The Role of DSM in Transforming Agriculture: *The Case of Ethiopian Soil Information System (EthioSIS)*

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Ministry of Agriculture and Natural Resources

Ethiopian ATA
Agricultural Transformation Agency
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Agenda

Background Information

Major Soil Health and Fertility Issues

The EthioSIS and Related Initiatives

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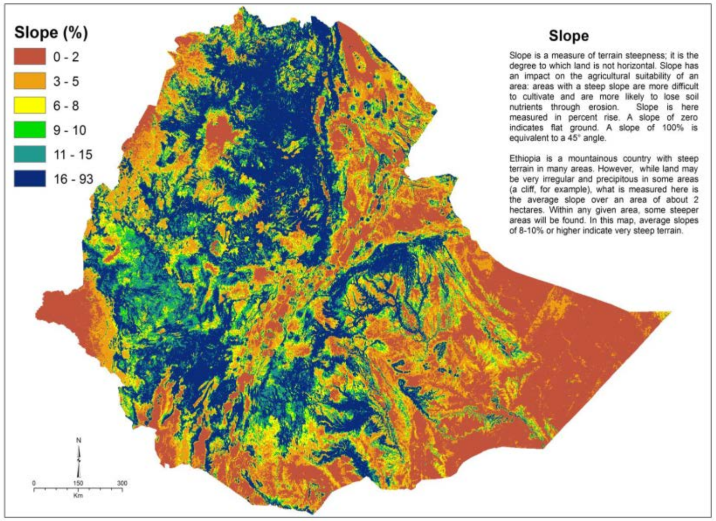
Major Soil Health and Fertility Issues

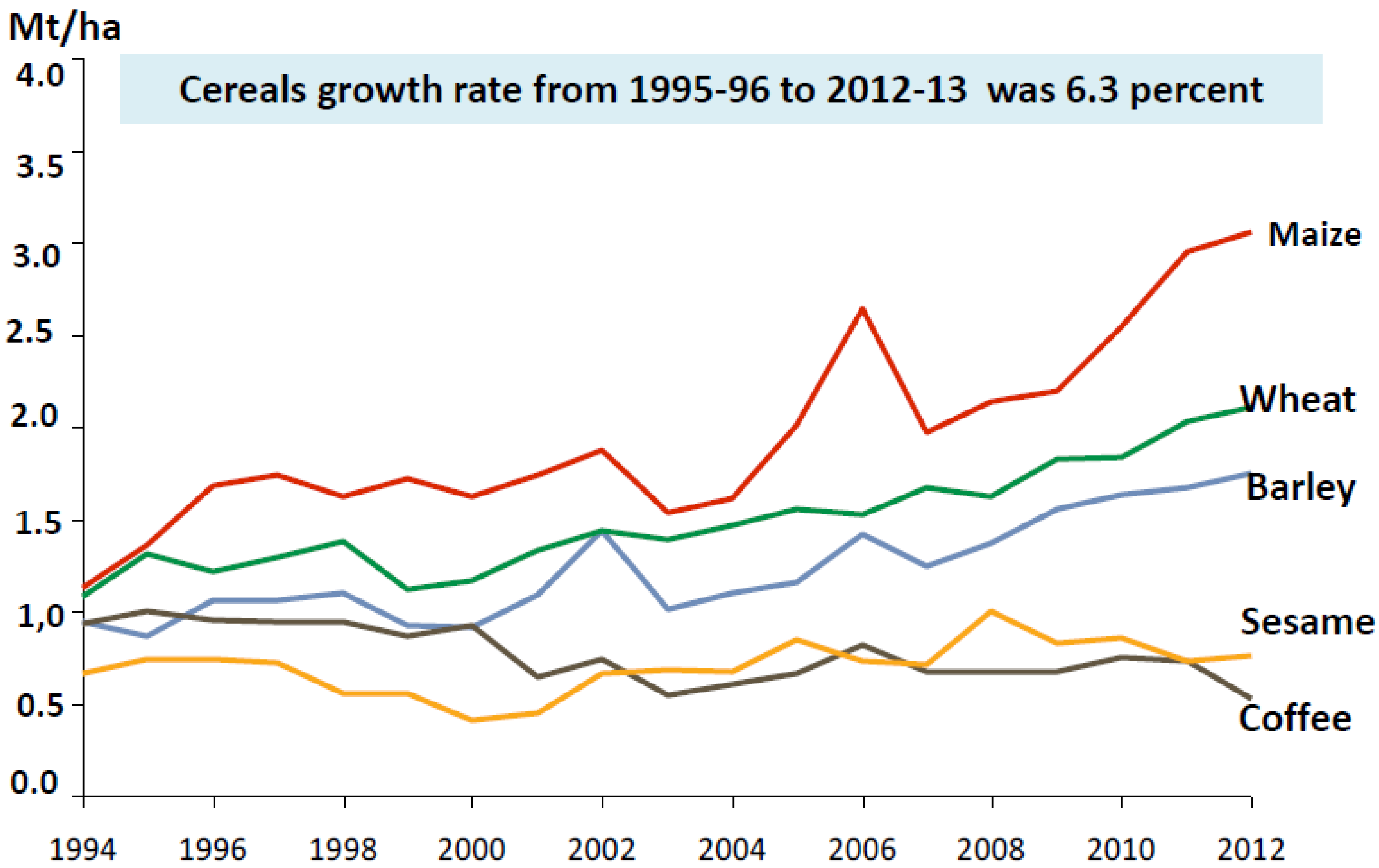
The EthioSIS and Related Initiatives

Agriculture employs >80% of the population; Contributes ~40% to the GDP, and > 60% to export.

- Smallholders account for 96 % of total area cultivated.
- Most reside in the moisture reliable cereal based highlands (i.e. 59 % of total cultivated area)
- Teff, wheat, maize, sorghum, and barley, account for about 75% of total area cultivated
- > 80% of agricultural lands have undulating topography, with up to 60 percent slope.

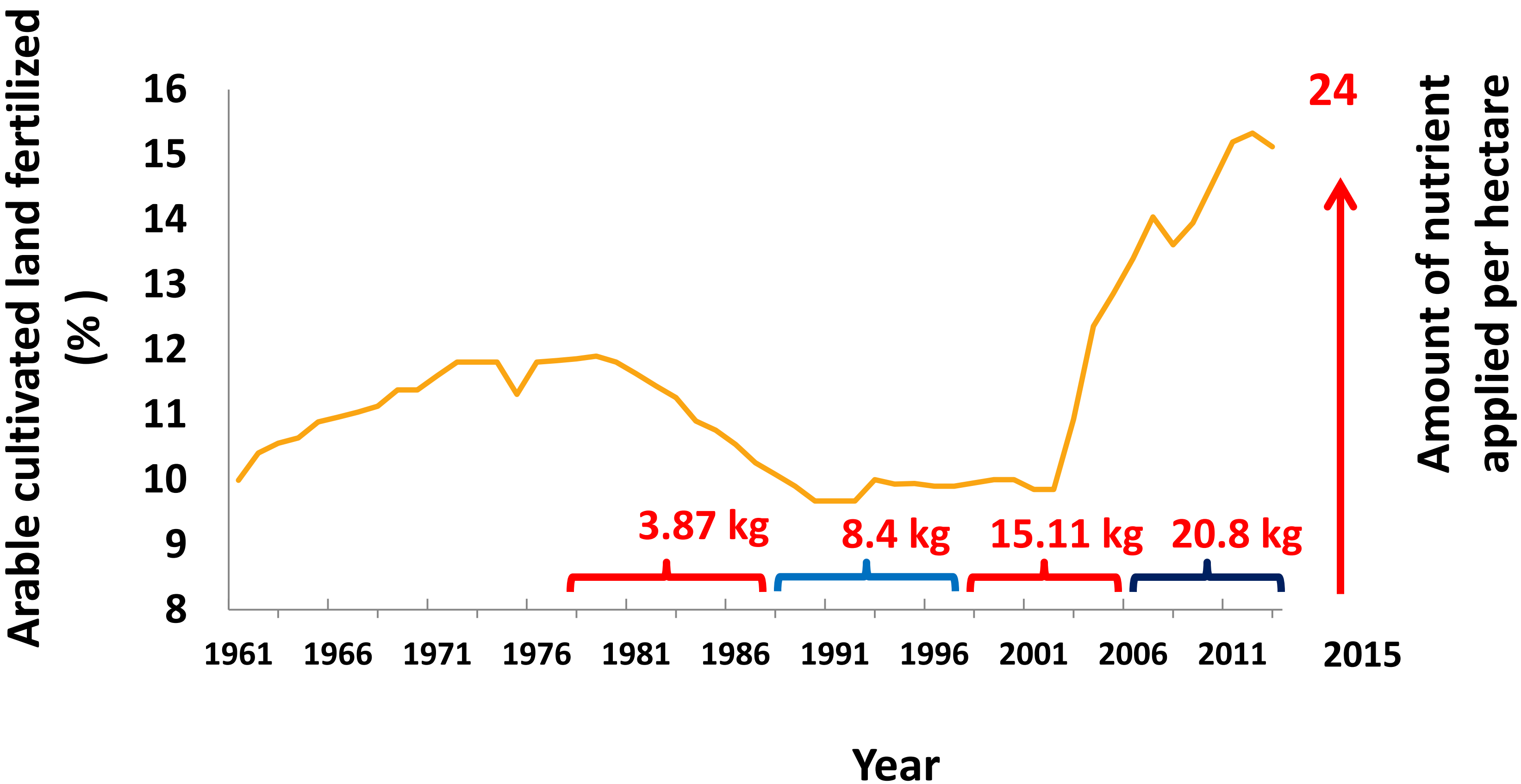


Yield pattern by crop is by far lower than the 3.6 Mt world average



FAO, 2013

In Ethiopia, positive trend in overall fertilizer consumption is observed during the past years, but in no way does this imply cause for satisfaction as application rates are still low.



