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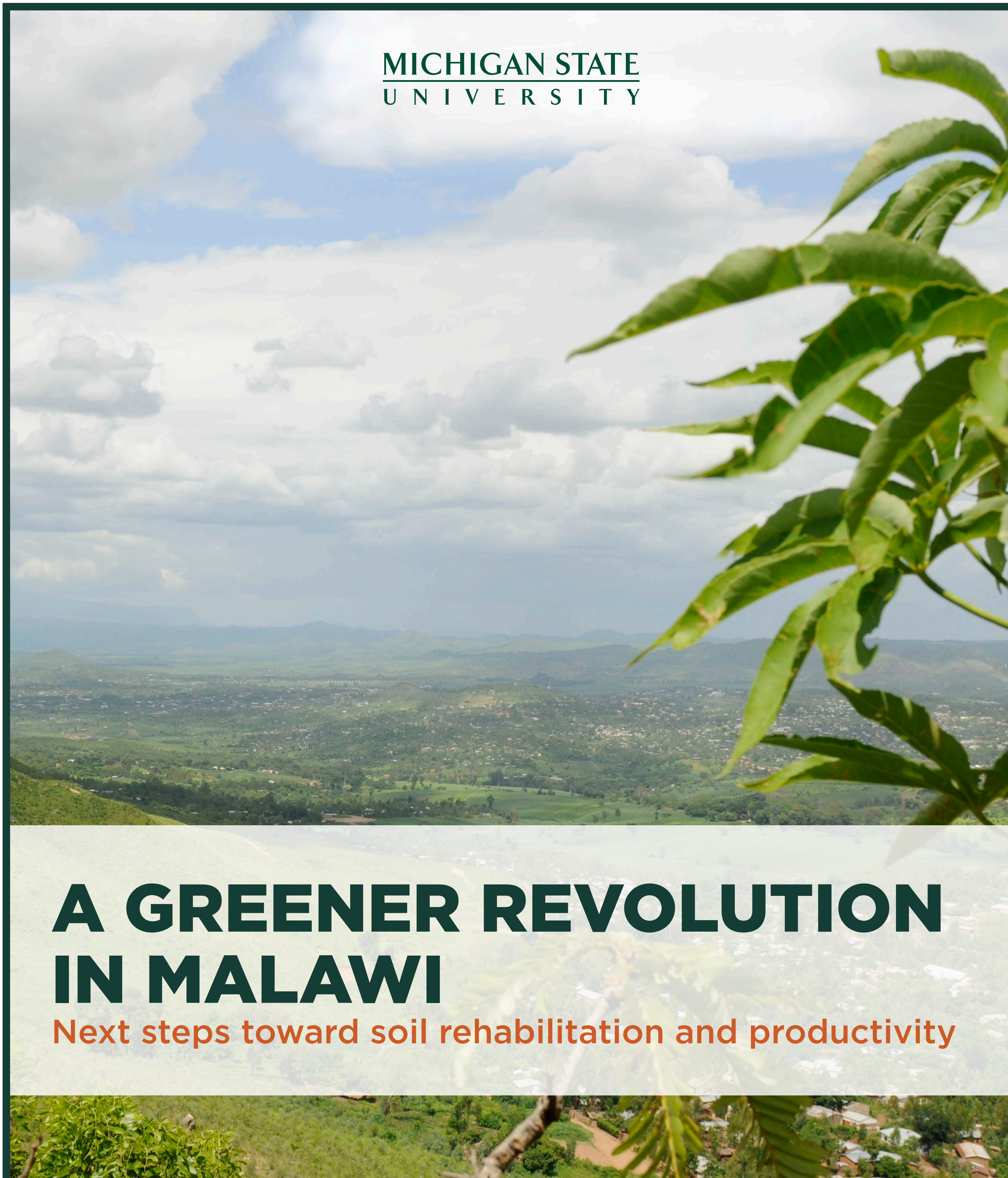

