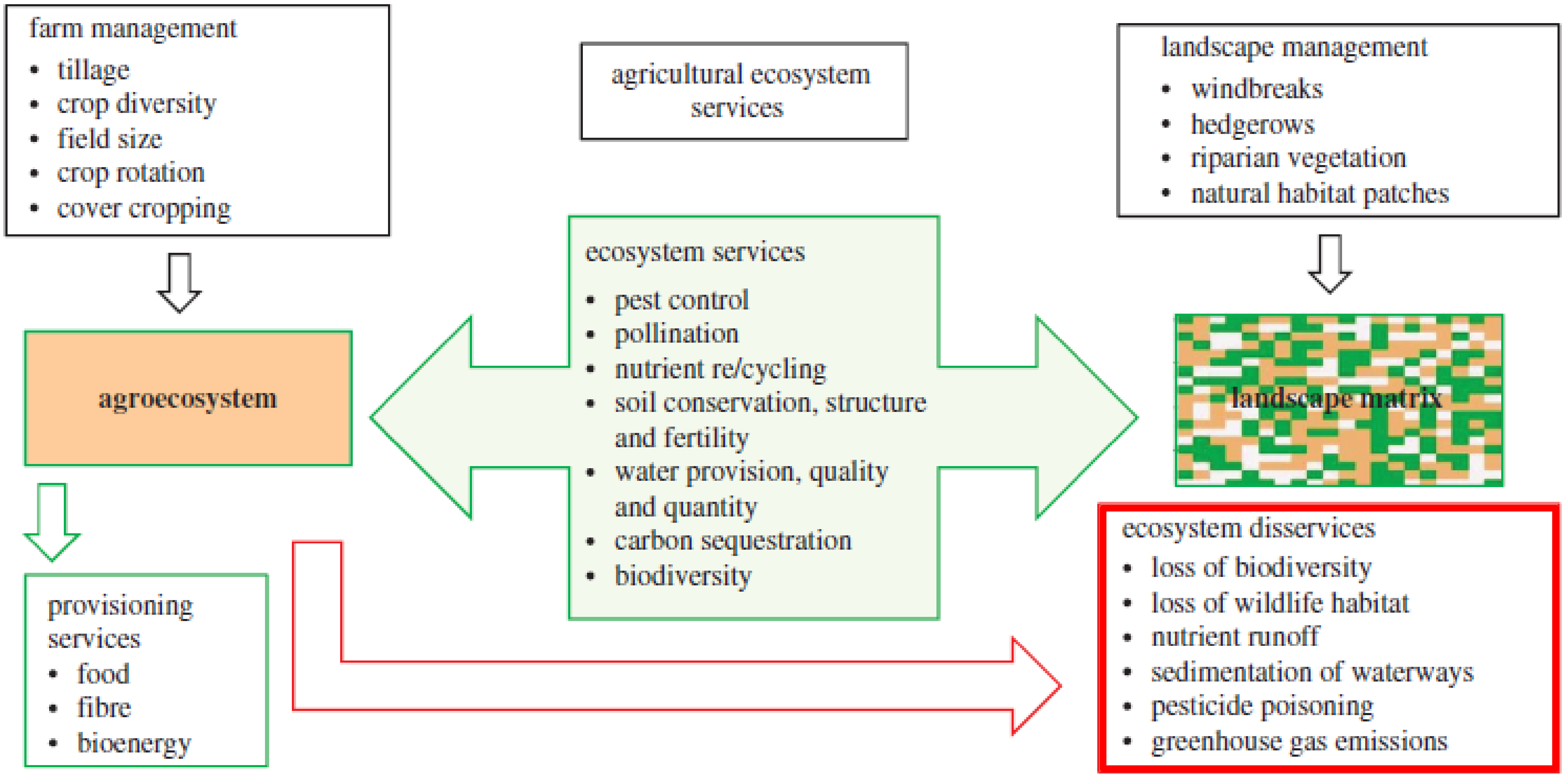


What the Evidence Tells Us About Agriculture and Nutrition

While household food production strategies hold promise for improving nutrition and health:

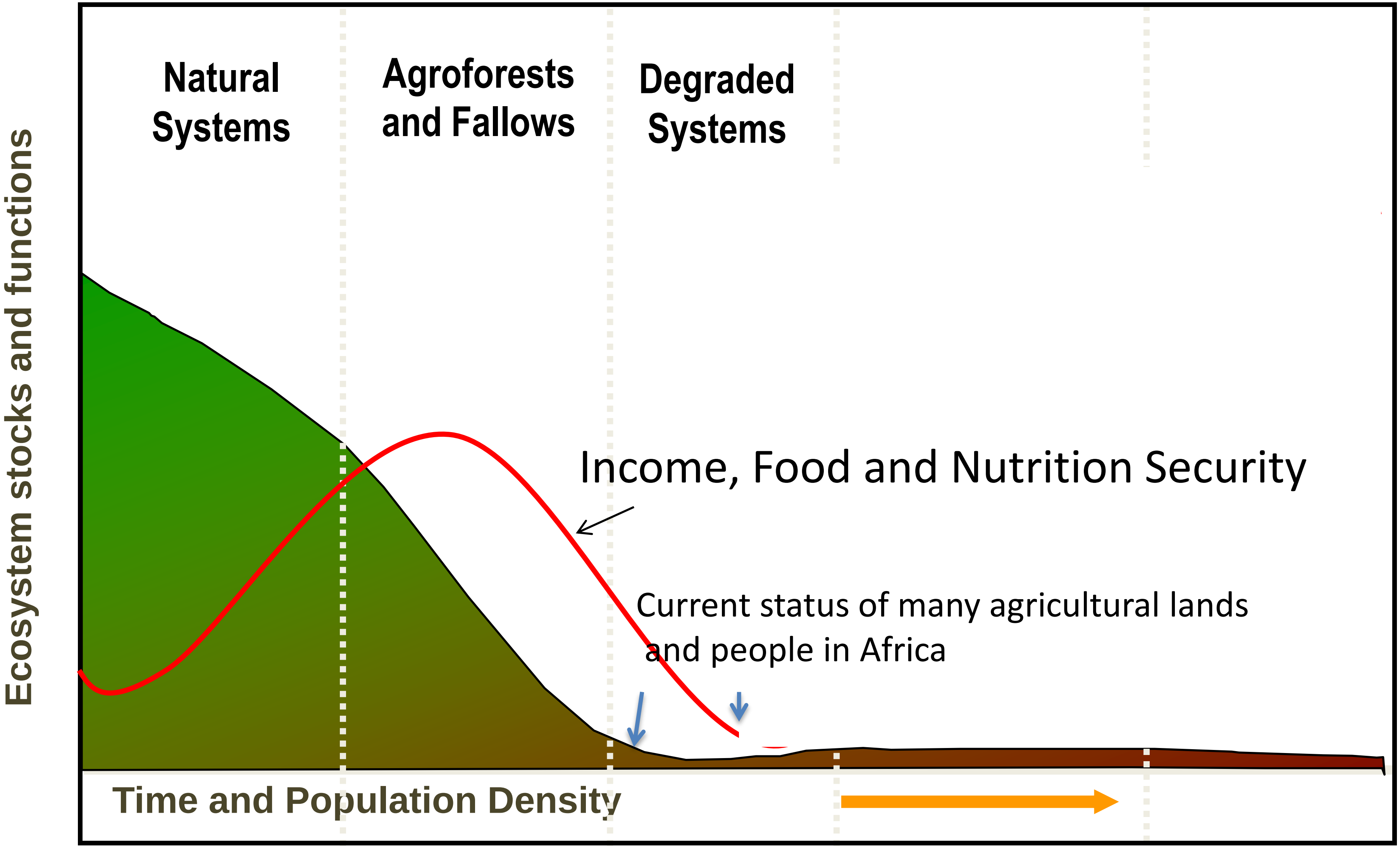
- the evidence base for agricultural strategies to improve nutrition and health is largely grounded in a limited number of quasi-experimental studies.
- the evidence base would be strengthened by additional research that uses agricultural and dietary indicators of nutrition.