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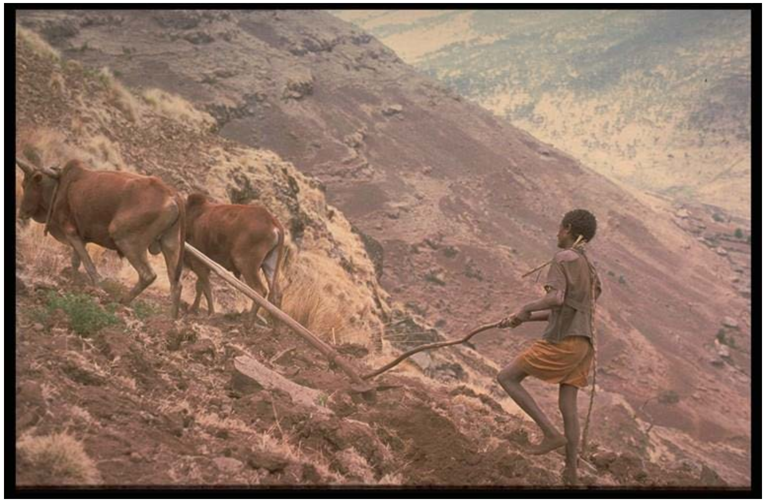
1. Soil Erosion

- Soil erosion and land degradation are major causes for low productivity and vulnerability of smallholders
- Annual soil loss from cultivated lands is about 42 tons ha^{-1}
- Reduce crop production up to 30% (Pimentel, 2003)



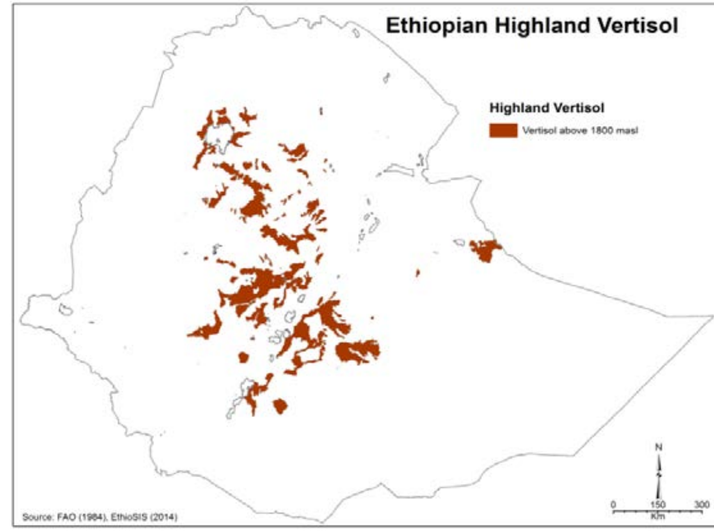
2. Nutrient depletion

- Nutrient export/ mining: cow **dung** and **stover** are sold for energy source

- **L**oss of P and N resulting from the use of dung and crop residues for fuel is equivalent to the total amount of commercial fertilizer use (IFPRI, 2010)

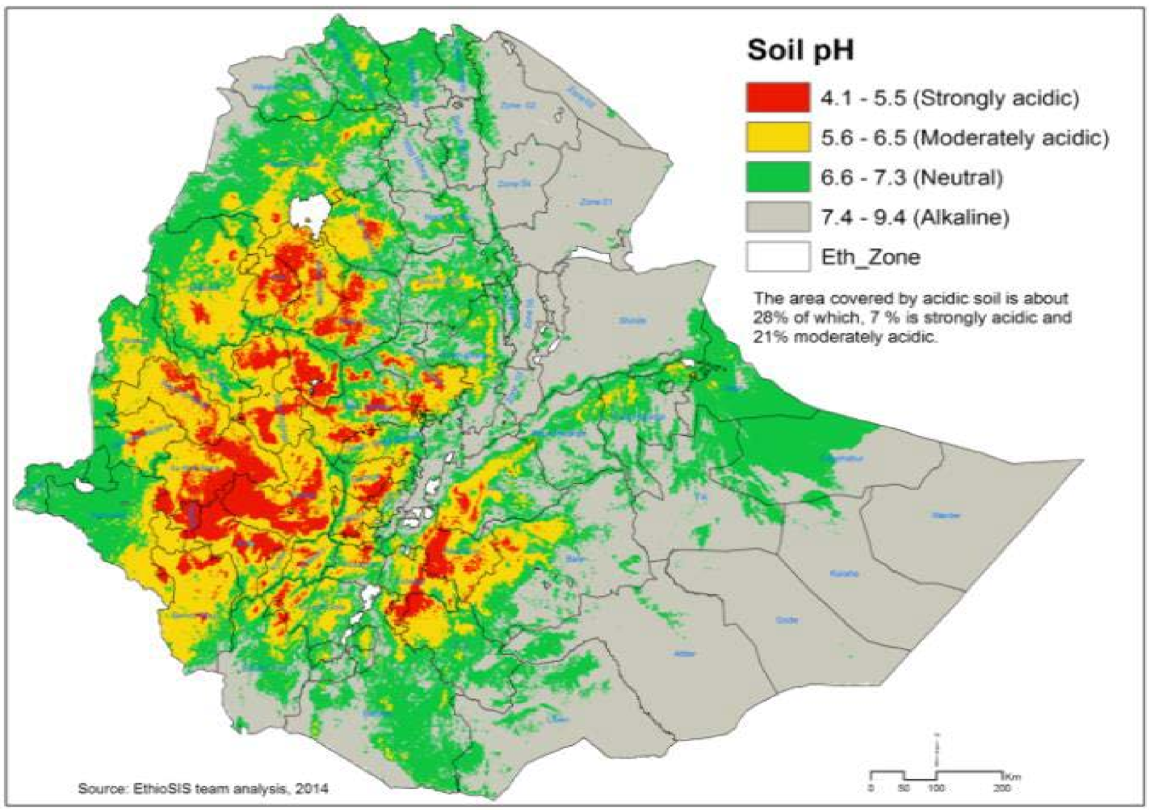
3. Seasonally waterlogged soils

- Of the country's @12m ha Vertisols, about 7m ha are found in the highlands and their productivity constrained by waterlogging.
- Traditionally crops grow and mature on late season rainfall and residual soil moisture



4. Soil Acidity

- Strong soil acidity affects @28.1% of the entire country.
- @ 43% of the agricultural land in the three high potential regions is affected by acidity (mostly in highlands)



5. Salt affected soils

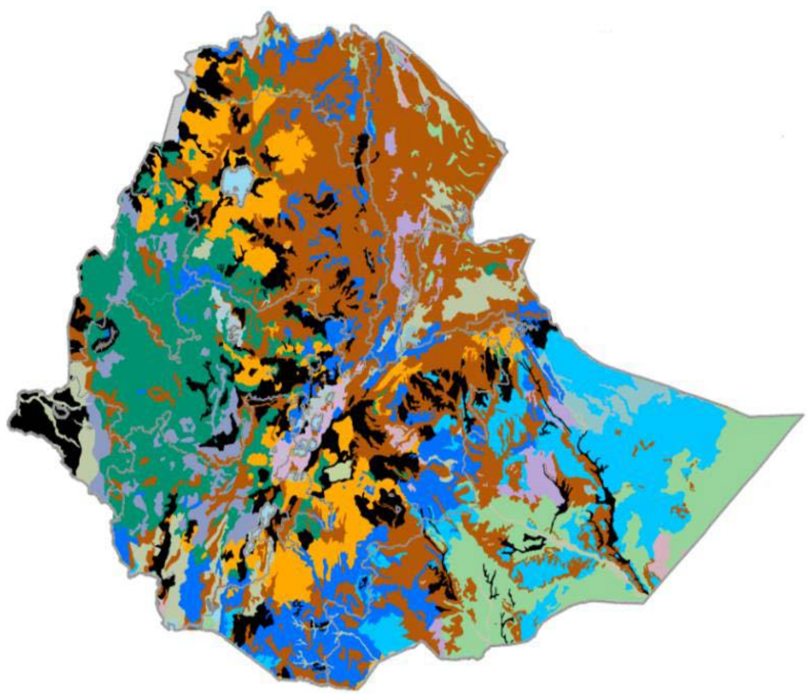
- About 1.5 m ha of fertile valley bottom soils are affected by salinity
- The problem increasing in connection with expansion of irrigation owing to poor on farm water management
- Salt-affected soils must be restored to productivity and effective steps taken to prevent salinization of new areas being brought under irrigation at huge cost.

Awash river basin

6. Lack of national soil information and unbalanced use of fertilizers; the past approach of fertilizer usage has not helped significantly increase yields

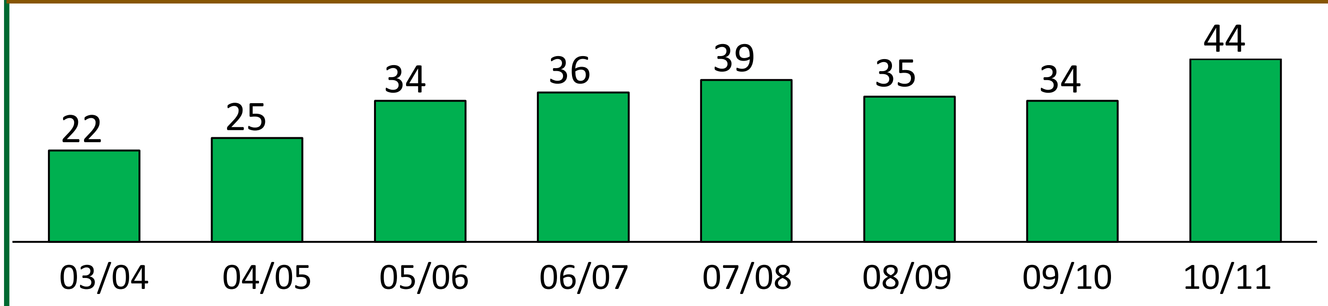
- **Existing soil maps in Ethiopia are obsolete with limited soil fertility information and need to be updated using contemporary technologies and analysis**
- **The world soil map was published in 1970s by FAO and UNESCO at a resolution of 1:5M, which was then focused to 1:2M for Ethiopia by 1984**
- **The soil map is based on soil surveys conducted in the 1930s to 1970s**
- **The map is generated using soil information and technology from the 1960s - spatial information technologies were not used**

Extracted for Ethiopia at a scale of 1:2M from the world soil map of FAO/UNESCO



Blanket fertilizer application recommendations was the order of the day; a poor approach regardless of the diverse agro-ecological and soil characteristics of Ethiopia

Total fertilizer applied for cereal crop (DAP and Urea)
0000' tones from 2003/04-2010/11

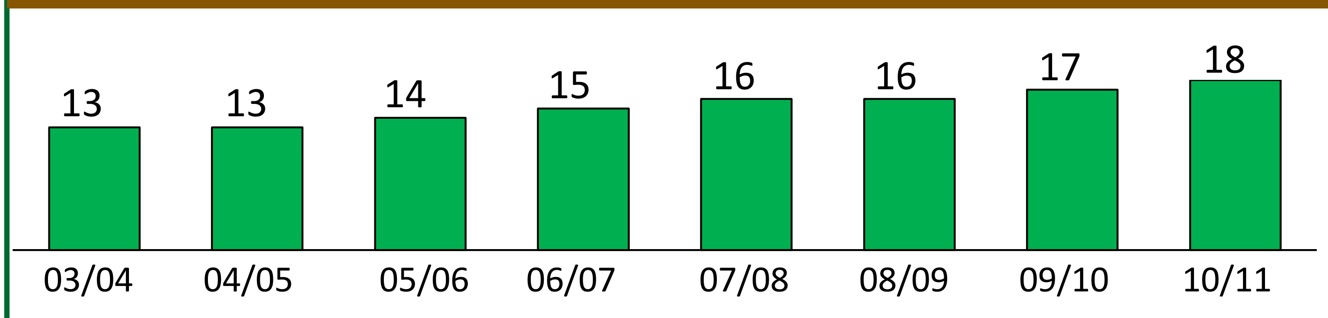


Annual Growth Rate (CAGR)

2003/04-10/11

≈ 10%

Total cereal yield
Qt/ht from 2003/04-2010/11



Annual Growth Rate (CAGR)