A GREENER REVOLUTION IN MALAWI

Next steps toward soil rehabilitation and productivity

SIEG SNAPP
Professor, Soils and Cropping Systems Ecologist
Department of Plant, Soil and Microbial Sciences
(517) 282-5644 • snapp@msu.edu

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BACKGROUND

Malawi has been heralded as ground zero for a green revolution in Africa. A commitment to agricultural subsidies has substantially increased access of smallholder farmers to modern varieties of maize and inorganic fertilizer. The question is whether this investment has translated into improvements in maize productivity, and in turn, has this led to improvements in food security and acted as an engine of growth for the agricultural sector. There has been considerable research evaluating the impact of subsidies on the agricultural private sector, determining factors that influence the effectiveness of subsidy implementation, and the sustainability of the subsidy (Jayne et al., 2013; Ricker-Gilbert et al., 2013). However, the fundamental issue is soil productivity; indicated by maize response to fertilizer, and the quality and quantity of food, fodder and fuel produced over time. This is at the foundation of sustainability. New evidence shows this is in jeopardy, and Michigan State University proposes interventions for rehabilitation of soil productivity in Malawi.

Malawi appears to have reached a tipping point, where soil organic matter (SOM) is below minimum levels. There are multiple lines of evidence that on many farms soil organic matter status has degraded to a level that no longer supports maize growth or responsiveness to fertilizer. The tipping point level for soil organic matter has been proposed to be 1.2% (equivalent to 0.7% organic carbon) based on long-term experiments in West Africa, and this was the same level associated with an on-farm household soil survey carried out recently in Zambia (W. Burke et al., unpublished data). This is lower than the level of soil organic matter associated with poor maize marginal productivity returns to fertilizer across a Kenya chronosequence of smallholder fields (Marenya and Barrett, 2009). That is, soil organic matters levels below 3% were associated with years of continuous crop use, and with very poor maize yield as well as modest yield response to fertilizer.