What will an African Green Revolution do to the Environment?

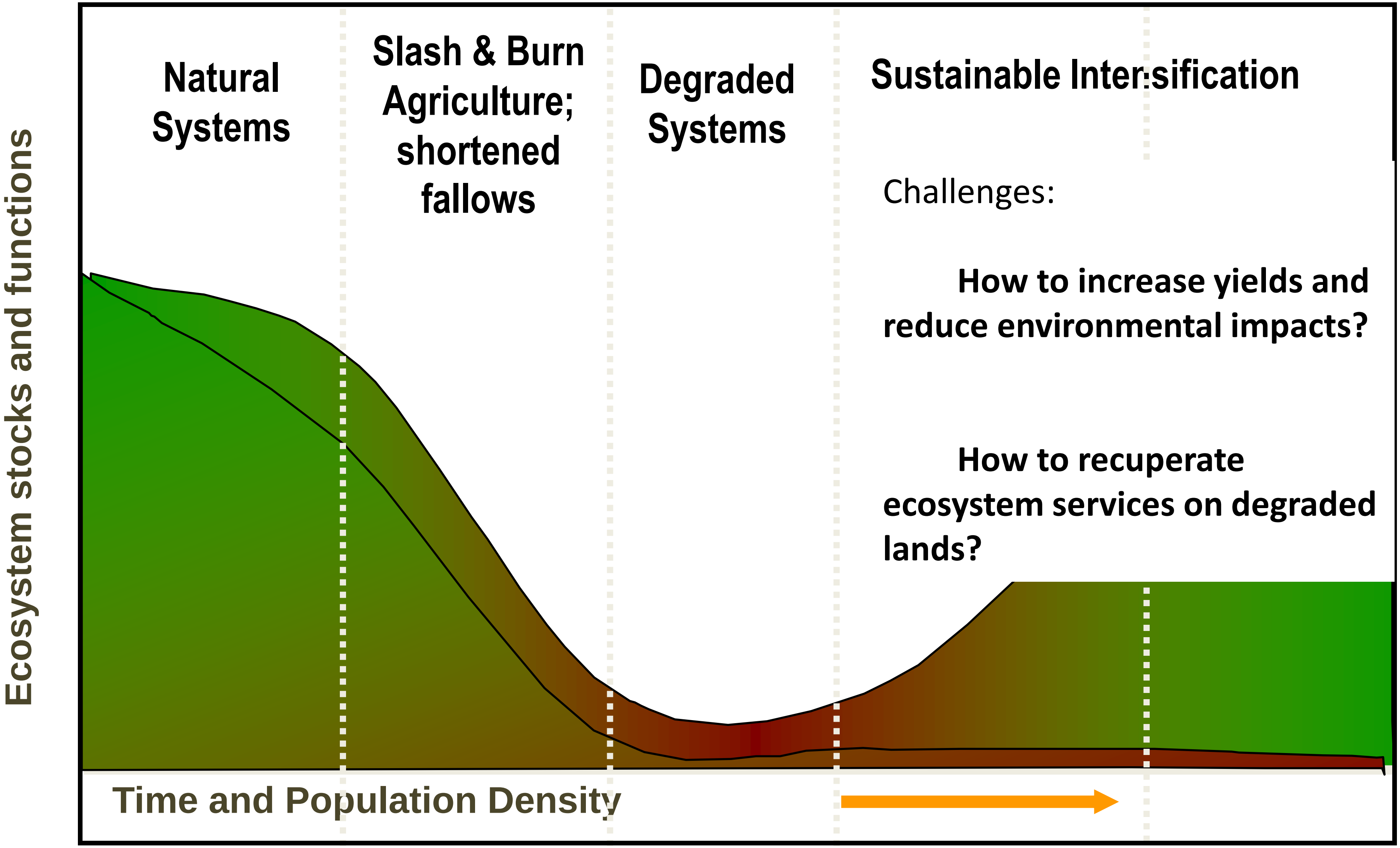


From: Power 2010

Land-use change, agricultural extensification, degradation and Livelihoods



Land-use intensification and Ecosystem Services



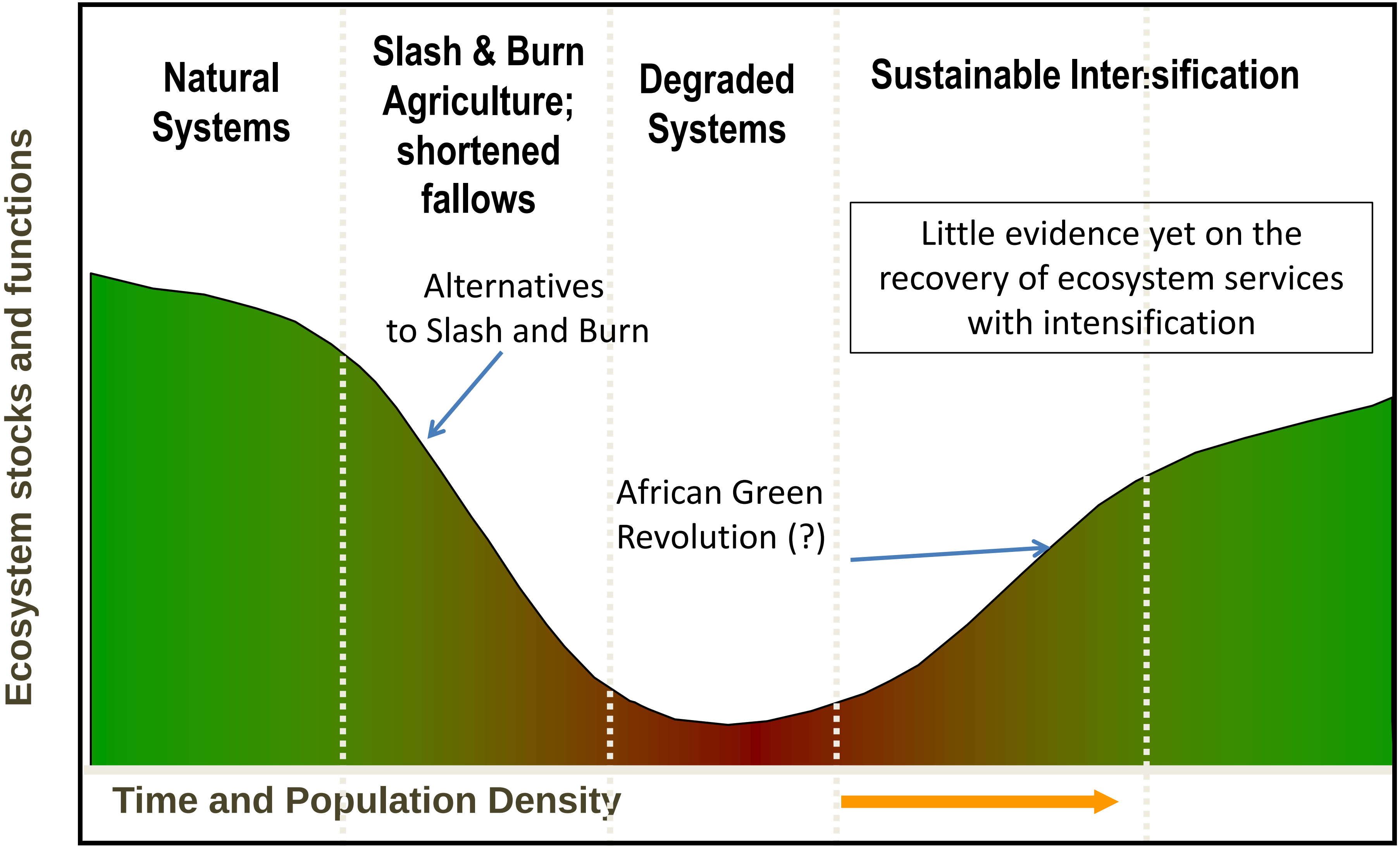
Additional challenges