2003/04-10/11

≈ 5%

Source: CSA; Agricultural Sample Survey 2003/04-11,

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Systematic problem lead to the establishment of EthioSIS projects and other follow up initiatives in 2012. The GOE committed finance and logistics to implement this at a national scale

Mapping

- Launch Digital Soil mapping (Grid and soil fertility)

Validation

- New fertilizer demonstration activities

Results

- Urgent need to supply **blended fertilizer** to small holders has been identified hence decision to **establish Fertilizer Blending Plants**

Capacity

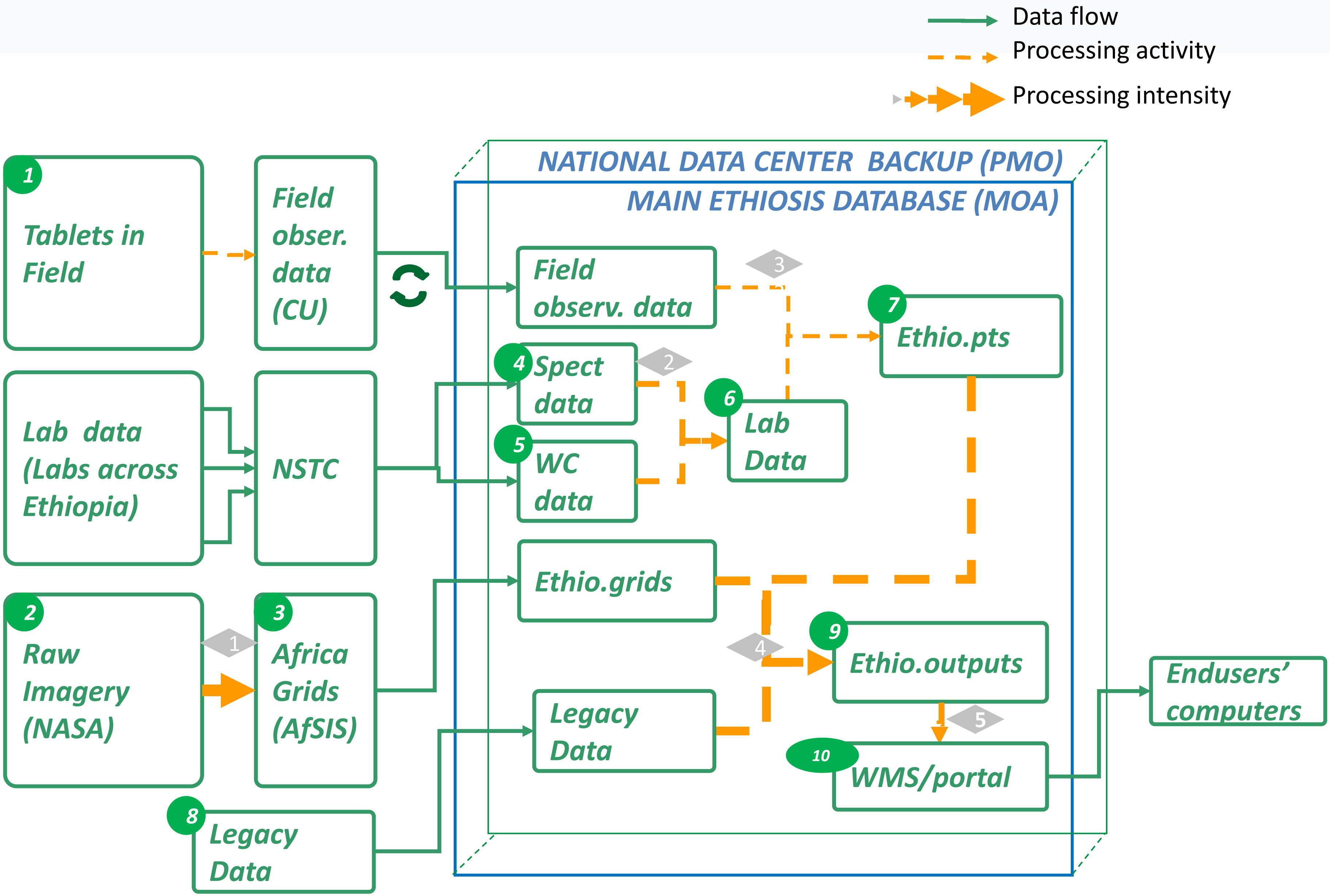
- **Capacity building** key factors in successful outcome of EthioSIS

EthioSIS was focused on mapping grid based bio-physical and woreda based soil fertility characteristics of agricultural lands of Ethiopia

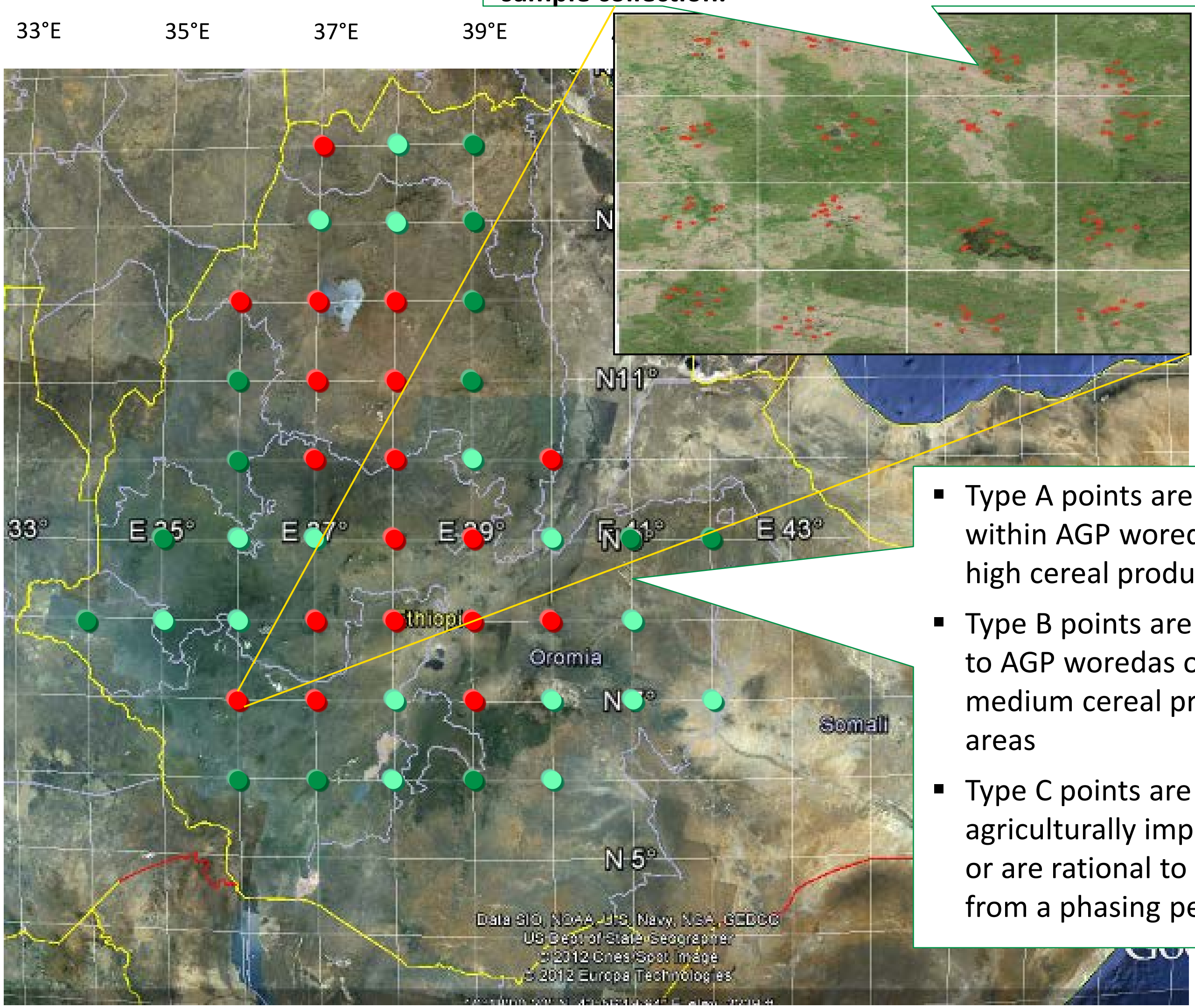
Specifically:

- To generate up-to-date soil fertility information and transform the fertilizer advisory service to farmers.
- To establish a strong and sustainable soil information system.
- To establish a soil resource information database infrastructure.
- To build national capacity in soil resource survey, processing, interpretation and mapping in the country.

EthioSIS workflow, products & services overview



97 latitude-longitude confluence points were expected to be covered across Ethiopia to allow for geo-statistics prediction of the country for land resource mapping



- Type A points are either within AGP woredas or are high cereal production areas
- Type B points are either close to AGP woredas or are medium cereal production areas
- Type C points are other agriculturally important areas or are rational to complete from a phasing perspective

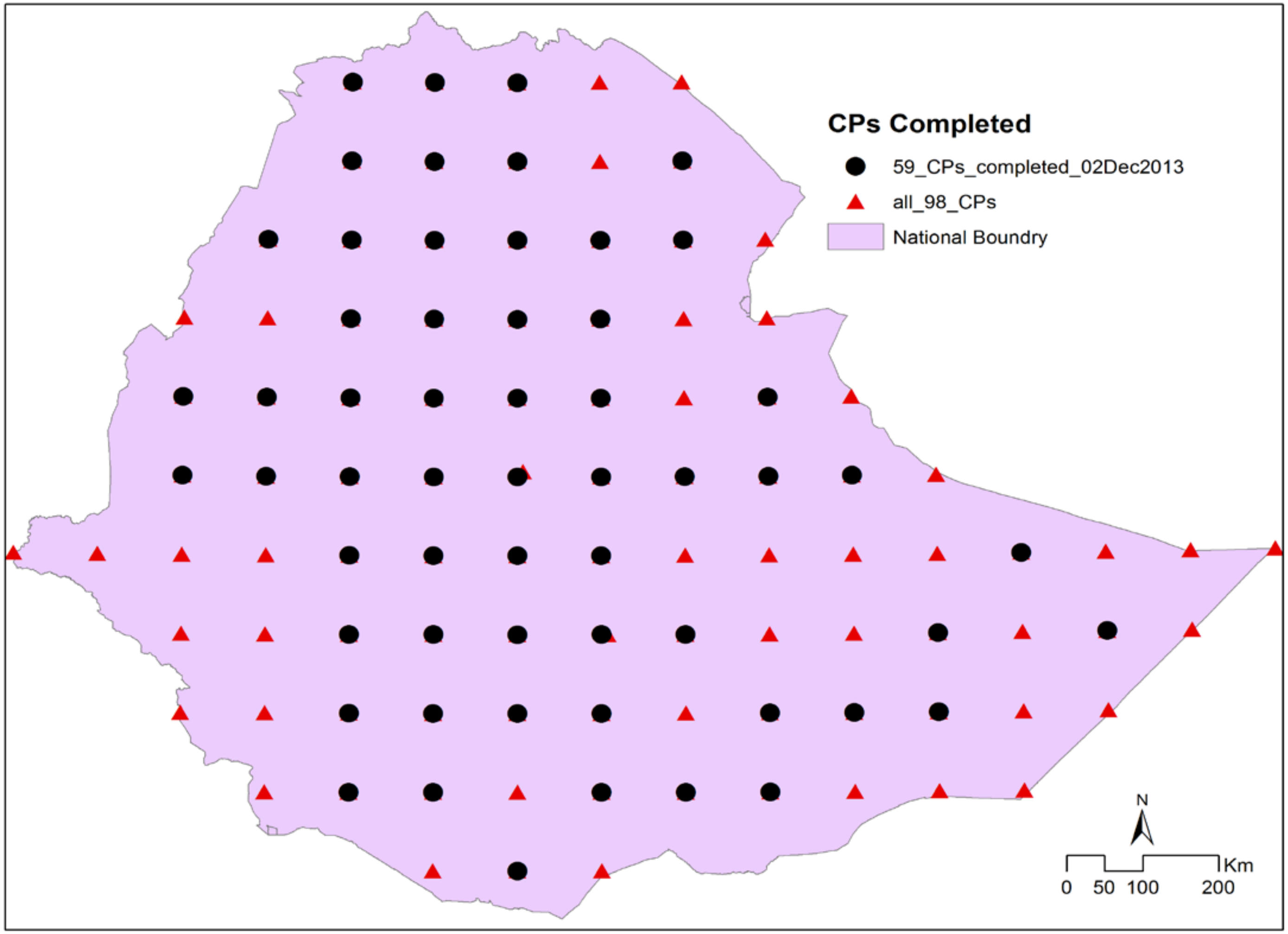
Type A (18)
- Oromia 7
- Amhara 7
- SNNP 3
- Tigray 1
- Gambella
- Benishangul

