AgMIP
The Agricultural
Model Intercomparison
and Improvement Project

ADVANCING GLOBAL AGRICULTURAL ASSESSMENTS:
Building the Next-Generation Global Gridded Biophysical Model System

USAID
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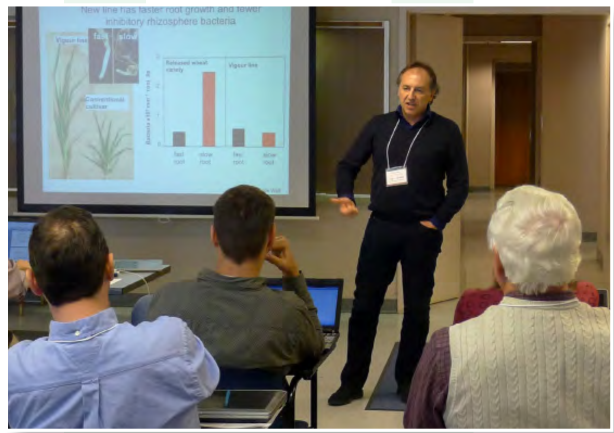
APRIL 9-11 2014
COLUMBIA UNIVERSITY
ARMSTRONG HALL
NEW YORK, NY



Advancing Global Agricultural Assessments: Building the Next-Generation Global Gridded Biophysical Model System

Report on the Workshop to improve the use of soil data in large-scale multi-model tools for climate impact assessments in Africa

April 9-11, 2014 | Columbia University, Armstrong Hall | New York, NY

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A special thanks to Columbia University's Center for Climate Systems Research for hosting this workshop.

Background

In April 2014, AgMIP, in association with USAID, hosted a workshop aiming to improve the use of soil data in climate impact assessments in Africa. The three day workshop, held at Columbia University's Center for Climate Systems Research at the NASA Goddard Institute for Space Studies, pooled the expertise of crop modelers, soil scientists and data/IT specialists to improve the interoperability of models and datasets for large scale assessments in the context of sub-Saharan Africa. This region is particularly vulnerable to the potential impacts of climate change thus necessitating the ability to evaluate the future food security and to assess the potential agricultural impacts into the future. Such analyses will become increasingly relevant for policymakers and stakeholders, as well as the greater African population, to develop coherent strategies for mitigating negative consequences and bolstering adaptation responses.

This workshop is the 3rd in the series. The first was hosted at the University of Florida in April 2013 and focused on issues around the development of software platforms for large-scale multi-model simulation of crop yields and climate impacts globally and in Sub-Saharan Africa (which was the focus of the first half of the project). The second workshop, hosted at the University of Chicago in September 2013, brought together modelers with experts on data and information technologies to demonstrate the prototype of the multi-model platform. This workshop concluded with plans for data and applications work that constituted the second half of the project.

The Columbia University workshop began with presentations overviewing a broad spectrum of topics ranging from the current state of APSIM and DSSAT multi-scale maize simulations in Southern and Eastern Africa to a presentation of ongoing soil projects and data products to a status report of S-world, a global dataset of soil properties, to an update of a recent meeting held in Australia on soils in APSIM. The workshop then devoted the remainder of the two and a half days to specialized breakout groups allowing for dynamic interactions and productive collaboration between specialists. This workshop was designed to facilitate the creation of a provisional multi-model simulation framework for an improved open-source gridded biophysical capacity at both global and regional scales using DSSAT and APSIM (as initial demonstration models), the assessment of multi-scale multi-model maize yields in Southern and Eastern Africa, and the preliminary exploration of gridded soil datasets designed for multi-model multi-scale assessment.

Notable Results

1. Development of a new version of S-world (S-world Africa)
   - Uses the AfSIS soil profile database instead of the ISRIC-WISE Harmonized Global Soil Profile dataset to do improved mapping in Africa
   - Greatly increased the number of output variables (shown separated into the 4 S-World variable groups in the Fig. 1.

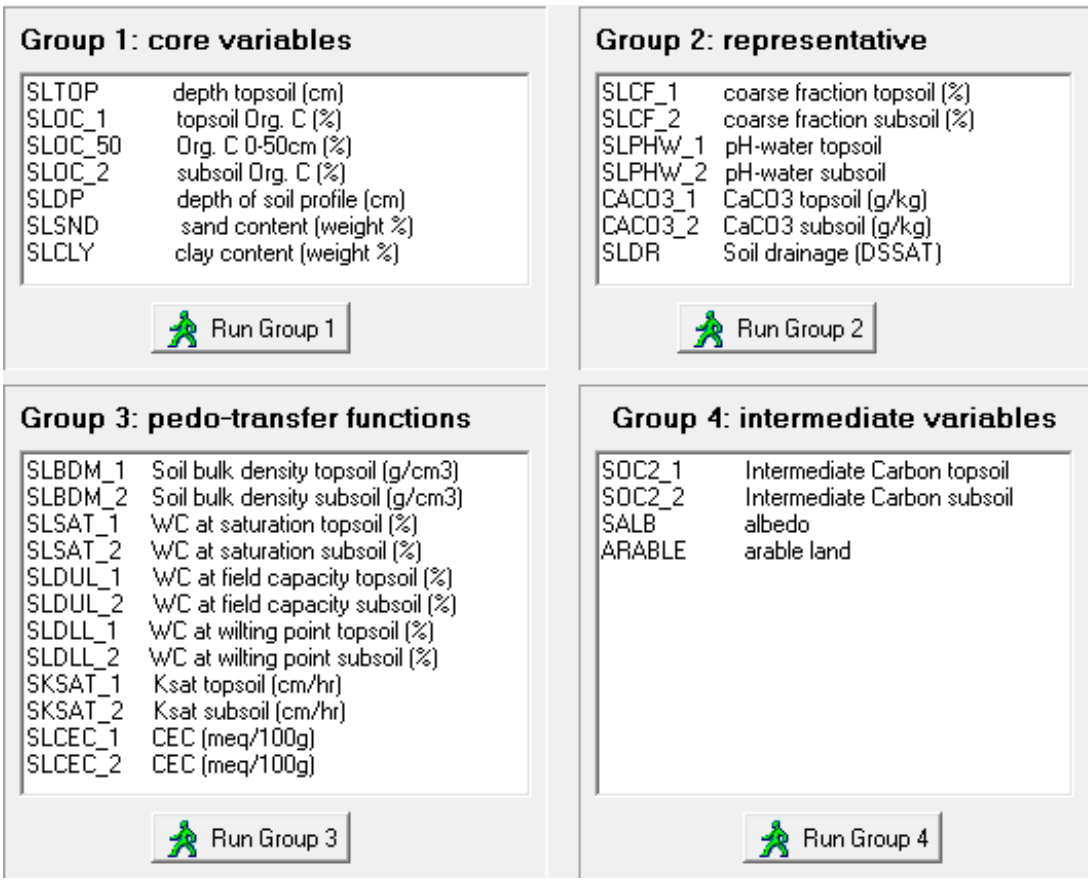

Figure 1: Screenshot of the output variables available through S-world Africa

2. Simulations and preliminary comparison of maize yields in Sub-Saharan Africa using 3 soil datasets of increasing complexity from Harvest Choice (Fig. 2):
   - HC3: A very simple representation using only 3 profiles (based on texture classes) to map soils globally
   - HC27: A representation using only 27 profiles (based on texture class, profile depth, and fertility level) to map soils globally
   - HC3K: A representation using the approximately 3,000 ISRIC WISE soil profiles to map soils globally.

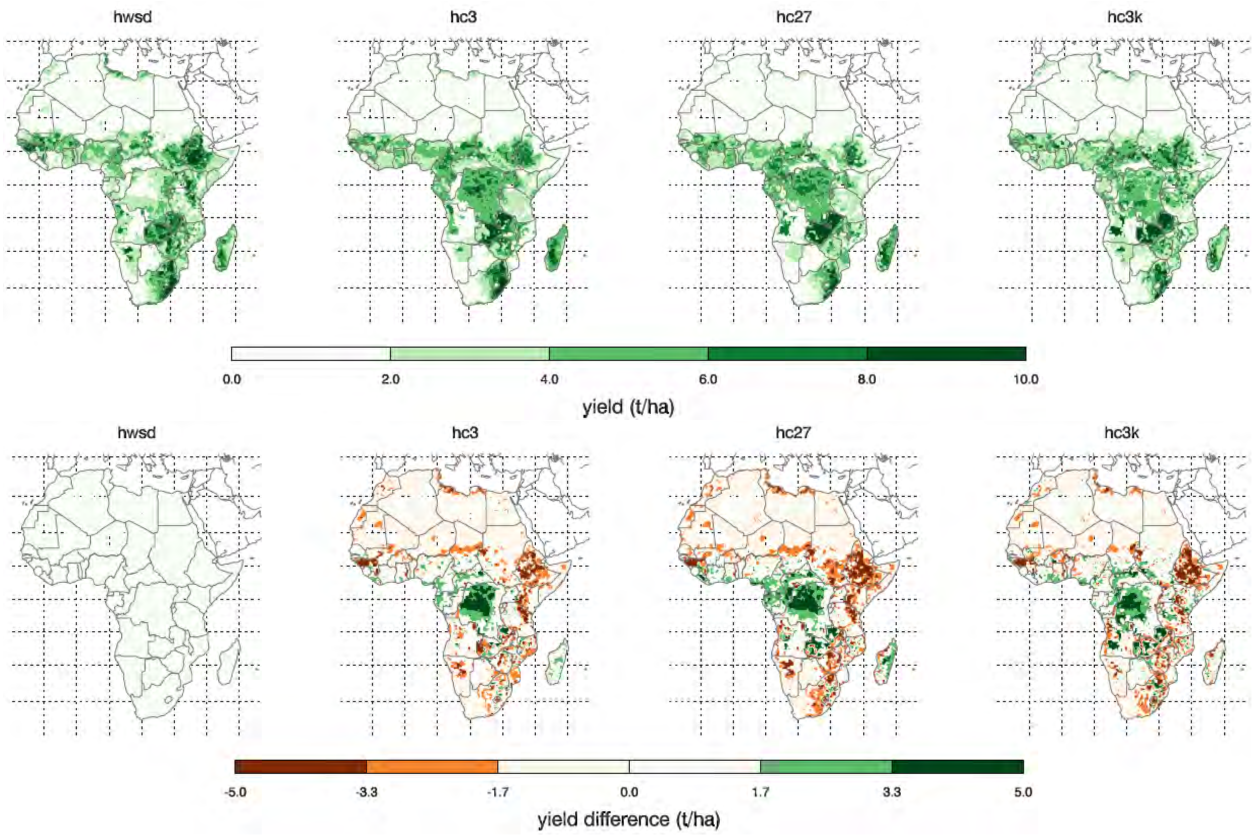

Figure 2: Comparison of simulated maize yields using inputs from HWSD, HC3, HC27, and HC3K.

3. Preliminary assessments between S-world (version 2, April 23 2014) and the AfSIS interpolated 1km soil maps (accessed April 7 2014) as shown in Figures 3-9 below. Our preliminary analysis highlights the importance that land-use change state and history plays in determining soil properties, especially in a region such as SSA with very dynamic soil properties and poor soil management in many areas. However, much work is still needed to understand these differences and the role they play.

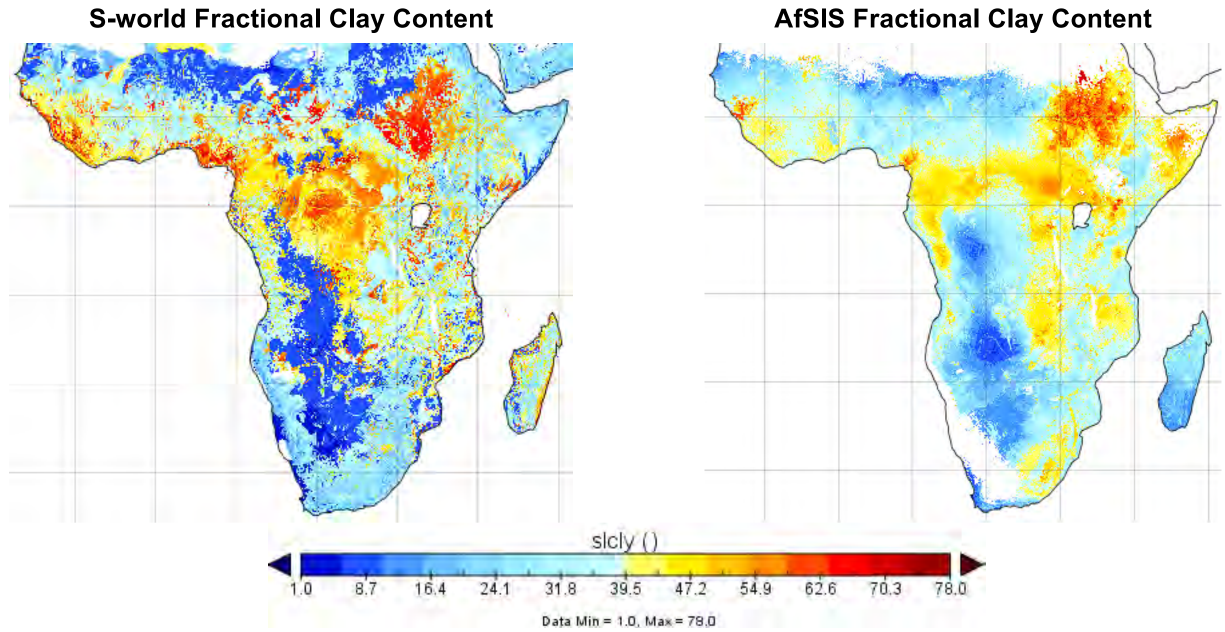

Figure 3: Fractional clay content from S-world (left, total profile) and AfSIS (right, 100-200cm subsoil only). On average, the AfSIS clay content in the top 5 cm is about 20-40% lower than the clay content in the bottom 100cm. The most obvious area of disagreement is the Congo basin, which S-world models show as having much higher clay content. The relatively lower S-world clay content in Eastern Africa, specifically in the Horn, is also notable.

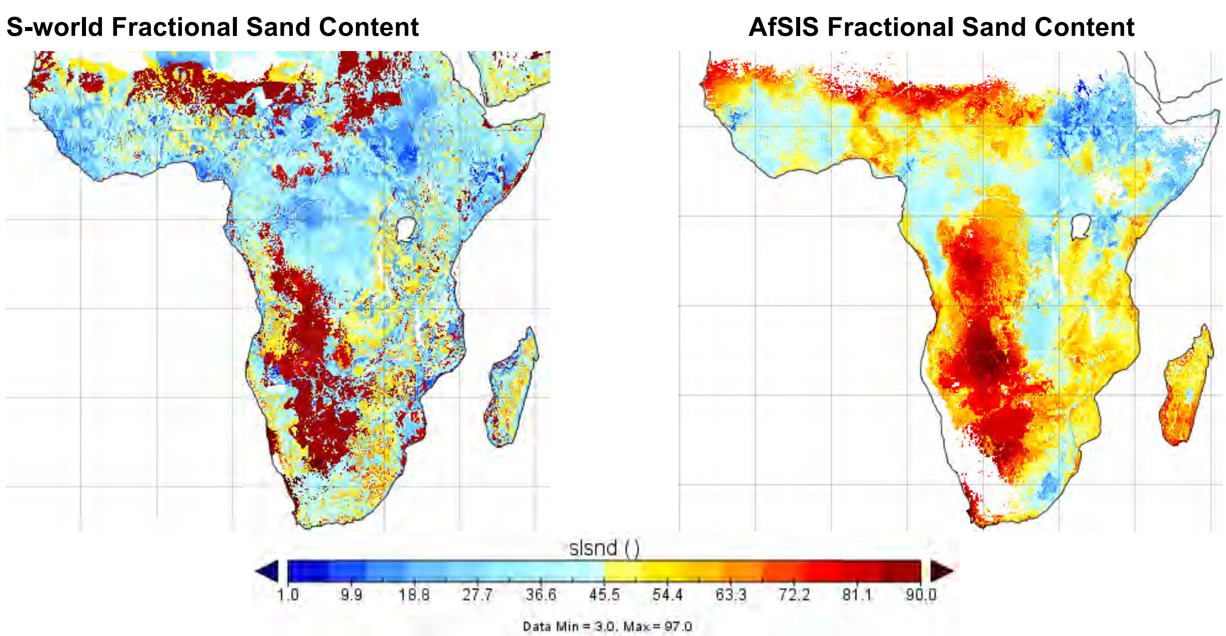

Figure 4: Fractional sand content from S-world (left, total profile) and AfSIS (right, 100-200cm subsoil only). On average, the AfSIS sand content in the top 5 cm is about 10-20% higher than the sand content in the bottom 100cm.

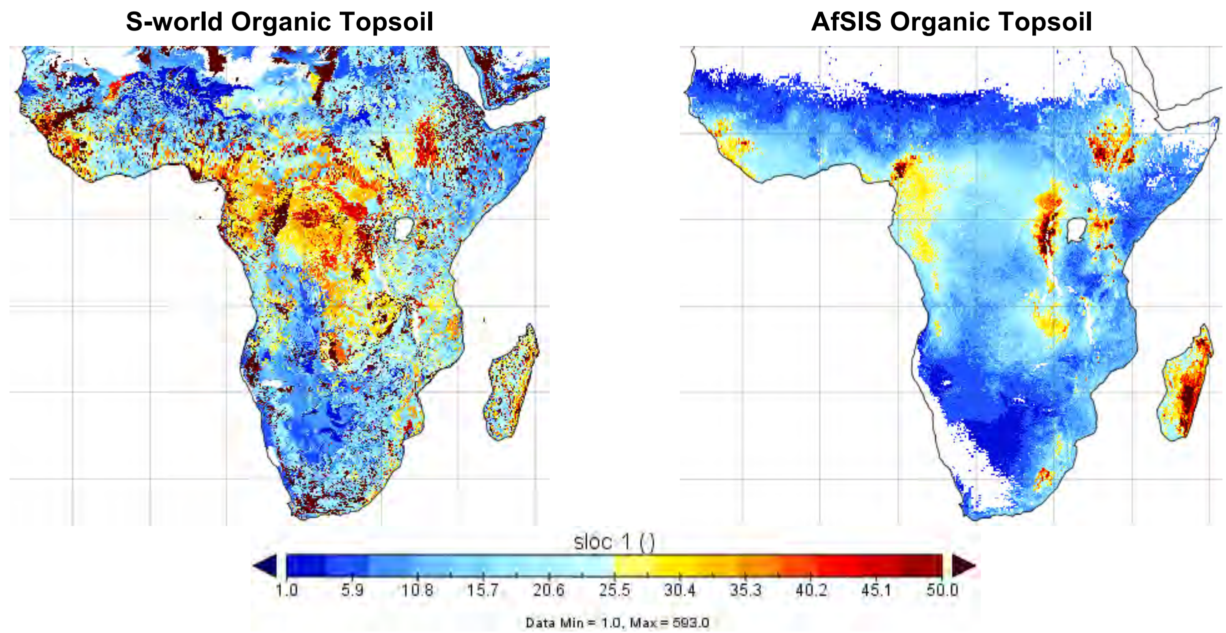

Figure 5: Top-soil organic for S-world (left, 0-50cm) and AfSIS (right, 0-5cm depth). The maximum value in the AfSIS file is 220 g/kg. Besides the obviously substantial difference in the Congo basin, the basic patterns are fairly consistent here. Presumably the high level of apparent "noise" in the S-world map is due to discrete changes in land-use and soil units in these regions and is thus a feature rather than a bug. The smooth gradients in the AfSIS map are the result of the interpolation. The comparison still deserves additional study.

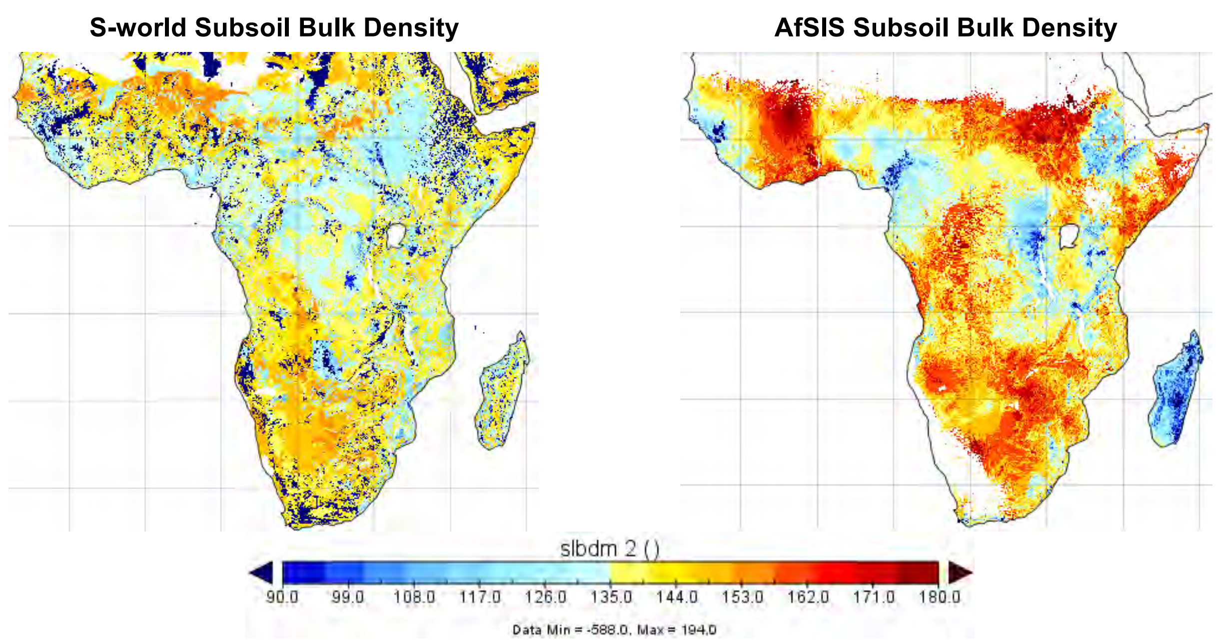

Figure 6: Subsoil bulk density for S-world (left) and AfSIS (right, 50-100cm depth).

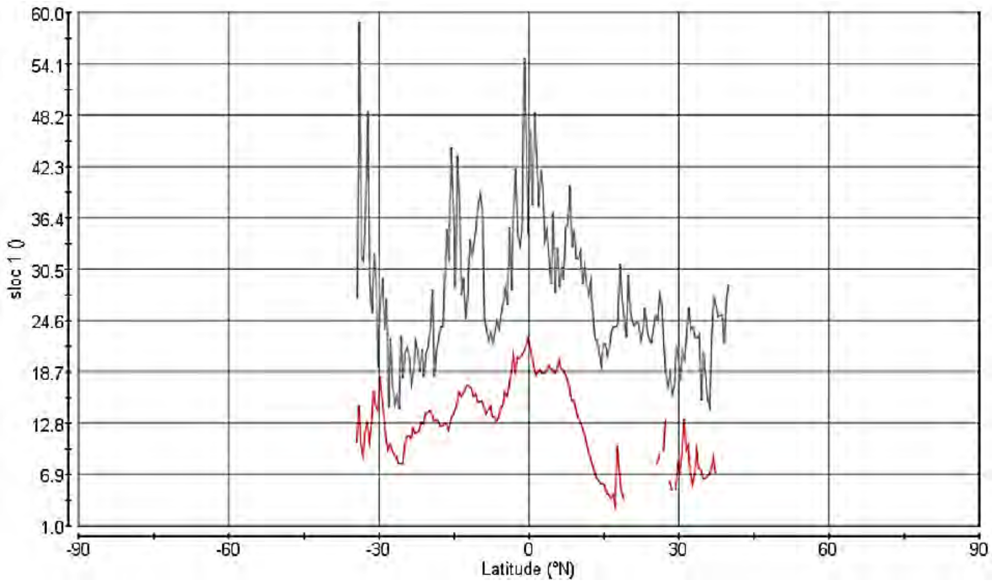

Figure 7: Topsoil SOC from S-world (black) and AfSIS (red) averaged by latitude. This view highlights the strong similarity in how the datasets vary North to South, though S-world tends to show 50-100% larger SOC values. In the South, it looks like this could be largely due to high SOC values in S-world in areas where AfSIS has no data (white in Figure 3). According to AfSIS, these white pixels are locations with zero vegetation.

S-world Arable Land Fraction

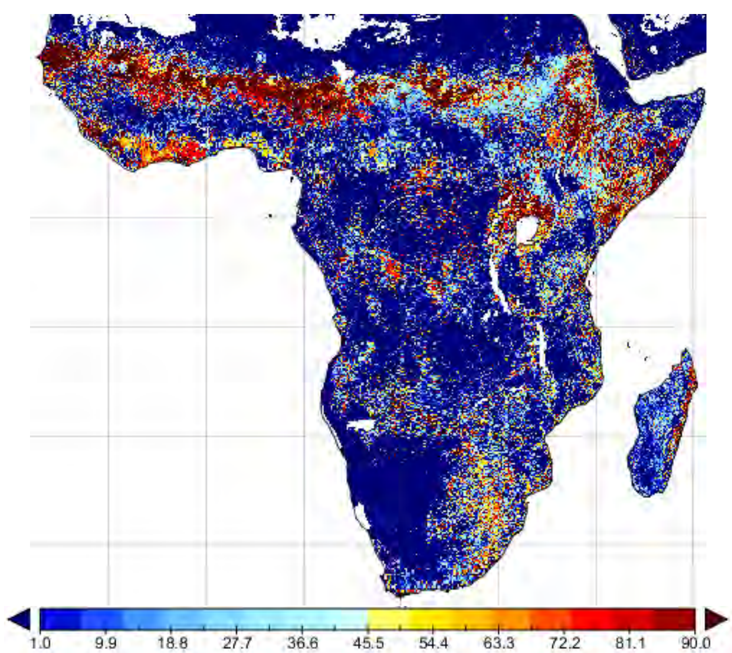

Figure 8: Fraction of gridcell denoted as arable land in S-World (based on the GlobCov database). A lot of the areas where there is the strongest disagreement between S-world and AfSIS are pixels that S-world considers to have little or no arable land. Perhaps these pixels should be masked out of both datasets before we do any rigorous comparisons.

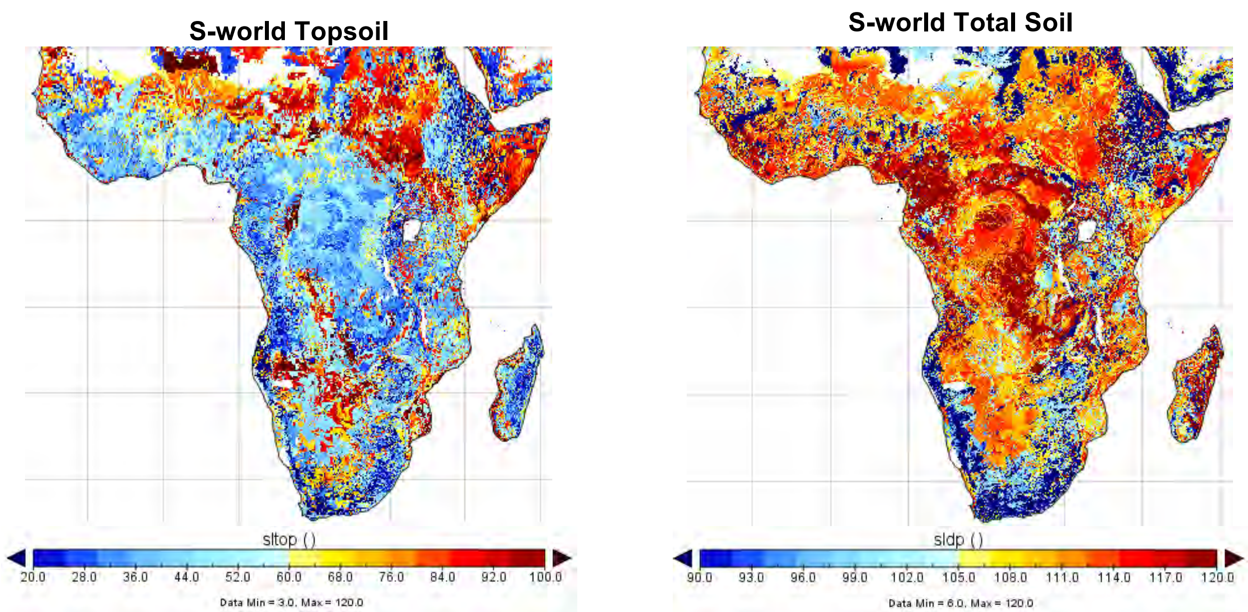

Figure 9: Topsoil (left) and total soil (right) depth from SWorld.

Additional Results

Other smaller or intermediate deliverables developed over the course of the project and during the 3 project meetings include the following:

1. Development of translators for soil datasets → pSIMS
2. Development of pedotransfer functions to be used by modeling community and AgGRID
3. Incorporation of AfSIS dataset in AgGRID framework
4. Agreeing on how best to harmonize soil initial conditions (H_2O, residues, mineral nitrogen (NO_3), and soil carbon pools (SOC) to allow for effective and prudent intercomparisons
   - Soil water will be initialized at 75% of the DUL 2 months before planting.
     - If user wants to initialize the model after harvest, then values close to DLL need to be used.
   - Soil NO_3 will be a function of the total N which is a function of the total carbon
     - Total soil N = 0.1 (10%) of total carbon
     - Soil NO_3 = 0.0001 (0.1%) of total nitrogen = 0.00001 (0.01%) of total carbon (ppm NO3+NH4 in a layer equals same absolute value as percent SOC).
   - Residues include roots which are 15% of the total above-ground biomass
     - Necessary to get an estimate of the total biomass (or yield) from FAO Regional Yields

        - Will use an average **0.4 harvest index** to estimate the possible residues left at the surface
        - Many areas in Africa are pastured/grazed so we can fairly assume that 20% of the total residues remain on the soil
    - Soil organic carbon pools will be initialized using Table 3 from Basso et al., 2011[1]
        - For Africa, will use soil SOC2 pool from the 20 year in cultivation under poor management from Table 3.
        - This fraction will be a product of S-world
5. Harmonized point-based simulation comparisons between APSIM and DSSAT to evaluate importance of initial conditions and the importance of long-term continuous series (sequential analysis) for capturing soil dynamics, especially areas with poor soil management.