to Agricultural Intensification on Degraded Lands
Comes at a cost

1. Rehabilitation of degraded agricultural lands requires:
   increased labor demand, increased capital inputs

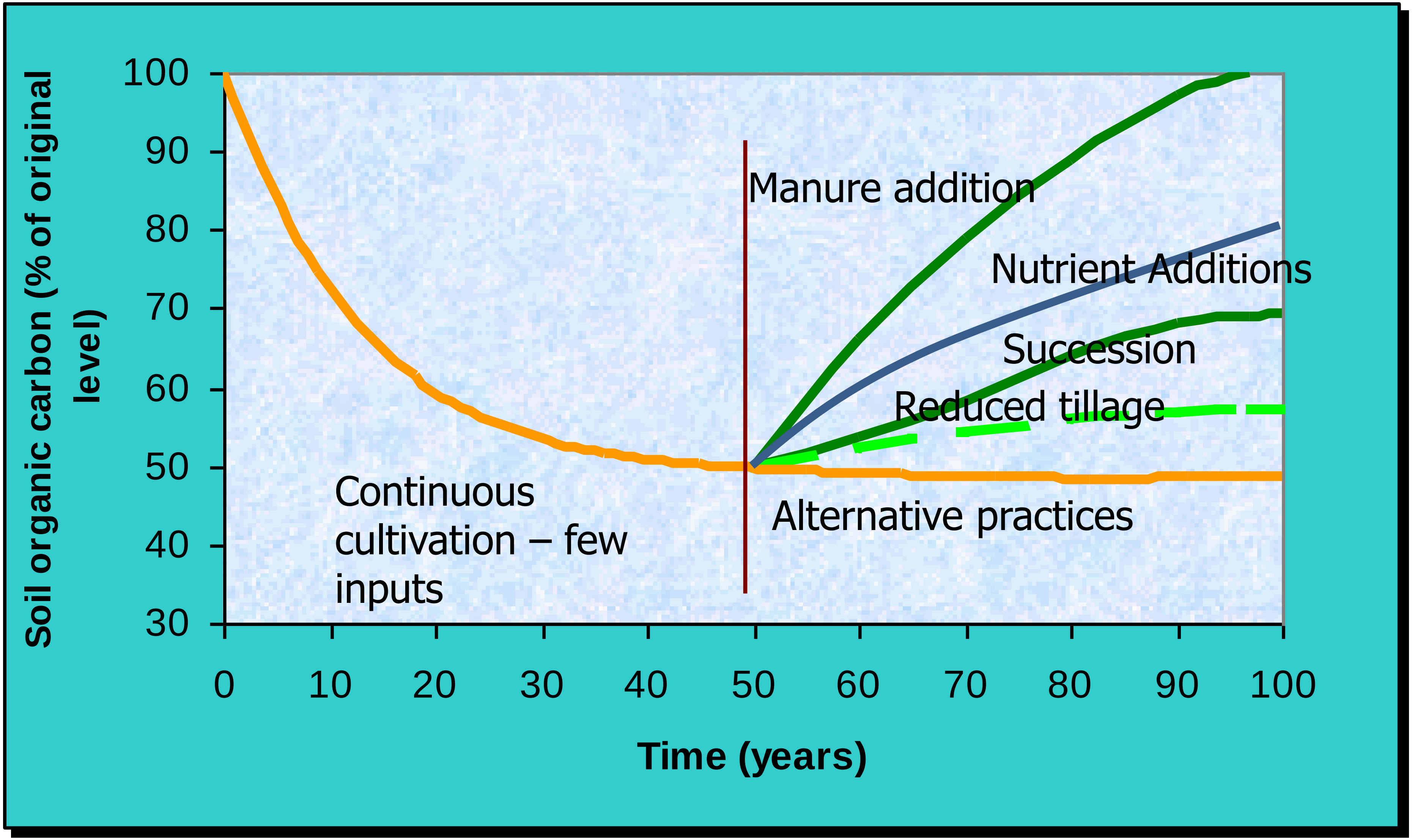
2. Rehabilitation of **production** on degraded agricultural lands requires:
   nutrients, carbon (biomass)