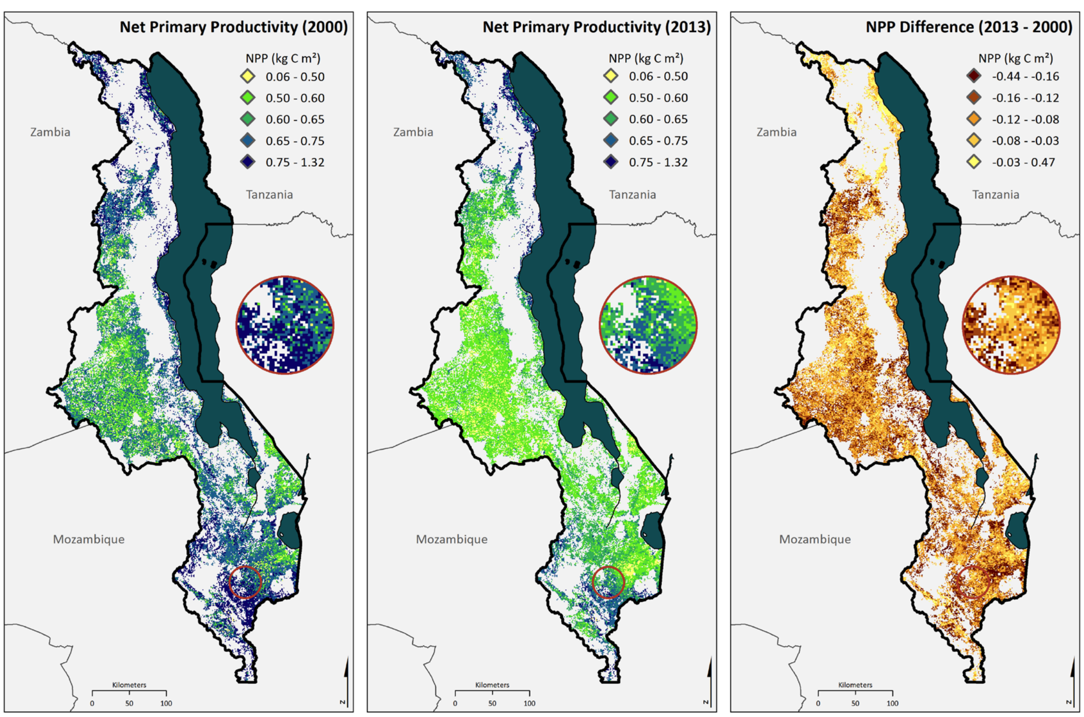

FIGURE 1A. **Change in Net Primary Productivity (NPP) over 14 years (2000–2013 NASA MODIS MOD17A3), on agricultural land.**

WHAT IS THE EVIDENCE FROM MALAWI?

1. Country-wide integrated household surveys provide one set of data. Maize response to fertilizer is much lower than expected. Surveys of tens of thousands of households have documented farmer-reported maize yield gains of about 10 kg grain per kg of fertilizer nutrients applied (Table 1). This is less than half of the expected response, and 20% of typical agronomic trial response (Snapp et al., 2014).
2. At the macro-scale, there is another line of evidence: over a decade of remote-sensing data tracks aboveground biomass productivity on agricultural lands in Malawi. The agricultural lands are dominated by maize, so this provides one measure of maize productivity from 2000–2013. In striking contrast to the expected gains in crop productivity, a steady decline in net primary productivity of agricultural lands has been observed (Figure 1A and Figure 1B; unpublished data, J. Messina et al. 2015). This is despite the major subsidy investments that have been made in Malawi. It is also surprising in view of reported gains in maize yields (FAO crop estimates; Sanchez, 2015).
3. The final line of evidence is from measurement of soil organic carbon status over a 22-year time period. In 1989 and 1990, soil profile characterization was carried out at thousands of sites across Malawi, on natural and agriculturally managed lands. This country-wide sampling grid was revisited over the 2013 and 2014 time period to collect soil samples, record land use, and conduct soil analyses, including soil organic carbon. Laboratory and spatial analyses of the data from the Machinga district in Southern Malawi has been completed. This is the first report from the six districts where the resampling exercise was conducted. A comparison of soil C status in 1990 to that found in 2013 documents declines in soil organic C on the vast majority of the sampled agricultural lands in Machinga (Figure 2; Placid Mpeketula PhD dissertation research). Biophysical properties that we expect to influence soil organic C include topographical position, soil texture, precipitation, temperature and elevation. Beyond these factors, land management is a major factor influencing soil organic C. Land that has been farmed continuously since 1990 has lost 0.3 units of soil C while natural areas have apparently gained modest amounts of soil C over the same time period. This data set provides a unique opportunity to better understand the relationship of land use to soil organic C. Analyses are underway to evaluate the role of land conversion—from woodland to crop production—and intensification of agricultural use, including the role of continuous cropping.

It is urgent to reverse the soil degradation trend in Malawi. Agricultural development will not be successful unless this is addressed, nor will investments in agricultural subsidies achieve returns in a sustainable manner. To build SOM requires sufficient organic matter inputs, particularly from plant roots. About 80% of SOM is derived from roots, and leguminous roots are preferentially converted to SOM (Kong et al., 2005; Kong and Six, 2010; Puget and Drinkwater, 2001). Aboveground biomass—such as from crop residues—is important for erosion control and as a crop nutrient source, but does not play a major role in building SOM. Animal manure is another important source