Plans for expansion of the gridded simulation framework to enable more models and data sources, evaluation and analysis of simulation outputs, visualization tools and broader user capability.

Example application of above outlined initialization conditions:

Assuming an average maize yield of 1,000 kg/ha:

300 kg/ha will be roots

2,000 kg/ha are the total residues because of animal feeding, the amount left on the soil will be 400 kg/ha (20% of the total residues will remain on the soil)

For our example, here is an estimation of the inorganic (mineral) N:

Bulk density: 1.33

Depth of the layer: 15cm

Organic C of soil: 1.3%

Initial organic carbon: 25935 kg/ha

Total organic N: 2593 kg/ha (10% of total organic carbon)

Mineral N (nitrates pool): 2.6 kg N-NO3/ha (0.1 % of total organic N)

[1] Basso, B., O. Gargiulo, K. Paustian, G.P. Robertson, C. Porter, P.R. Grace, and J.W. Jones. (2011). Procedures for Initializing Soil Organic Carbon Pools in the DSSAT-CENTURY Model for Agricultural Systems. *Soil Sci. Soc. Am. J.*, **75**, 69-78. doi: 10.2136/sssaj2010.0115.

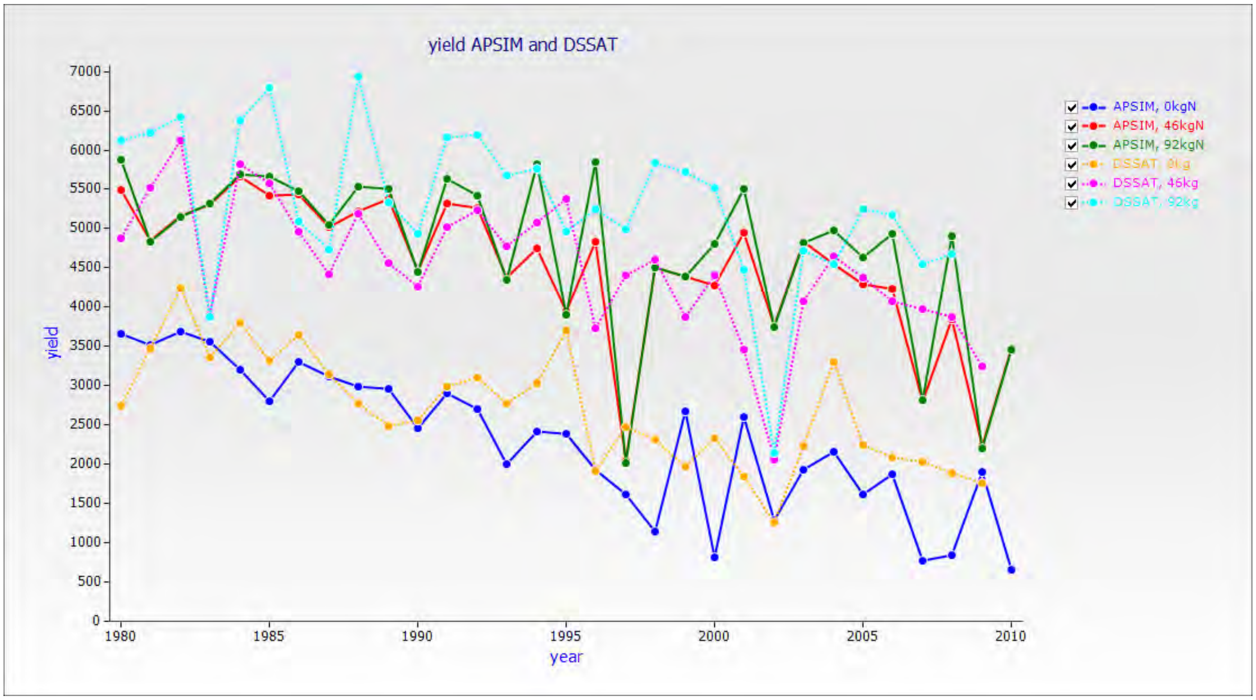

Figure 10: Yields in DSSAT and APSIM for 3 different fertilizer application scenarios when the models are run sequentially (continuously) with realistic (i.e. poor) residue management for Ethiopia, latitude = 7.625, longitude = 34.625. Yields show strong declines over 30 years to degrading soil quality due to poor soil management.

By all measures, the three day workshop was a huge success and significant strides were taken towards the development of the next-generation AgMIP Global Gridded Biophysical Model System. The new version of S-world, designed specifically for sub-Saharan Africa, allowed for the workshop to focus on soil data intercomparisons between S-world and AfSIS as can be seen in Figures 3-9. Conclusively, the soil datasets themselves will require substantial assessment before they can be intercompared and implemented for use in a gridded modeling effort of the sub-Saharan African region.

Many important decisions concerning the harmonization and initialization of the models and soil data products were made but, as preliminary comparisons between APSIM and DSSAT highlighted, there are a number of parameters that must be more thoroughly analyzed. These comparisons between APSIM and DSSAT attempted to determine how best to harmonize soil initialization both for model intercomparison as well as to best simulate the soil conditions at a point-based location in Africa. This comparison highlighted the importance of properly initializing the residues while also demonstrating the sizable improvements gained from running the models in continuous sequence (as opposed to seasonal runs with re-initialization). These comparisons did, however, expose a number of differences between the models that will have to be addressed by the modeling community. Importantly, APSIM and DSSAT generally simulated similar yields of the modeled time period (the models produced results that appeared to be well-correlated); yet, there was a substantial difference in the magnitude of the results that will have to be addressed and considered.

There were also a number of technical enhancements that were made to the AgGRID database including a weather translator for Salus, the development of pedotransfer functions, and the ingesting and translating of a number of soil datasets, including S-world and AfSIS, into the AgGRID framework.

We envision three kinds of impacts and uptake of results associated with this global gridded modeling approach. First, through the capacity-building activities of AgMIP, we anticipate working closely with developing-country researchers and stakeholders creating and analyzing the tools, datasets, and outputs from this methodology. Second, we expect the scenario and assessment results to feed a range of future assessments including follow-on activities of Rio+20, ISI-MIP, and the IPCC AR5 assessment as well as improving the outcomes of those activities. Finally, we anticipate that the crop and economic models themselves will be improved with substantial multiplier effects due to benefits in current as well as future simulations of agricultural production and food security.

Next steps

- Extend the pSIMS platform to include additional models (e.g. EPIC, SALUS, and InfoCrop)
- Enable high-resolution sequential simulations in pSIMS to study the long-term effects of soil management on producivity.
- Continue to develop and test new high-resolution gridded soil data products for Africa to better understand the impacts of soil representation complexity, land-cover, and land-use history in assessments of crop productivity and climate impact for the continent.
- Apply these multi-model/multi-dataset tools to a perform a longitudinal analysis of the impacts of soil quality and historical management across Africa, including an exploration of several alternative management regimes for tillage, residue application, and crop rotations/cover.

Appendix 1 - Workshop Agenda

Wednesday	Speaker/Moderator	Topic	Notes
8:30- 9:00		Breakfast	
9:00- 9:10	Jim Jones (Skype)	Invitation	USAID and AgMIP; Soils and Ag-GRID
9:10- 9:40	Joshua Elliott*	Results from multi-model prototype	APSIM and DSSAT multi-scale maize simulations in Southern/Eastern Africa
9:40- 10:10	Bruno Basso*	AgMIP soils	Soil projects and data products ongoing in AgMIP and elsewhere
10:10- 10:40	Jetse Stoorvogel*	SWORLD	Status and updates
10:40- 11:00		Coffee Break	
11:00- 11:30	Sotirios Archontoulis*	Soils in APSIM	Including report from recent meeting in Australia on this topic
11:30- 12:30	Ken Boote	Moderated discussion	Improving representations of soil data for gridded multi-model studies in Africa
12:30- 1:30		Lunch	
1:30- 5:30	Various	Breakouts	See following page.

***Please leave 10-15 minutes for discussion if possible.**

Thursday	Speaker/Moderator	Topic	Notes
8:30- 9:00		Breakfast	
9:00- 1:00		Breakout 2	See following page.
1:00- 1:30		Lunch	
1:30- 5:30		Breakout 3	See following page.
6:30- ????	Everyone!	Dinner	Mel's Burgers – 2850 Broadway (on the east side between 110^{th} and 111^{th})

Friday	Speaker/Moderator	Topic	Notes
8:30- 9:00		Breakfast	
9:00- 1:00		Breakout 4	See following page.
1:00- 2:00		Lunch	
2:00- ~3:30	Various	Wrap-up	• Next steps • Where does it all fit into AgMIP?
~3:30 pm		Departure	

Appendix 2 - Workshop Participants

Name	Institution	Email
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Advancing Global Agricultural Assessments:
Building the Next-Generation Global Gridded Biophysical Model System

Introduction

Increased demand for more and higher-quality food is projected in developing countries while climate change is projected to reduce the productivity of many existing agricultural resources. Assessing the range of plausible outcomes for sustainable food security and the potential for policies and programs to mitigate negative consequences is the task of linked global model systems that include both biophysical processes and socioeconomic behavior.

AgMIP is leading a coordinated, transdisciplinary process that provides rigor, robustness, and reliability to regional and global assessments of climate change impacts on agricultural production and food security (www.agmip.org). Although there have been many agricultural impact studies in the past, the lack of consistency in the data, models, and assumptions used has caused major problems in interpreting and using results. Furthermore, recent research has shown that multiple crop models need to be used to produce the best estimates of crop production responses and uncertainties in those estimates. Until now, all prior agricultural impact assessments have used single models, with a lack of understanding of uncertainties in predicted results. Also it is not clear what input data and assumptions were used in simulating the agricultural responses in some of the past studies.

The work proposed here will provide a more rigorous framework that uses multiple crop models, provides detailed documentation of climate, soil, and management input data to the crop models, provides documentation on the characteristics of the crop models used, provides traceability to the climate scenario data used, and creates a prototype platform for routinely simulating global and regional gridded simulations. The prototype will be used to demonstrate example simulations for one selected region (in either Sub Saharan Africa or South Asia) and for the world.

The proposed work will provide capabilities for developing country scientists to make use of AgMIP protocols and data such that countrywide, regional and global results could benefit from the latest methods and data while providing full traceability and uncertainty estimates for use in global and regional decision-making. The initial prototype will simulate major food crops, but will be designed to include simulations of pastures, agroforestry, and pests and diseases. Finally, the system will be designed to simulate climate impacts over the near term (e.g., for climate scenarios produced in a companion project for assessing management options at 1 to 5 or 10 years) in addition to longer-term climate change scenarios.

The prototype will be developed using gridded simulation systems that have been used in recent assessments. We have learned effective approaches for gridded simulations and will build off of these systems to create the harmonized platform described above that uses multiple crop models and improved climate, soil, and management inputs and provides traceability documentation. It will also be developed as an open-source project to ensure that all researchers, including those in developing countries, have full access to the system. The system will be provided to AgMIP Research Teams in Sub-Saharan Africa and South Asia with capacity building that is planned through our project activities in these regions.

Other AgMIP activities that link to the proposed work include the development of state-of-science climate scenario data sets for use in regional and global assessments, site-based crop-based model intercomparisons, and representative agricultural pathways (linked to the Representative Concentration Pathways of the IPCC AR5 process).

The proposed work, as in all AgMIP activities, will develop baselines, modeling tools, and assessment approaches in collaboration with developing country researchers and stakeholders in order to build adaptive capacity at the national and regional scales. It will also enhance the sustainable use of soils, watersheds, forests, grasslands and productive agricultural areas.

Aims and Objectives of the Project

- Develop a functional prototype multi-model simulation framework for an improved open-source gridded biophysical capacity at both global and regional scales using DSSAT and APSIM as the initial demonstration models. This will consist of a platform that will simulate crop yields at global and regional scales using gridded databases of the required inputs at those scales and its outputs will connect to global economic models. Initially, the prototype will connect to the IMPACT model of IFPRI as a demonstration of this capacity. Building this multi-model capacity within a single framework lends substantial advantages for characterizing consistent multi-model ensemble information in climate impact projections, allowing harmonization of input data and methods that is not otherwise possible.
- Develop data library components (input/output data pipelines) for gridded multi-model simulations. Identify and utilize the best available databases, and identify gaps and methods to fill them. This will be done in cooperation with current efforts by the World Bank, UN FAO, CCAFS, Global Futures, Gates Foundation, FAO, and others.
- Develop a suite of data translation tools to allow generation of input files for multi-models, using gridded data inputs. Initially, this library will be developed for DSSAT and APSIM models, but can be expanded as additional models are added to AgMIP spatial simulation exercises.
- Develop aggregation tools will be developed to process the gridded inputs to run the crop model simulations and to produce aggregated yields and other output variables as needed to connect biophysical model outputs to global and regional economic models.
- Use the databases and modeling platform to simulate responses of major crops in developing and developed countries for global and regional climate change studies using, initially, DSSAT and APSIM run in parallel. This multi-model capacity will be expanded in subsequent stages of the project and will significantly improve projections by adding ensemble information to characterize uncertainty and improve the robustness of results. This will be done with the AgMIP suite of agricultural scenarios in order to provide assessments of relevance to such efforts as Rio+20, the IPCC, and others (see www.agmip.org).
- Share results of AgMIP global and regional assessments with developing country stakeholders and scientists with the goal of strengthening capacity to use agricultural models for planning across a range of scales and time horizons.
- Produce plans for long-term development of an open source multi-model simulation infrastructure, including the following components:
    - Multiple models and crops, various input datasets, and versatile experiment, management, and scenario options.
    - A modular approach that allows straightforward addition of new models and versions, data sources, scenario and experiment dimensions, and post-processing utilities.
    - User-defined experiment files to easily specify the region, scale, crops, scenarios, input data, methods, and other simulation bounds.
    - Post-processing tools for aggregating multiple gridded crop model outputs to administrative or environmental boundaries (e.g., county, state, watershed, nation) for linking to regional and global economics models, as well as for presenting biophysical model outputs for visualization and further analyses at decision-relevant scales.
    - Accessibility options designed around different levels of use cases and user skill levels.
    - Support for hardware platforms ranging from single machines and small clusters to supercomputers, grid, or cloud resources.
    - Specifications for hardware and software requirements to install the gridded modeling framework.

Methodology for Global Gridded Biophysical Model System

1) Develop Workplan

The first step is for AgMIP to bring together the primary group that will develop the next-generation gridded biophysical modeling capacity in order to design the system and create a workplan for developing the prototype during this project time period. Long-term objectives for the multi-model gridded simulation system will be defined, such that the initial prototype, defined by this proposal, will include core components of the final product. We will hold a meeting or workshop in the Summer/Fall of 2012 to initiate this effort. Core team members would include Jim Jones (UF), Cynthia Rosenzweig (GISS), Jerry Nelson (IFPRI), Joshua Elliott (GISS/UChicago), Alex Ruane (GISS), Ricky Robertson (IFPRI), Jetse Stoorvogel (Wageningen), Gerrit Hoogenboom (WSU), Cheryl Porter (UF), Sander Jansen (Wageningen) and John Antle (OSU). The first meeting will be a small kick-off and then we will open it to other global crop modeling teams for their contributions and input. As with all AgMIP activities, this will be done in a team approach with open participation.

2) Build Platform

Building on existing platforms and the AgMIP matrix approach, we will develop a next-generation global modeling capability, that will incorporate the tools that the AgMIP IT team is developing for multiple crop model inputs and outputs and build on the ISI-MIP global gridded crop model intercomparison that AgMIP is coordinating. The platform will be open-source, multiple-model, gridded, scale-neutral (i.e., the simulation environment will enable both inputs and outputs to be aggregated on multiple space and time scales), linked to site-based simulations, and operable with harmonized, open input and output databases. The goal is to ensure that the gridded simulations can be done with multiple crop models on a routine basis with the prototype and will demonstrate this functionality using the DSSAT and APSIM models. Aggregation tools will be developed to process the gridded inputs to run the crop model simulations and to produce aggregated yields and other output variables as needed to connect biophysical model outputs to global and regional economic models. Validation and analysis tools will also be created to assess the quality of global and regional gridded input data and global biophysical simulations as well as provide information on the reliability of results. This effort will also identify and produce crop model outputs that are needed for visualizations and analyses of alternative scenarios.

3) Create Harmonized Databases

This effort will include the design of harmonized databases for the gridded simulations in tandem with the harmonized site-based databases that AgMIP is already creating. The gridded database will be similar to the AgMIP sentinel site database, but it will not include observed data and it will not have all of the detailed crop management inputs that are collected in experiments. However, it will have the crop model inputs that are essential for running the gridded models for the global and regional analyses. Major components are the daily weather and soil data, including initial conditions for water, N, and soil C, and crop management data, all of which are highly important for producing credible biophysical simulations at global or regional scales.

4) Run Assessments

The improved global gridded capacity will be run with the full set of 4 RCPs for the full set of CMIP5 GCMs, with and without CO_2 fertilization, and with and without irrigation. The results of these assessments will initially be used to drive the IFPRI IMPACT model and in multiple economic model intercomparisons and assessments at global and regional scales.

5) Hold Conference and Briefing Sessions

AgMIP will participate in and contribute to the Food Security Future Conference to be held in the Spring of 2013. It will also hold decision-maker briefing sessions as part of the AgMIP Regional Workshops to be held in Sub-Saharan Africa and South Asia in 2013. At these workshops, the outcomes of the global biophysical and economic model assessment will be presented and discussed with developing country decision-makers.

Results and Outcomes

Summary of Deliverables in Year 1:

- Gridded database design and advanced data for climate, soils, initial conditions, and crop management for use in gridded simulations of agricultural production responses to climate change scenarios.
- Operational interfaces between the gridded database and DSSAT & APSIM crop models.
- Documentation of harmonized gridded database and simulation tools. This includes documentation to facilitate use of additional crop models and additional data sources.
- Demonstration of prototype globally and for one selected region.
- Plans for expansion of the gridded simulation framework to enable more models and data sources, evaluation and analysis of simulation outputs, visualization tools and broader user capability.

The initial development of the next-generation AgMIP Global Gridded Biophysical Model System is the primary result of this project. Building on it, we envision three kinds of impacts and uptake of results. First, through the capacity-building activities of AgMIP, we anticipate working closely with developing-country researchers and stakeholders creating and analyzing the tools, datasets, and outputs from this project. Second, we expect the scenario and assessment results to feed a range of future assessments including follow-on activities of Rio+20, ISI-MIP, and the IPCC AR5 assessment as well as improving the outcomes of those activities. Finally, the crop and economic models themselves will be improved with substantial multiplier effects due to benefits in current as well as future simulations of agricultural production and food security.

This next-generation AgMIP Global Gridded Biophysical Model System provides an essential tool in order for developing countries to have a better picture of future challenges as they seek to improve their capacity to plan for food security, watershed management, and population growth. This project complements the current AgMIP Regional Assessments in Sub-Saharan Africa, South Asia, and other important agricultural regions around the world. It also develops tools and baselines and future climate change scenarios for land use-related policy analyses.

In its activities, AgMIP engages with food security and climate change agricultural researchers in all developing regions of the world. AgMIP brings together climate, crop, and economic experts to work together to create scenarios, design protocols, conduct assessments, and analyze results. This process enables ‘co-production’ of knowledge, so that developing country scientists and their decision-makers have ownership of the entire research process.

Personnel

The proposed work will be led by Drs. Jim Jones, Cynthia Rosenzweig, both Principal Investigators of AgMIP, and Gerald Nelson of IFPRI, the Global Economic Leader of AgMIP, with science and technology coordination led by Dr. Joshua Elliott of the University of Chicago (who is currently working in the AgMIP team at Columbia University). The AgMIP Leadership Team will guide the overall work.

Phone call 9/11/2013 regarding soil functions needed for gridded modeling analyses

Ken Boote
Jetse Stoorvogel
Sotirios Archontoulis
Cheryl Porter

Relationships for SWorld

1. SOM3 = f(topsoil depth, rooting depth, SOM3 fraction in topsoil)
    a. SOM3 fraction in topsoil = f(texture, land use, temperature?)
        i. Texture – Adiku equation for Stable C
            1. SOM3 = (0.015 * (CLAY + SILT) + 0.069) / OC
        ii. Land use - look up table, topsoil and subsoil values:
            1. Forest, $SOM3_0$ = .4
            2. high forest pasture mosaic, $SOM3_0$ = .45
            3. low forest pasture mosaic, $SOM3_0$ = .5
            4. irrig, $SOM3_0$ = .55
            5. pasture, $SOM3_0$ = .4
            6. arable, $SOM3_0$ = .6
        iii. Temperature? – would need to be exported from SWorld
    b. Topsoil depth known in SWorld
    c. Rooting depth – use profile depth?
    d. Temperature effects - DSSAT lookup tables do not include this.
        i. need simulations for temperature sensitivity on SOM dynamics
        ii. check with Osvaldo Gargiulo
2. SLPF
3. Root distribution

Calculate outside SWorld

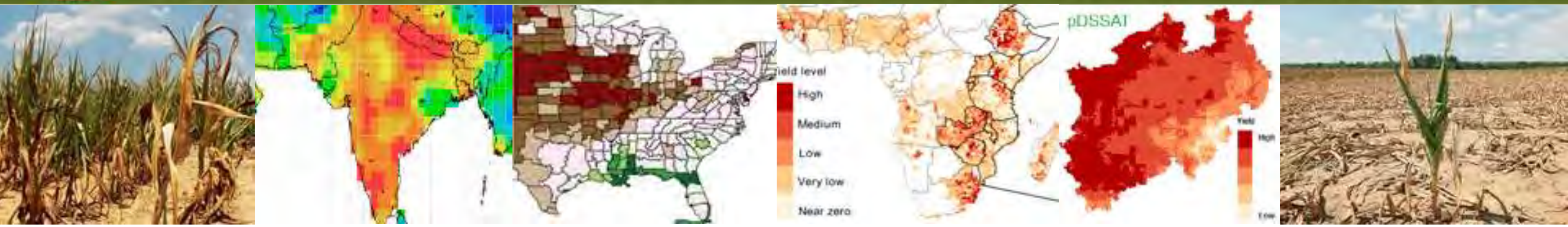
4. Fbiom = f(soil depth) = -0.006 ln(x) + 0.0394
5. Finert = f(soil depth) = 0.1839 ln(x) + 0.1188
    a. May use 3 sets of curves for OC>1, 0.5<OC<1, and OC<0.5
    b.

Follow-up phone call on 9/13/2013 at 9am EDT

RDCEP

Center for Robust Decision Making on Climate and Energy Policy

http://rdcep.org/



High-resolution multi-model assessment of climate extremes, vulnerabilities, impacts, and adaptation

Joshua Elliott

with Michael Glotter, James Chryssanthacopoulos, Christoph Müller, Ian Foster, Jim Jones, Ken Boote, Cheryl Porter, Cynthia Rosenzweig, Alex Ruane, Jerry Hatfield, Leonard Smith, and many more….

Computation Institute

Argonne NATIONAL LABORATORY

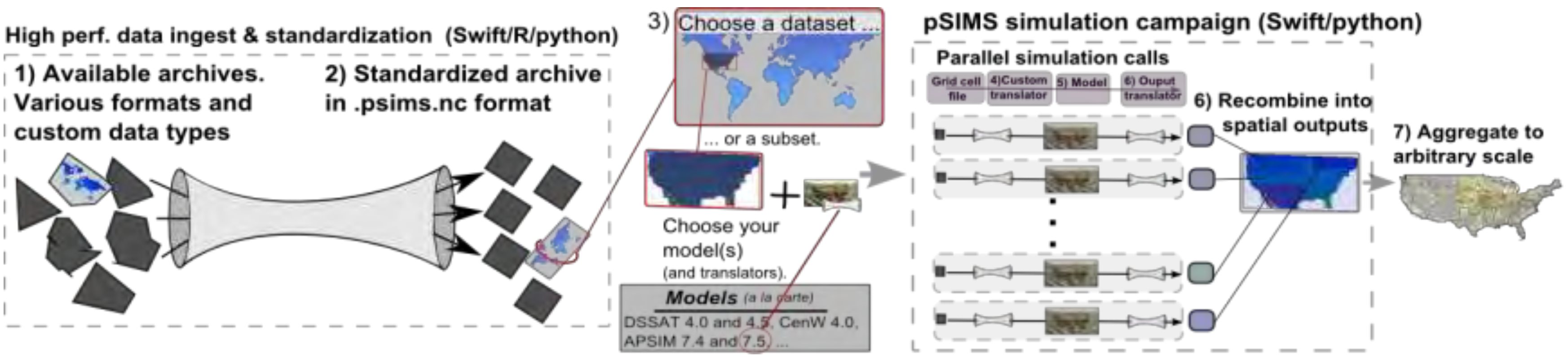
THE UNIVERSITY OF CHICAGO

AgMIP The Agricultural Model Intercomparison and Improvement Project

ISI-MIP

The parallel System for Integrating Impacts Models and Sectors (pSIMS)

- Highly modular software framework for medium-to-large scale gridded simulations with environmental/crop/climate impact models.
- Currently supports the widely used **DSSAT** and **APSIM** families of crop models, as well as the **CenW** model of plantation forestry.
- Constantly being expanded with new models and functions (next up: EPIC and InfoCrop).