3. Rehabilitation of **ecosystem services** on degraded agricultural lands requires:
   nutrients, carbon (biomass) and biodiversity

Land-use intensification and Ecosystem Services



Hypothetical effects of different agricultural practices on soil carbon?



Modified from Tilman (1998)

AGRICULTURAL NITROGEN BALANCES
too much and too little
Can we achieve a balance?

	Nitrogen Balance by Region (kg N ha^{-1} yr^{-1})		
N Inputs and Outputs	**North China**	**Midwest USA**	**Western Kenya**
N Inputs to Crops	**588**	**155**	**7**
N Outputs from Harvest	**361**	**145**	**59**
(Inputs - Outputs) **Partial N Balance**	**+227**	**+10**	**-52**

Vitousek et al., 2009

Experiment: To assess what N additions will do in Africa?

N Additions and losses - leaching and gaseous emissions

The role of fertilizer rates and soil types

Site	Major Soil Type	Percent Clay at 0-20 cm (range)	Mean Annual Rainfall (mm)
Yala, Kenya	Ultisols/Oxisols	31 (17-46) Variable charge clays	Bimodal (1816)
Tumbi, Tanzania	Alfisols	20 (12-35) Sandy with few variable charge clays	Unimodal (928)

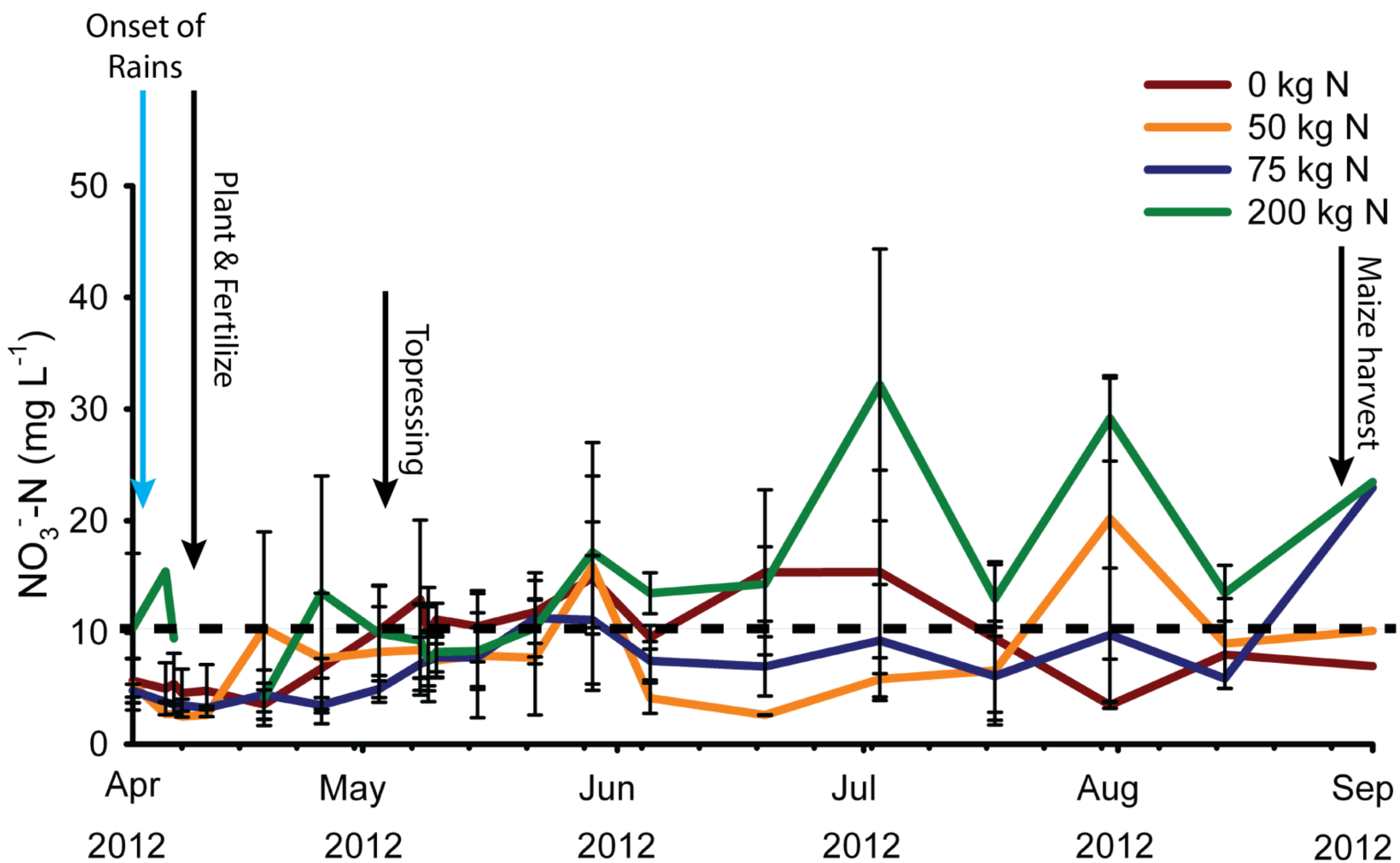
Loading Africa with Nitrogen?