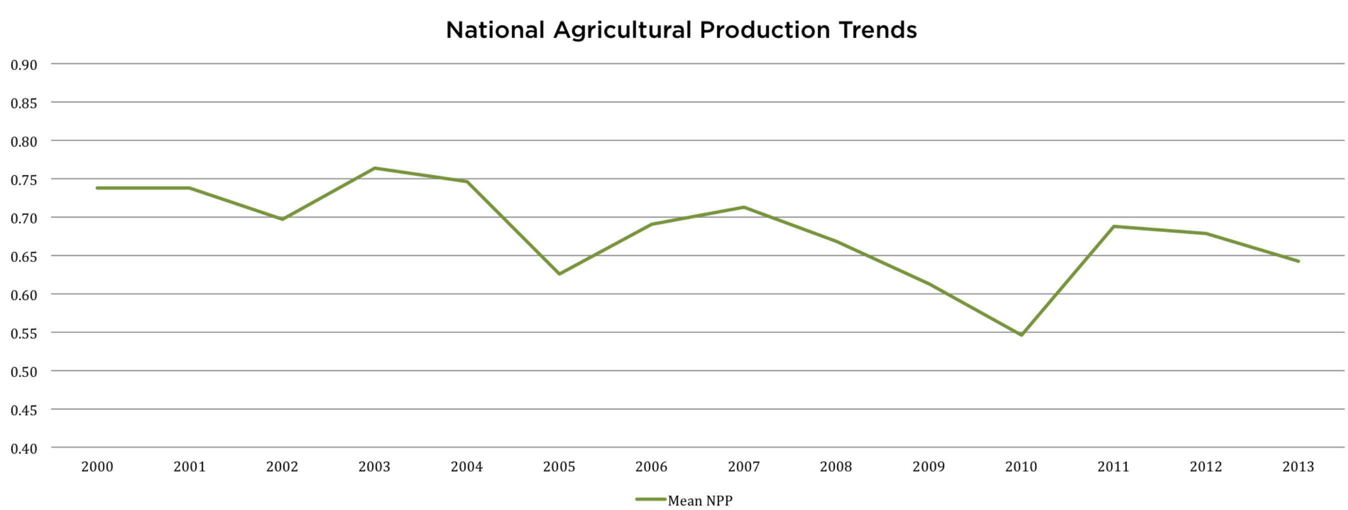

FIGURE 1B. Net Primary Productivity (NPP) status over 14 years (2000–2013 NASA MODIS MOD17A3), on agricultural land.

of organic matter with proven SOM building properties (Snapp et al., 2010b). The vast majority of smallholder farmers in Malawi (85% in one survey) do not have access to livestock manure (Snapp et al., 1998). Disturbance due to tillage is often portrayed as reducing SOM, but recent meta-analyses of hundreds of experimental studies have brought about a paradigm shift in our understanding (Powlson et al., 2014; Ugarte et al., 2014). No-till is consistently associated with increases in soil C at the soil surface (0-5cm), but not lower in the profile, where in fact tillage is consistently associated with increases in soil C lower in the profile (20-30 cm) (Powlson et al., 2014). Reducing disturbance combined with mulch on the soil surface markedly improves water capture and soil productivity—but what is key is the presence of organic inputs as a management practice to supports gains in soil organic matter (Ugarte et al., 2014). Further, there is evidence that 'mixed quality' residues with biochemistry that includes nitrogen-enriched, labile and recalcitrant compounds from legumes and shrubs are much the most effective means to build SOM (Puget and Drinkwater, 2001; Snapp et al., 1998).

FIGURE 3. **Doubled up legume system with groundnut as an understory and pigeon pea as an intercrop overstory.**
Photo by Jim Richardson

In Malawi, sustained effort to improve soil organic C is required, and there is a growing body of evidence that the surest way to achieve this is to promote leguminous plants with life-forms that are shrubby or viney (Table 2). These can provide substantial amounts of biomass over an 8–24–month time period (Snapp et al., 2010a). In comparison, annual food legumes are grown for about four months and have a high harvest index, which minimizes residue biomass as about half the plant is harvested. The aboveground residues produced by leguminous shrubs and vines such as pigeon pea, mucuna, climbing beans and tephrosia are nitrogen-enriched and of mixed quality biochemistry, with 3 to 5 MG biomass per ha (Snapp et al., 1998; 2010a). Root biomass measurements have recently been conducted for pigeon pea grown on over 40 fields in Central Malawi, where biomass ranged from 0.9 to 2.0 MG biomass per ha. This is expected to translate into improved soil organic C, although the variability is high on-farm, and detection of accumulation over time is difficult with the exception of longer-term research station trials where gains of 15% or more have been demonstrated (Beedy et al., 2010; Snapp et al., 2010a).