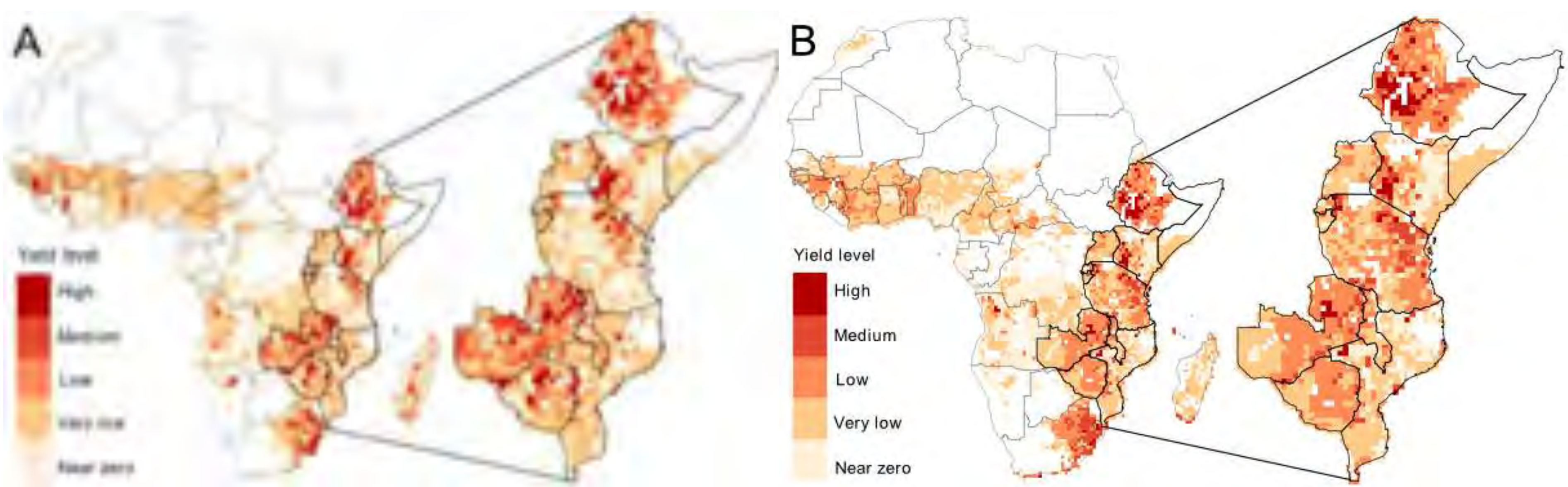


Elliott, J., D. Kelly, J. Chryssanthacopoulos, M. Glotter, Kanika Jhunjhnuwala, N. Best, M. Wilde, and I. Foster (2014). **The Parallel System for Integrating Impact Models and Sectors (pSIMS).** *Special issue of Environmental Modeling and Software: Agricultural systems modeling & software, accepted.*

Project	Campaigns	Sim Units (Billion)	CPU Hours (K)	Jobs (M)	Output data (TBytes)
NARCCAP USA (pDSSAT)	16	1.3	13	1.9	.47
ISI-MIP Global (pDSSAT)	80	11.8	216	4.38	4.14
Prediction 2012 (pDSSAT)	2	0.2	2	0.24	0.5
NZ climate impacts (pCenW)	2	0.4	3	0.1	0.6
GGCMI Phase 1 (pDSSAT and pAPSIM; ongoing)	~96	~12	~200	~25	~1

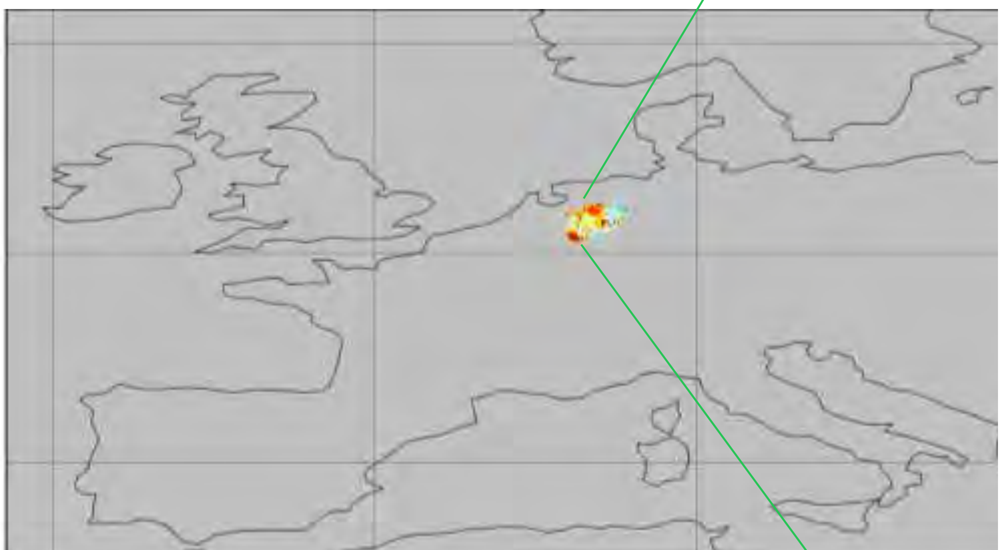
Multi-model multi-scale multi-soil maize in Africa

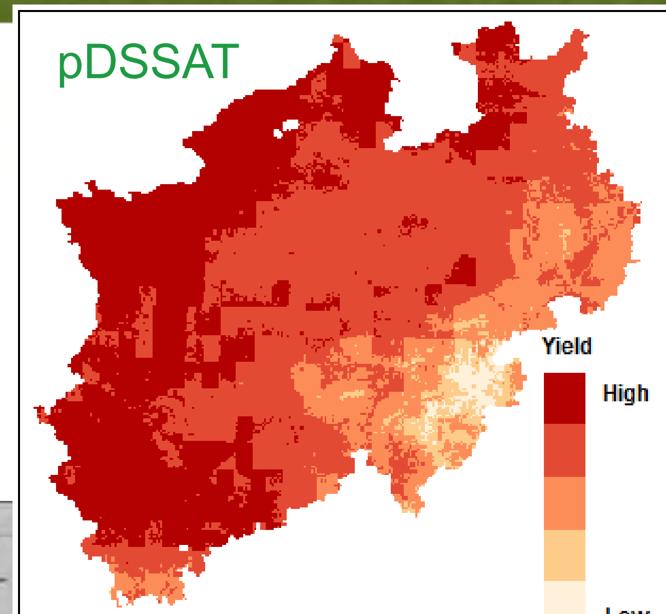
- Two models (pDSSAT and pAPSIM),
- Full continent at 0.5 degree spatial resolution
- The Southern/Eastern African countries of Zimbabwe, Malawi, Zambia, Tanzania, Mozambique, Ethiopia, Burundi, Rwanda, Uganda, Kenya, and Somalia at 0.25 degree spatial resolution

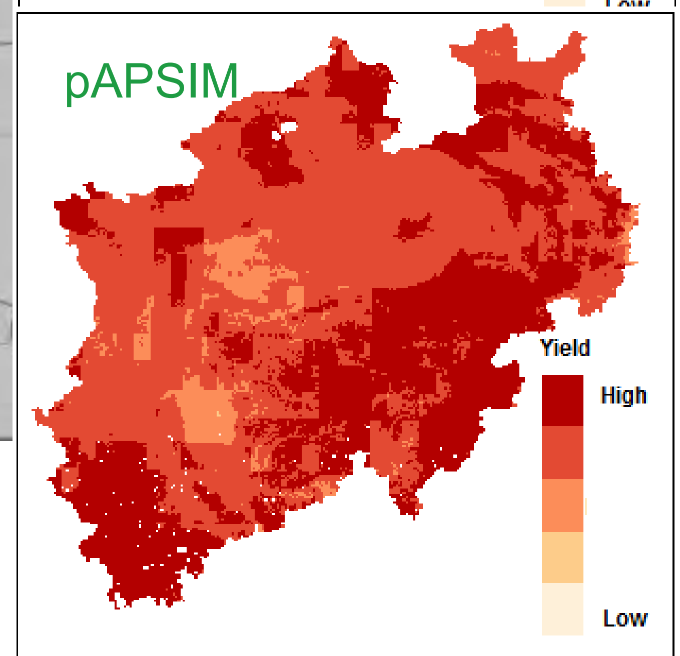


Multi-model wheat study in W. Germany

- 1 km^2 resolution Winter Wheat study for NRW state in Western Germany, 1982-2011 (~35k grid cells).



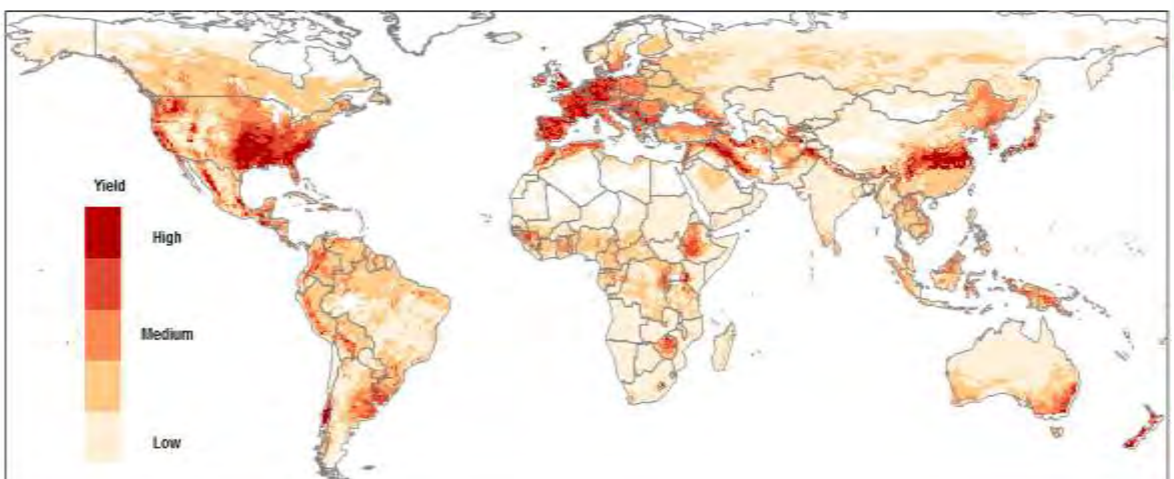


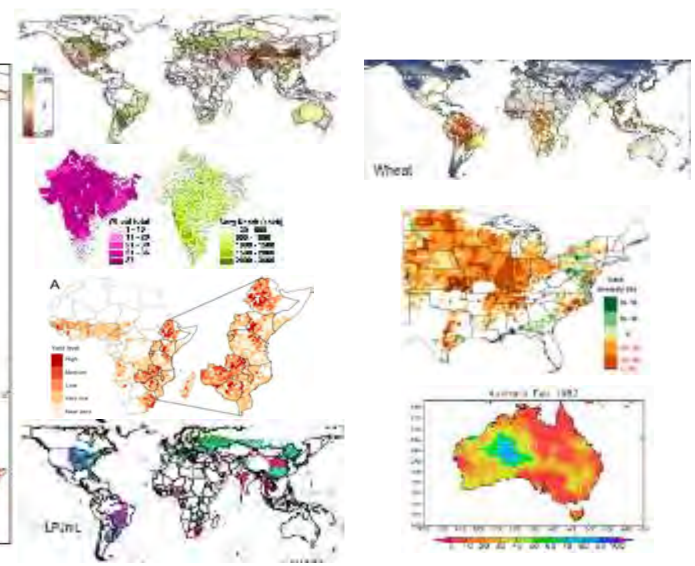


AgMIP GRIDded Crop Modeling Initiative

- Ag-GRID is an organizing hub for a new generation of gridded crop modeling and data activities within AgMIP.
- Includes >20 modeling groups so far and >10 data partners
- Helps coordinate global and regional multi-model assessments.
- Three distinct model types: 1) Gridded process models,
  2) Dynamic global vegetation and land-surface models, and
  3) Empirical/process model hybrids and large-area models

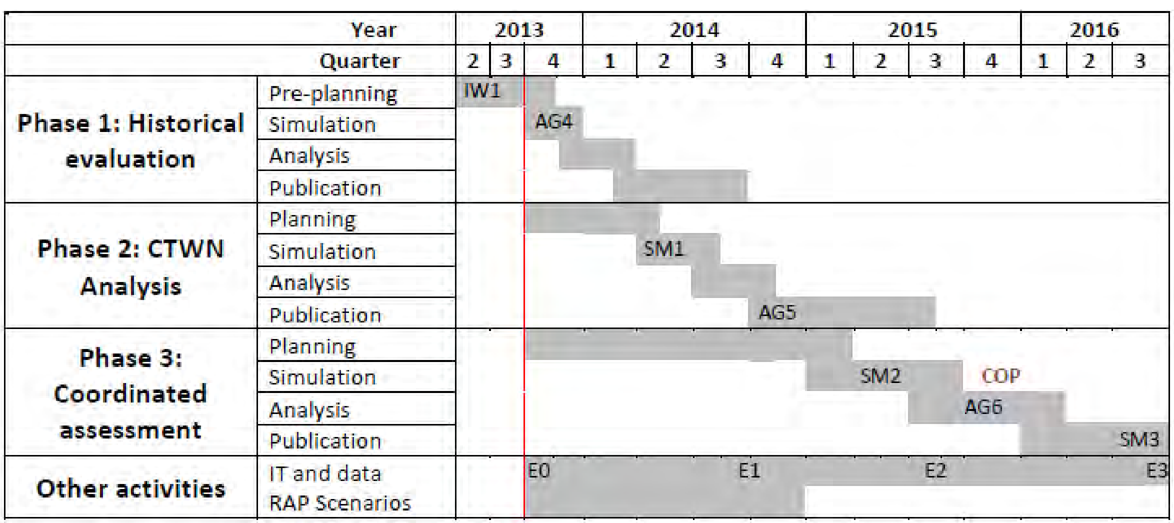
Mean simulated rainfed wheat yields, 1980-2010



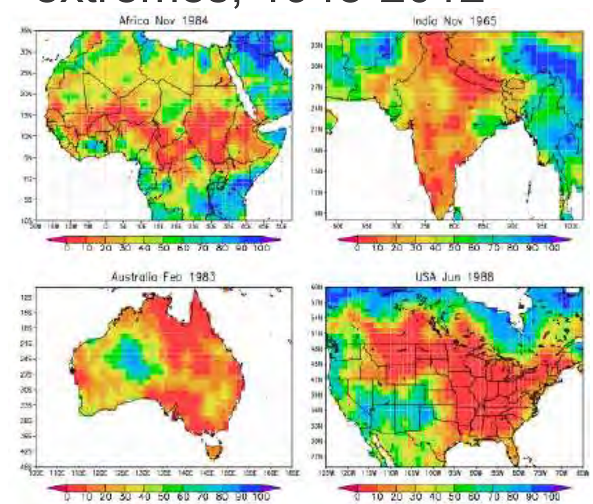


Global Gridded Crop Model Intercomparison

- Phase 1: Global/0.5 degrees/1948-2012/9 climate forcing products/ harmonized on fertilizer, sowing, maturity, etc.
- Results from 12-15 models from 11 countries, each for 4-16 crops.
- pSIMS contributing pDSSAT and pAPSIM results for maize, soy, wheat, rice, sorghum, millet, and pasture.
- Many outputs: ensemble evaluation, importance of evapotranspiration models for yield projections (especially in arid regions), etc.
  - Special focus on characterizing and comparing extreme events in the historical record and their implications for food production.

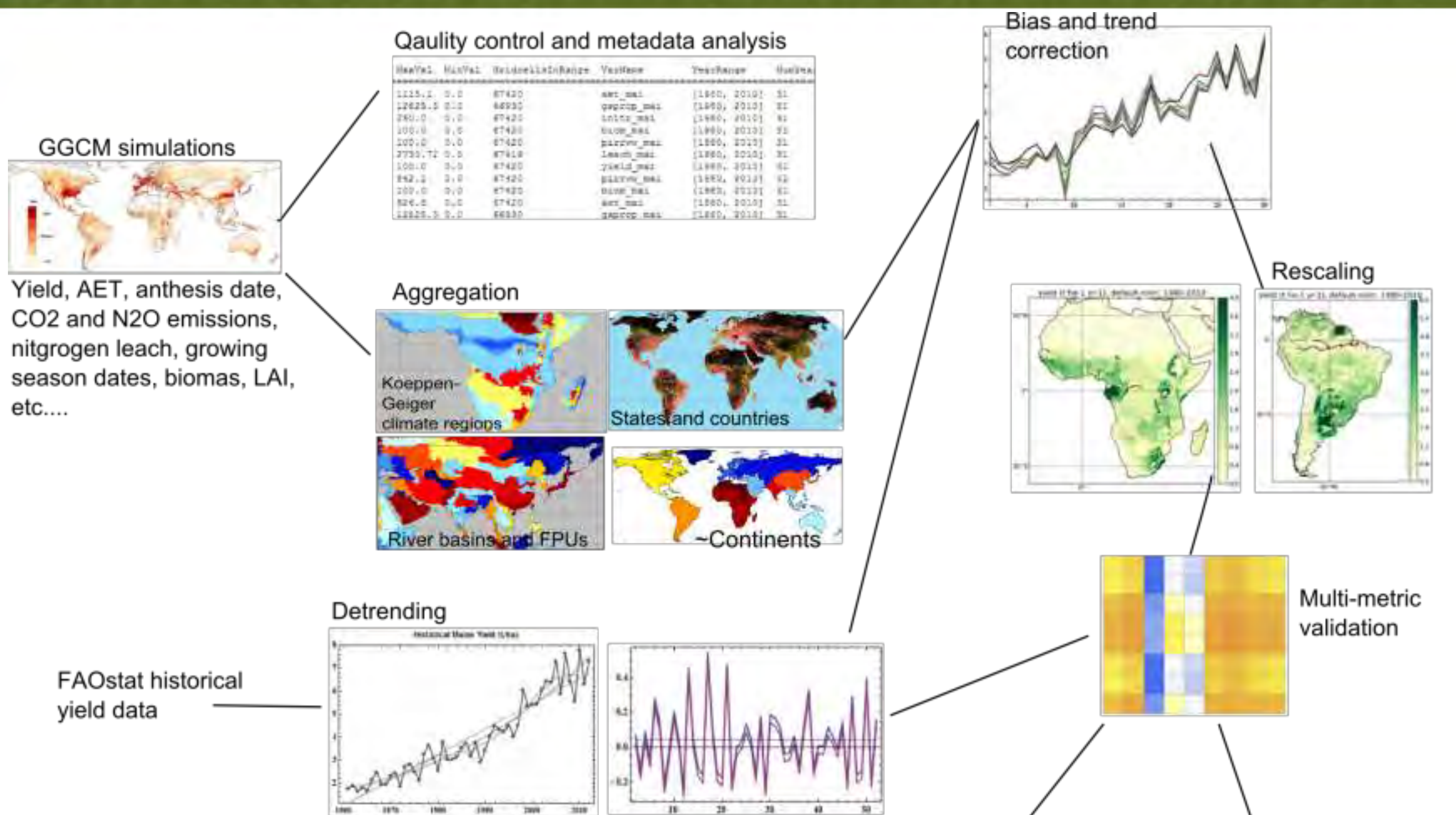


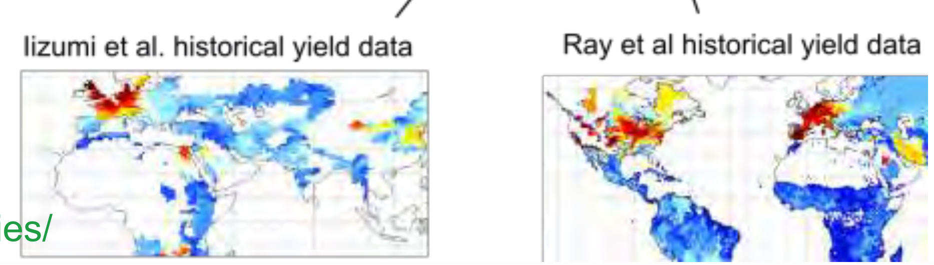
Examples of large-scale extremes, 1948-2012



Sheffield et al. 2011

Open source model analysis pipeline





All codes available online at:
https://github.com/RDCEP/ggcmi

Quality control reports updated regularly:
http://users.rcc.uchicago.edu/~joshuaelliott/ggcmi-summaries/

Six papers planned from Phase I

1. Historical analysis of model and ensemble hindcasting skill;
2. Agro-climatic analysis of the relative import of different methods for developing climate forcing datasets (reanalysis models, bias-correction technique, and target datasets; from the priority 2.1 “Climate Track” simulations);
3. A summary of Phase 1 results for priority 2 crops (from the priority 2.2 “Crops Track” simulations).
4. A detailed assessment of all national- and continental-scale extreme climate events in the historical record, and the ability of models to reproduce the agricultural impacts of these events.
5. Sensitivity of simulated crop yields to the ET0 equation used within the crop model, which has been identified as a priority model process difference to evaluate and understand in Phase I. Preliminary results, obtained using pDSSAT run with both Penman-Monteith and Priestley-Taylor ET equations, show a difference in simulated yield up to 30% in some regions (most notably in rainfed systems in arid regions.
6. Variability from models, weather, …

Future phases

- Phase II: CTWN (~2014/15)
  - Multi-dimensional sensitivity study of model response to carbon, temperature, water, and nitrogen.
- Phase III: New coordinated inter-sectoral assessment with ISI-MIP2 (~2015/16)
  - Vulnerabilities, impacts, and adaptations
  - Climate forcings from CMIP5 and CORDEX

Soil datasets

- HWSD + WISE
- Harvest Choice 3
- HC27
- HC3K (WISE)
- GSDE (
- S-World-default
- S-World (disturbed and undisturbed)

The AgMIP Soil and Crop Rotation and more thoughts on modeling soils

Bruno Basso, Iurii Shcherbak et al.

(Michigan State University)

Outline

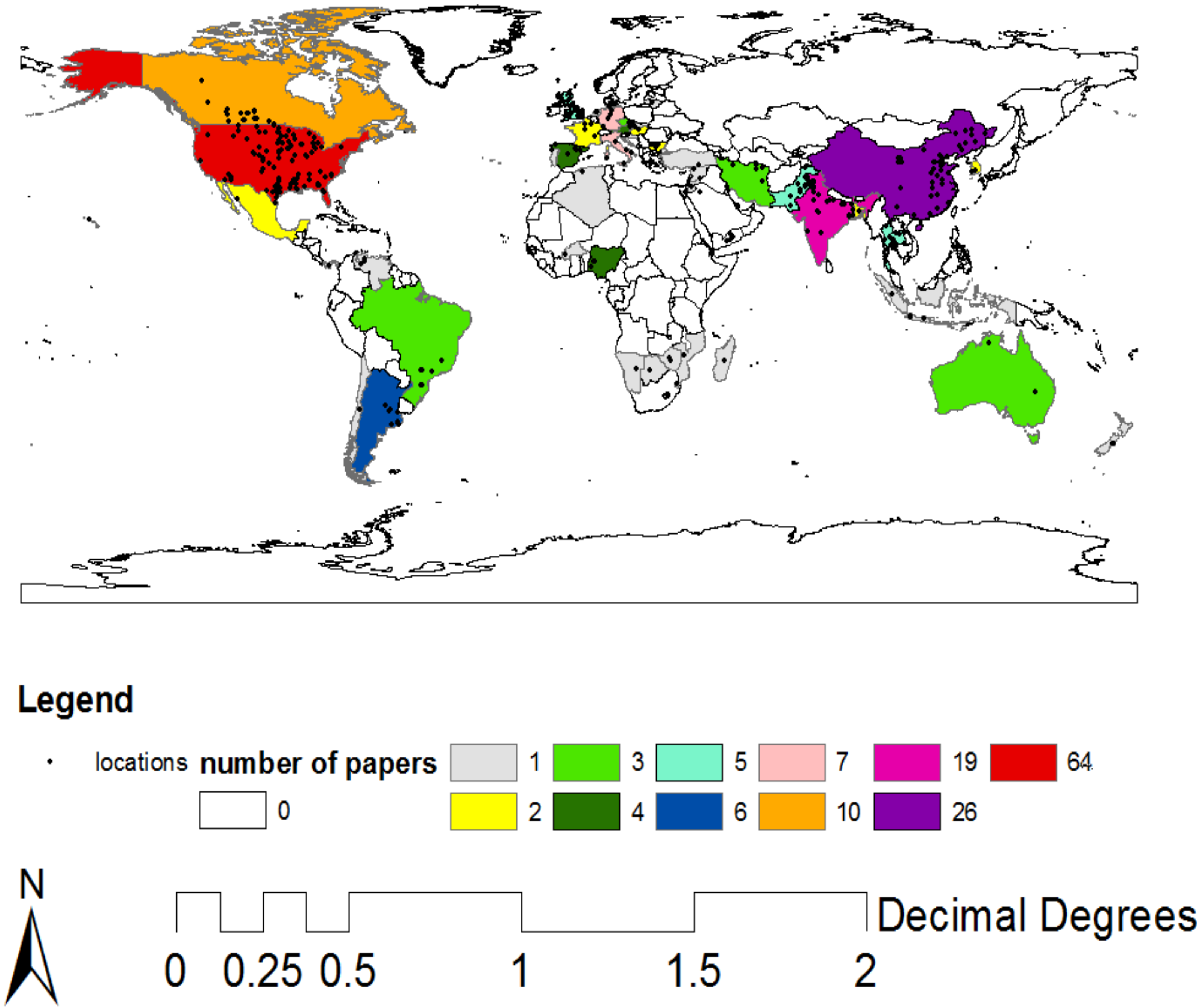
- Present AgMIP Soil and Crop Rotation results
- Discuss next steps
- My thoughts on what it is need for modeling soil and climate impacts on crop yield

Objective

- To assess crop model intra and inter-annual variability when simulating long-term soil carbon, nitrogen and soil water dynamics in a maize-fallow and wheat-fallow crop rotation under different management strategies.

Rationale

- Crop models have been extensively tested for yields. A recent review on CERES MZ, WH, RI found 230 papers of comparison of measured vs simulated yield (Basso et al 2014).
- Model validation for soil water balance (22), and carbon (2) and nitrogen cycling (13) in agricultural systems has been limited.



Legend
locations
number of papers
1
3
5
7
19
64
0
2
4
6
10
26
N
0
0.25
0.5
1
1.5
2
Decimal Degrees

Participating Models

Name	Maize	Wheat
APSIM	X	X
DAYCENT	X	X
MONICA	X	X
NWHEAT		X
SALUS	X	X
STICS	X	X
XNSPA		X
DSSAT		
EPIC		
CROPSYST		
ECOSYS		X

Factors with number of Levels

Factor	Factor Levels	Maize	Wheat
Site	4 sites	V	V
Temperature (°C)	-3, Baseline, +3, +6, +9	V	V
Tillage	No-till, Convent. Tillage	V	V
CO_2 (ppm)	360, 450, 540, 630, 720	V	V
N	-50%, Baseline, +50%		V
Rain	-30%, Baseline	V	

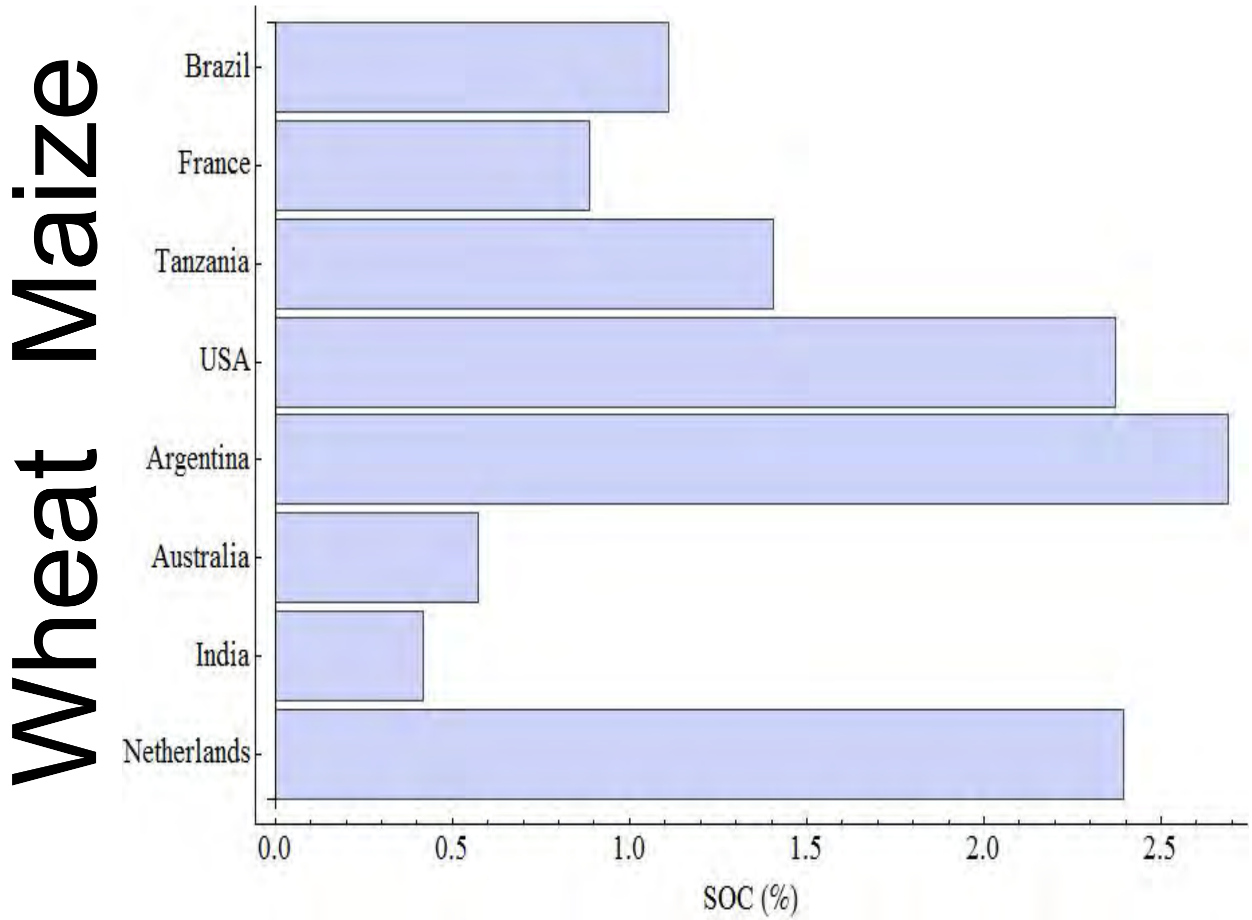
Sites

Maize	Wheat
Rio Verde, Brazil	Balcarce, Argentina
Lusignan, France	Wongan Hill, Australia
Morogoro, Tanzania	New Delhi, India
Ames, Iowa, USA	Wageningen, Netherlands

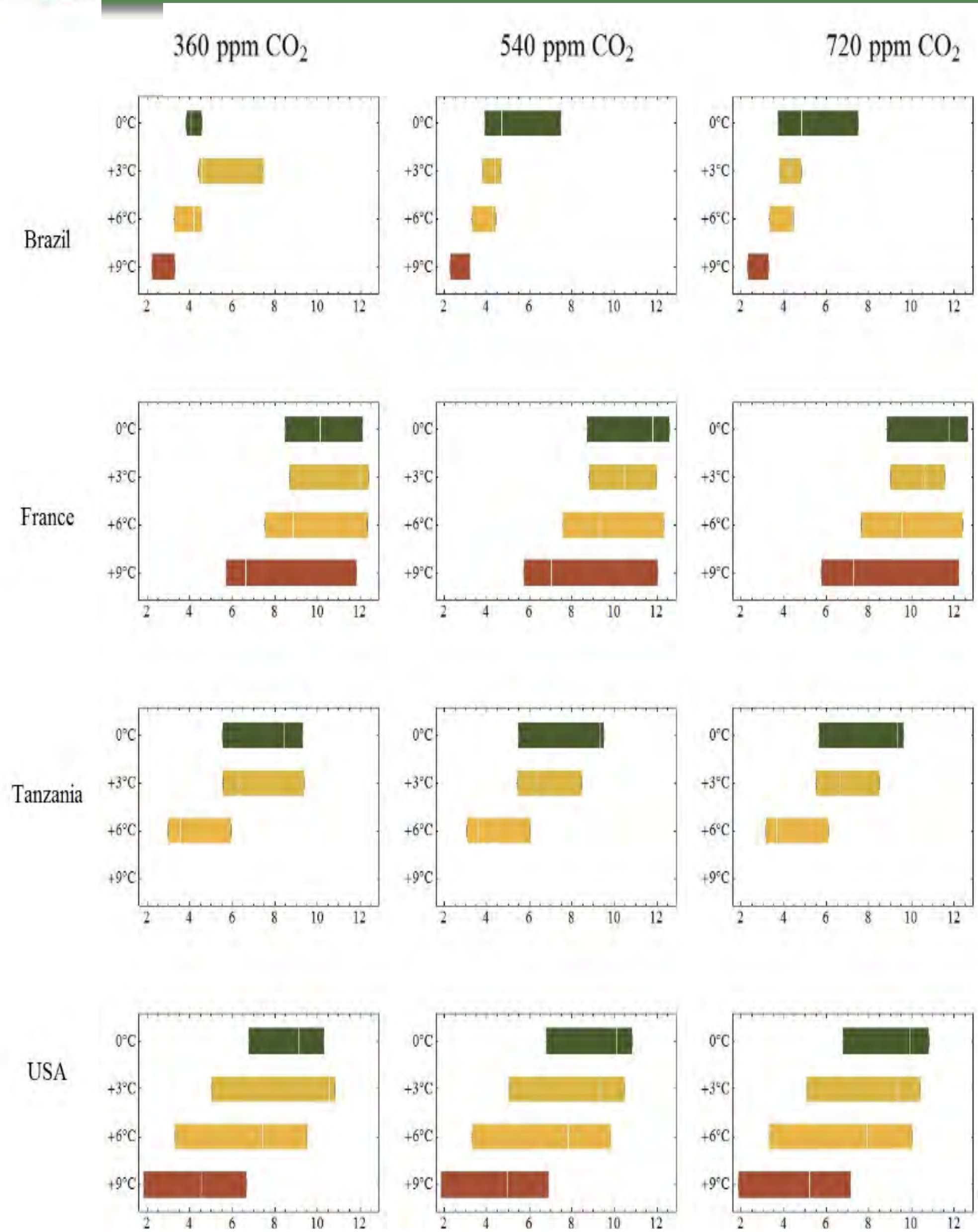
Variables Reported

- Biomass
  - Anthesis
  - Maturity
- Date
  - Anthesis
  - Maturity
- Yield
- Maximum Leaf Area Index
- Soil Organic Carbon and Nitrogen
  - 0-25 cm
  - 25-50 cm
- Inorganic N
- N Leached
- Soil Available Water
  - Anthesis
  - Maturity
- Evaporation
- Transpiration
- Runoff
- Drainage
- Emissions of CO_2 and N_2O