N_2O emissions
Jonathan Hickman

NO_3 leaching
Kate Tully

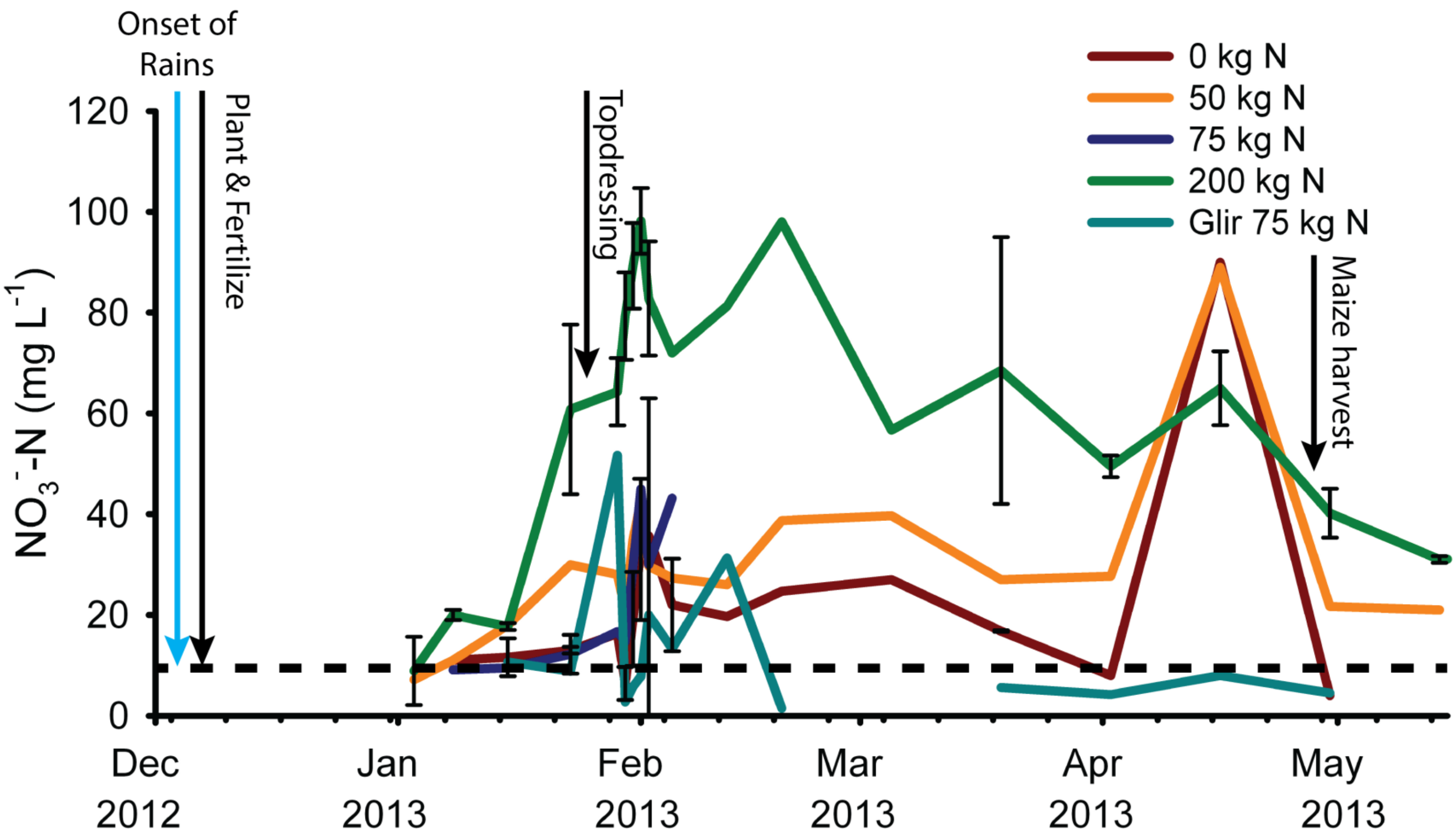
Nitrate concentration of leachate

at 200 cm in Kenyan Clay



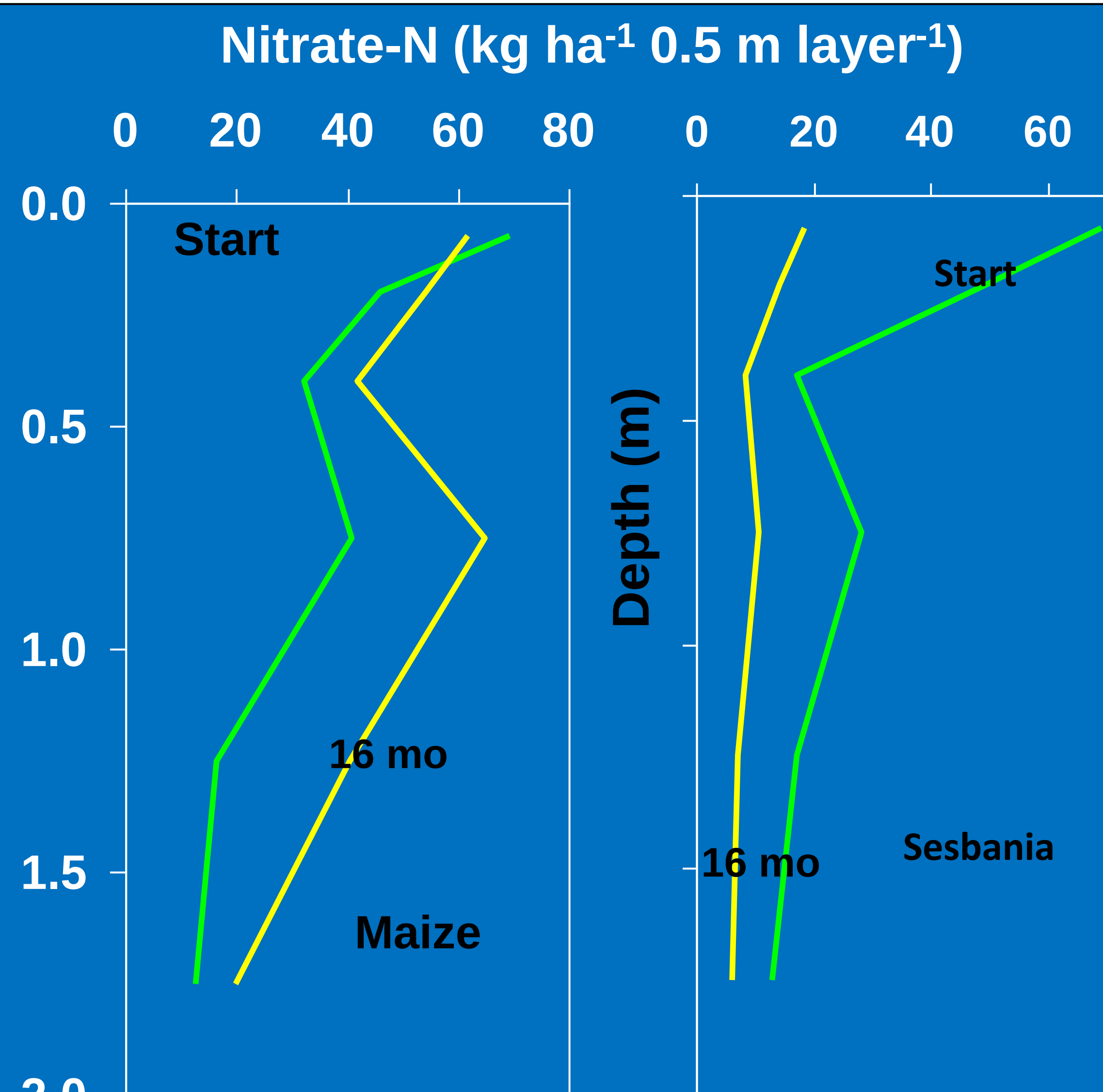
Nitrate concentration of leachate