Type B (16)
- Oromia 11
- Amhara 3
- SNNP 1
- Tigray 1
- Gambella
- Benishangul

Type C (13)
- Oromia 4
- Amhara 3
- SNNP 2
- Tigray 1
- Gambella 1
- Benishangul 2

Source: Team analysis; AGP; CSA

We have achieved soil collection only at 59 CP's. Various challenges have curtailed full performance that will be addressed in the future



Confluence point approaches

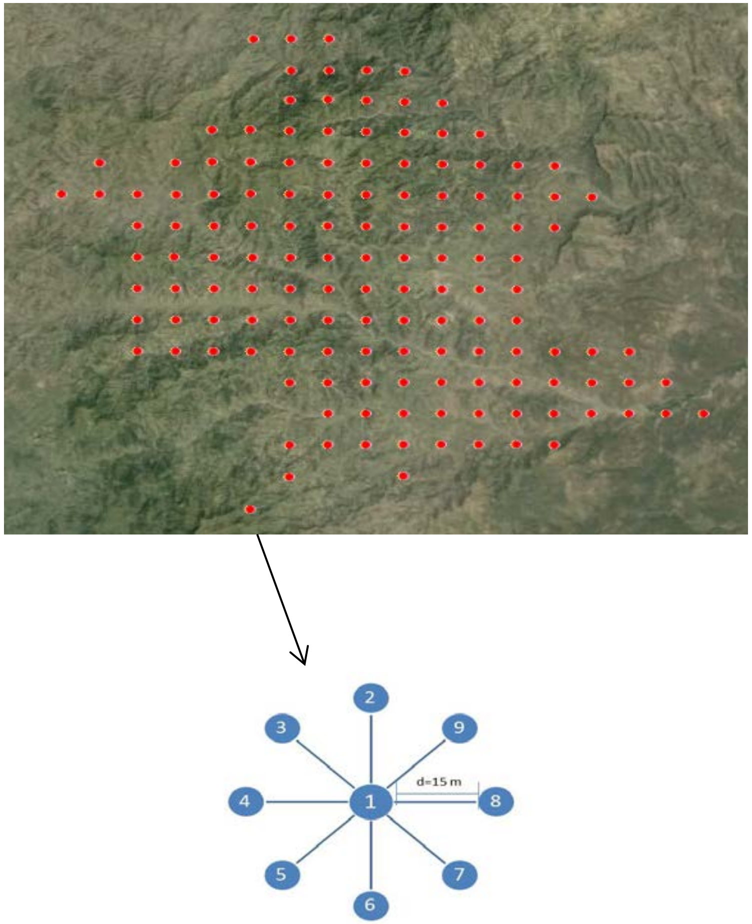
- For physiographic mapping
- Ethiopia has 97 confluence points of latitude and longitude lines

Field Data and Soil Samples Collection Protocol

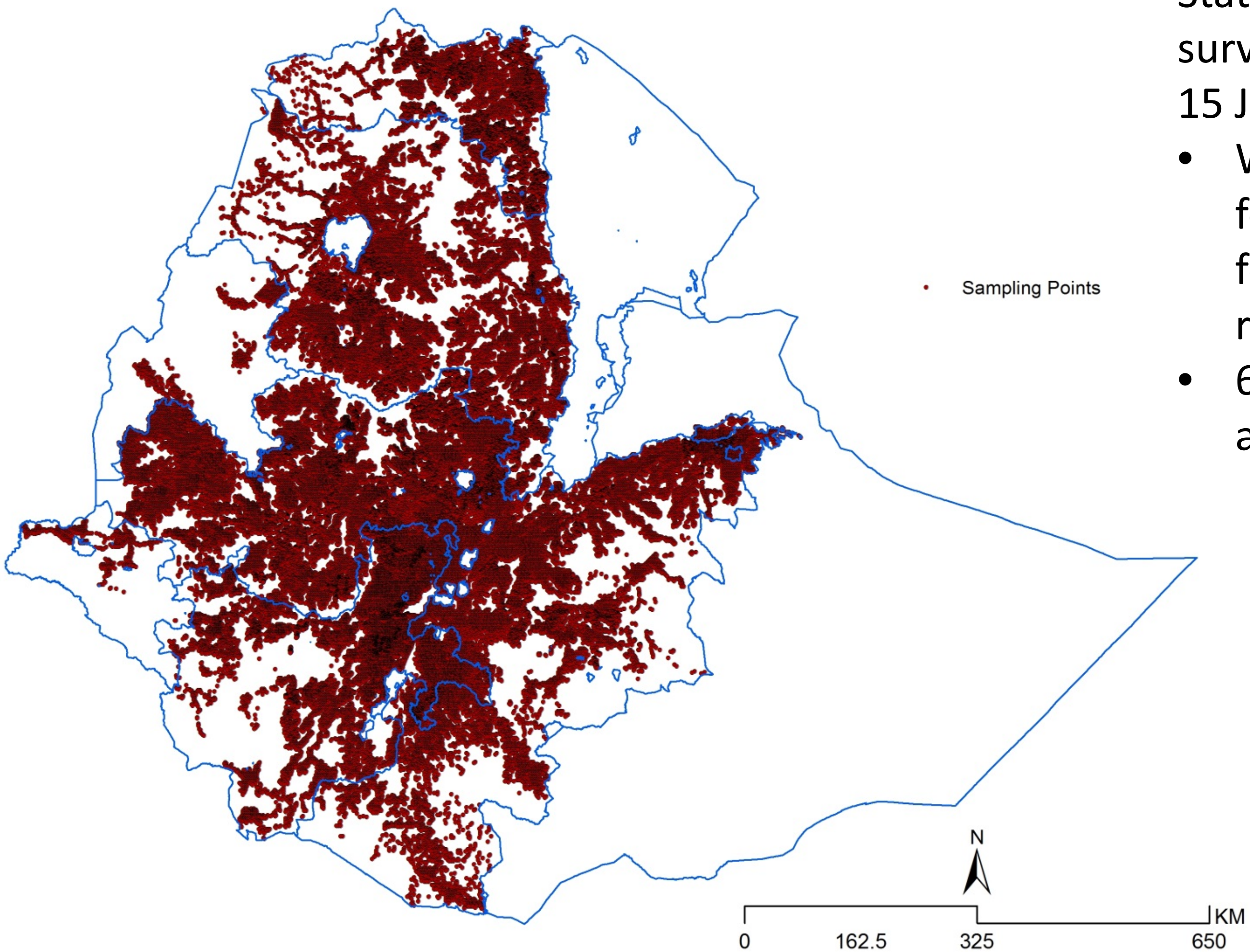
The Sampling Design

- Pre-defined, systematically stratified sampling points
- Top soil: (0 -20 cm) vs (0-50cm)
- Random sub-samples composited to represent a sample
- Geo-coded
- Slope, Topography
- Land management History
- Land use/ land Cover
- Crop growing
- Local soil naming
- Soil color
- Crop residue management
- Other information

Example: Argoba Woreda



Woreda level samples collected from over 65,500 sampling locations to be able to predict the fertility status of the country

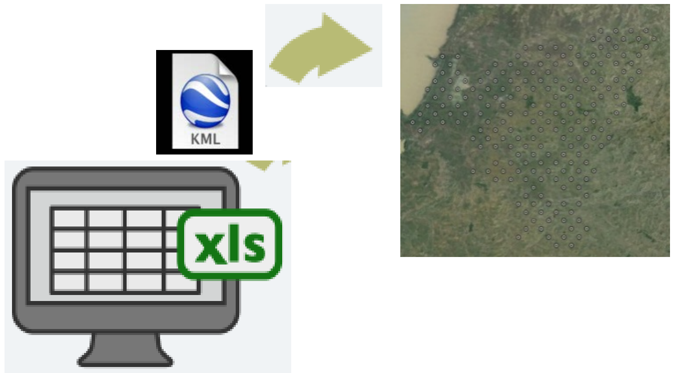


Status of soil fertility survey (585 woredas at 15 June 2016)

- Woreda level soil fertility mapping & fertilizer recommendation
- 65,500 soil samples are collected to date

Mobile/tablets assisted data collection is being implemented

Design



Feed-in Pre-defined points

Collect and send to server

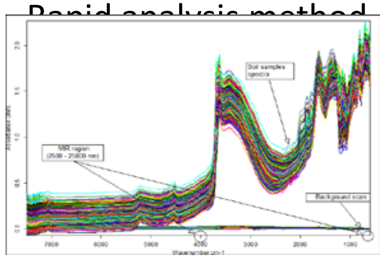
Retrieve, Clean and DB Update

- https://formhub.org/

State-of-the-art technologies are used to analyze soil samples, store and retrieve data

Infrared (IR) spectroscopy and LDPSD analysis

- Analyzing soils using light (IR)
- Rapid analysis method



Wet-chemistry analysis using instruments having high detection limits

- Analysing soils using chemical solutions
- Process is much **slower** than spectral analysis but helps for calibration

Field and laboratory data are being stored in the MOA server

Soil samples are being archived in Kality soil library

SOURCE: Team analysis;

Besides basic wet-chemistry analysis (pH, EC, EA and $CaCO_3$), we are using multi nutrient extraction (Mehlich III) that is able to adequately extract many macro and micro-elements quickly and at a low cost under a wide range of soil conditions