Plow Layer Initial Soil Organic Carbon (%)



Baseline Rain

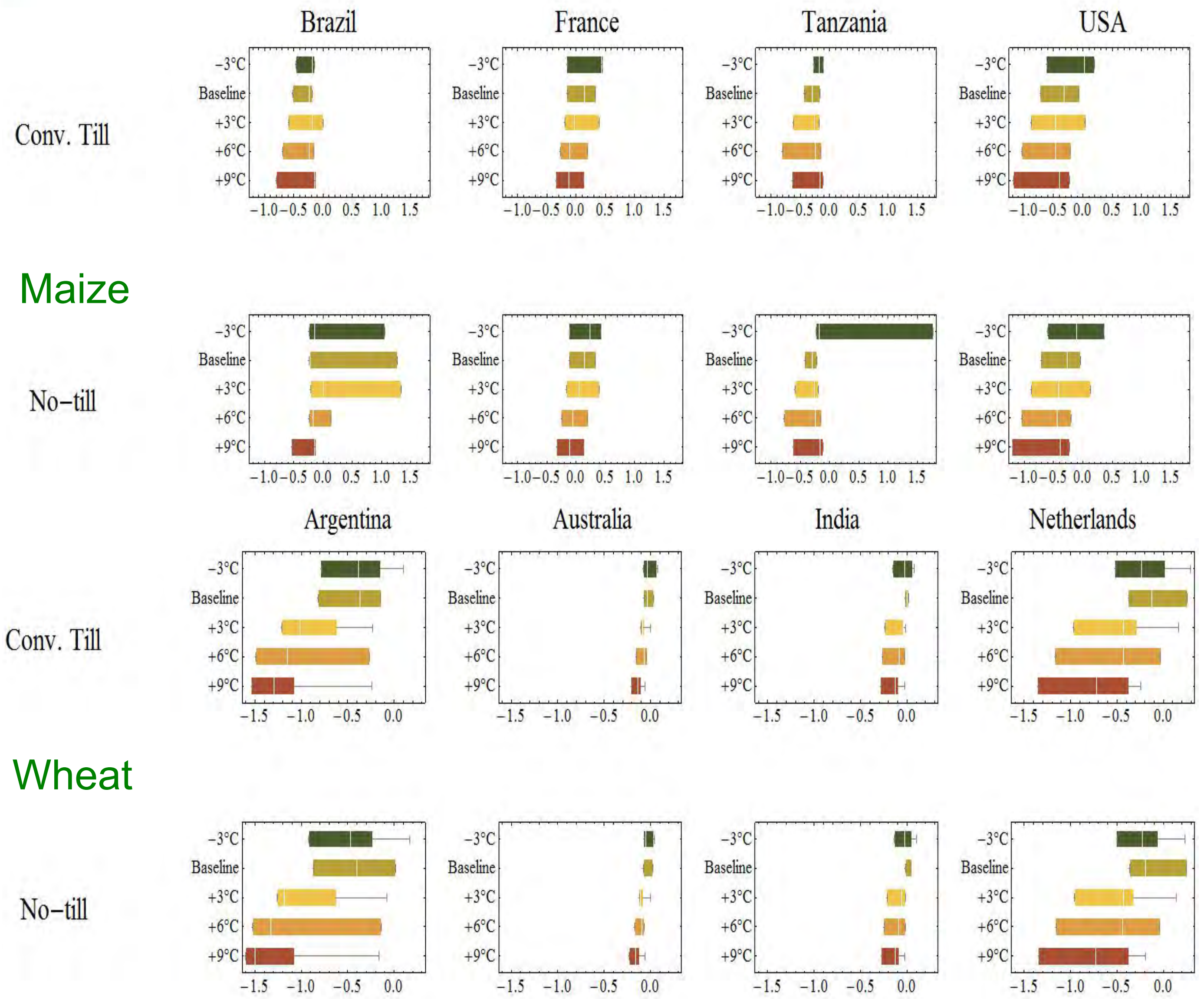


Mean Yield (t/ha) 1980-2010

The Agricultural Model Intercomparison and Improvement Project

MICHIGAN STATE UNIVERSITY

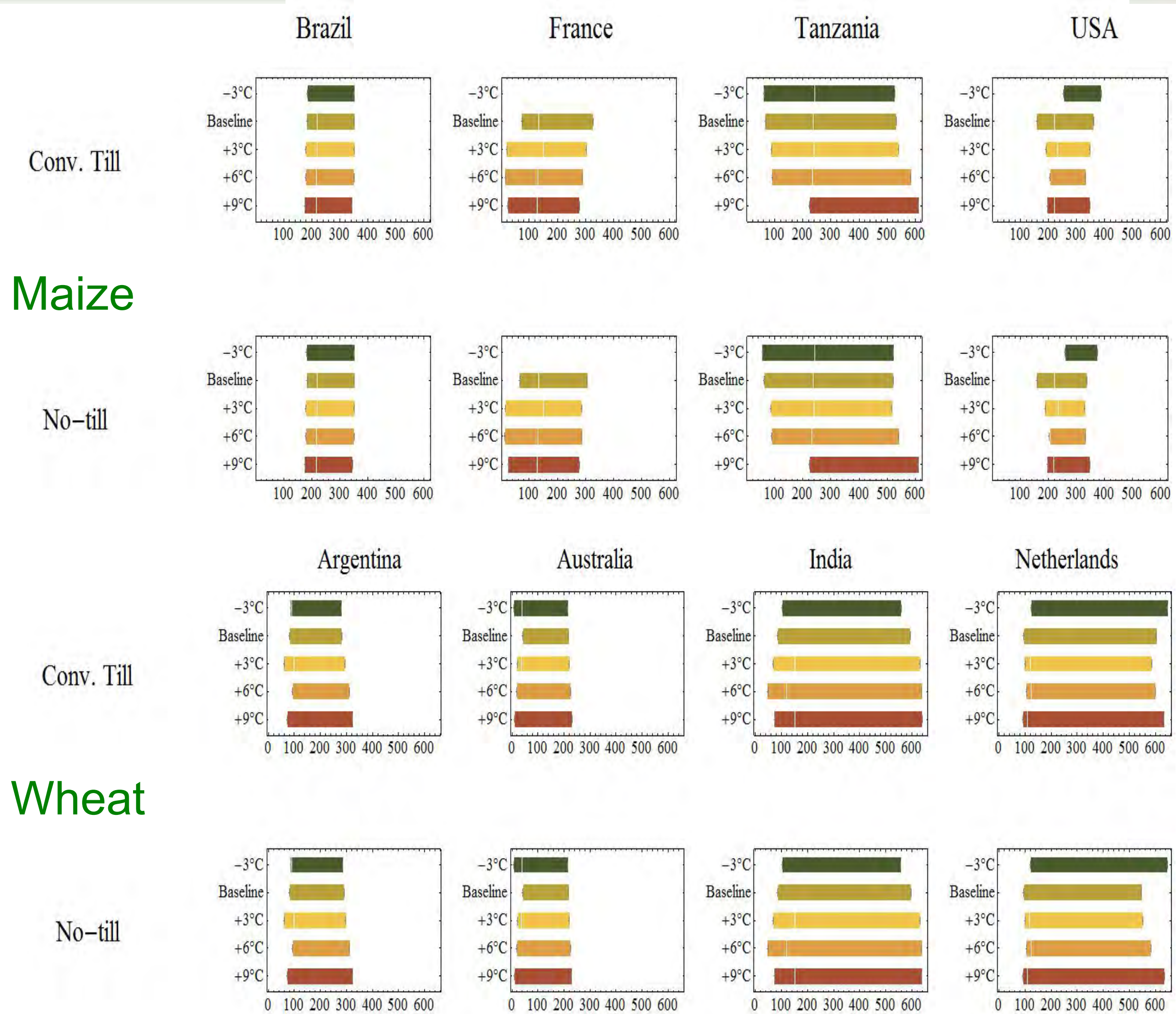
SOC % Change (1980-2010) in Plow layer at baseline Rain and 360 ppm CO_2



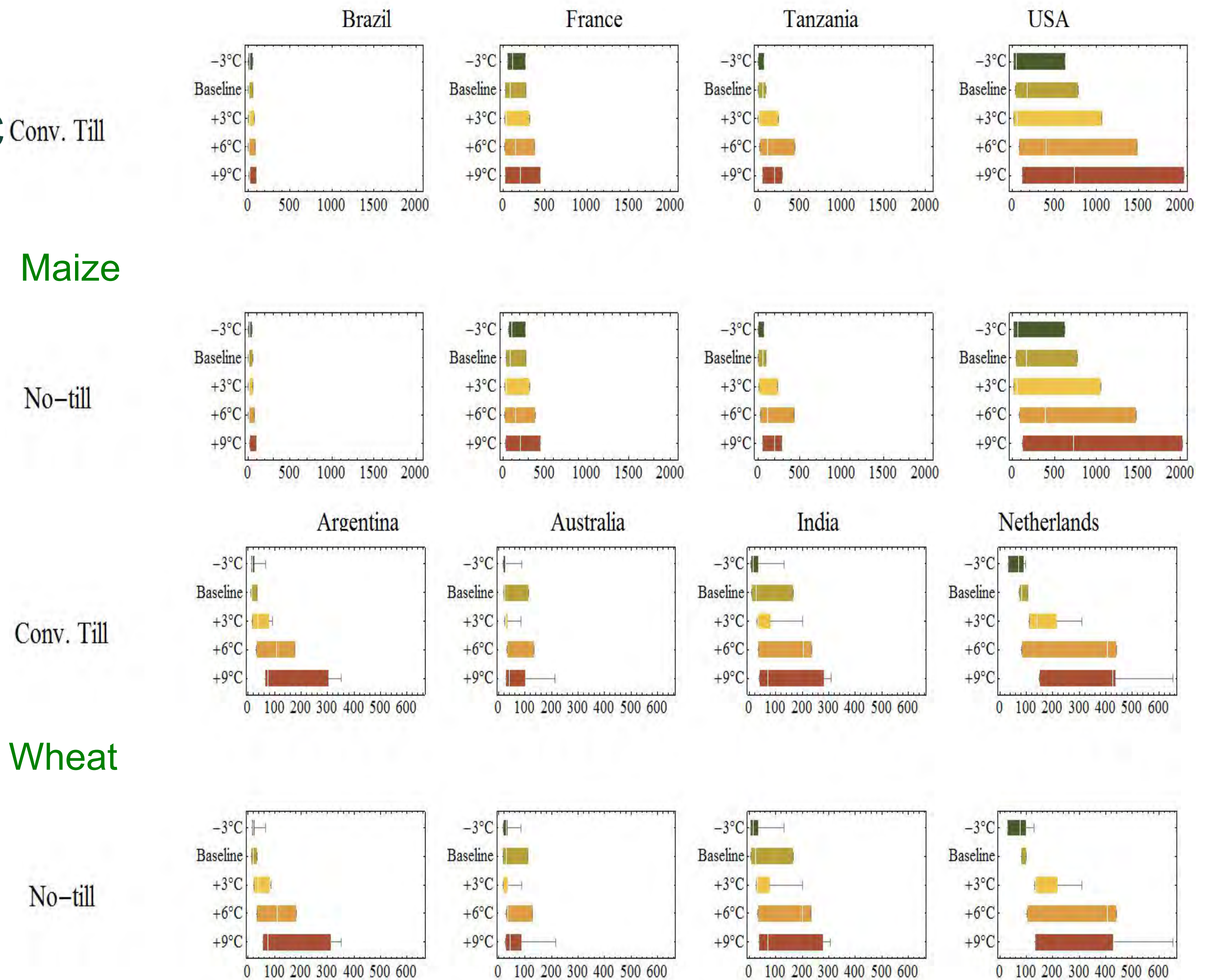
SOC Outcomes

- Temperature increase magnified Soil Organic Carbon (SOC) loss
- Soil N and C have identical patterns of change
- SOC was lost from plow layer (0-25 cm) in Tanzania and USA sites stayed unchanged in France site with tillage only having a minor impact.
- Plow layer SOC in Brazil was lost for Conventional Tillage and gained for No-tillage treatments.

Plant Available Water (mm) at Maturity 360 ppm and Baseline Rain



Inorganic N in soil (kg/ha) at Maturity 360 ppm and Baseline Rain



Future Steps

- Complete phase 1 – publish results
- Start Phase 2 with long-term observed data from various places across the world:
- (USA, Argentina, Italy)
- Collaborate with CN-MIP, GRA and other initiatives to develop common protocols and to share data

What we need to consider in modeling soil…

- Models need to run in a rotational mode (carry over effects)
- Need to properly initialize soil carbon pool (land use)
- Need to account for management (tillage, residues management) that impact soil properties and possibly provide feedback (ponding, porosity, water holding capacity etc)
- Assumptions on initial conditions and exploitable rooting depth
- Infer about management and model validation by linking models with remote sensing and mobile technology

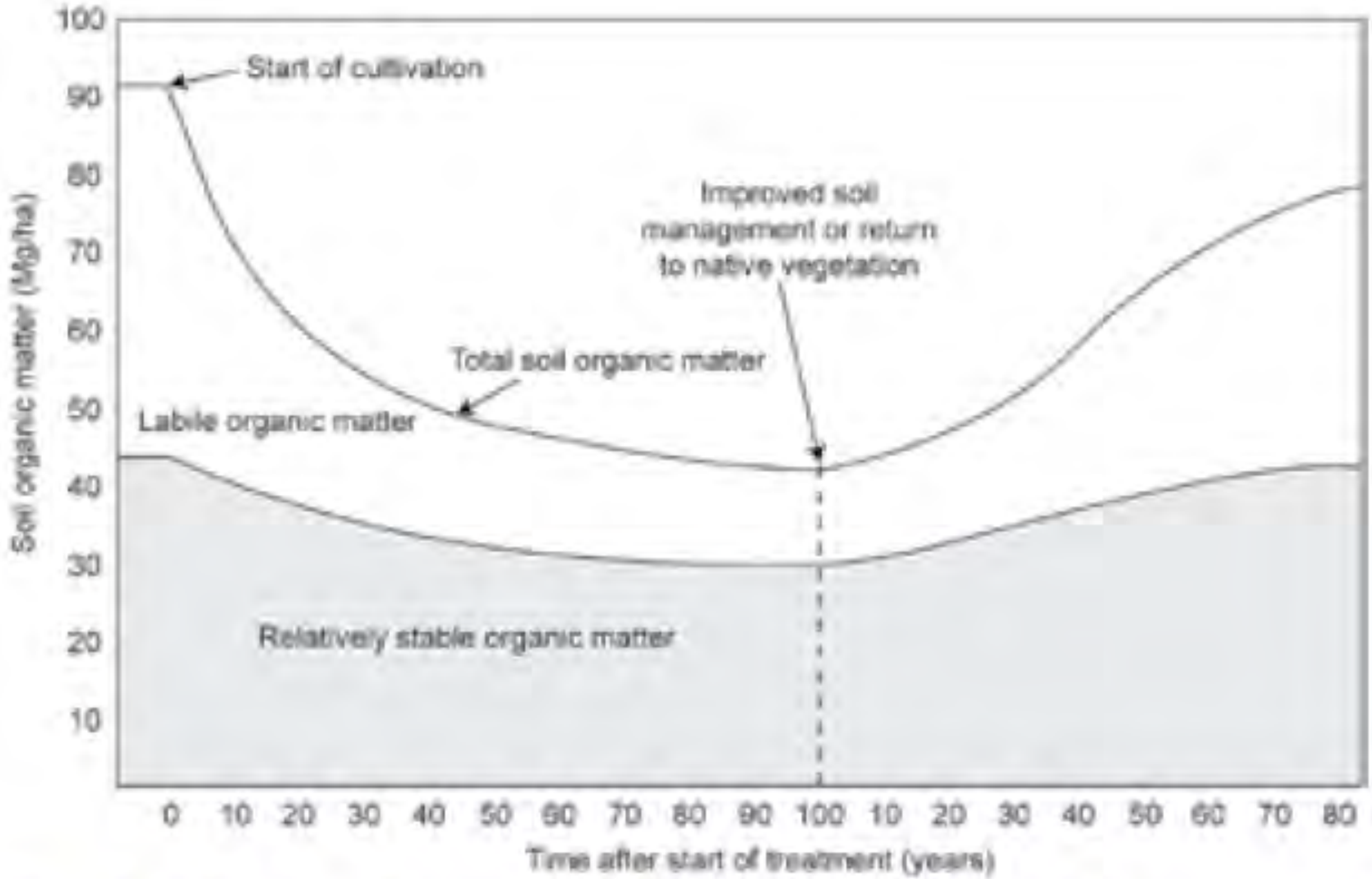


Fig. 3. Changes in soil carbon content after deforestation/ cultivation and reforestation. Hillel and Rosezenweig, 2011

Soil Biology & Biochemistry

Procedures for Initializing Soil Organic Carbon Pools in the DSSAT-CENTURY Model for Agricultural Systems

Changes of intermediate soil organic carbon pool (SOC2) over time in a cultivated soil (0-20 cm) with good and poor management practices for 12 soil types at Tifton, GA.

Soil Type	0 years		5 years		10 years		20 years		60 years		100 years	
	Management											
	Poor	Good	Poor	Good	Poor	Good	Poor	Good	Poor	Good	Poor	Good
Sandy	0.54	0.54	0.45	0.50	0.41	0.51	0.30	0.58	0.10	0.68	0.06	0.70
Loamy Sand	0.54	0.54	0.43	0.44	0.40	0.39	0.37	0.37	0.13	0.39	0.05	0.39
Sandy Loam	0.54	0.54	0.46	0.49	0.45	0.47	0.45	0.49	0.23	0.55	0.10	0.56
Sandy Clay Loam	0.54	0.54	0.43	0.42	0.37	0.34	0.32	0.27	0.18	0.24	0.14	0.24
Sandy Clay	0.54	0.54	0.44	0.43	0.39	0.35	0.34	0.29	0.20	0.25	0.16	0.25
Loamy	0.54	0.54	0.46	0.47	0.44	0.43	0.43	0.42	0.29	0.43	0.19	0.44
Clay Loam	0.54	0.54	0.45	0.45	0.41	0.40	0.37	0.35	0.26	0.31	0.20	0.31
Clay	0.54	0.54	0.45	0.46	0.41	0.40	0.36	0.36	0.24	0.32	0.19	0.32
Silty Loam	0.54	0.54	0.47	0.50	0.46	0.50	0.46	0.52	0.34	0.55	0.25	0.56
Silty	0.54	0.54	0.48	0.50	0.47	0.51	0.47	0.53	0.35	0.56	0.26	0.56
Silty Clay Loam	0.54	0.54	0.46	0.47	0.43	0.44	0.40	0.41	0.28	0.39	0.22	0.39
Silty Clay	0.54	0.54	0.47	0.48	0.44	0.45	0.42	0.43	0.33	0.42	0.26	0.42

Basso et al., 2011, SSSAJ

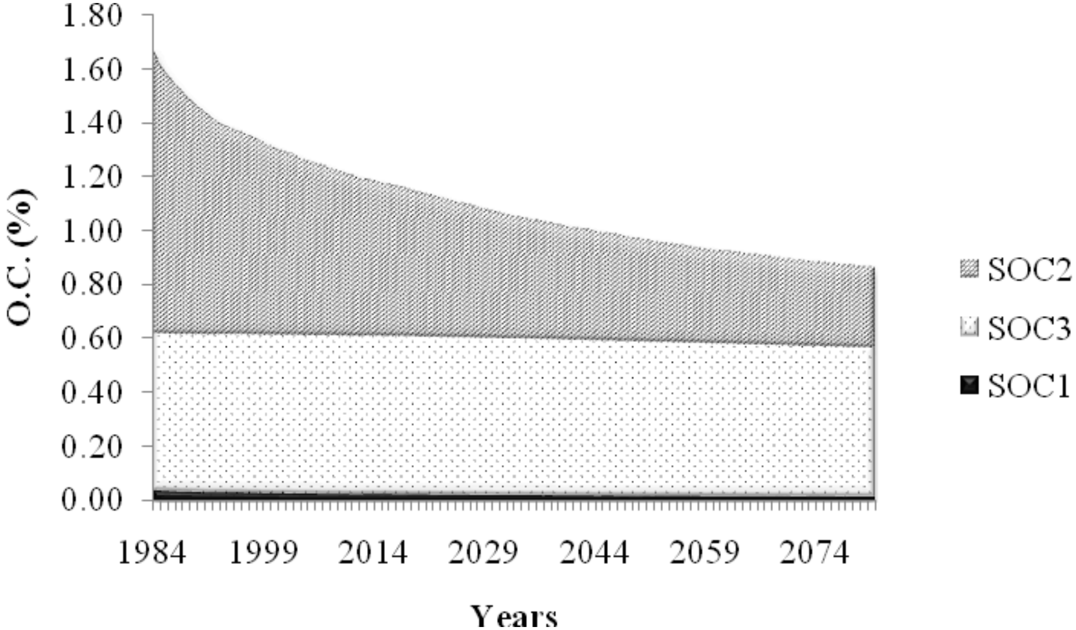
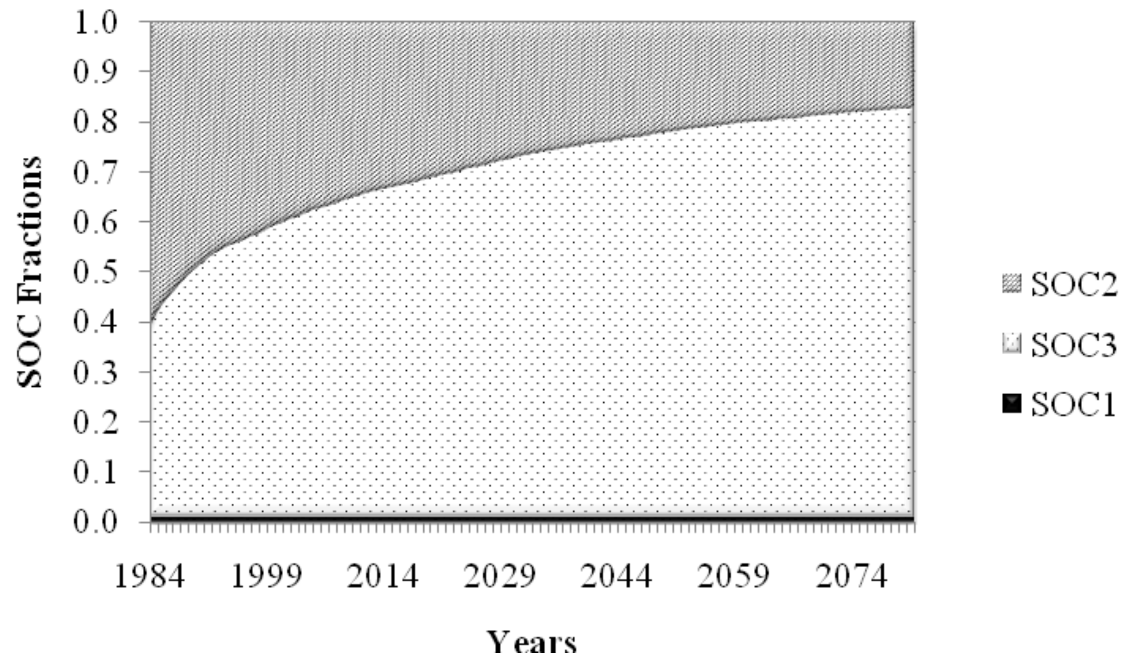


Fig. a. Soil organic carbon (%) change in 100 years of maize rotation, in a clay soil (0-20 cm), with poor management – Field History Grassland.

Fig. b. Soil organic carbon fractions (SOC) change in 100 years of maize rotation, in a clay soil (0-20 cm), with poor management – Field History Grassland



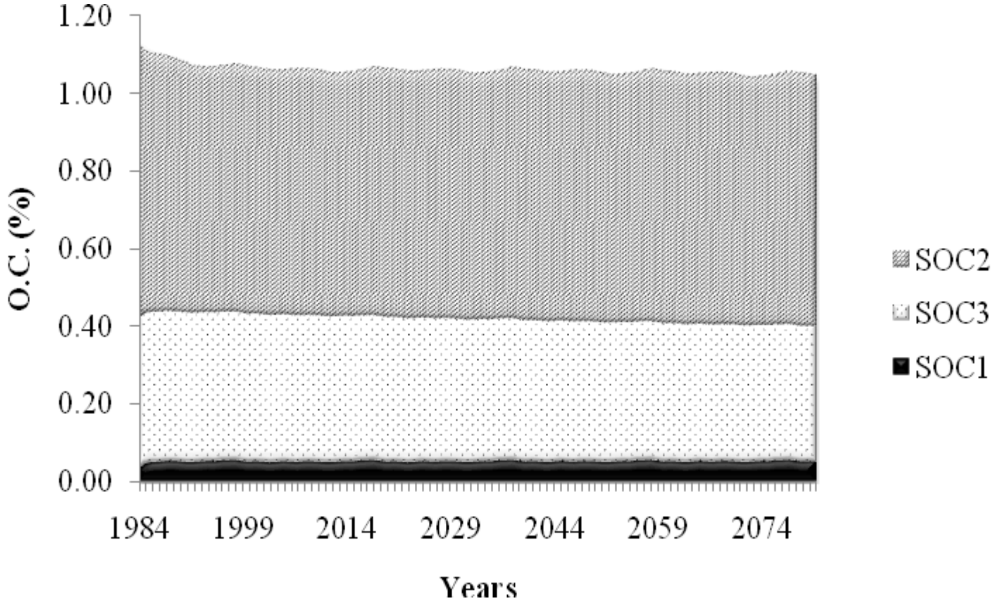
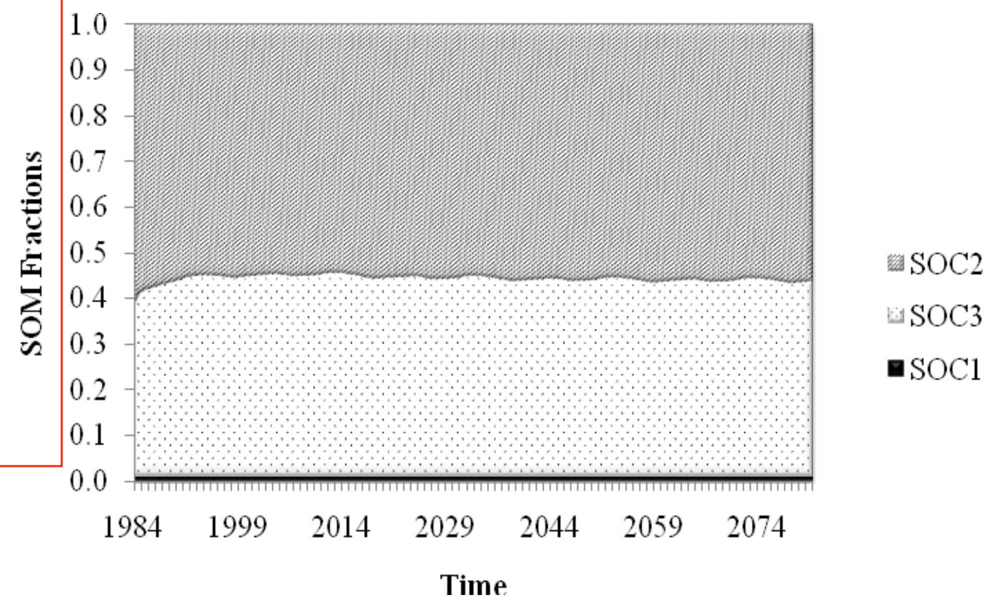


Fig. a. Soil organic carbon (%) change in 100 years of maize rotation, in a Silt soil (0-20 cm), with good management – Field History Grassland .