at 200 cm in Tanzanian loamy sand exceed WHO standard of 10



Anion Exchange Capacity in Variable Charge Solis of Tropics

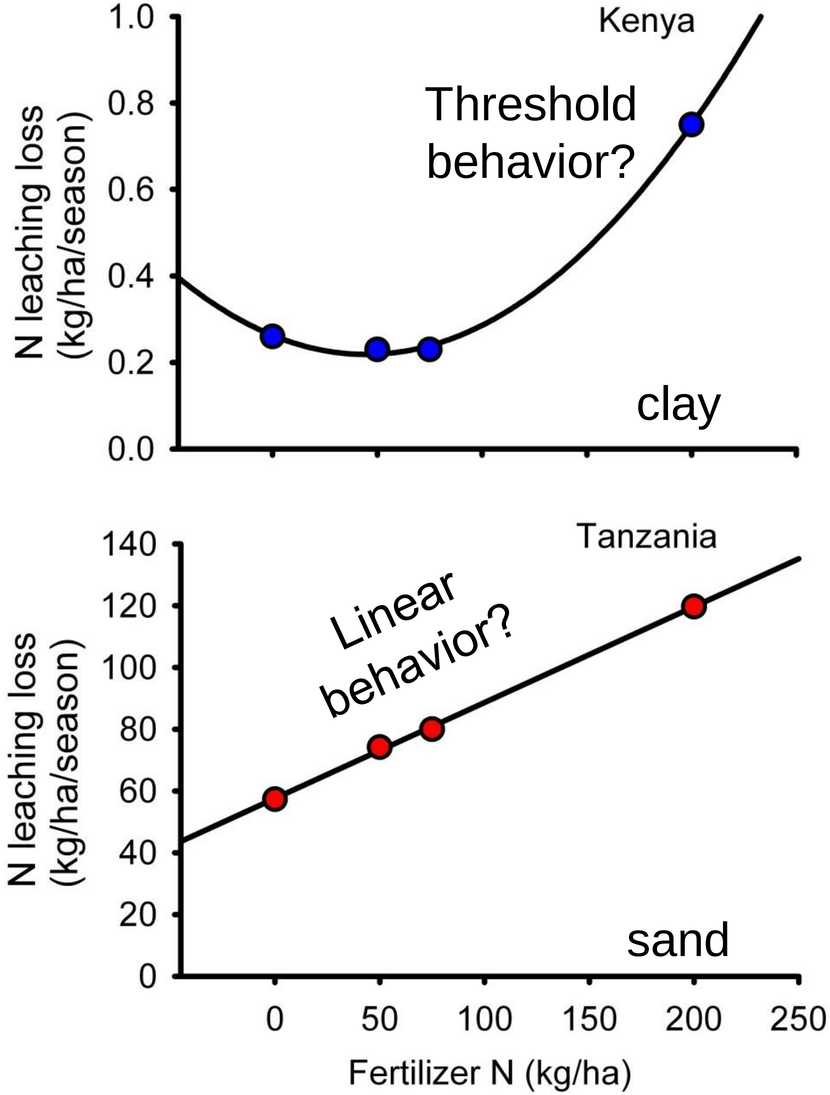
Holds nitrate (NO_3-) within the soil



Harteminck et al. 1996. SSSAJ 60: 568-574.