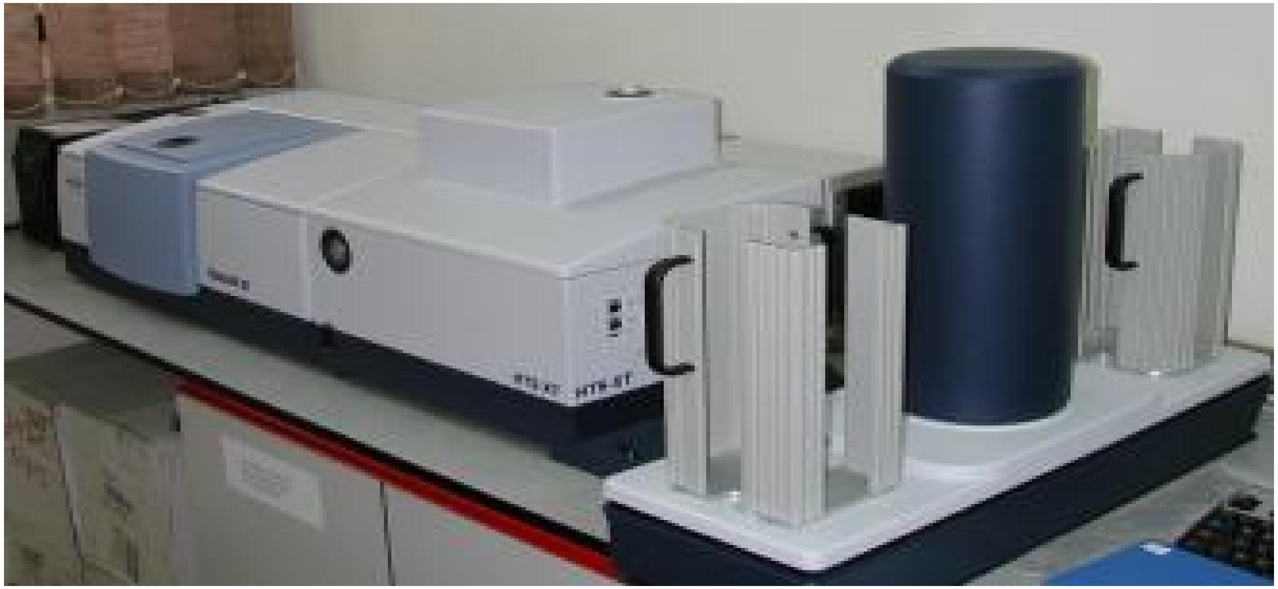
Mehlich 3 (Mehlich, 1984)

This procedure has been proved to work for Ethiopian soils (Tekalign et al., 1996; Haque et al., 2000)

Use to Analyze

- Use of Inductively Coupled Plasma (ICP) spectroscopy – High detection limits
- Determination of Exchangeable Ca, Mg, Na, K, Micronutrients (Cu, Fe, B, Mo, Zn, Mn, Si, Co), Available fractions (P, So_4^{-2}-S), total fraction of Al

IR spectral analysis spectroscopy that is rapid, fast, non-destructive and more accurate techniques that only require limited sample preparation, and enable to determine several properties from a single scan.



Spectral prediction method

Wet chemistry data

Spectral data on samples also analyzed by wet chemistry

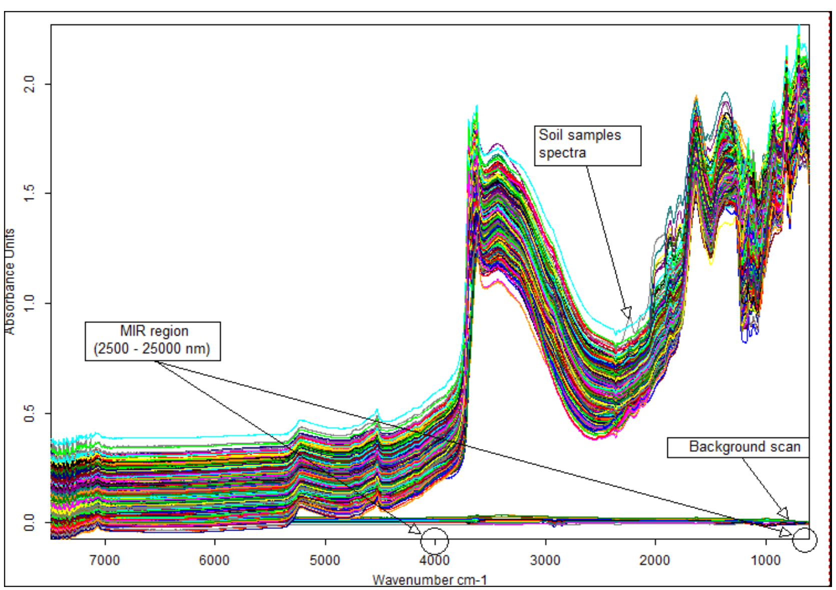
Creation of a multivariate regression model, e.g. by PLS

Prediction

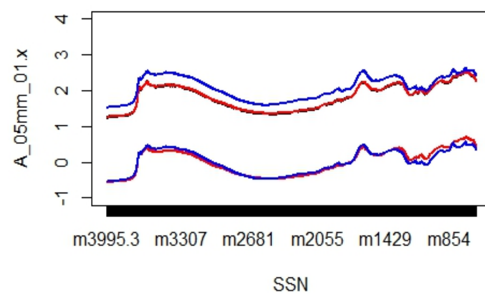
Predicted dataset

Spectral data of unknown samples

MIR spectra (4000 – 400 cm^{-1})



Preprocessing Spectra



Mean Normalized spectra

- First derivative
- Removal of CO_2 region
- Kennard stone algorism

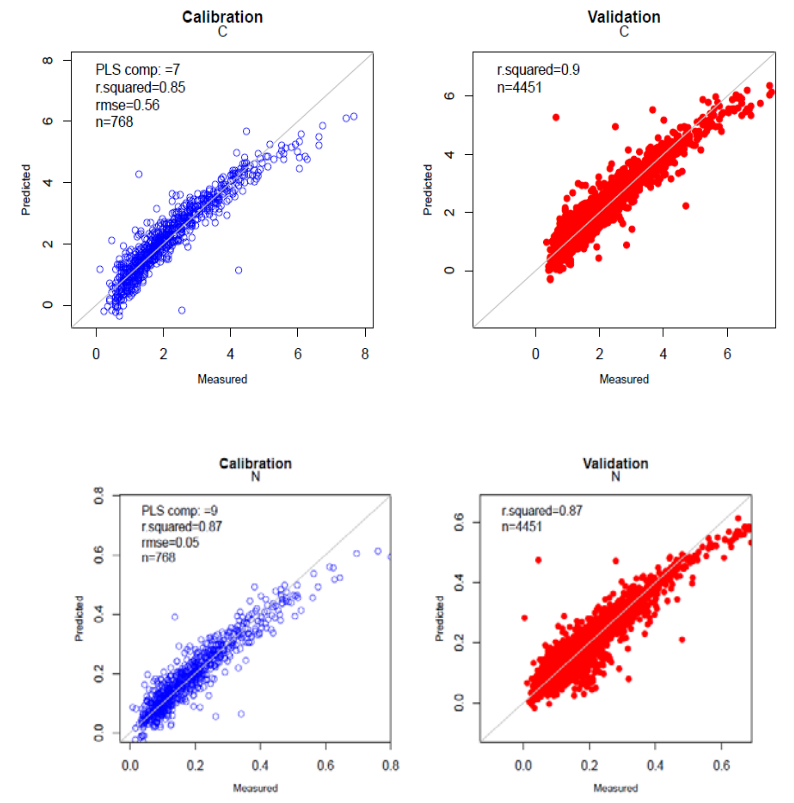
To get pre-processed spectra for modelling

We have developed partial least square regression model (PLSR) models to predict soil properties using spectral data

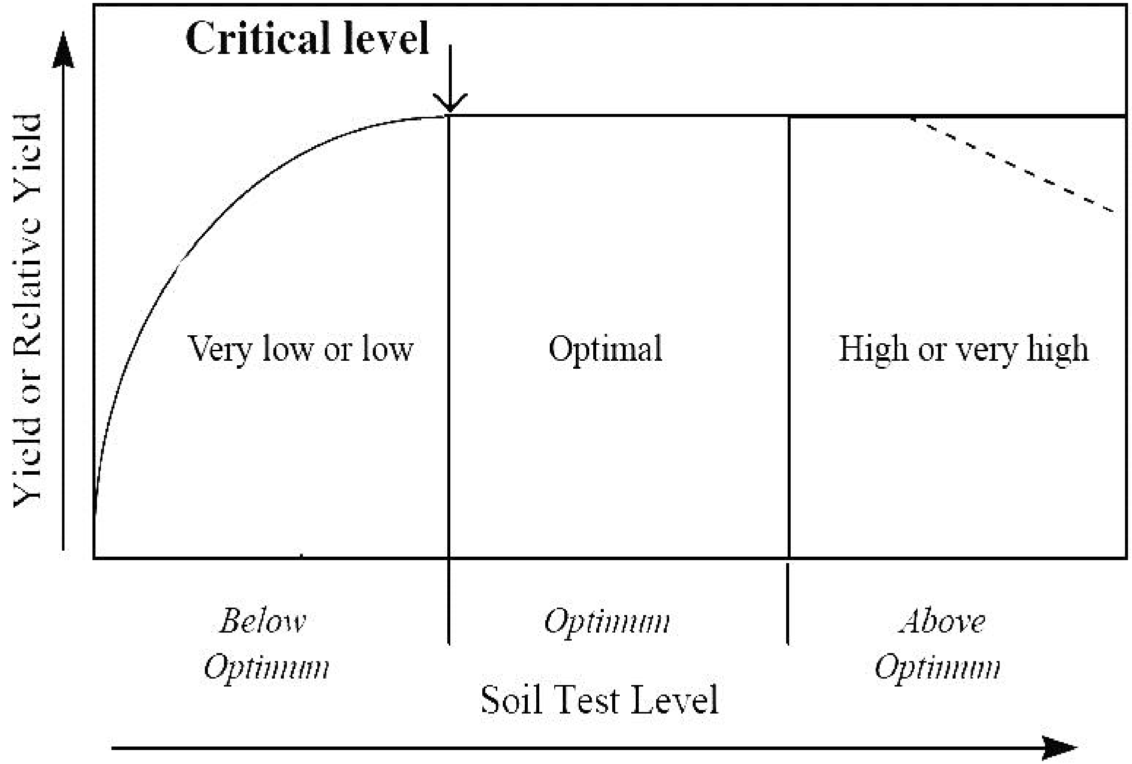
Model Summary

Soil Properties	Coefficient of Determination(R^2)
Si	0.89
N	0.87
pH	0.86
C	0.85
Mo	0.84
Ca	0.83
Al	0.8
Mg	0.72
Fe	0.62

Partial Least Square Regression Model (PLSR)



Methodology: The critical level concept



The curve describes the relationship between yield and below optimum and above optimum soil test values. The critical level is the soil test level, below which a crop response to a nutrient application may be expected. At very high soil test levels crop yield decrease due to toxicity

Based on the soil critical point concept P, K, S, Zn, Cu and B are deficient below 30, 190, 20, 0.5, 0.9, and 0.8 ppm, respectively.