Fig b. Soil organic carbon fractions (SOC) change in 100 years of maize rotation, in a Silt soil (0-20 cm), with good management – Field History Grassland



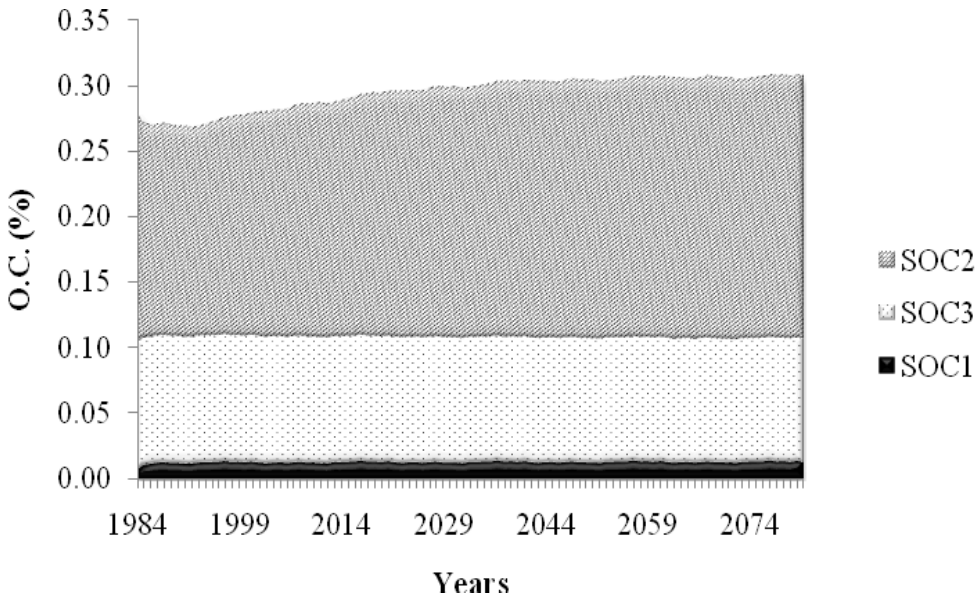
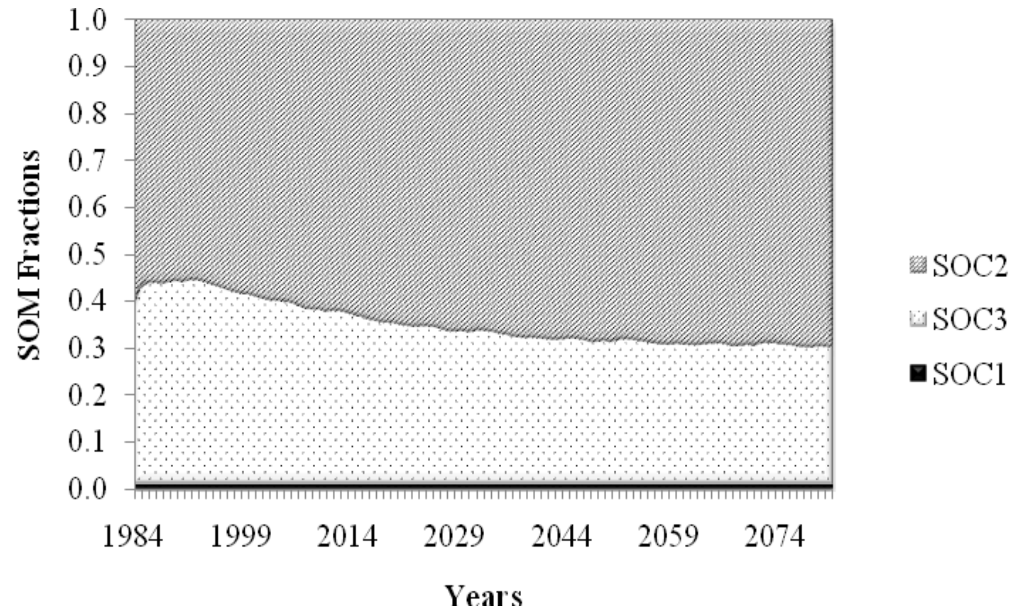
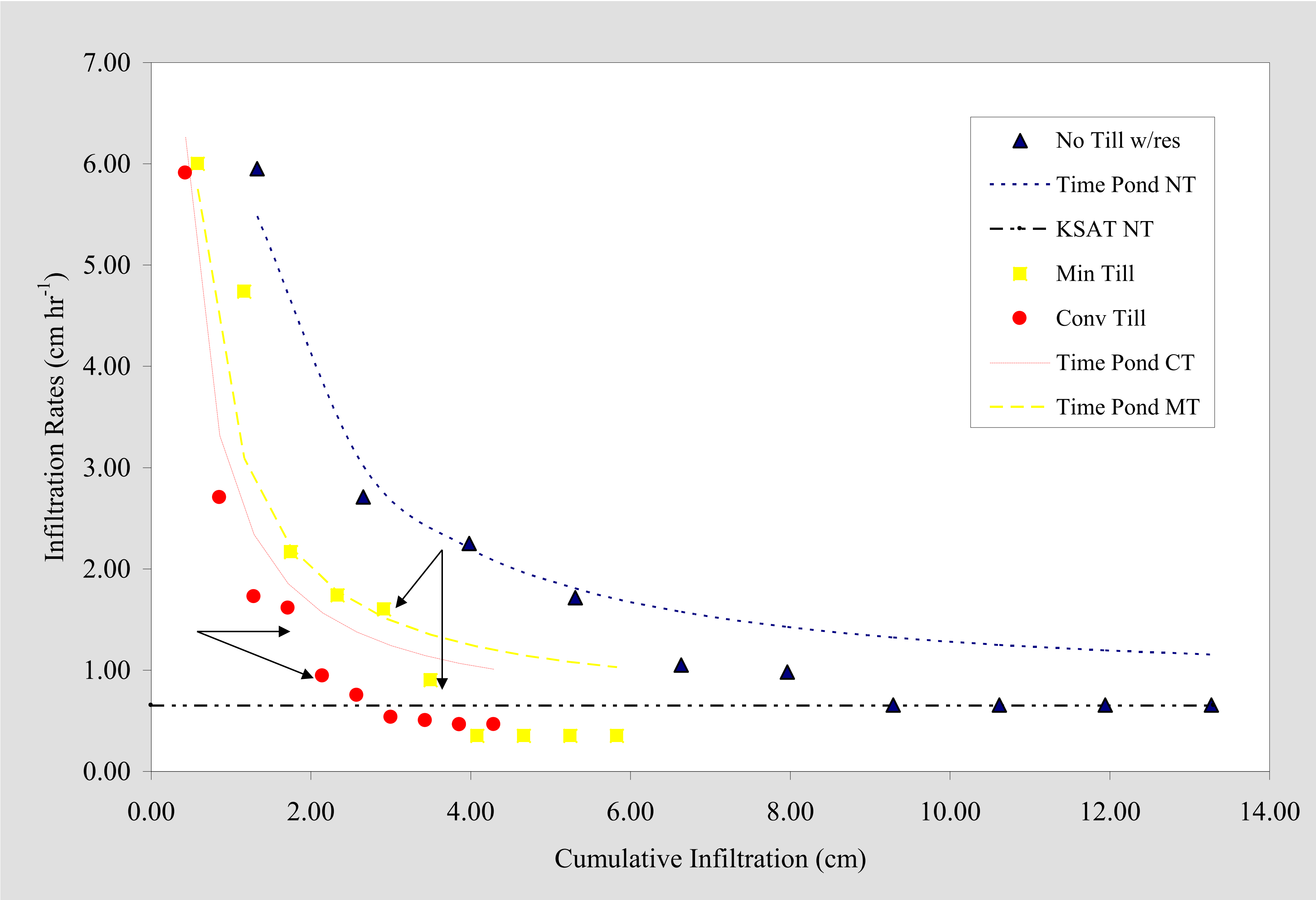


Fig. a. Soil organic carbon (%) change in 100 years of maize rotation, in a Sandy soil (0-20 cm), with good management – Field History Grassland.

Fig. b. Soil organic carbon fractions (SOC) change in 100 years of maize rotation, in a Sandy soil (0-20 cm), with good management – Field History Grassland

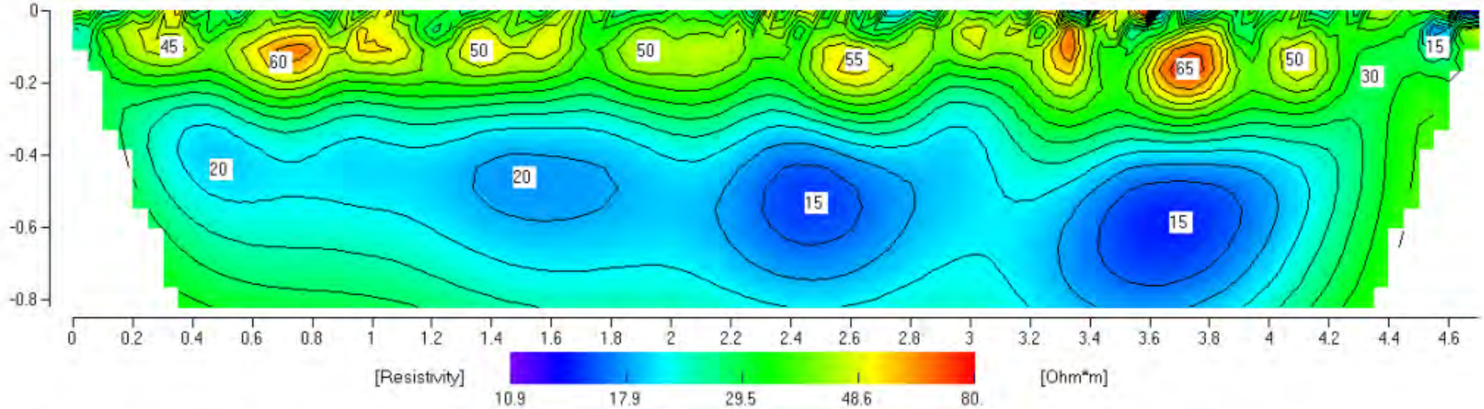




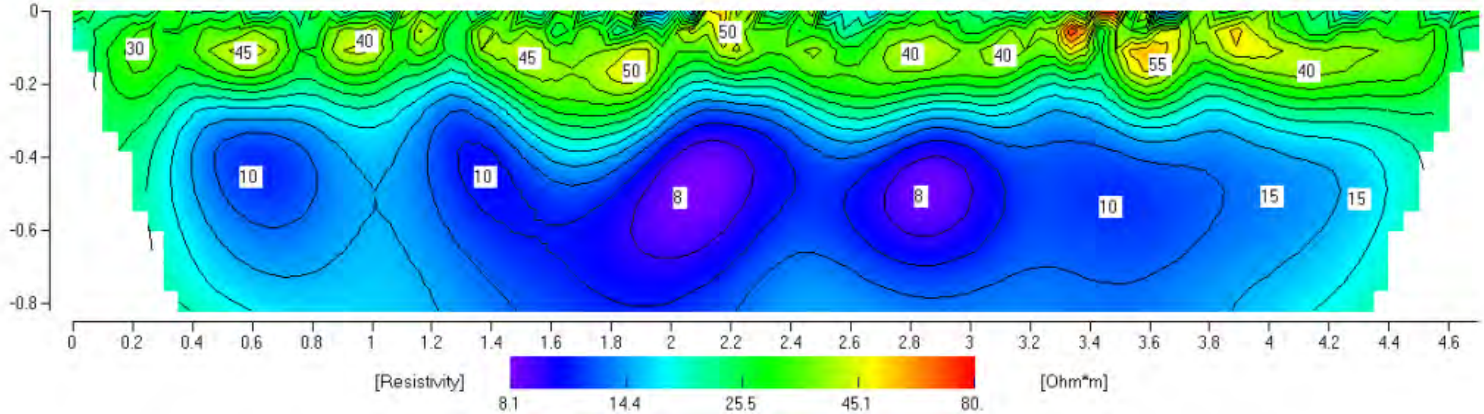
Infiltration Rates (cm hr^{-1})
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
Cumulative Infiltration (cm)
No Till w/res
Time Pond NT
KSAT NT
Min Till
Conv Till
Time Pond CT
Time Pond MT

High-resolution 2-D resistivity tomography

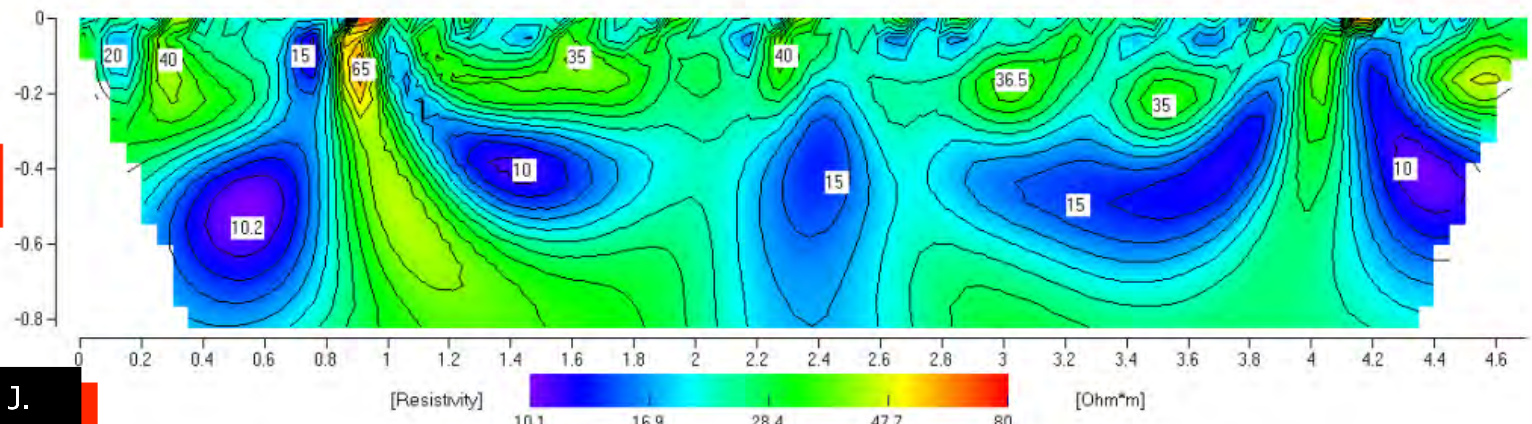
Conventional Tillage



Minimum Tillage

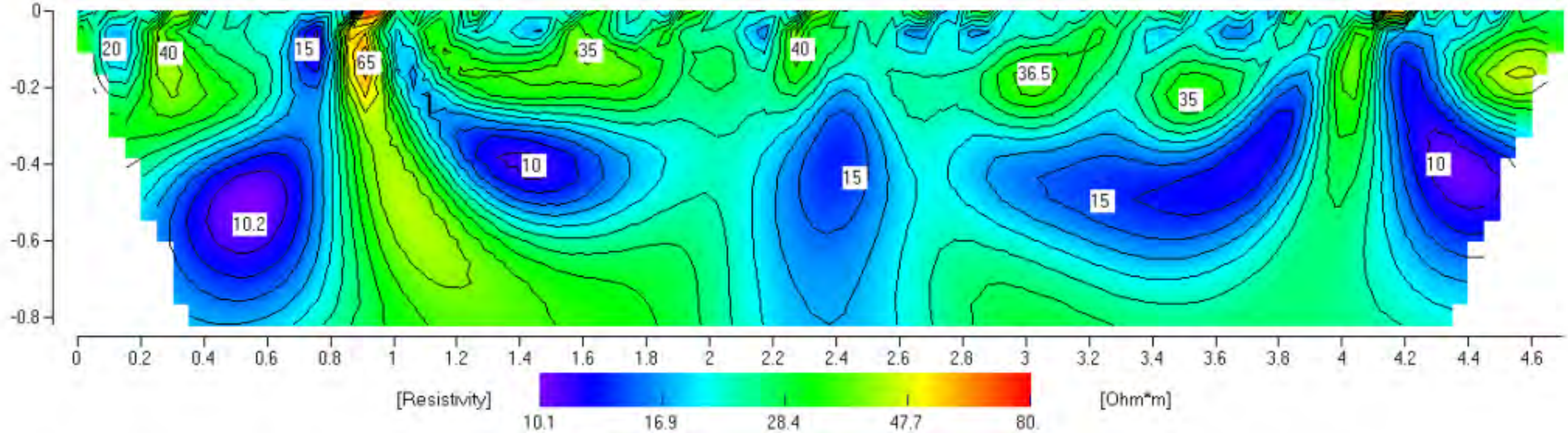


No Tillage

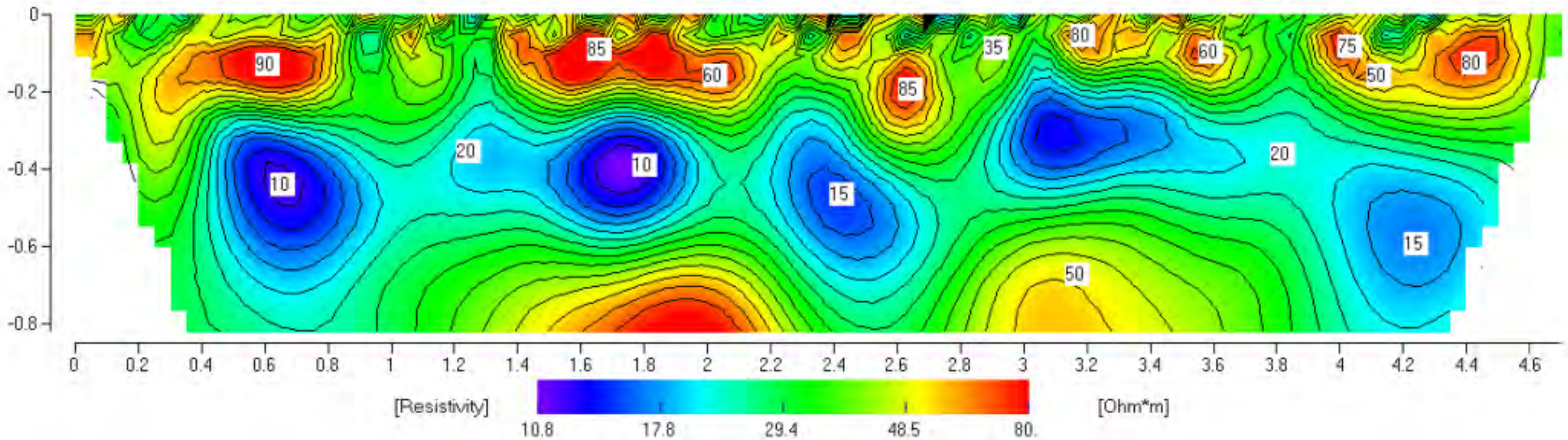


Basso et al., 2010 Agron J.

No Tillage



No Tillage plot right after a tillage event



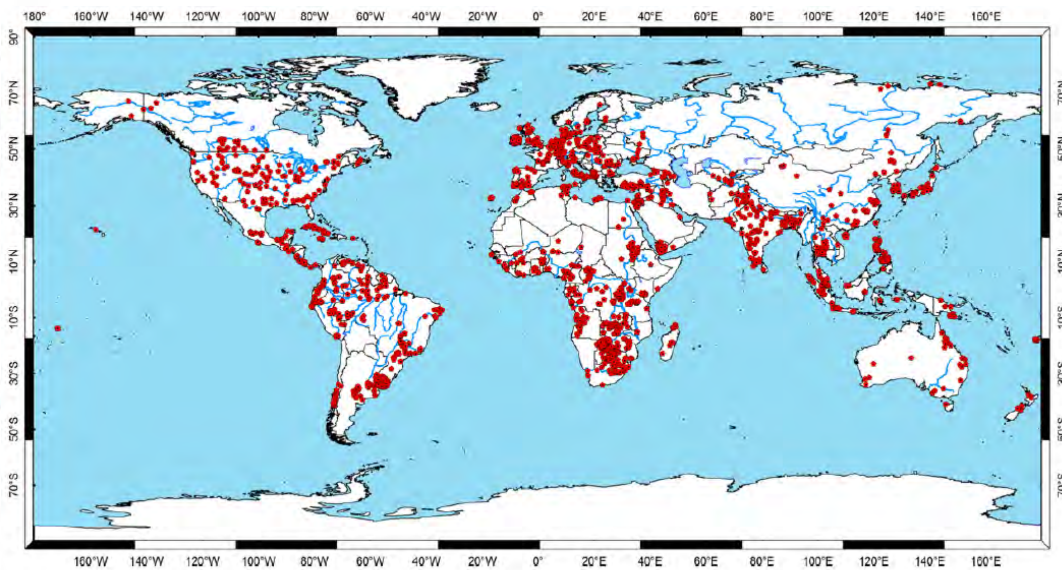
Basso et al., 2010 Agron J.

Soil WISE Database

The soil groups, according to FAO (1990) and included in WISE v. 1.1[a].

Soil class	Africa	Asia	North America	Central & South America	Europe	Oceania
Acrisol	117	32	8	46	2	7
Alisol	5	33	5	14	5	—
Andosol	12	25	1	51	15	5
Anthrosol	—	20	1	—	3	—
Arenosol	187	12	4	10	5	1
Calcisol	35	59	9	3	12	—
Cambisol	100	189	20	57	113	15
Chernozem	9	11	10	—	18	—
Ferralsol	129	40	1	63	2	11
Fluvisol	64	181	6	23	44	4
Gleysol	80	40	7	19	37	2
Greyzem	—	1	4	—	1	—
Gypsisol	1	9	2	1	1	—
Histosol	—	—	—	2	2	—
Kastanozem	—	4	9	7	7	1
Leptosol	21	15	1	13	13	1
Lixisol	49	11	1	14	—	—
Luvisol	189	51	26	21	89	10
Nitisol	8	14	4	24	—	2
Phaeozem	37	15	19	71	29	1
Planosol	18	1	4	14	7	2
Plinthosol	6	7	—	5	1	—
Podzol	10	6	1	5	24	3
Podzoluvisol	—	1	2	—	7	—
Regosol	33	11	1	16	6	1
Solonchack	20	26	3	6	6	—
Solonetz	19	17	5	12	2	3
Vertisol	121	64	4	25	27	9
Xerosol	2	—	—	—	—	—
Yermosol	—	—	—	—	—	1
TOTAL	1272	895	158	522	478	79

[a] Soil groups were summarized by continent. The value indicates the number of soil profiles in WISE 1.1 database.



Global Strategy
IMPROVING AG-STATISTICS

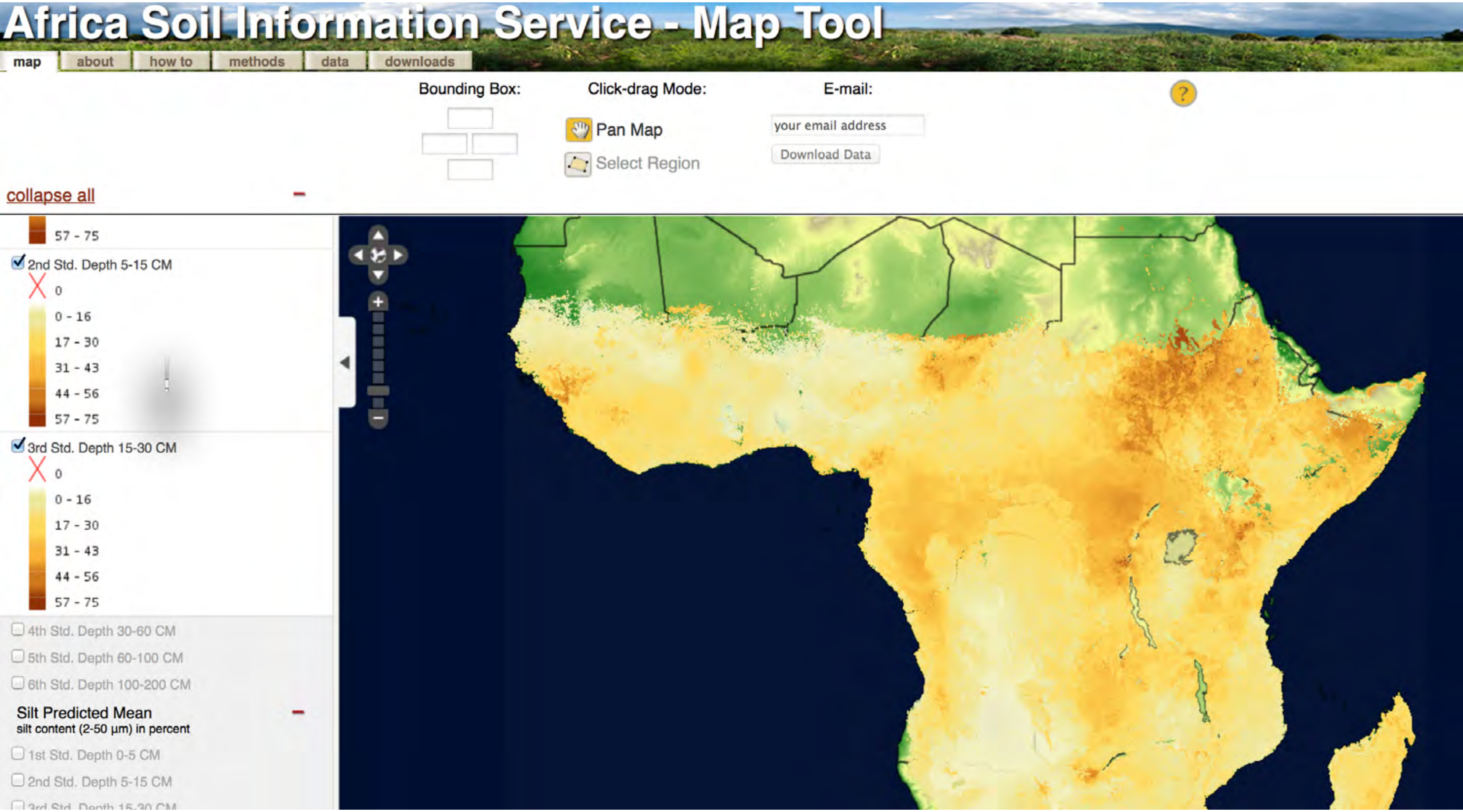
Soil data

Globally Integrated African Soil Information Service (AFSIS). AFSIS data was used to develop a number of different databases, which can be used to generate a wide variety of maps ranging from soil and ecosystem health indicators to the impact of various soil conditions on soil health and agricultural productivity. AfSIS remote sensing data sets can be downloaded from AfricaGrids. ftp://africagrids.net/500m/Albedo/

WorldSoilProfiles.org as a contribution to Global Earth Observation System of System (GEOSS) and the Global Soil Partnership (GSP). ISRIC is accredited by the International Council of Science (ICSU) as the World Data Center for Soils. With this mandate, ISRIC aims to stimulate and organize the collation and harmonisation of legacy soil data. So far 31720 soil profiles

Database 4 – ICRAF –ISRIC VNIR (visible near infrared spectra) spectral database http://www.isric.org/data/icrafisric-spectral-library.

The data consist of 785 soil profiles consisting of 4,438 soil samples were collected in 58 countries spanning Africa, Asia, Europe, North America, and South America.



Africa Soil Information Service - Map Tool
map
about
how to
methods
data
downloads
Bounding Box:
Click-drag Mode:
E-mail:
Pan Map
Select Region
your email address
Download Data
?
collapse all
57 - 75
2nd Std. Depth 5-15 CM
0
0 - 16
17 - 30
31 - 43
44 - 56
57 - 75
3rd Std. Depth 15-30 CM
0
0 - 16
17 - 30
31 - 43
44 - 56
57 - 75
4th Std. Depth 30-60 CM
5th Std. Depth 60-100 CM
6th Std. Depth 100-200 CM
Silt Predicted Mean
silt content (2-50 µm) in percent
1st Std. Depth 0-5 CM
2nd Std. Depth 5-15 CM

Global Strategy
IMPROVING AG-STATISTICS

FAO Agricultural Stress Index System (ASIS)

ASIS assesses the intensity, duration and spatial extent of drought based on the Vegetation Health Index (VHI). The VHI is an index that combines NDVI and air temperature

A low VHI indicates water stress while the high values of VHI are indication of a healthier crop.

The data are obtained from Metop-AVHRR S10 or "ENDVI10" which are near-global, 10-daily composite images synthesized from the "best available" observations registered in the course of every ten days by the orbiting earth observation system.