Fertilizer-NO_3 leaching losses

differ in sands and clays

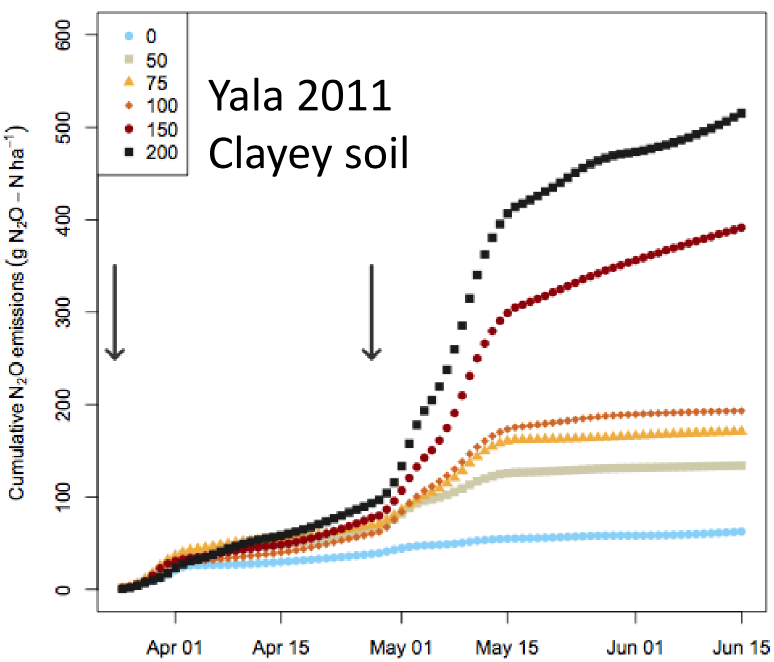


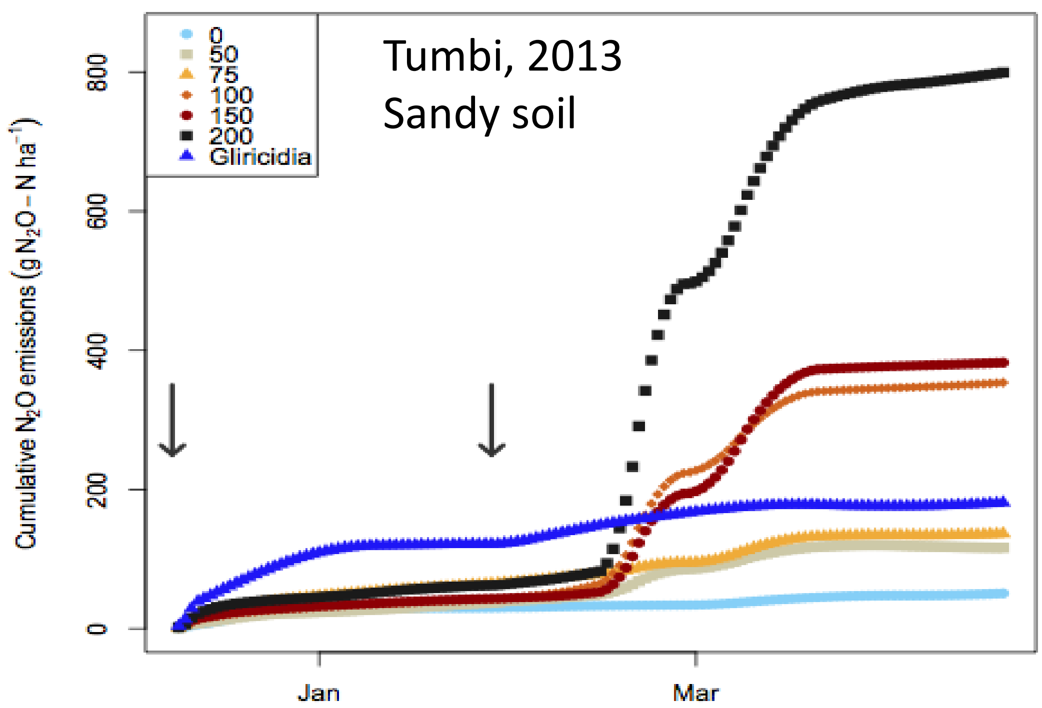
Cumulative N_2O losses

($g\ N_2O\text{-}N\ ha^{-1}$)

also differ in sands and clays

- Threshold around 100 to 150 kg N/ha
- Losses are less than 0.2% of N applied compared to 1% estimates for IPCC





Partial Nutrient Balances

KENYA

Treatment (kg N ha^{-1})	Maize yield (tons/ha)	N leaching (kg/ha/season)	N_2O+NO (kg/ha/season)	Loss Factor (g N lost/ kg maize)
0	6.4	0.26	0.32	0.09
50	7.6	0.23	0.38	0.08
75	8.7	0.23	0.39	0.07
200	8.8	0.75	0.88	0.19

TANZANIA

Treatment (kg N ha^{-1})	Maize yield (tons/ha)	N leaching (kg/ha/season)	N_2O+NO (kg/ha/season)	Loss Factor (g N lost/ kg maize)
0	1.1	57.3	2.7	52.2
50	2.9	74.2	4.7	26.8
75	2.8	80.0	4.5	30.5
200	2.5	119.7	5.1	49.7

Tradeoffs or Synergies with Agricultural Intensification? Sauri, Kenya after five years

METRICS and TARGETS

AGRICULTURE PRODUCTION

- Increase staple crop from 1 to 3 t/ha
- Increase agrodiversity
- Increase fuelwood production to meet demand

HUMAN WELLBEING

- Reduce Poverty by 50% ($1.25/day/pp)
- Increase food consumption to minimum daily requirement
- Reduce stunting by 75%

ENVIRONMENT

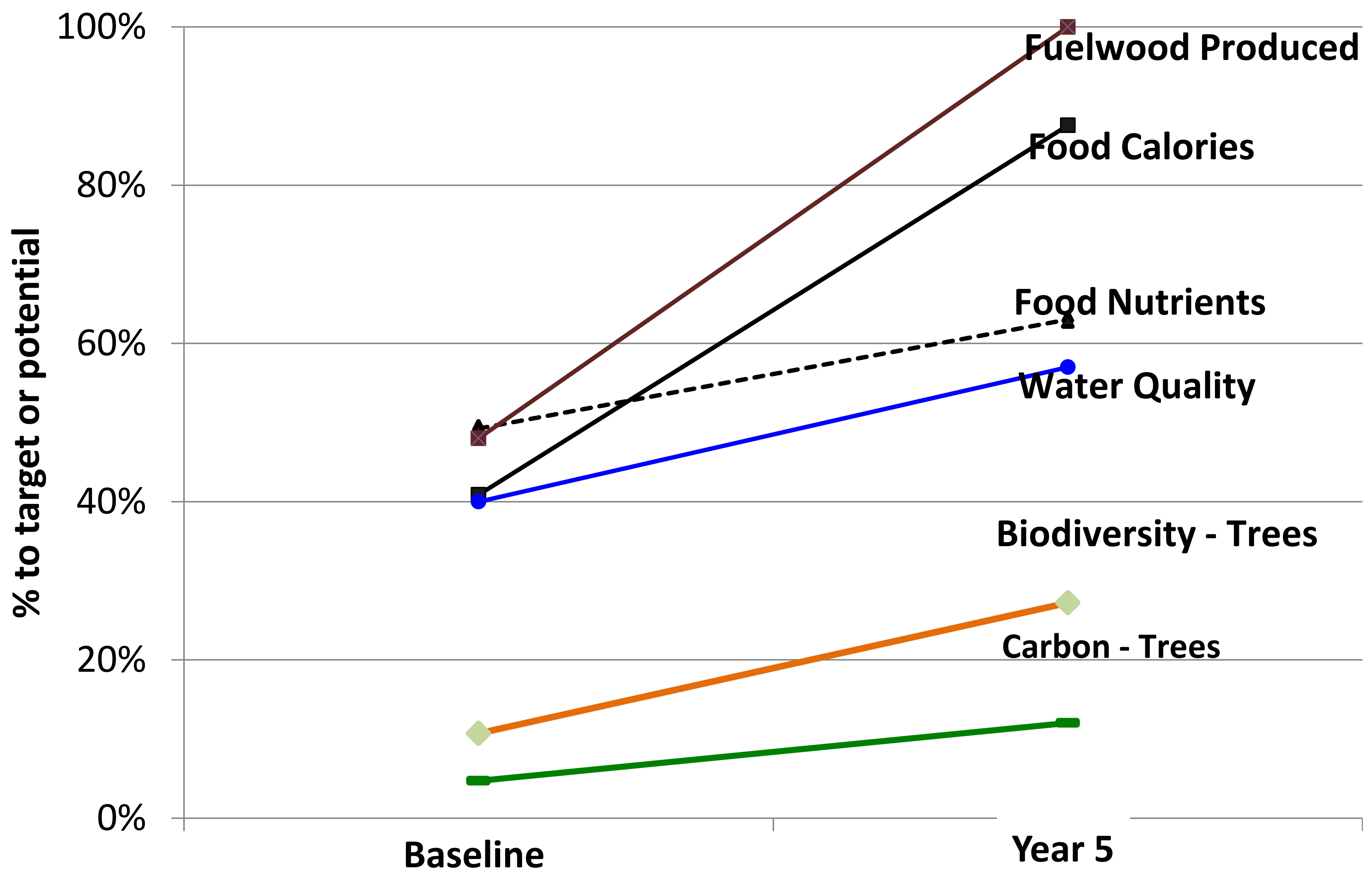
- Carbon increase to 50% of original
- Global warming potential
- Tree Diversity- 50% original species
- Water quality
- Conserve wildlands
- Increase tree cover