Status	Phosphorus (ppm)	Potassium (ppm)	Sulfur (ppm)	Zinc (ppm)	Copper (ppm)	Boron (ppm)
Very low	**0 – 15**	**< 90**	**< 10**	**< 1**	**< 0.5**	**< 0.5**
Low	**15 – 30**	**90 – 190**	**10 – 20**	**1 - 1.5**	**0.5 – 0.9**	**0.5 – 0.8**
Optimum	30 – 80	190 – 600	20 – 80	1.5 – 10	1 – 20	0.8 – 2.0
High	80 - 150	600 – 900	80 – 100	10 – 20	20 – 30	2.0 – 4.0
Very high	> 150	> 900	> 100	> 20	> 30	> 4.0

Source: Rutgers, Karltun et al., 2013

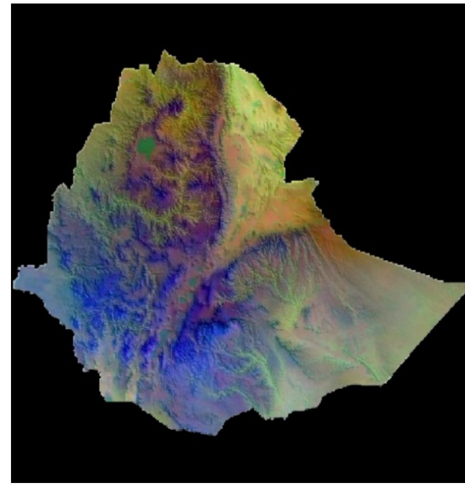
Data types and sources used for geo-statistical modelling and mapping

Data Types:

- Observations (Field Data – Geographic locations)
- Lab Data (wet chemistry and spectral data)
- Covariates (satellite imageries & other legacy data, 2000-2012 average from NASA & Columbia University via AfSIS)
- Admin boundaries (region, zone, woreda & kebele, CSA-2007)

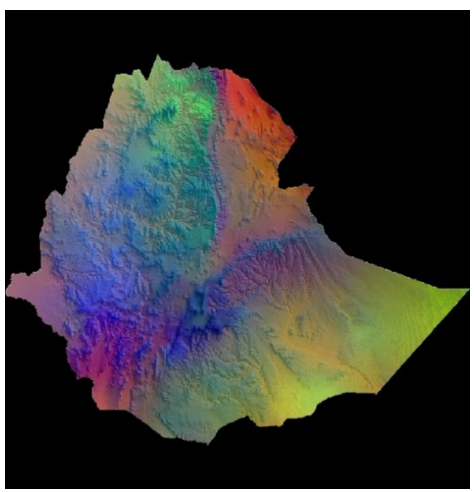
Examples of useful remote sensing covariates for digital soil mapping

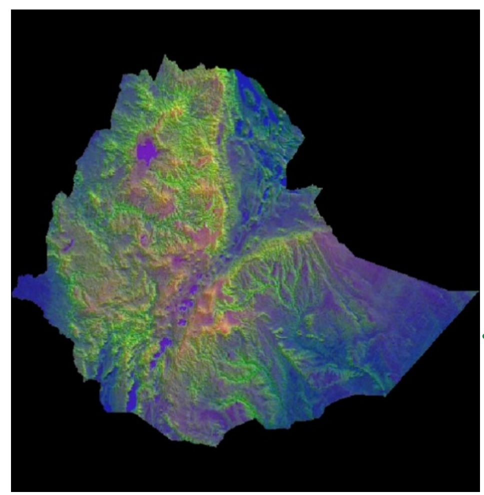
MODIS & Landsat reflectance & vegetation products



MODIS energy balance (e.g, LST, fPAR, albedo)

WorldClim & TRMM climatologies (e.g, MAP Fournier Index & PET)





SRTM & ASTER terrain models (e.g, elevation, CTI, slope, relief)

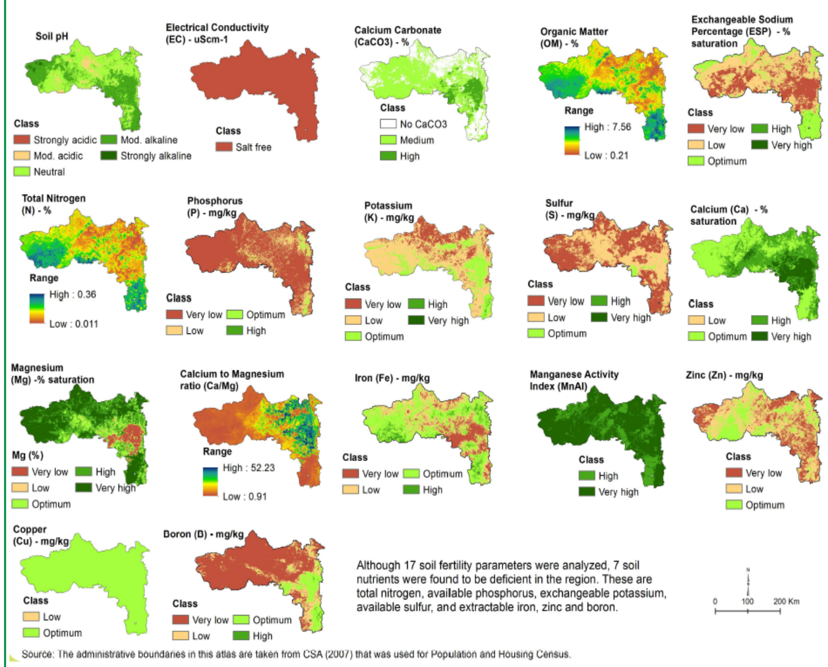
available at: ftp://africagrids.net

- **Using geo-statistical modelling / MLA and Model Ensemble:** Predicted soil nutrients <- as a function of soil nutrient results from lab and other relevant covariates
- **Predict at 250m grid size:** comparing with 1km cell

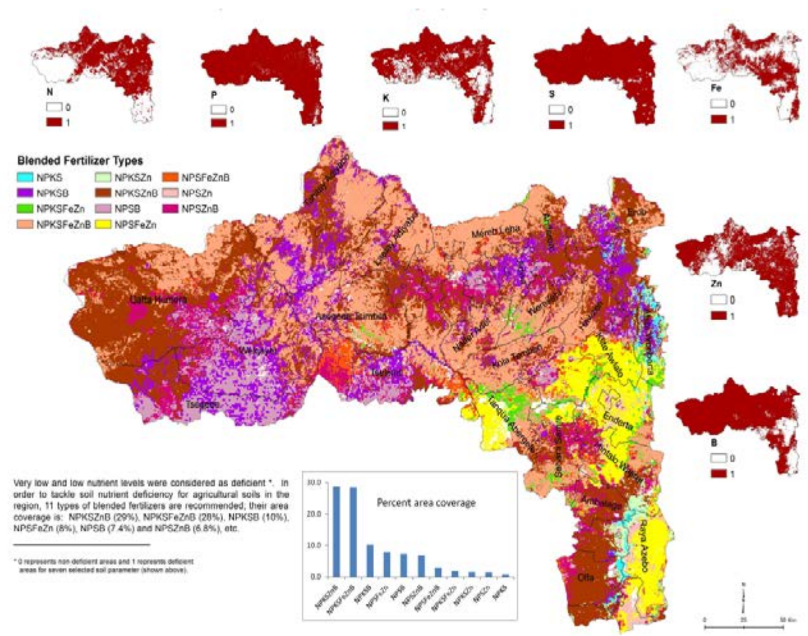
$$pH = \beta_0 + \beta_1 Elevation_i + \beta_2(Slope_i) + \beta_3(RF_i) + \beta_4(Temp_i) + ... + \varepsilon_i$$

In July 2014, Tigray region soil fertility map recommends 11 types of blended fertilizer.