Global Strategy
IMPROVING AG-STATISTICS

Geo-Global Agricultural Monitoring Initiative GeoGlam

GeoGlam summarizes latest crop conditions for maize, wheat, rice and soybean crops, based on regional expertise and analysis of satellite data, ground observations, and meteorological data and was conducted by experts from global, national and regional monitoring systems. Additional information on GeoGlam can be found at: http://geoglam-crop-monitor.org

Global Strategy
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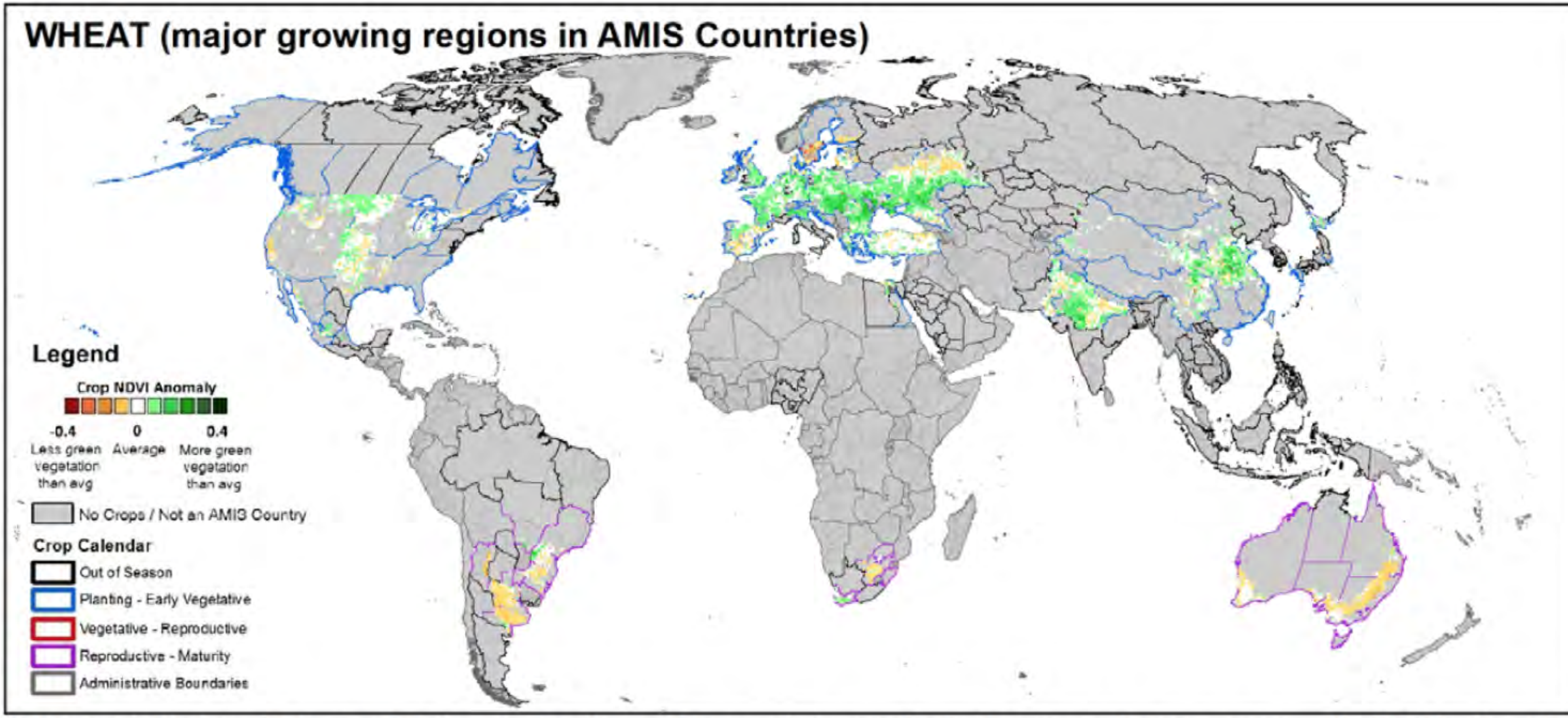
Geo-Global Agricultural Monitoring Initiative GeoGlam



NDVI is a satellite-based indicator of photosynthesis often used for monitoring croplands. These anomaly images compare the NDVI for November 28th, 2013 to the average NDVI for the same date from 2000-2012, over the main growing regions of the four AMIS crops. Orange to red indicates less green vegetation than average, green indicates higher than average vegetation. Administrative unit outline colours indicate crop growth

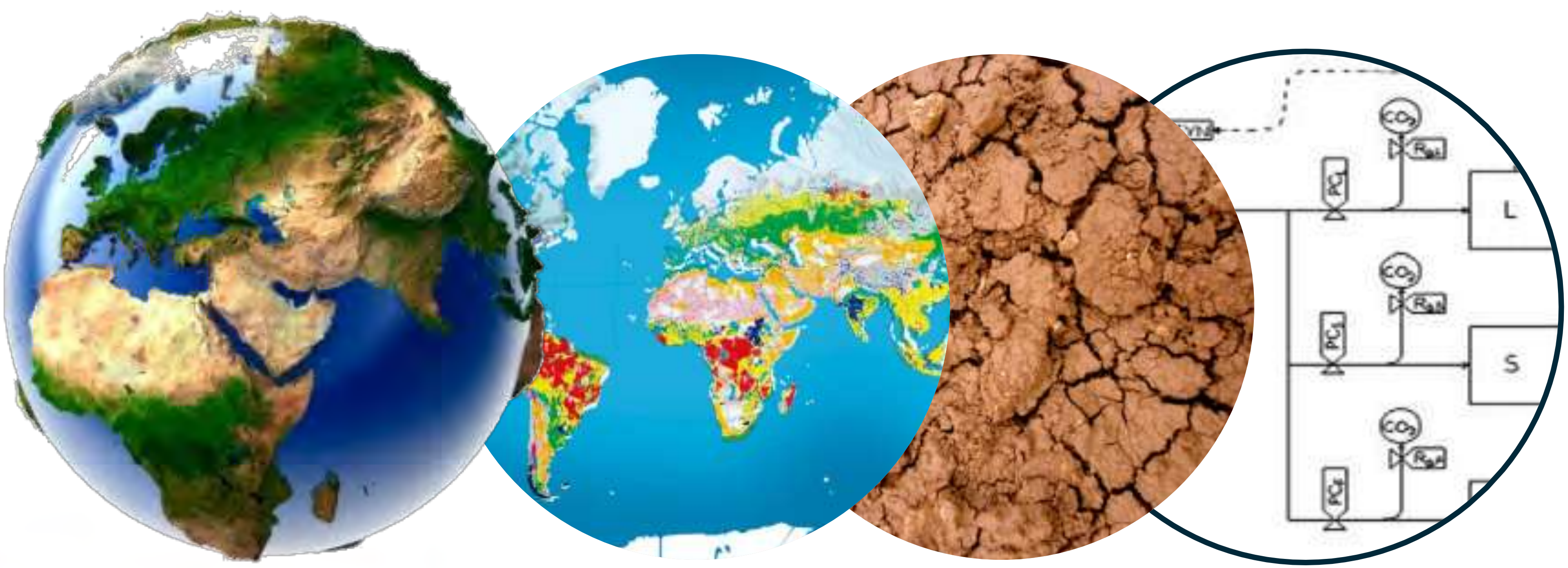
Conclusions

- Modeling of soils processes (soil fertility, available water, soil quality/degradation) must be included in every crop model that aims to model long-term impact of management strategies and climate change on crop yield
- We need to account for changes on water, carbon and nitrogen
- We need to properly initialize soil carbon pool
- We need to account for management (tillage, residues management)
- We can back-calculate initial conditions and rooting depth and management and model validation by linking models with remote sensing

S-world

A global map of soil properties for modeling

Jetse Stoorvogel



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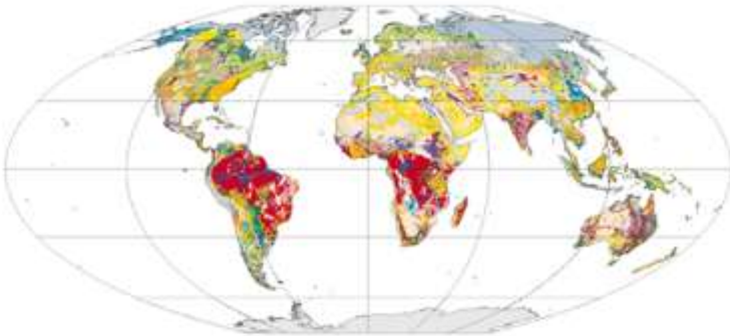
What do the models need?

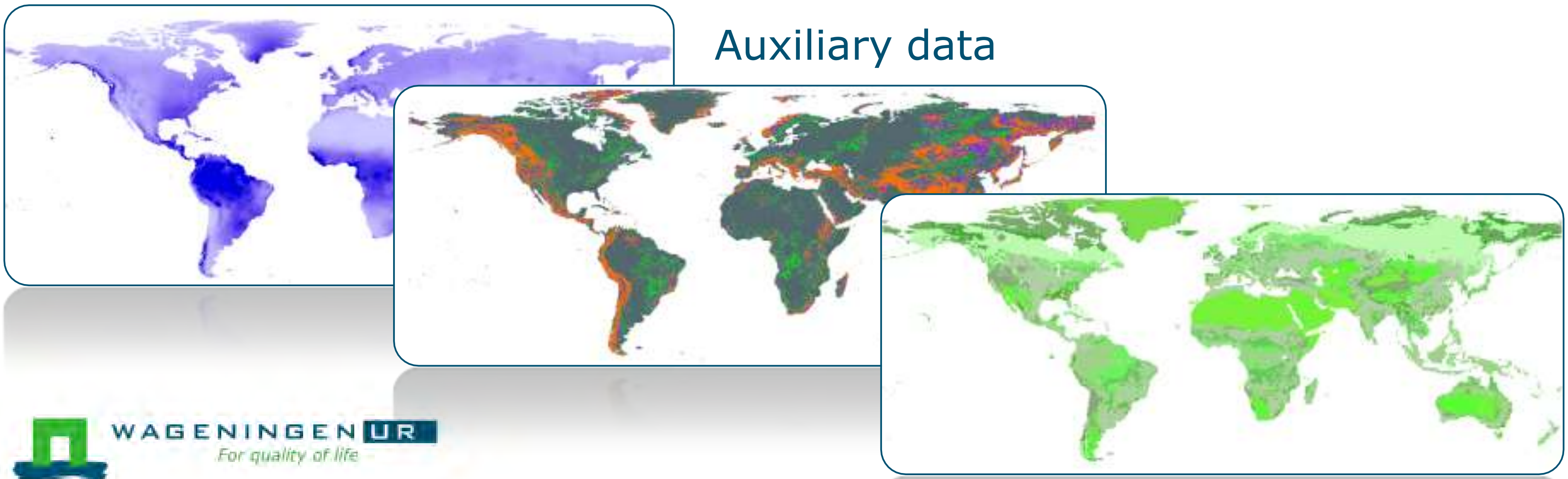
- Spatially exhaustive
- Quantitative
- Pedon information
- Site-specific
- Based on available data

What do we have?

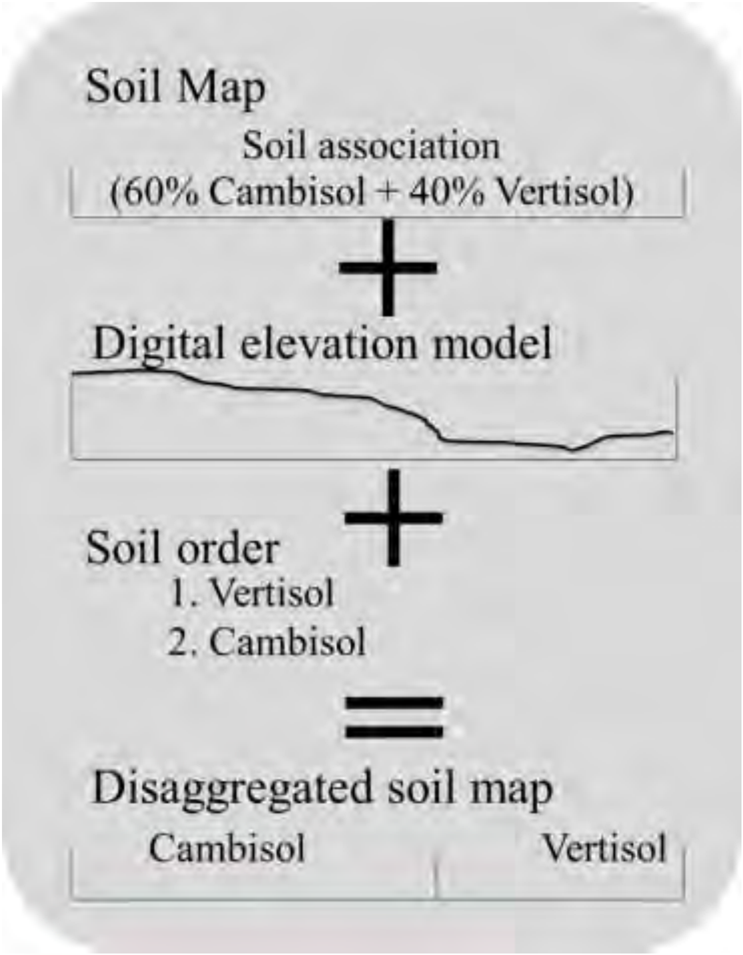
Legacy data

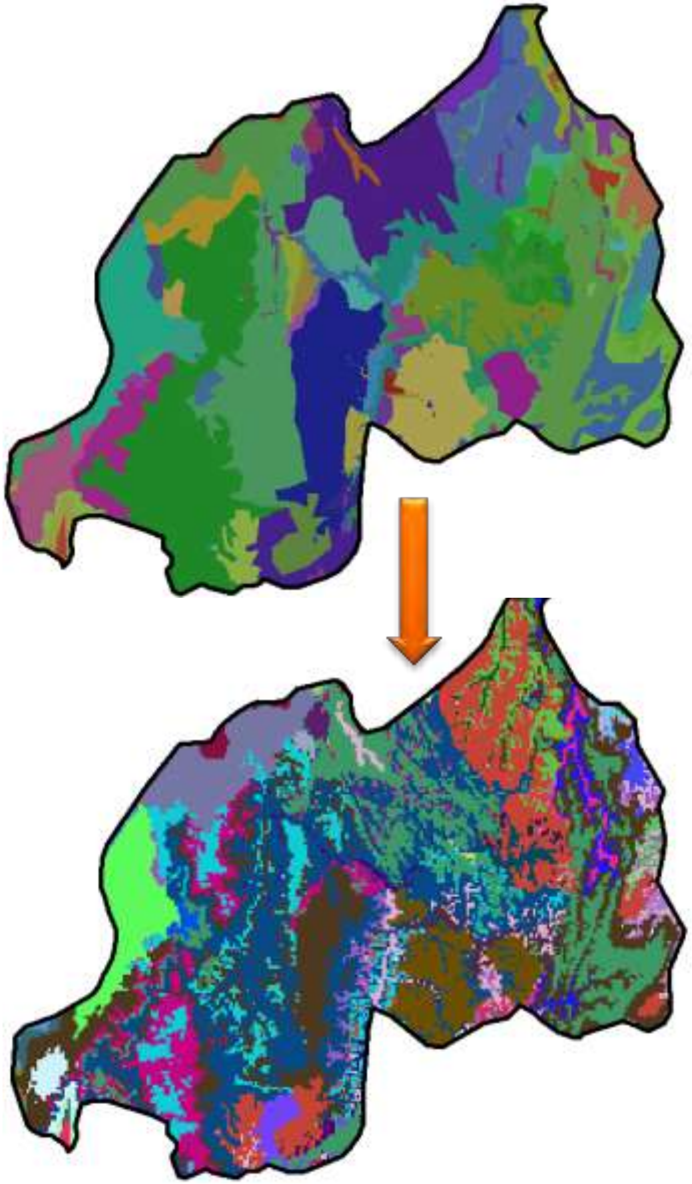


Auxiliary data

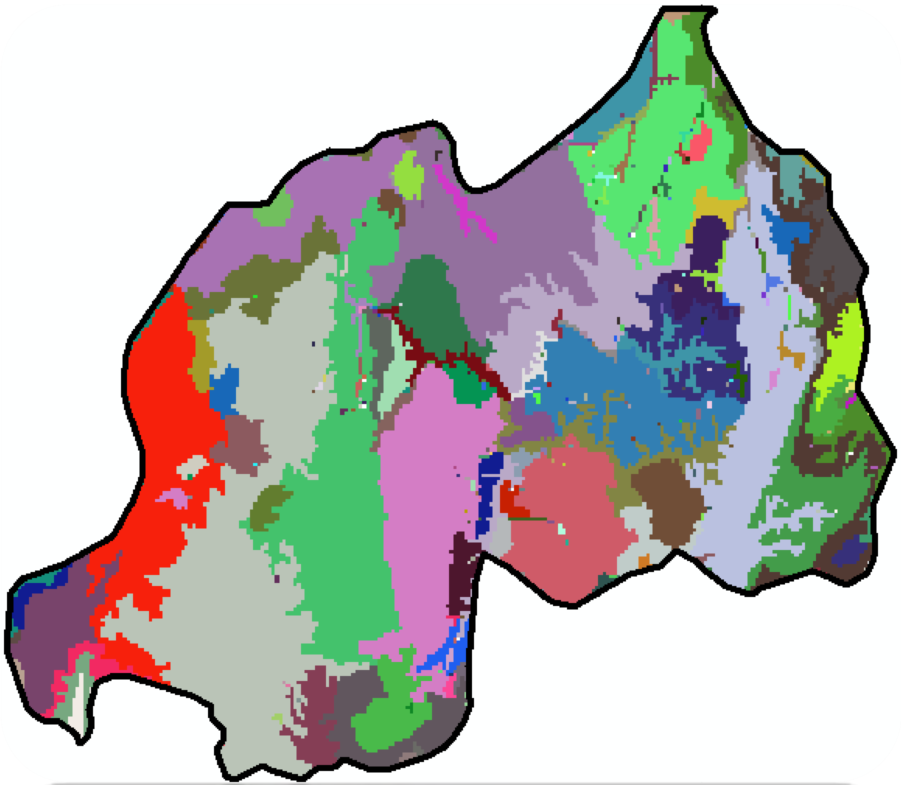


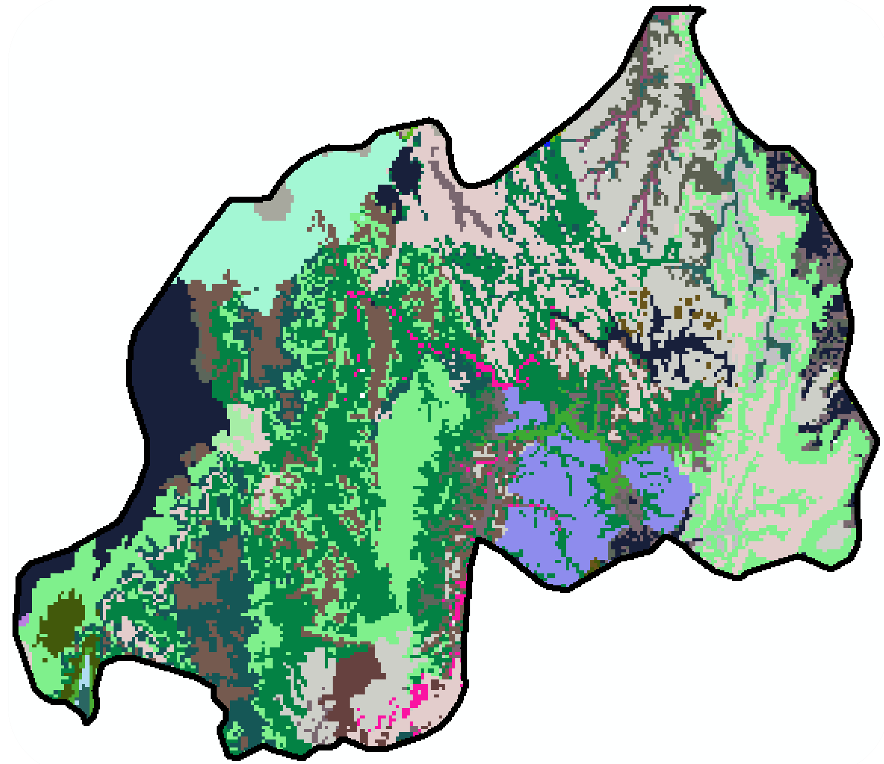
Complex mapping units



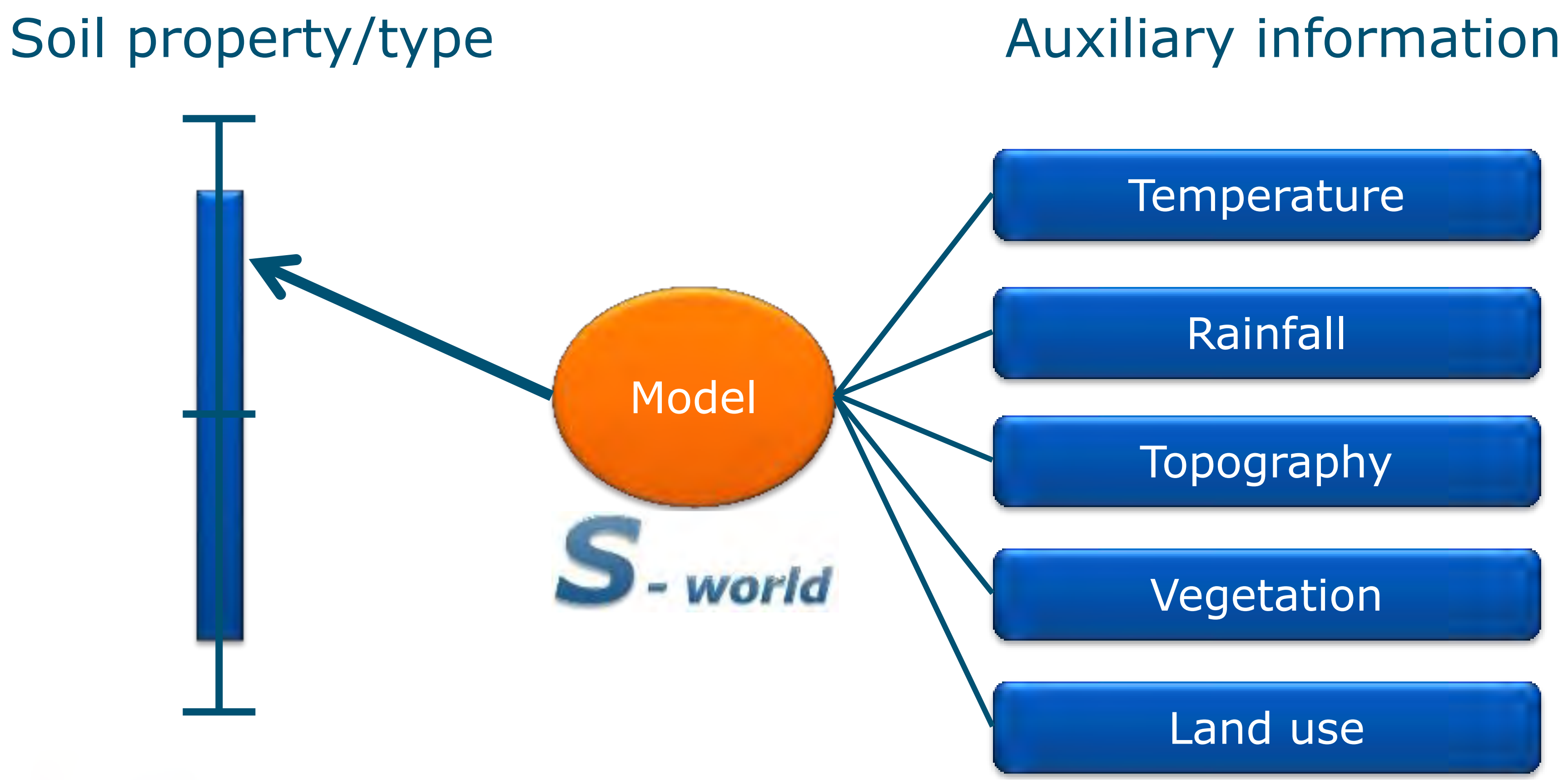


Disaggregated soil map

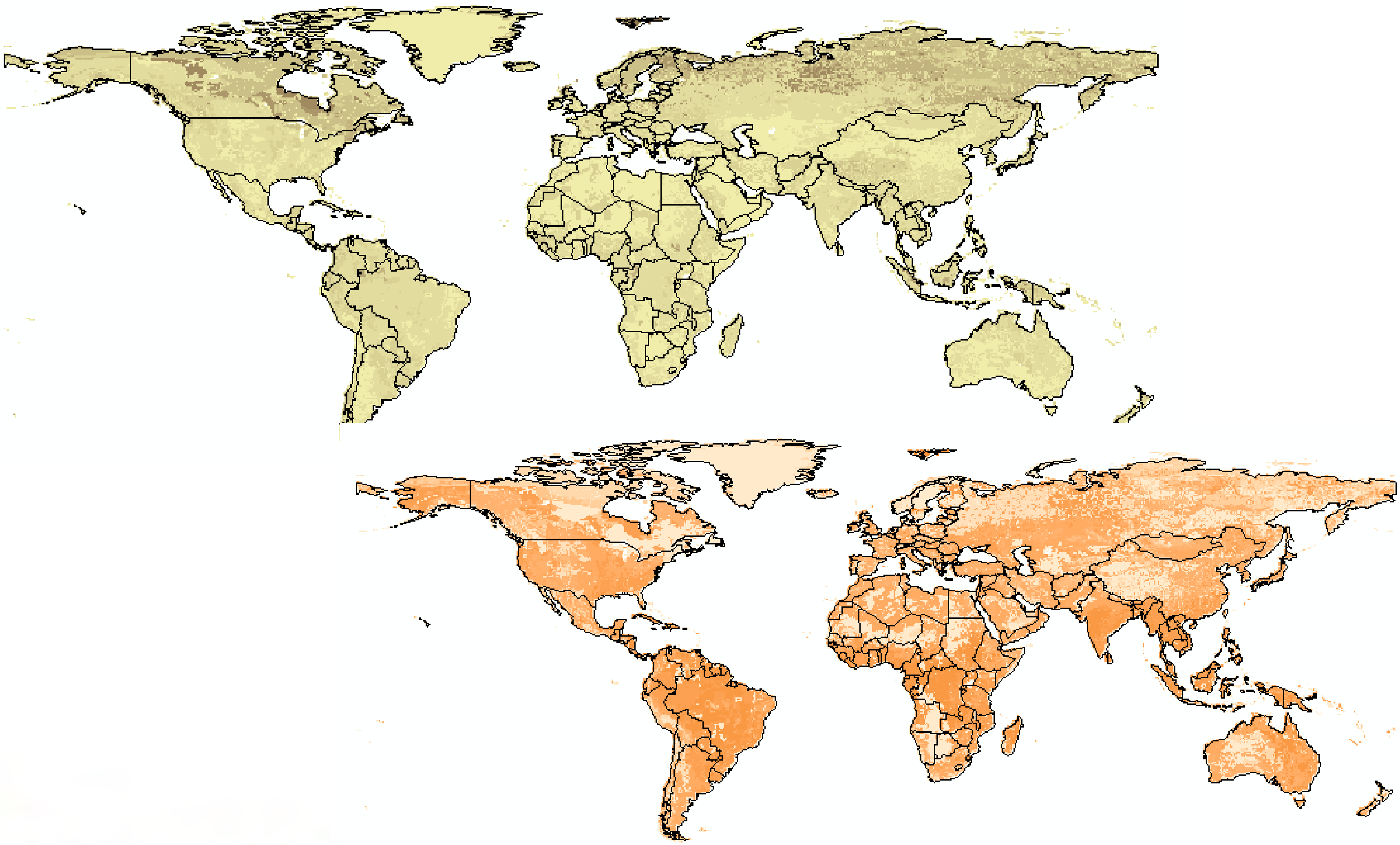




Towards soil properties



Results



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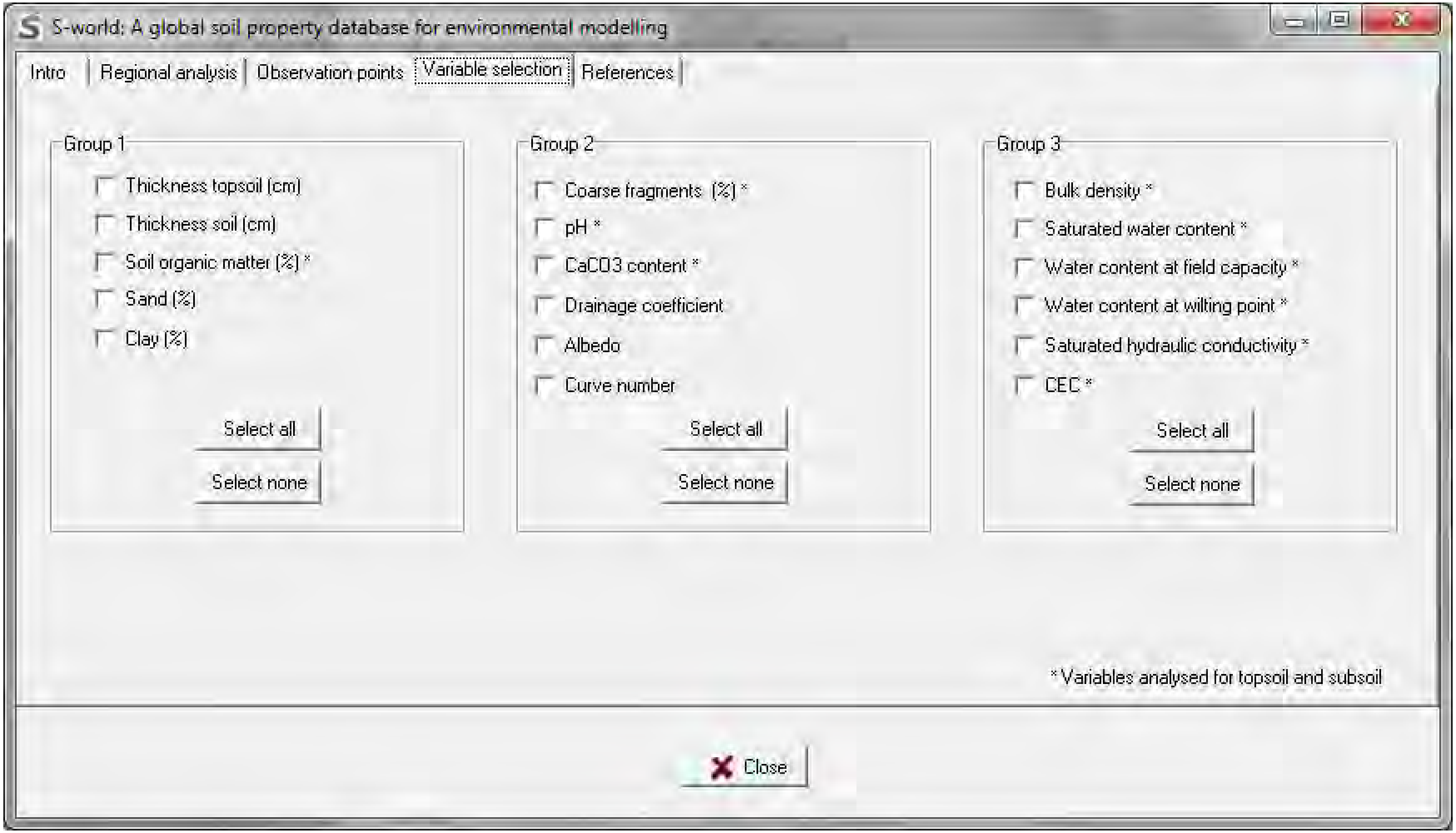
An operational dataset