MVP SITE SAURI, NYANZA PROVINCE, KENYA

1400 m elevation
600 people per sq km
Maize based farming system
Avg farm size: < 1 ha

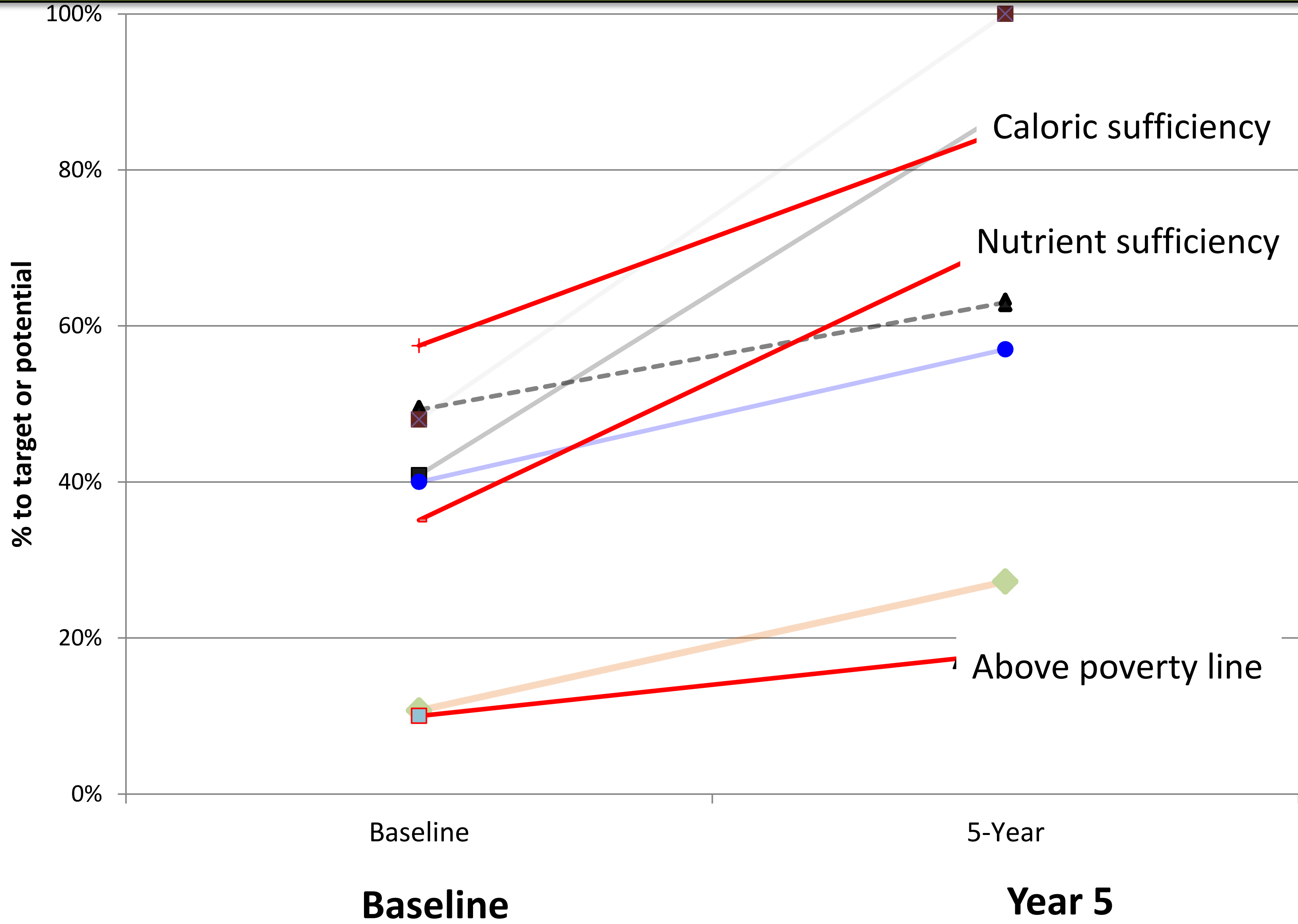
AGRICULTURE AND ENVIRONMENT

SYNERGIES IN SAURI, KENYA



HUMAN WELLBEING

SYNERGIES WITH AGRILCULTURE AND ENVIRONMENT SAURI, KENYA



SUMMARY FINDINGS

Agricultural intensification in degraded landscapes can result in synergies with environmental and human wellbeing outcomes

Nutrient sufficiency

- Food production increased significantly without changing the area under agriculture.

- Provisioning ecosystem service (food and fuelwood) increased substantially in terms of producing more calories, nutrients, and fuel

- Regulating services of water quality increased

- Tree biodiversity and landscape carbon increased slightly

- Human wellbeing increased substantially in terms of nutrition though poverty reduction was slight.