Soil Fertility Status of Tigray Region



Fertilizer Type Requirement of Tigray Region

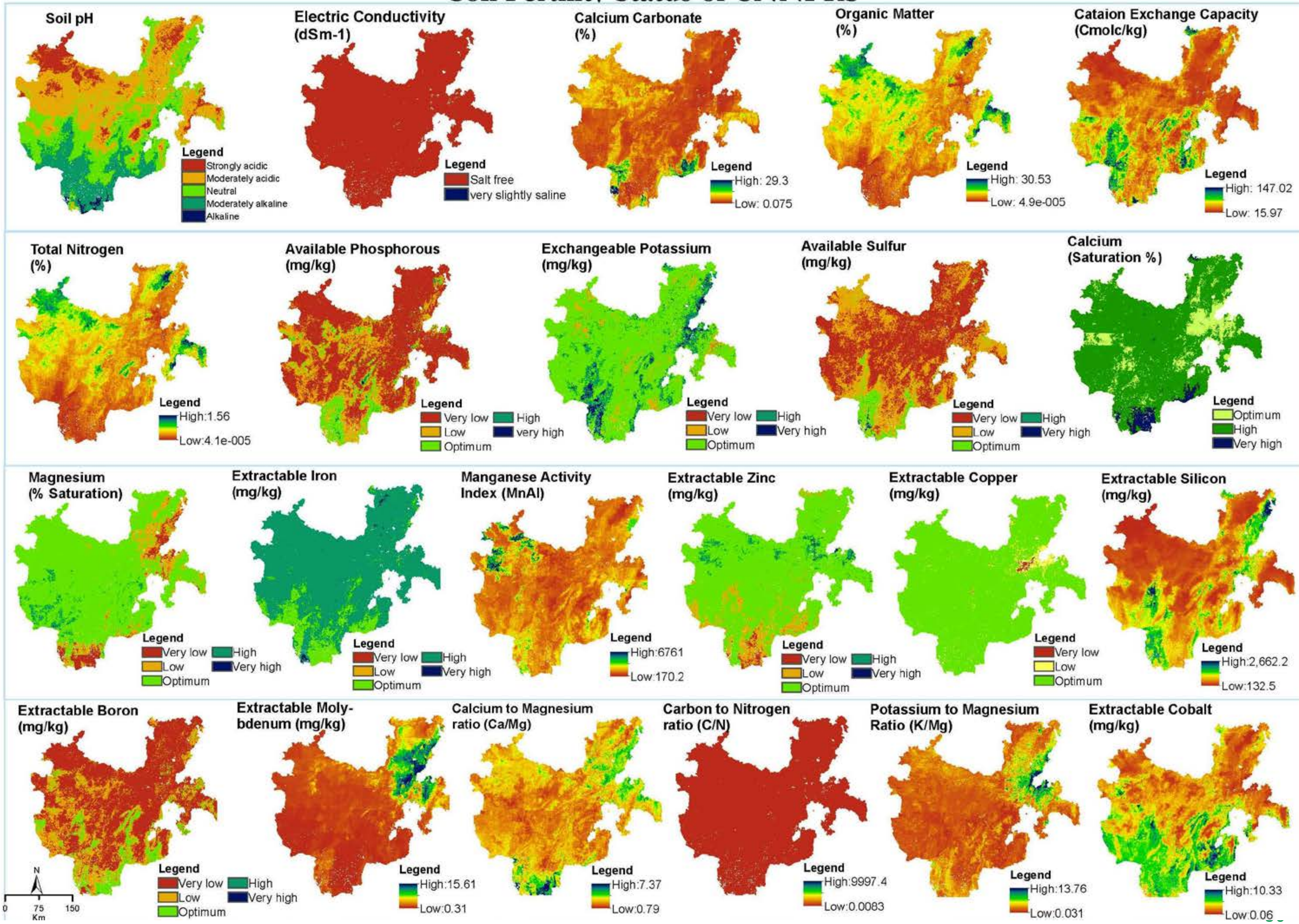


Tigray regional state fertilizer recommendation was revised

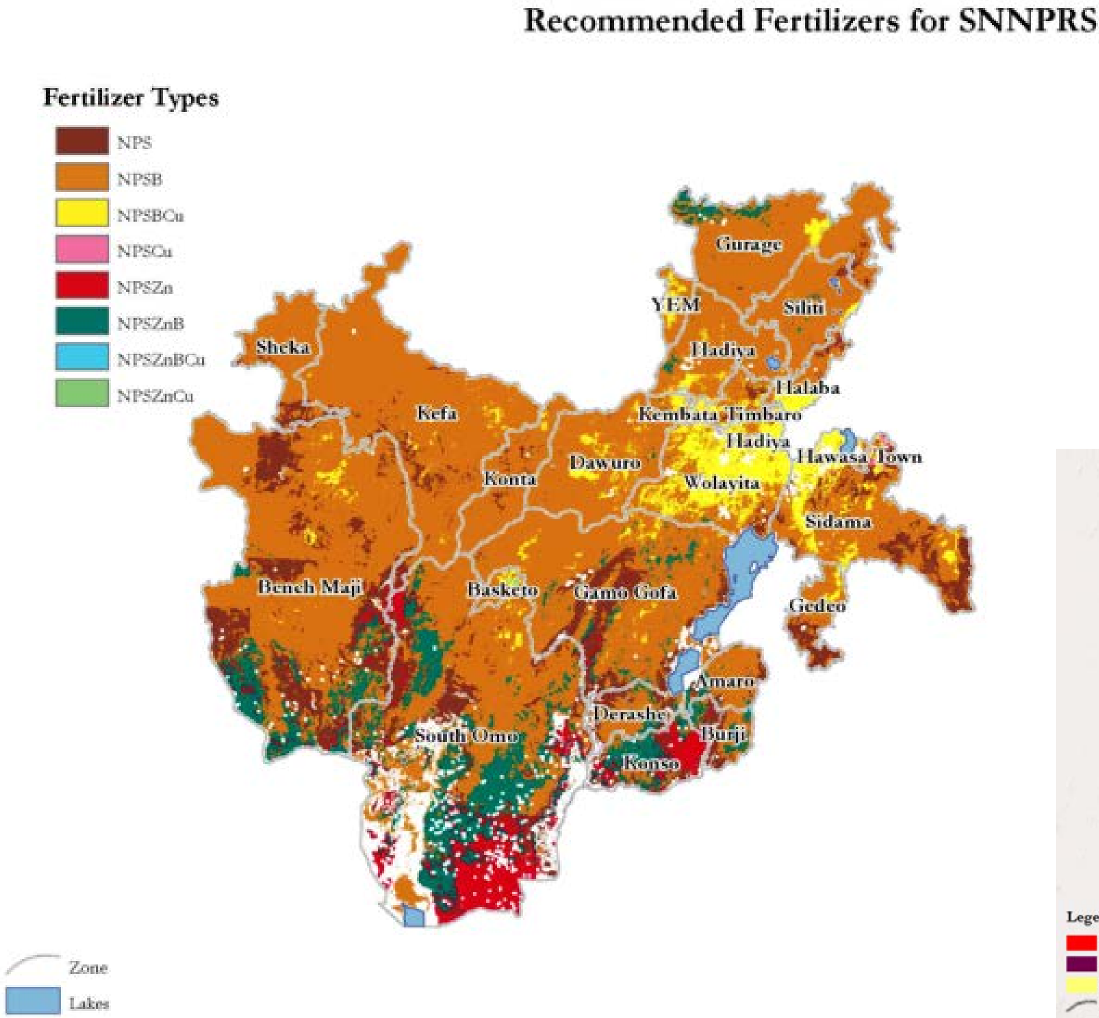
Fertilizers Recommended in 2014	Revised Fertilizer Formulae
1. NPSB: 18 N – 36 P_2O_5 + 7S + 0.71B	1. NPSB (18.9 N - 37.7 P2O5 - 6.95 S - 0.1 B)
2. NPKSB: 13.7 N – 27.4 P_2O_5 – 14.4 K_2O + 5.1S + 0.54B	2. NPSB plus **Potash**
3. NPSZnB: 17 N – 34 P_2O_5 + 7S + 2.2Zn + 0.67B	3. NPSZnB (17.8 N - 35.7 P2O5 - 7.7 S - 0.1 B - 2.2 Zn)
4. NPKSZnB: 13.0 N –26.1 P_2O_5 –13.7K_2O +5.6S+1.7Zn+0.5B	4. NPSZnB plus **Potash**
5. NPSZn: 17.7 N – 35.3 P_2O_5 + 6.5S + 2.5 Zn	5. NPSZn (18N - 35.9 P2O5 - 7.7 S - 2.2 Zn)
6. NPKSZn: 15 N – 31 P_2O_5 – 8K_2O + 7 S+ 2.2 Zn	6. NPSZn plus **Potash**
7. NPSFeZn: 17 N – 35 P_2O_5 + 8S+ 0.3 Fe+ 2.2Zn	7. NPSFeZn (17.8 N - 35.2 P2O5 - 7.6 S - 2.2 Zn - 0.3 Fe)
8. NPKSFeZn: 15 N–30 P_2O_5– 8K_2O + 7.0 S+0.3 Fe chelate + 2.2Zn	8. NPSFeZn plus **Potash**
9. NPSZnFeB: 17 N – 33 P_2O_5 + 7S+ 2.2 Zn+ 0.3 Fe+ 0.5 B	9. NPSBFeZn (17.4 N - 34.6 P2O5 - 7.5 S - 0.1 B -0.3 Fe- 2.2 Zn)
10. NPKSFeZnB: 17 N–20 P_2O_5–8K_2O+11 S+2.2 Zn+0.3Fe+0.5B	10. NPSBFeZn plus **Potash**
11. NPS: 19 N – 38PP_2O_5 +7S	11. NPS (19 N – 38 P_2O_5 +7S)
12. NPKS: 15 N – 29P_2O_5 – 8K_2O + 10S	12. NPS plus **Potash**

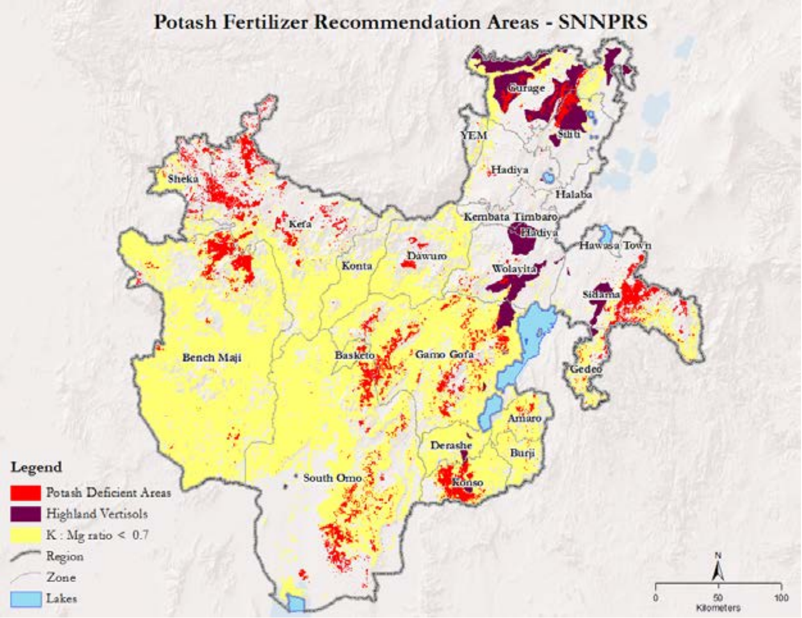
Since we took out potassium from the blend, potash will go with every blend/ compound fertilizer depending upon the soil potassium level

Soil Fertility Status of SNNPRS



Fertilizers recommended for SNNPRS





Fertilizers recommended for SNNPRS, Cont'd

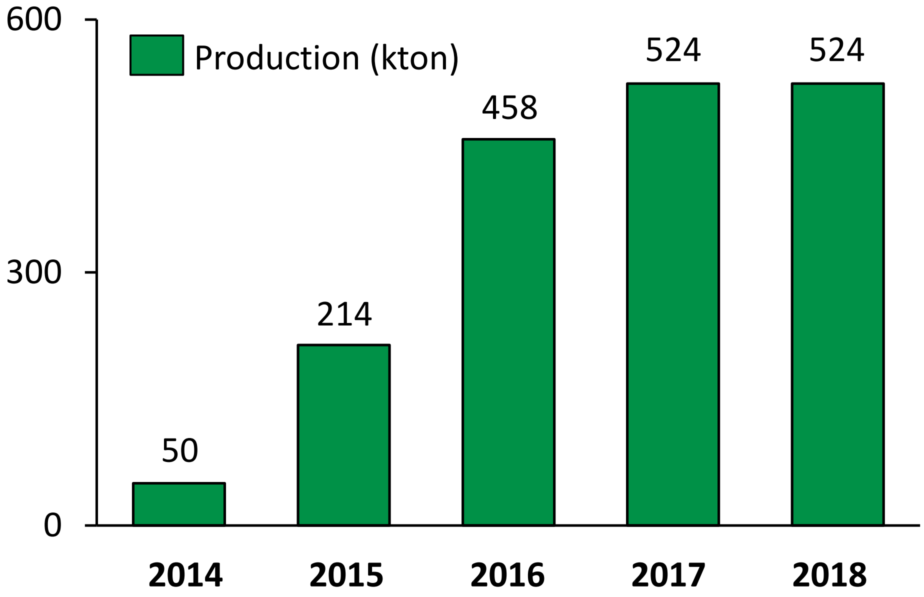
Fertilizer Types	Chemical Formulae
NPS	19 N – 38P2O5 +7S
NPSB	18.9 N - 37.7 P_2O_5 - 6.95 S - 0.1 B
NPSZn	18N - 35.9 P_2O_5 - 7.7 S - 2.2 Zn
NPSBZn	17.8 N - 35.7 P_2O_5 - 7.7 S - 0.1 B - 2.2 Zn
NPSCu	17.6 N - 35.2 P_2O_5 - 8.1 S -1.6 Cu
NPSBCu	17.5 N - 35 P_2O_5 - 8.1 S - 0.1 B -1.6 Cu
NPSZnCu	16.6 N - 33.2 P_2O_5 - 8.8 S - 2.2 Zn - 1.6 Cu
NPSZnBCu	16.5N - 32.9 P_2O_5 - 8.8 S - 2.2 Zn - 0.1 B - 1.6 Cu

The Fertilizer Blending initiative will make it possible for Ethiopia to locally produce up to 500k ton of blends

The Fertilizer Blending initiative

Where	Tigray, Amhara, Oromia(2) & SNNP
Capacity	100kton per plant (500kton total)
When	Production started in June 2014
Status	All the factories are operational

Expected production of local plants (kton)



Distribution of Blended fertilizer is started in 2014/15 planting season

All blending plants are operational. As such, Becho Woliso blending plant alone produced more than 30,000MT of different blends and distributed to smallholder farmers during the last planting season for Oromia region

New fertilizer demonstrations

Executed in partnership with different stakeholders

- Federal and Regional Agricultural Research Institutes
- ATA, MoANR, Agricultural bureaus
- Sasakawa Global 2000
- Higher learning institutions (32 M.Sc and PhD degree students).
- >40, 000 demonstrations, >4.5m farmers.