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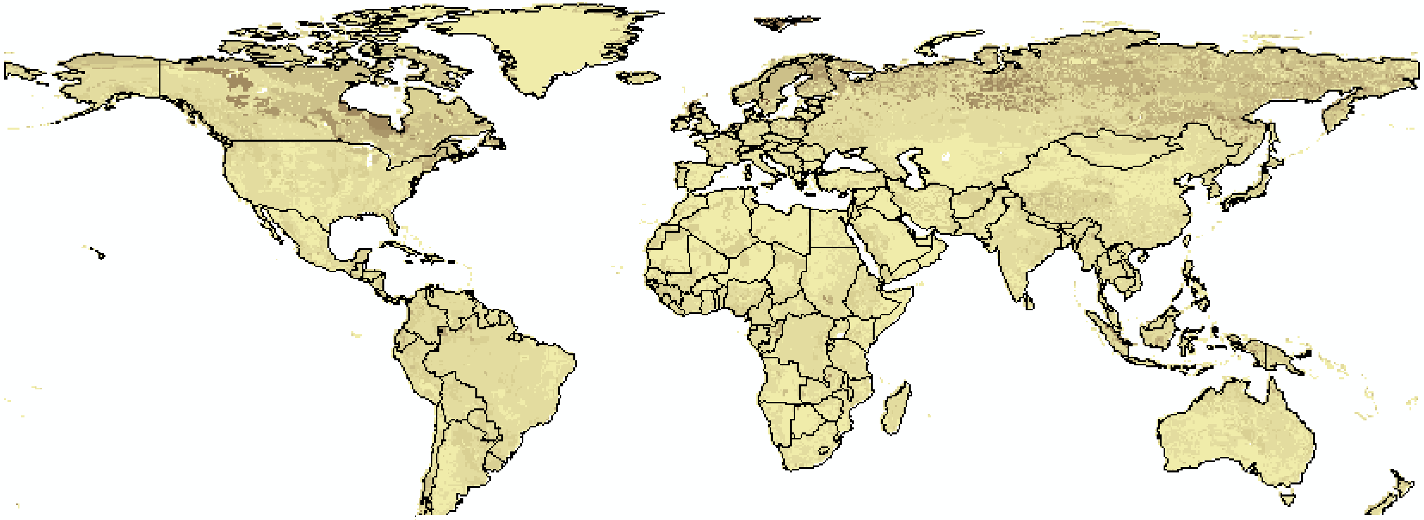
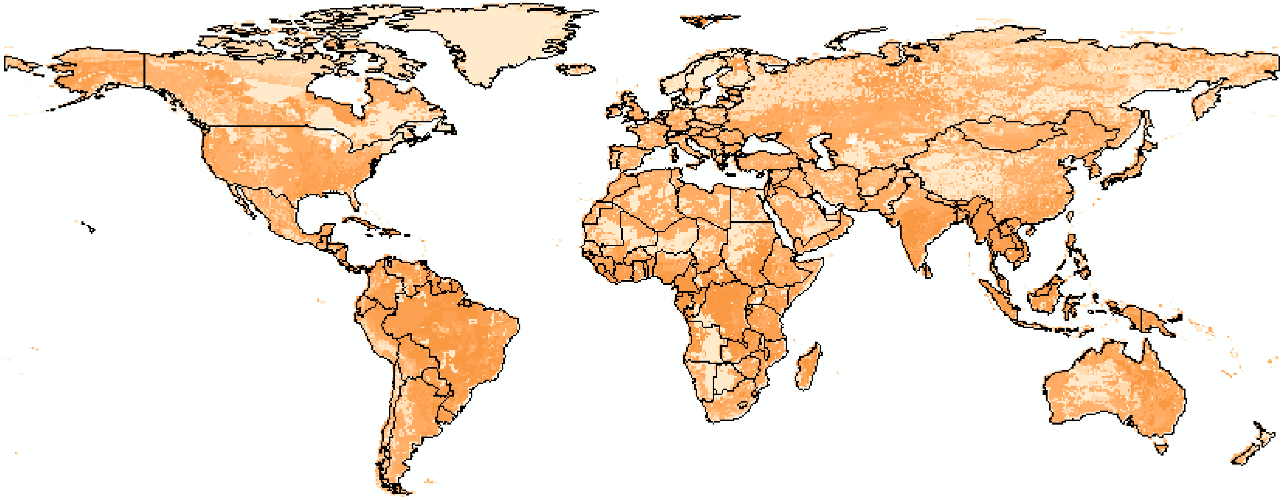
Results





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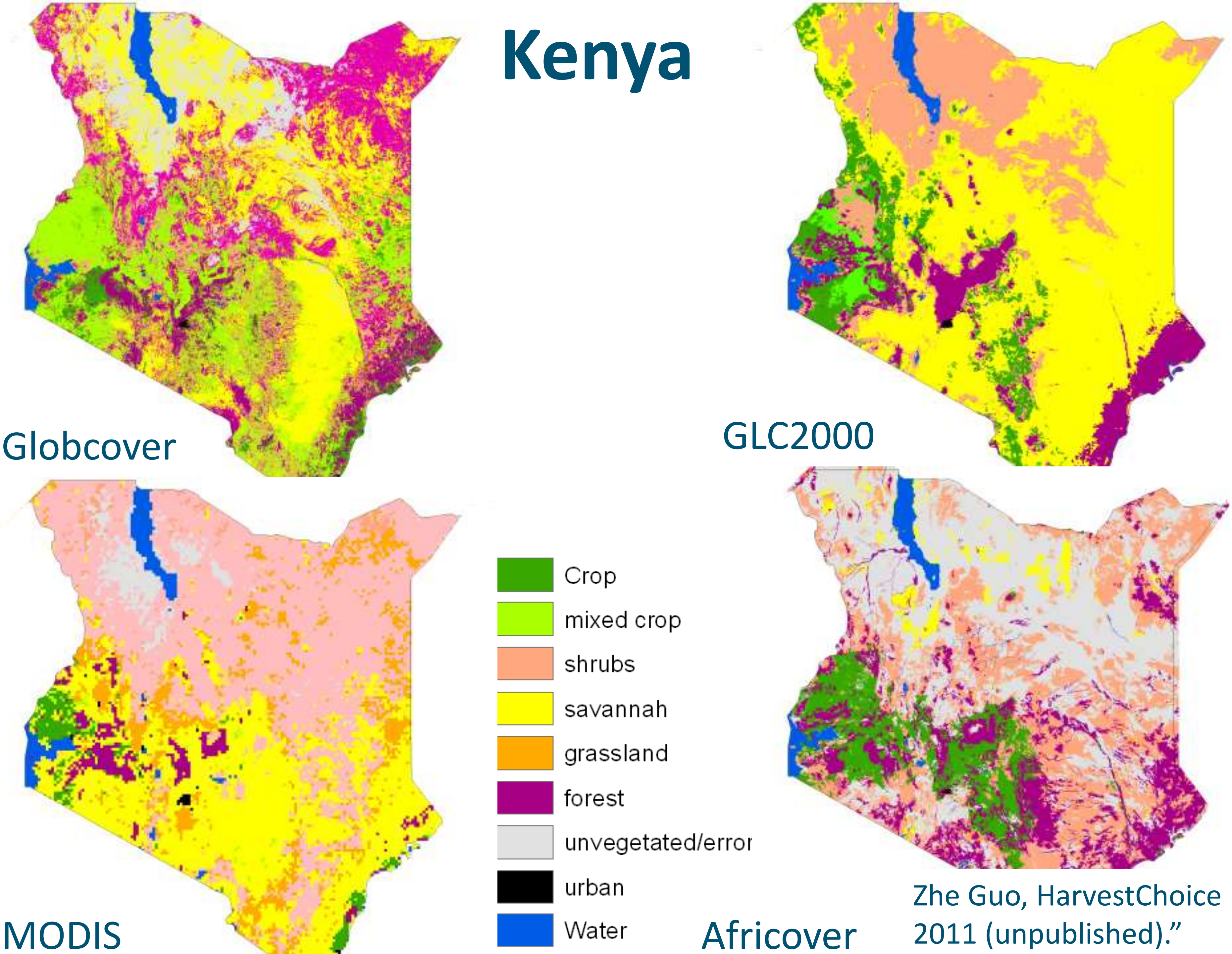
Results

Group 1	SLOC_1	Soil organic carbon, topsoil, g[C]/100g[soil]
	SLOC_2	Soil organic carbon, subsoil, g[C]/100g[soil]
	SLTOP	Depth of topsoil, cm
	SLDP	Depth of soil profile, cm
	SLSND	Sand content, weight %
	SLCLY	Clay content, weight %
Group 2	SLCF	Coarse material, weight %
	SLPHW_1	Soil pH in water, topsoil
	SLPHW_2	Soil pH in water, subsoil
	CACO3_1	Calcium carbonate, topsoil, g/kg
	CACO3_2	Calcium carbonate, subsoil, g/kg
Group 3	SLBDM_1	Soil bulk density, topsoil, g/cm3
	SLBDM_2	Soil bulk density, subsoil, g/cm3
	SLSAT_1	Volumetric water content at saturation, topsoil, mm3/mm3
	SLSAT_2	Volumetric water content at saturation, subsoil, mm3/mm3
	SLDUL_1	Volumetric water content at drained upper limit, topsoil, mm3/mm3
	SLDUL_2	Volumetric water content at drained upper limit, subsoil, mm3/mm3
	SLLL_1	Volumetric water content at lower limit, topsoil, mm3/mm3
	SLLL_2	Volumetric water content at lower limit, subsoil, mm3/mm3
	SKSAT_1	Saturated hydraulic conductivity, topsoil, cm/hr
	SKSAT_2	Saturated hydraulic conductivity, subsoil, cm/hr
	SLCEC_1	Cation exchange capacity, topsoil, cmol/kg
	SLCEC_2	Cation exchange capacity, subsoil, cmol/kg
Group 4	SALB	Soil albedo (fraction)
	SLDR	Soil drainage coefficient (fraction/day)
	SLRO	Runoff curve number
	SLPF	Soil photosynthesis factor (0-1)
	aggrid_iscrop	Logical variable denoting that grid cell contains agricultural land

Practical questions

- Large databases
- Version per continent
- Better input data

Kenya

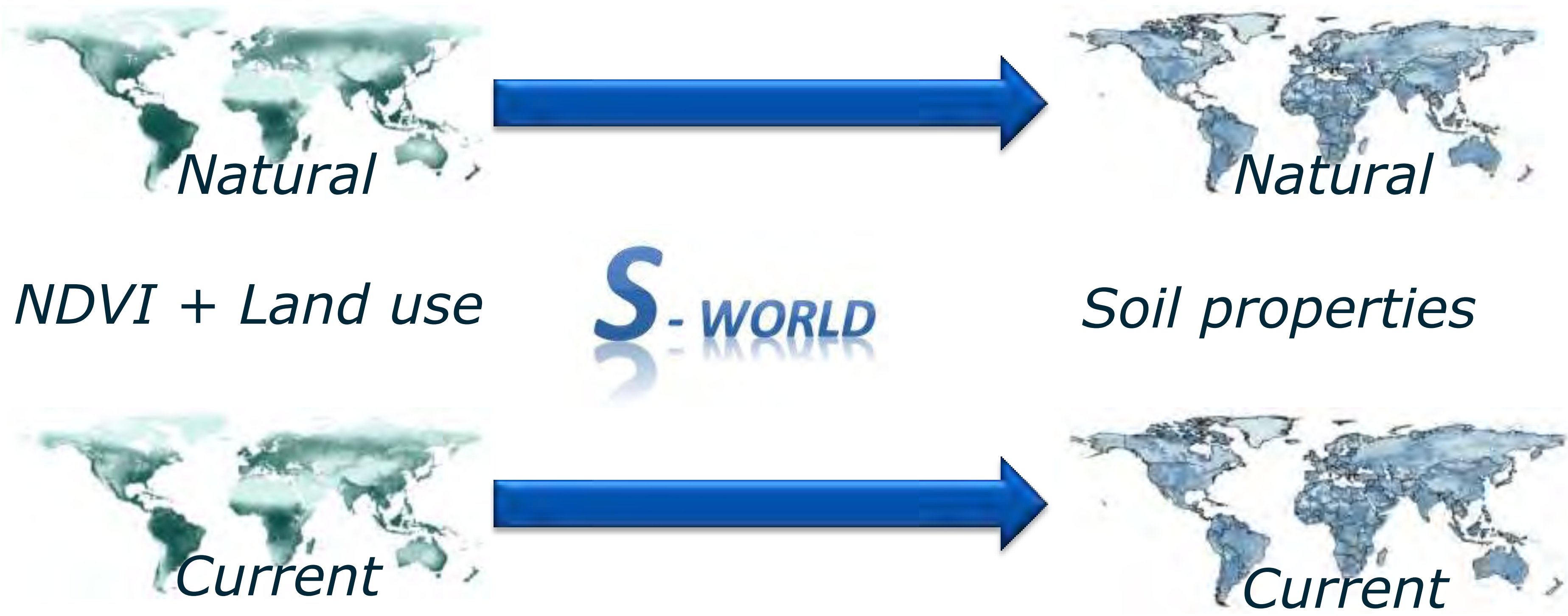


Zhe Guo, HarvestChoice 2011 (unpublished)."

Practical questions

- Large databases
- Version per continent
- Better input data
- Land use change

A global soil property map



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Practical questions

- Large databases
- Version per continent
- Better input data
- Land use change
- Better model parameters

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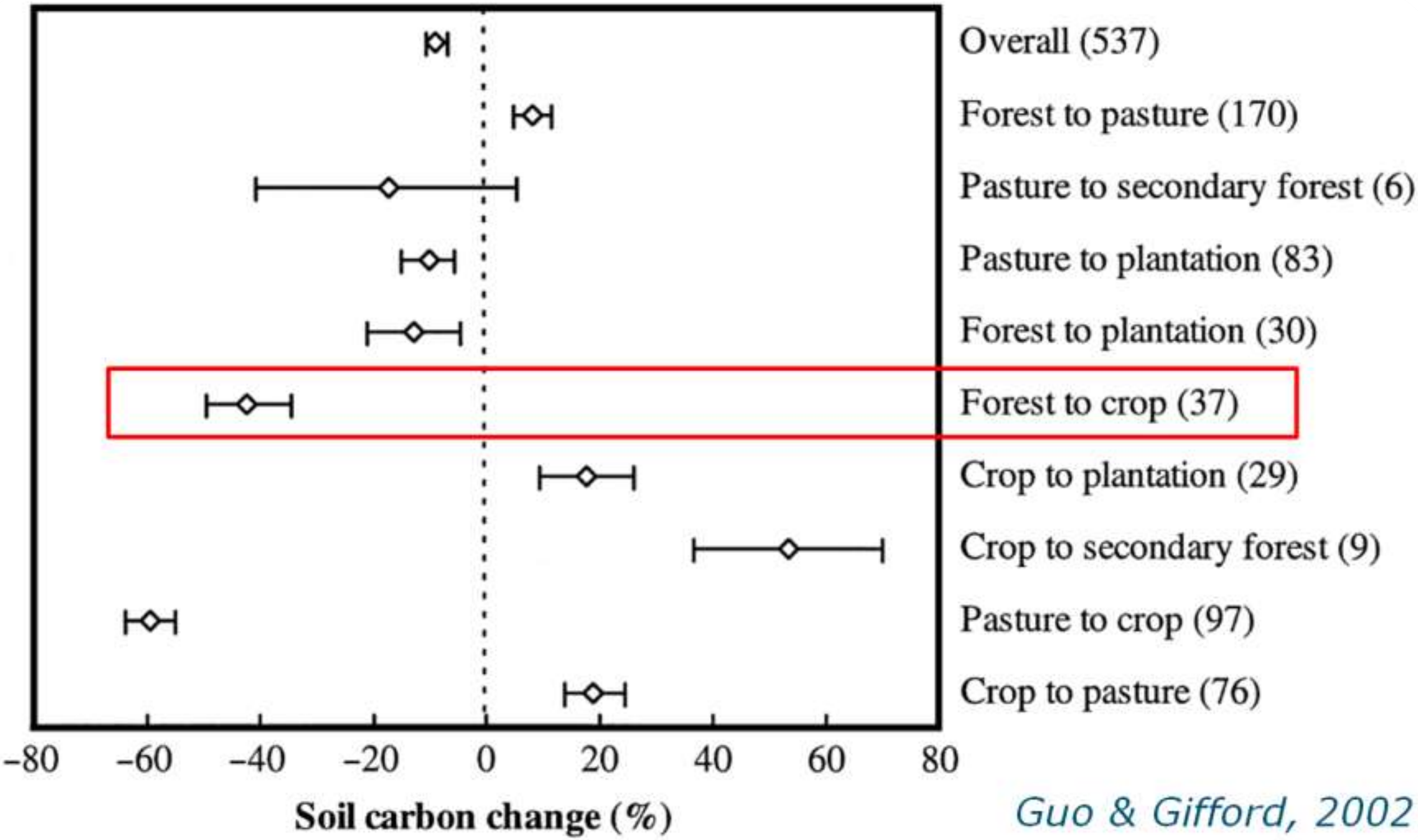
Soil changes over time



Guo & Gifford, 2002

Current activities

S - world

- Validation
- Continuous depth profiles
- Improved pedotransfer functions
- Robustness of methodology

In close collaboration with:

PBL Netherlands Environmental Assessment Agency

AgMIP

ISRIC World Soil Information

Soil & Water Assessment Tool SWAT

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Iowa State University
Department of Agronomy

Soils in APSIM

Sotirios Archontoulis

(sarchont@iastate.edu)

Peter Thorburn

APSIM SOM workshop, Feb 2014, Australia

Representing the effect of SOM on soil function in farming systems models

3 days

Peter Thorburn

APSIM SOM workshop, Feb 2014, Australia

What soil functions does SOM affect?
- Literature review
- APSIM
- Biochar
- Century – DayCent
- Other models
- Development of a systems diagram

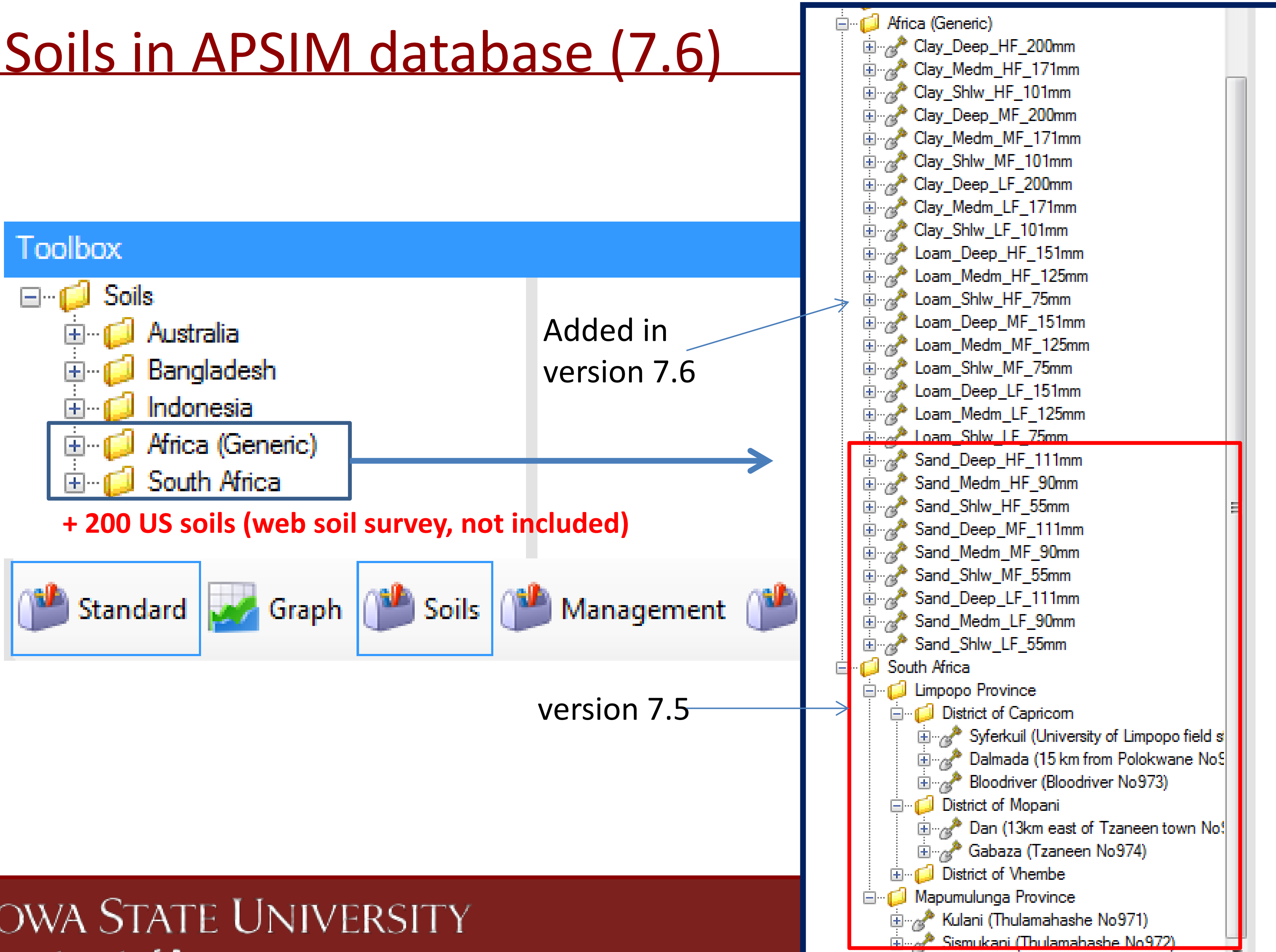
Which of these should be included in APSIM?
- Review/discussion of equations, processes
- Review/discussion of datasets
- Programming issues

Workshop outcomes for review by the APSIM team
- Implementation

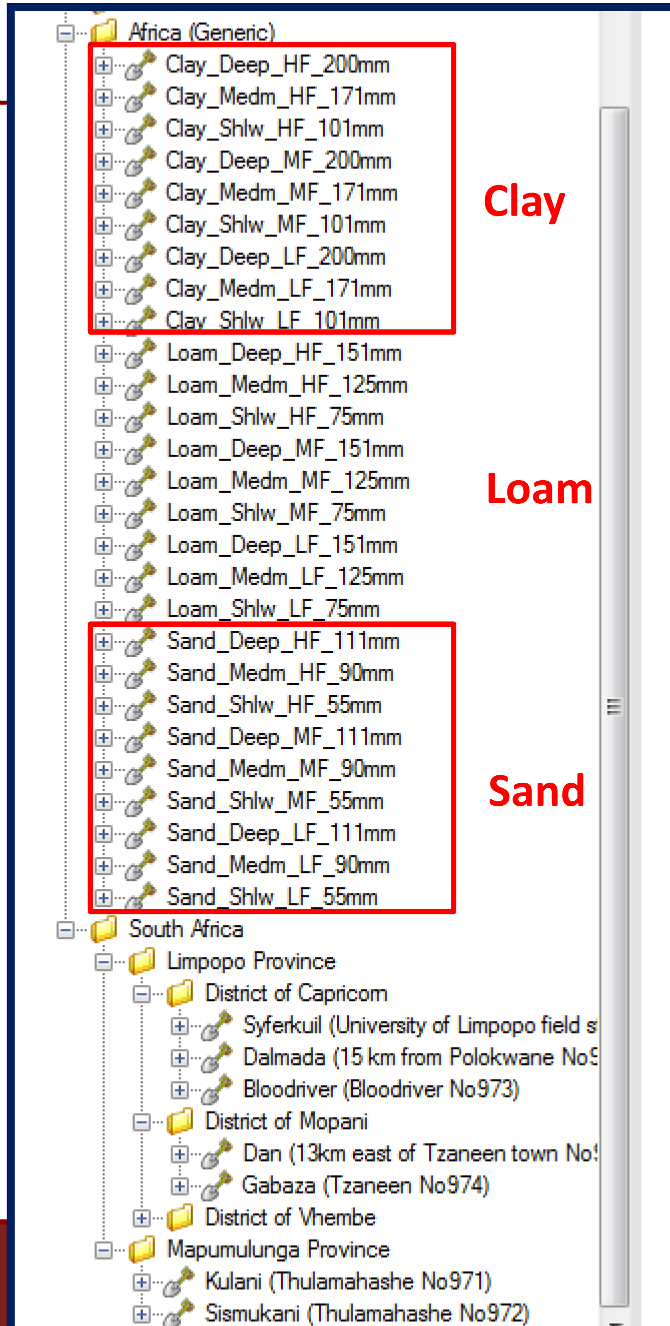
Representing the effect of SOM on soil function in farming systems models

3 days

Soils in APSIM database (7.6)



Soils in APSIM database (7.6)

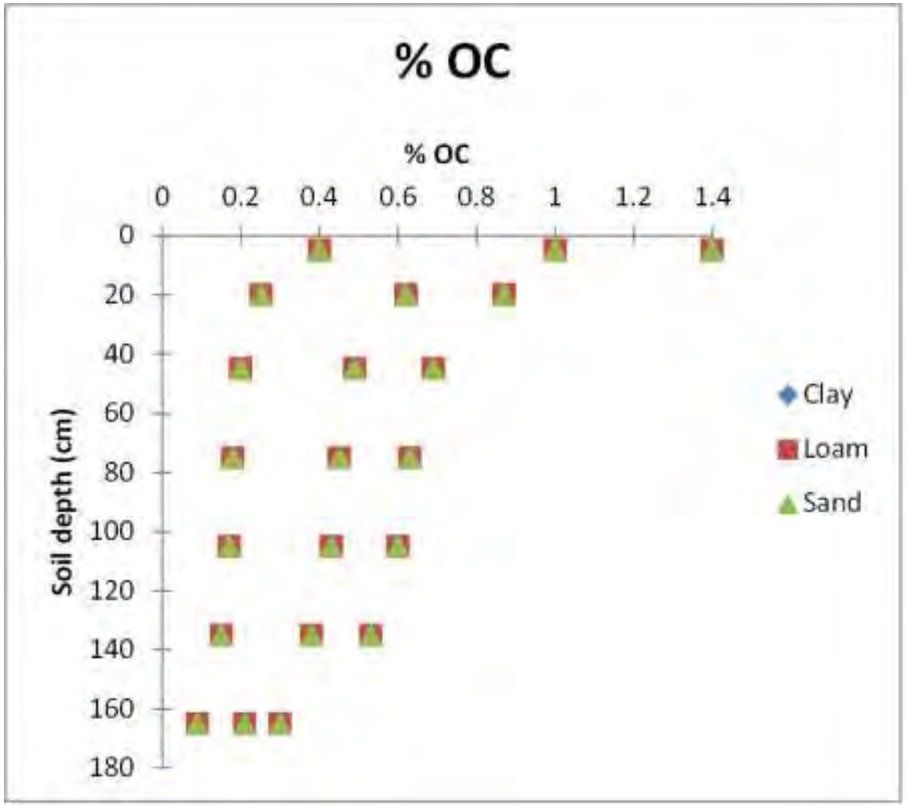


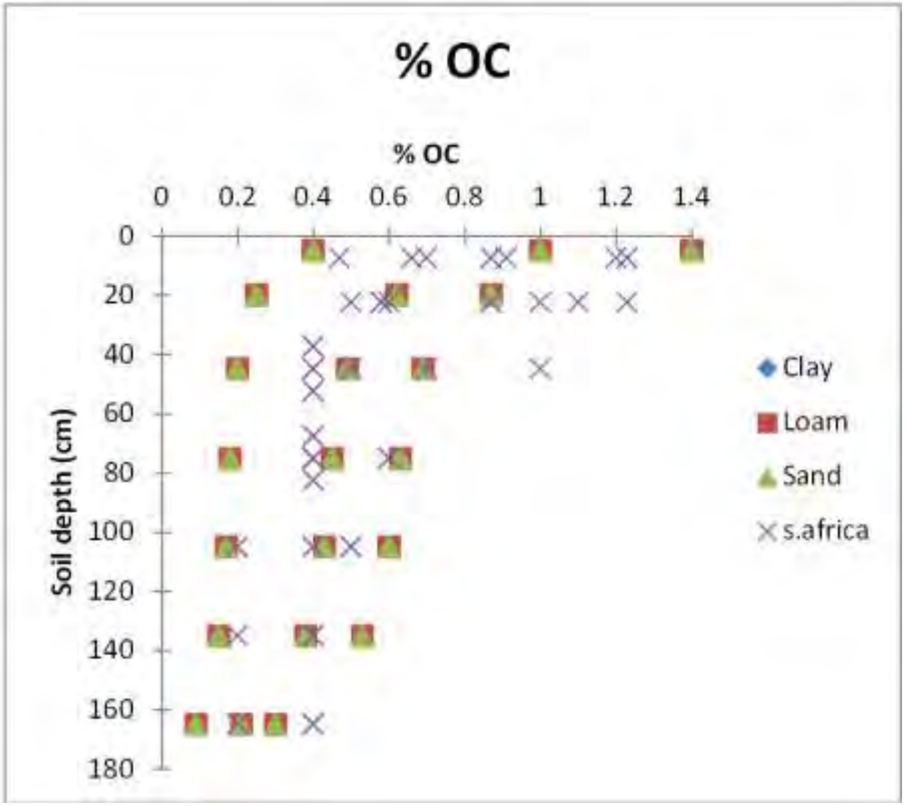
Within each generic group:

Differences in fertility (basically OC%)
- HF = high fertility
- MF = medium fertility
- LF = low fertility

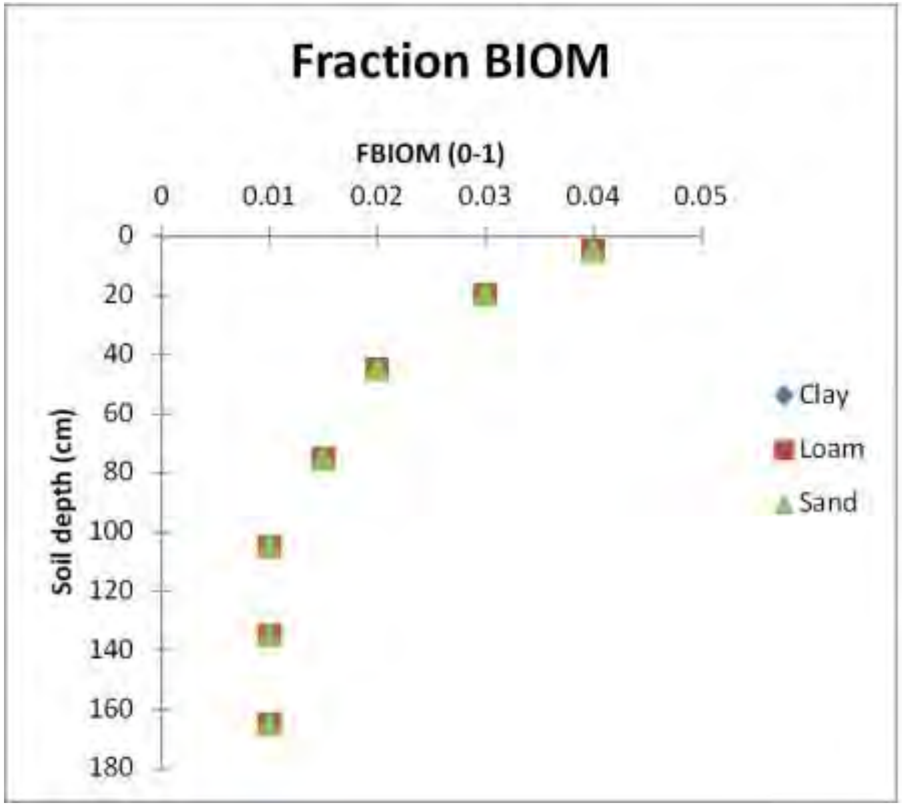
Soil depth
Hydrological parameters

Organic carbon

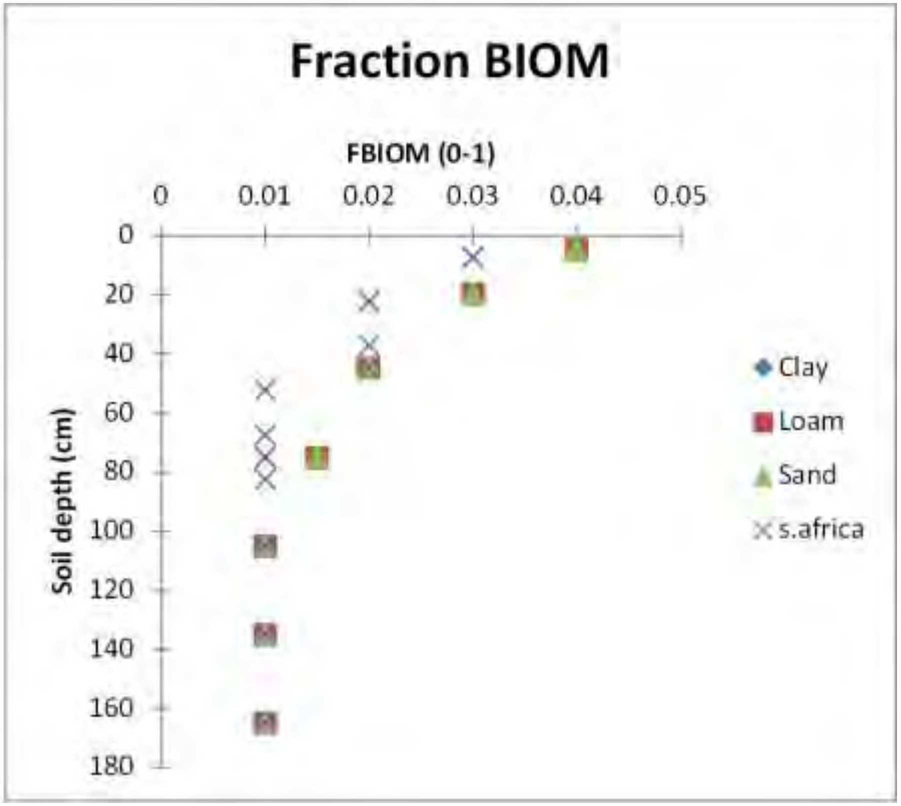




F-BIOM

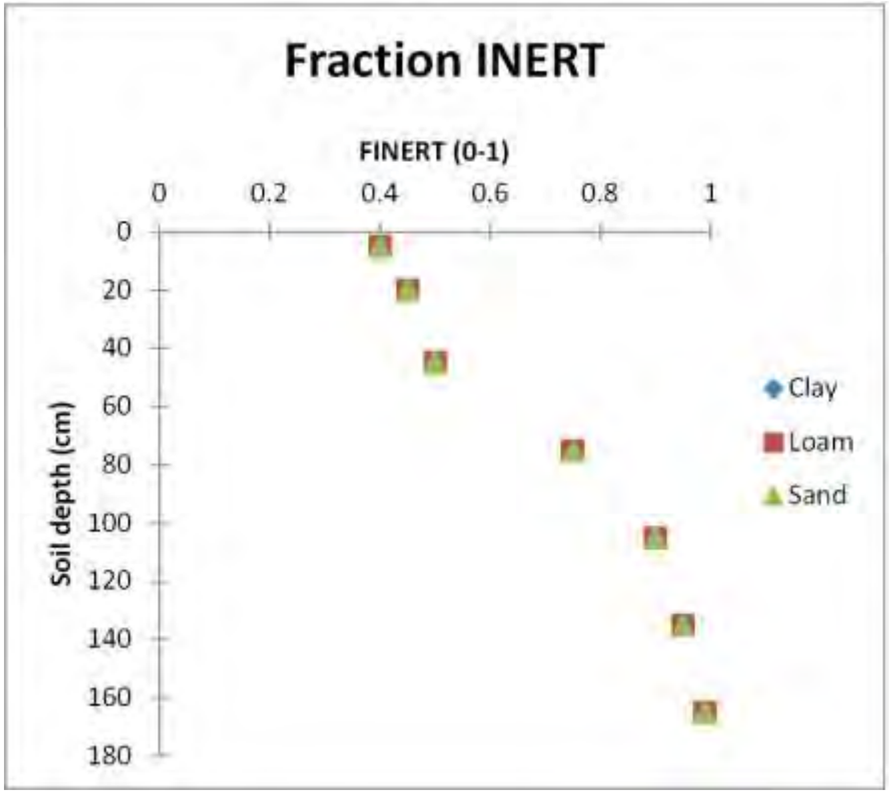


Fraction BIOM
FBIOM (0-1)
0
0.01
0.02
0.03
0.04
0.05
Soil depth (cm)
0
20
40
60
80
100
120
140
160
180
Clay
Loam
Sand

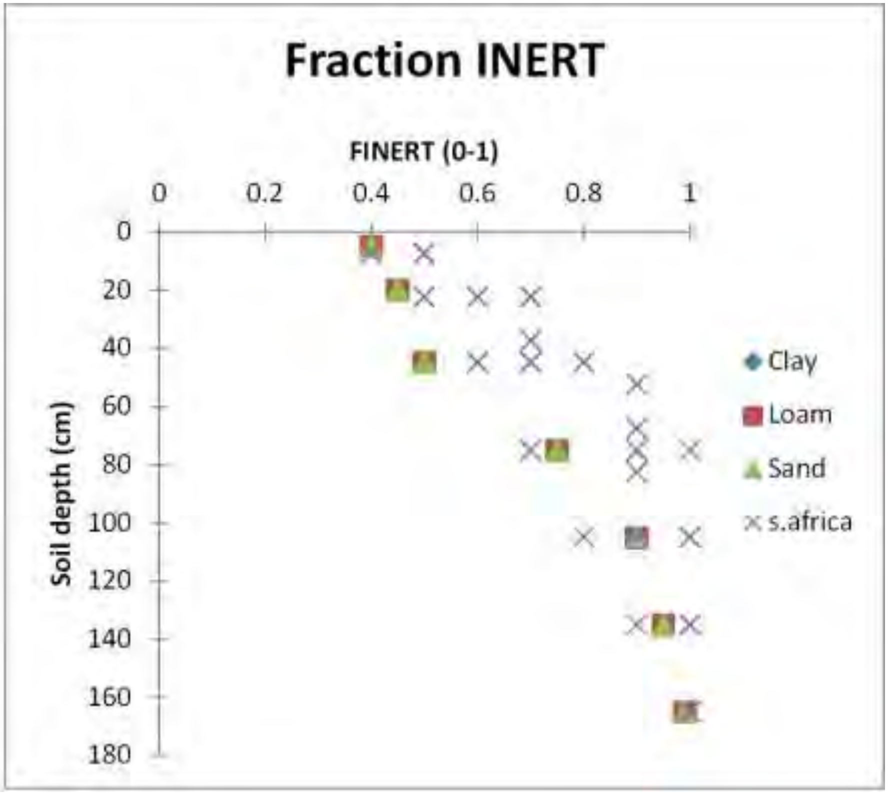


Fraction BIOM
FBIOM (0-1)
0
0.01
0.02
0.03
0.04
0.05
Soil depth (cm)
0
20
40
60
80
100
120
140
160
180
Clay
Loam
Sand
s.africa

F-INERT

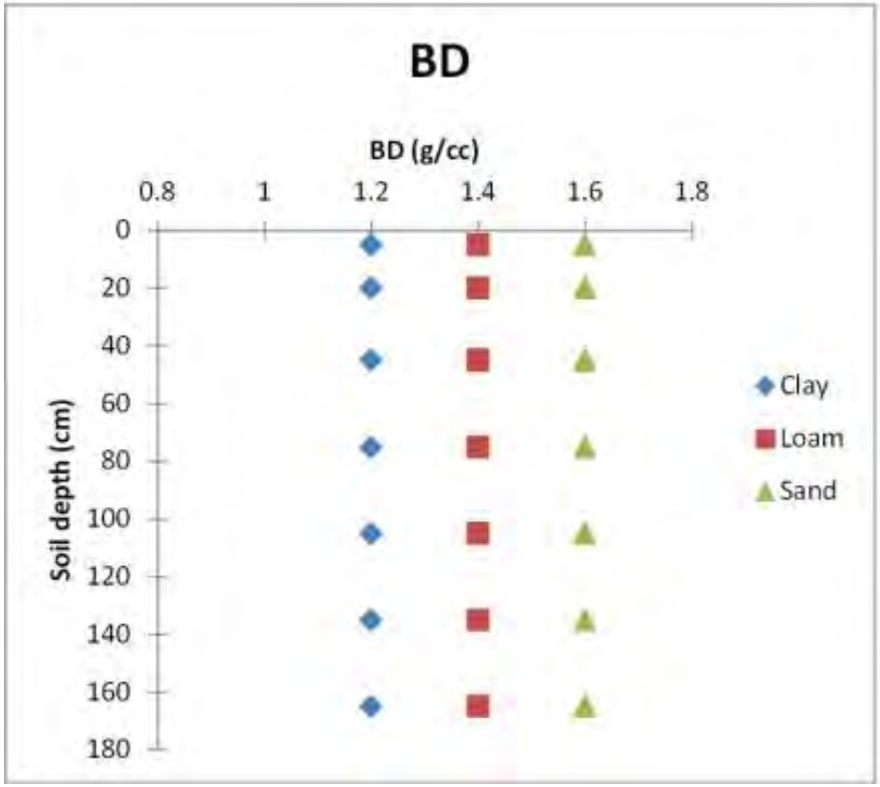


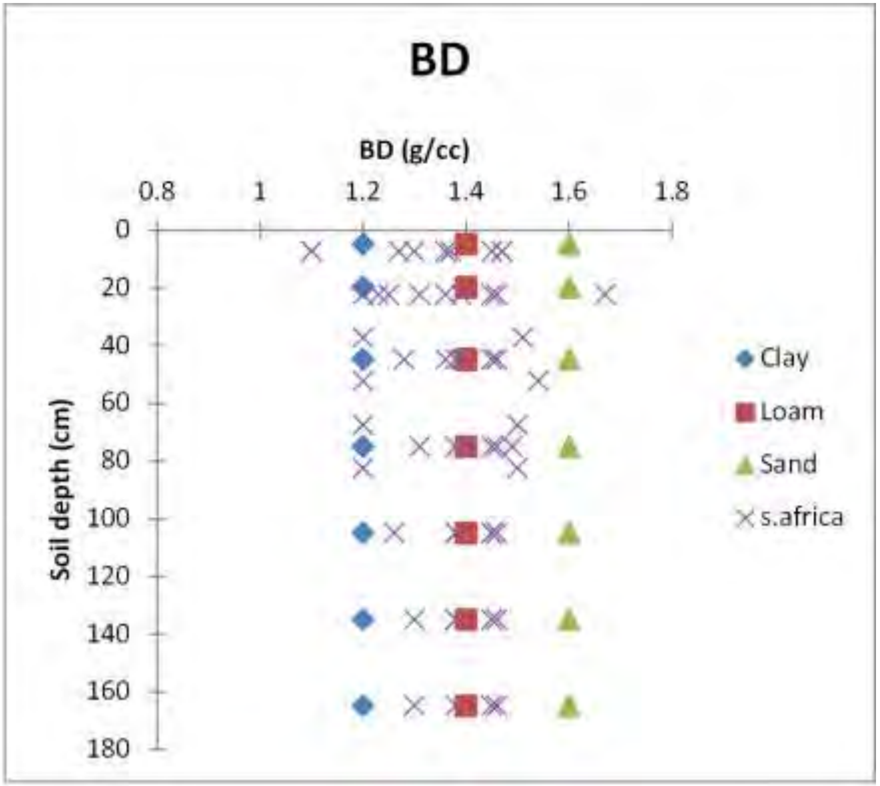
Fraction INERT
FINERT (0-1)
0
0.2
0.4
0.6
0.8
1
Soil depth (cm)
0
20
40
60
80
100
120
140
160
180
Clay
Loam
Sand



Fraction INERT
FINERT (0-1)
0
0.2
0.4
0.6
0.8
1
Soil depth (cm)
0
20
40
60
80
100
120
140
160
180
Clay
Loam
Sand
s.africa

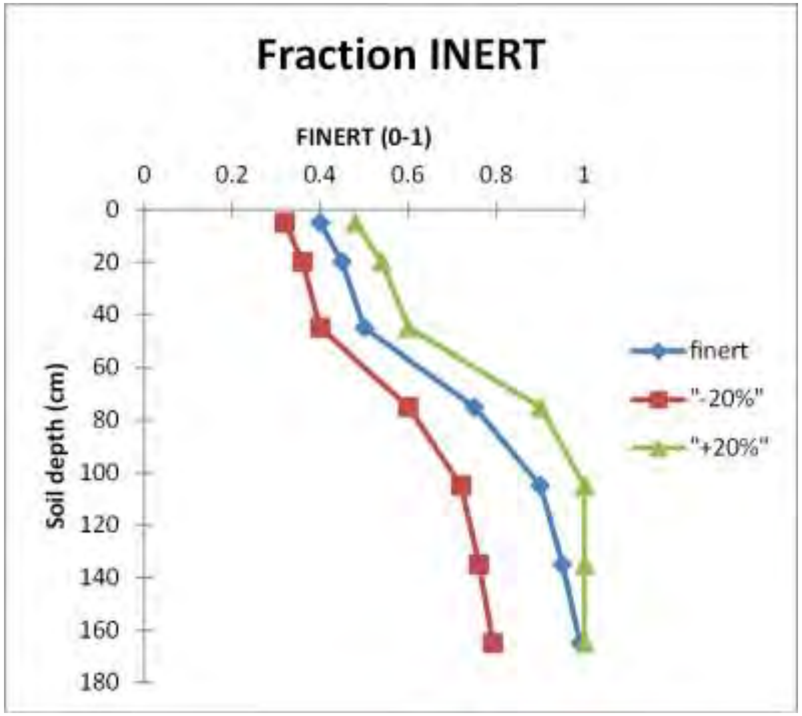
Bulk density



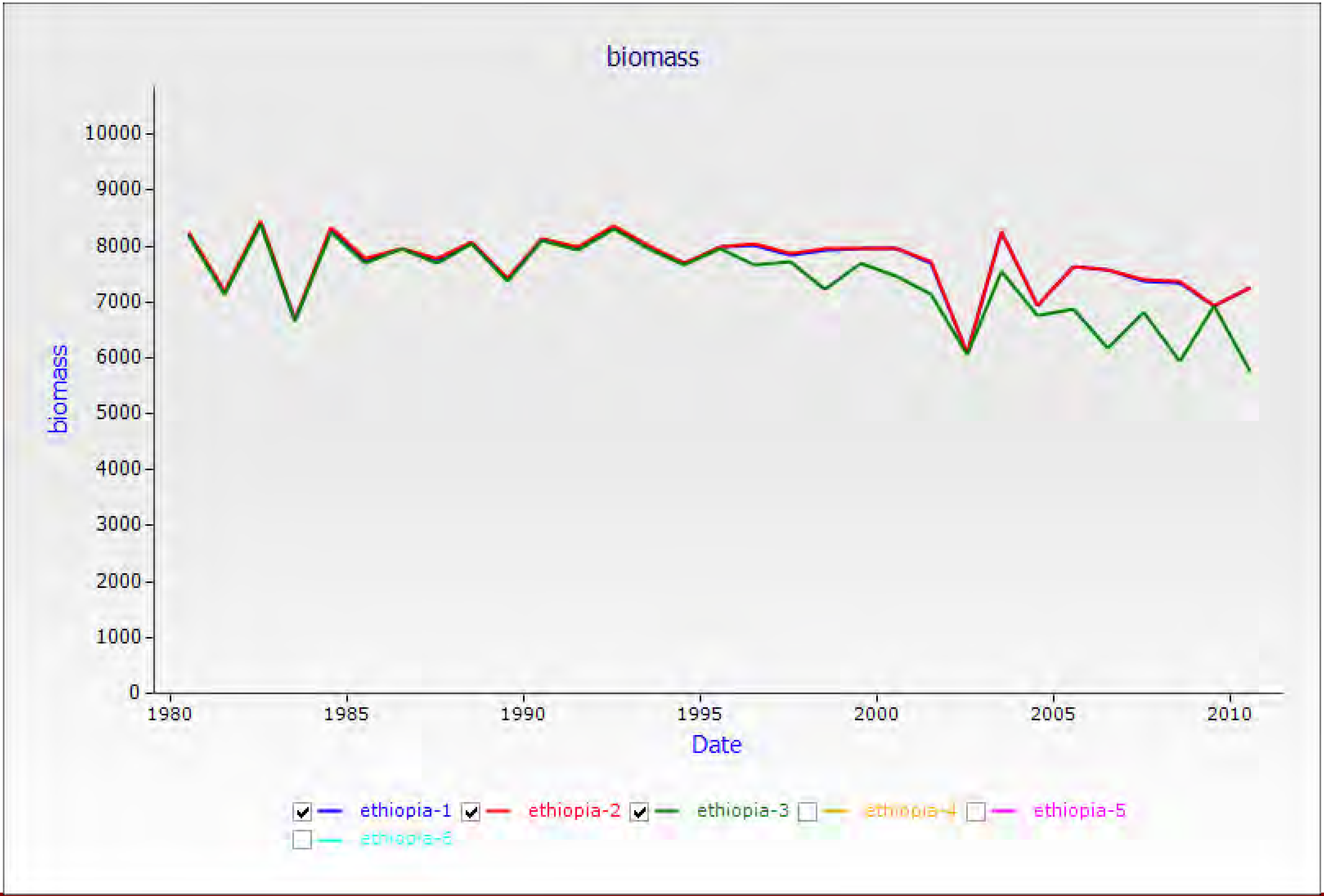


Simulations

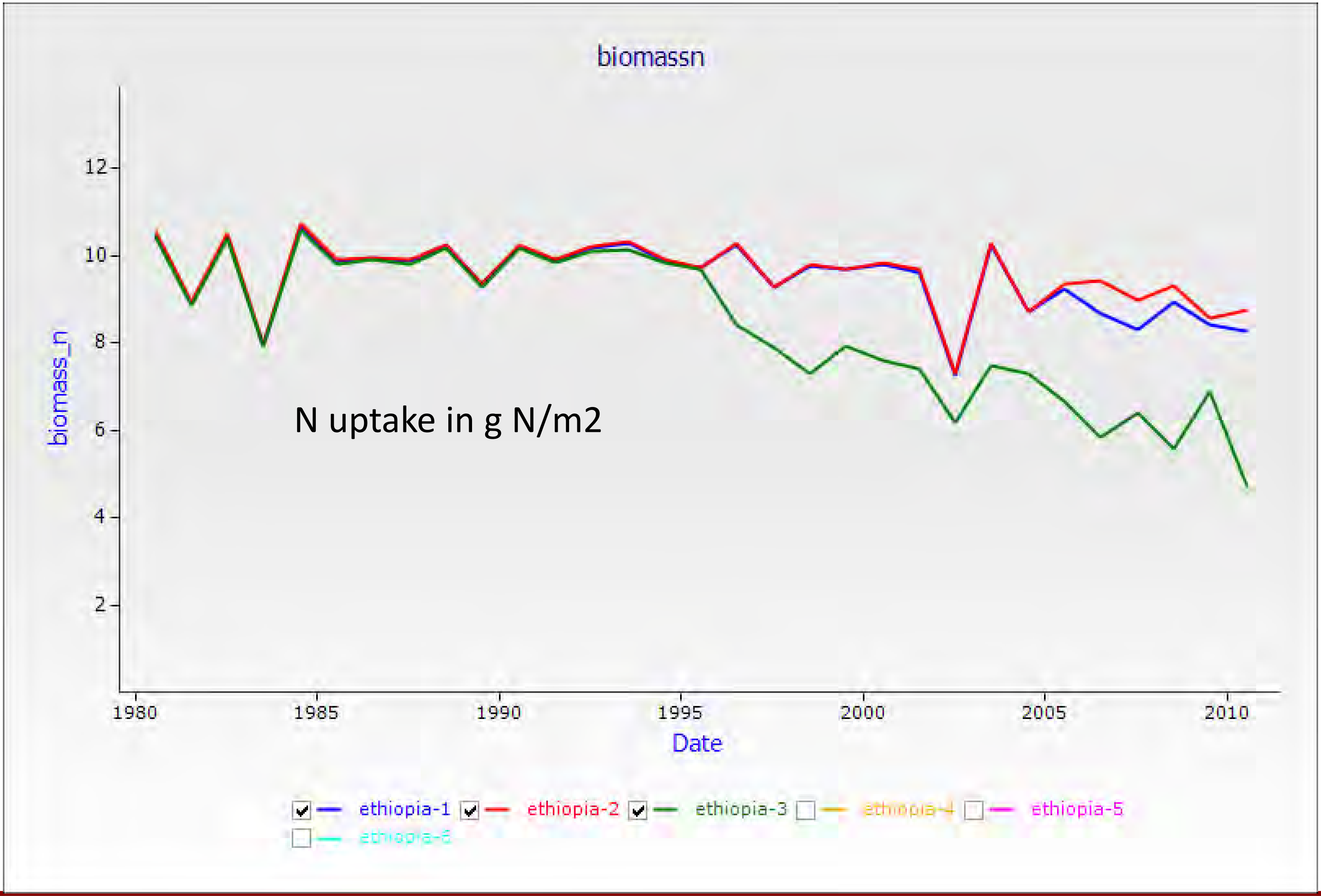
Met file – Ethiopia
Soil – Loam high fertility (top soil OC = 1.4%)
Crop/management - maize sowing mid April, 0 kg N/ha, plant density = 4 pl/m2
Sensitivity to FINERT



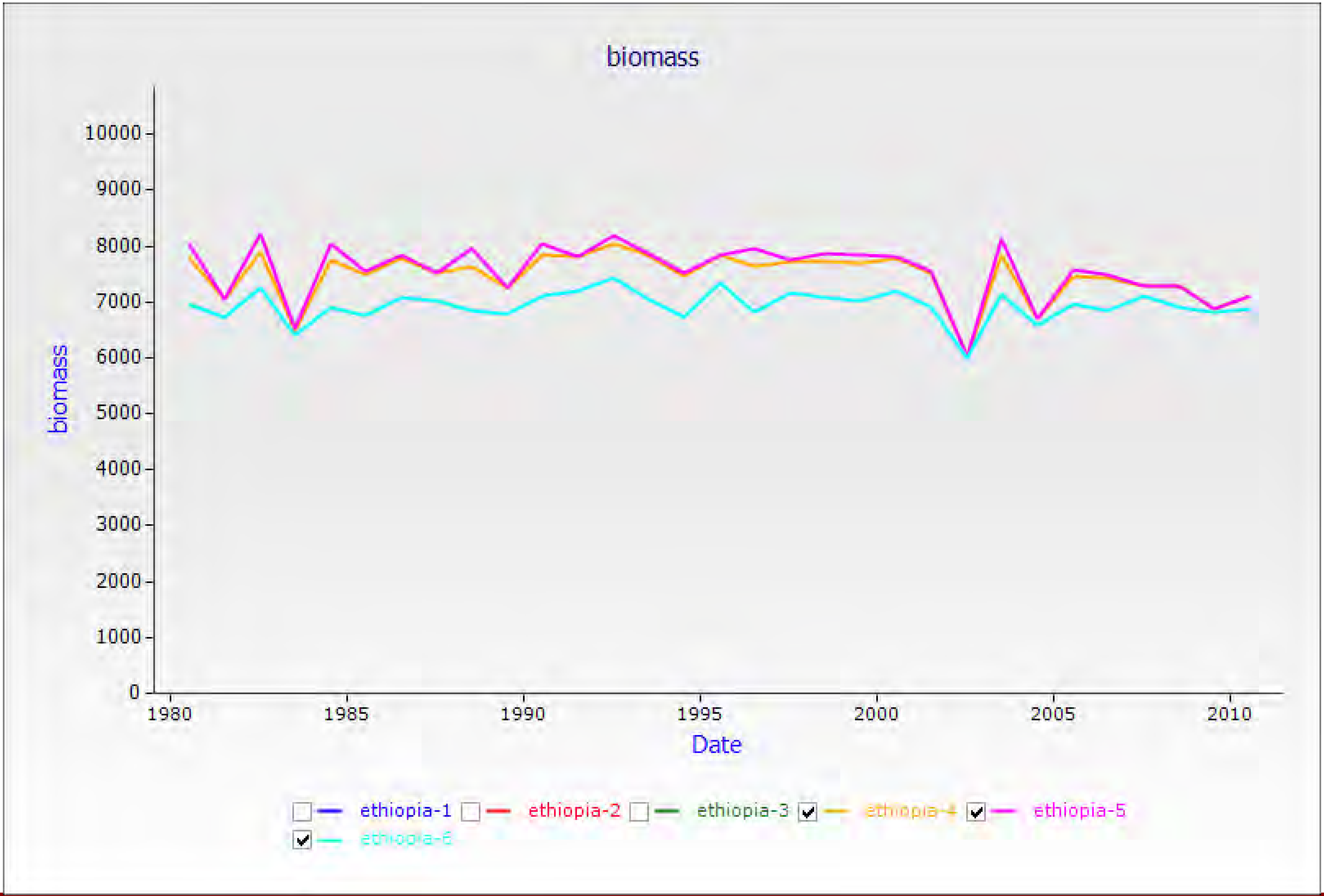
Simulations – sequential analysis



Simulations – sequential analysis



Simulations – seasonal analysis



Simulations – seasonal analysis