Dendi, West Shoa (2013)

Tef variety *Kuncho* planted with blended fertilizer had good emergence, grew faster with uniform stand while plots with DAP and urea had less population and irregular stands (Diga woreda, Oromia, 2013)

Row planted, Urea+ Blended fertilizer, planted 15 days after.

Broadcast, DAP + Urea applied, planted 15 days earlier.

Expert demonstrating wheat plot fertilized with NPS Vs, NPS + K (Jawi PA, Lemo woreda, SNNPR, 2013)

Bread wheat response to blended fertilizer without (left) and with (right) potassium (Jjihur kebele, Moretina Jiru woreda, 2015)

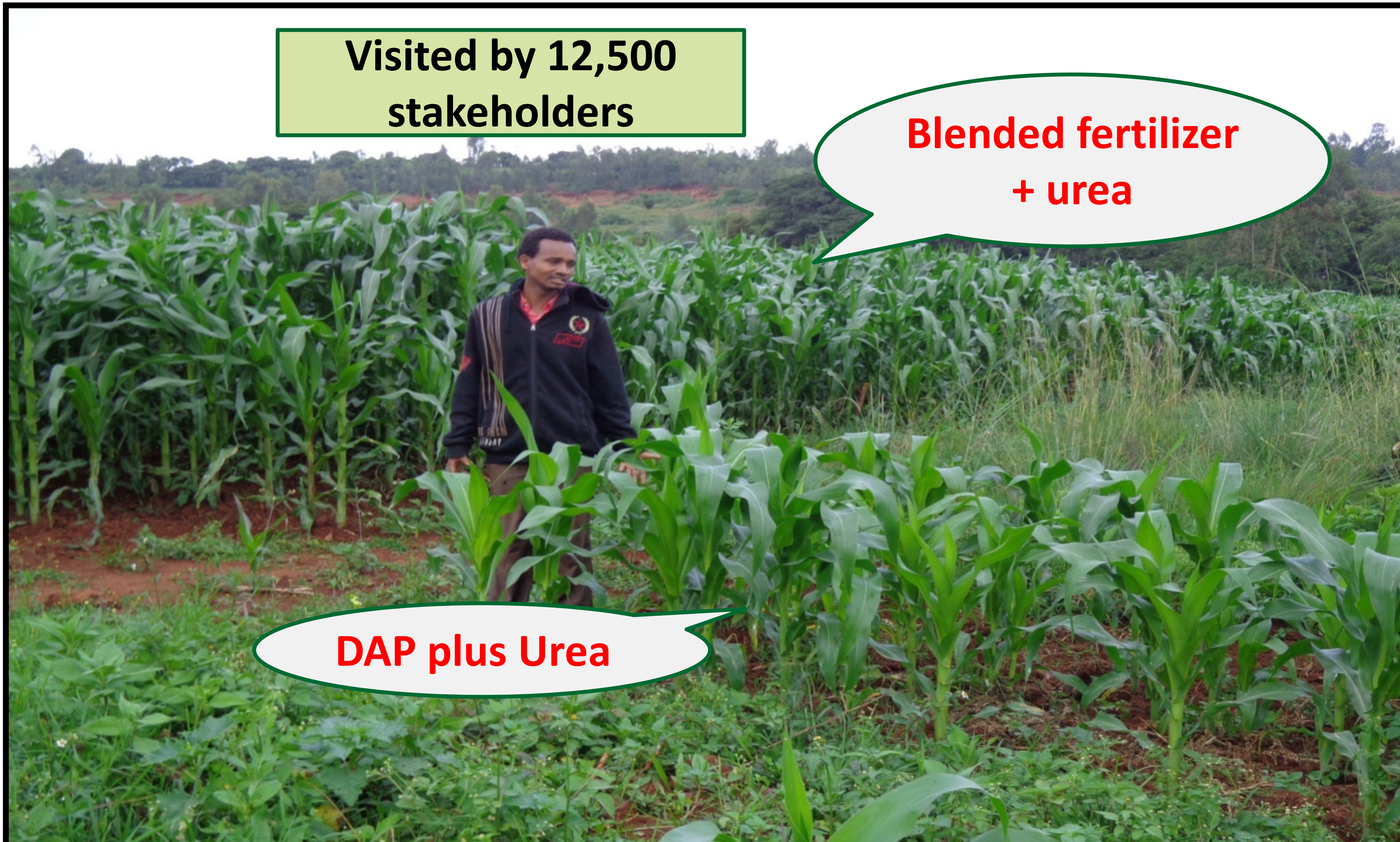
Is this tef , wheat or sugar cane? with 62 tillers? Potassium fertilizer effect, 2015

Response of bread wheat (variety Dand'aa) to fertilizer treatment (NPSZnB) with and without KCl on Vertisols in Woyra Amba Kebele, North Shoa Zone, Moret and Jiru Woreda, Ethiopia (2014)

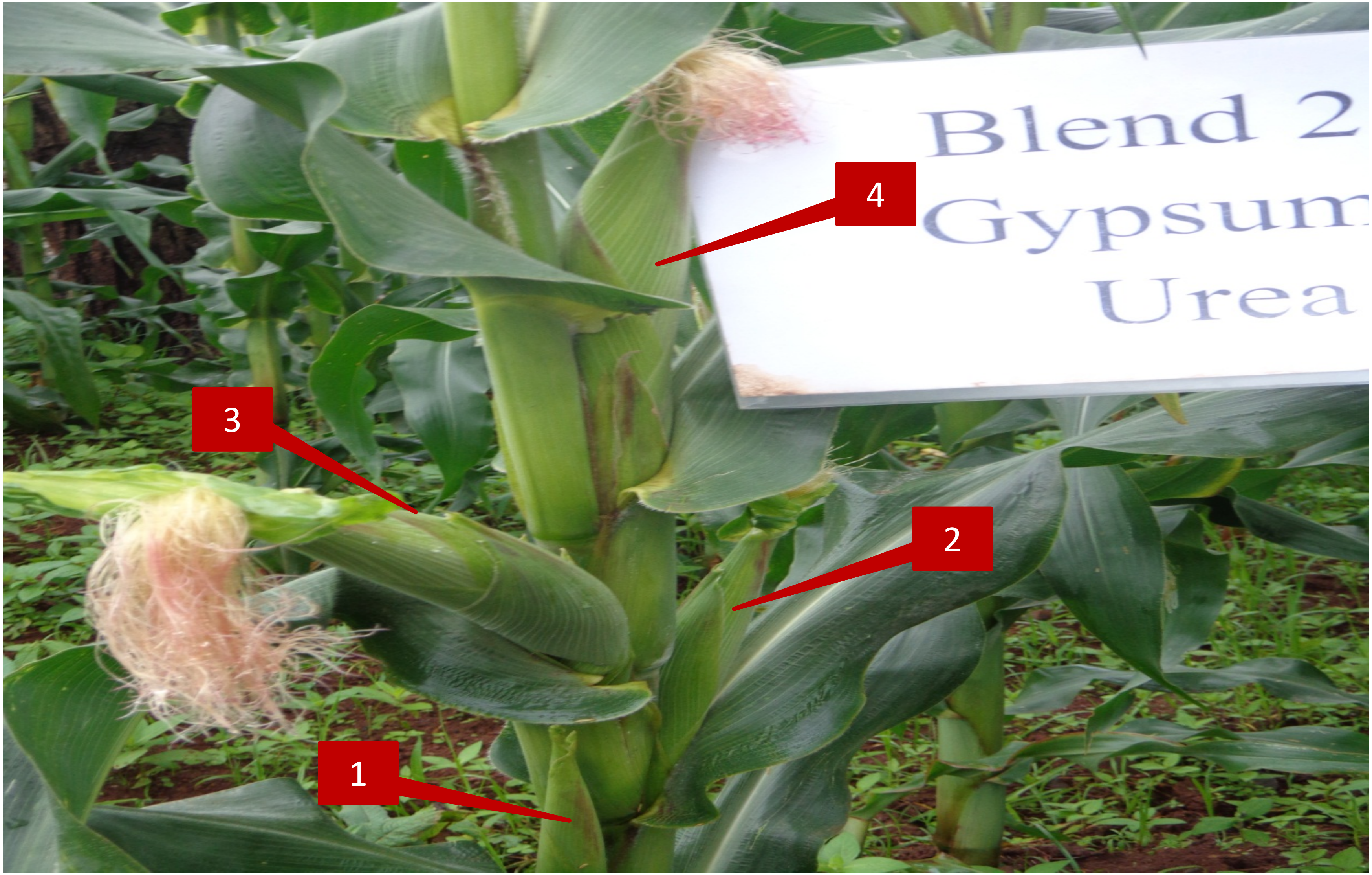
Without potassium chloride

With potassium chloride

Maize planted with blended fertilizer 15 days after the other plot fertilized with DAP + Urea was planted outperformed it after 8 weeks (Wolayta Sodo, SNNPR, 2013)



Maize with blended fertilizer had good emergence, grew faster with uniform stand and 4 ears (Oromiya, Dabo Hana Woreda)



Partners in the implementation of EthioSIS and Fertilizer Blending Initiatives

Federal and regional institutions	Provided soil surveyors , laboratory experts, project support
AfSIS	Technological platform
WU-CASCAPE-Altera	EthioSIS has benefitted from Wageningen University in technical support (IT and Geo-statistics) and funding of 30 woredas' soil mapping.
FAO	Training of geo-statisticians (finance) by sending them to Arusha for four weeks to be able to develop the soil fertility maps.
Yara	International Laboratory in London has volunteered to analyze all soil samples at reduced cost
OCP	Soil fertility mapping and new fertilizer demonstrations
Hawassa/Haramaya University	The EthioSIS team has worked with Haramaya University and extended funding for 9 MSC and 4 PhD students to work on soil mapping and potassium research.
AGP/AMDe	Co-funding one fertilizer blending facility and providing capacity building for staff and management of the five plants.
ICL	Soil fertility mapping and new fertilizer demonstrations

Innovations to help our country grow