Year	Survey	N-use Efficiency *(kg maize/kg N applied)*	Reference
2006, 2009, 2010	IHS-II, IHS-III, AISS-I and AISS-II	5.3-8.8	Ivanyna, 2015
2009, 2010	IHS-III, AISS-I and AISS-II	6.6-11.5	Ricker-Gilbert and Jayne, 2011
2006, 2007, 2009	Random sample of 450 farmers in central and southern Malawi	9.0	Holden and Lunduka, 2010

TABLE 1. **Nationally representative Malawi household survey data on farmer recall of maize grain yield and inputs applied per plot, used to calculate marginal production response to nitrogen fertilizer. Adapted from Snapp et al, 2014.**

The benefits of pigeon pea, grown in mixtures with maize or as a doubled up legume system (pigeon pea and an understory of soybean or groundnut), rotated with maize, have been proven in country-wide trials (Snapp et al., 2010a; 2014). The climate resilience gains are particularly marked when maize hybrids are grown with targeted fertilizer, in rotation with doubled up legume and mucuna rotations. This has been shown to not only improve maize fertilizer response by 50% or more, but also to dramatically enhance yield stability.

NEXT STEPS

Over the long-term, technologies such as residue mulch systems, agroforestry and intensified livestock systems that support manure production are expected to play a role in building soil productivity in Malawi. Knowledge of soil erosion control is also urgently needed, including planting on the contour, building bunds to control water flow and related management practices all require widespread education efforts. These are investments that we recommend the Malawi government extension make a priority, and innovative education approaches such as farmer field school and ICT be pursued.

	Annual—Food Legume				Semi-Perennial Food Legume		Green Manure	Agro-forestry
Value	**Soybean**	**Bean**	**Cowpea**	**Groundnut**	**Climbing bean (vine)**	**Pigeon Pea (shrub)**	***Mucuna pruriens* (vine)**	***Tephrosia vogelli* (shrub)**
High-protein food	High	High	High	High	High	High	Poor[1]	None
Biomass for forage	Medium	Low	Low-Medium	Medium	Medium-High	High	High	High biomass *(not animal fodder)*
Improve soil fertility	Medium	Low	Low-Medium	Medium	High	High	High	Medium-High
Good intercrop	Medium	Medium	Low[2]	Medium	Low[3]	High	Low[2]	High
Established market	High	High	High	High	High	Variable	Low to None	None
Maturity Period	Medium	Short	Medium	Medium	Long	Long	Long	Long
Labor demand	Medium	Medium	Medium	High	High	Low	Low	High

TABLE 2. Legume life-forms and example species grown in Malawi agriculture and the value of associated products. Adapted from Mhango et al, 2013.

1. *Requires extended cooking to detoxify*
2. *Competition for water is high, particularly by viney growth types*
3. *Competition for light is high, viney growth type suppresses intercrop*

To complement these long-term investments, we propose immediate research and extension attention be given to multipurpose legumes such as pigeon pea and climbing bean (as the only food producing and soil building legumes, Table 2). Initial evidence suggests these are promising, economically feasible approaches to building soil organic matter to ensure a response to fertilizer and improved maize seeds. These multipurpose crops we call 'pulse plus' systems, which have been uniquely shown to rehabilitate soils under poorly resourced environments, mitigating risk and enhancing returns to inputs—a necessary basis for farmers to adopt intensified production in a highly variable climate. We have fine-tuned pulse plus systems over two decades of research using crop modeling and participatory action research trial conducted country-wide in Malawi (Snapp et al., 2010a; 2014b). Soil carbon measurements have been initiated, but wide spread evaluation of impact on soil properties is urgently required.

Curriculum is under development at MSU working closely with LUANAR and University of Malawi, along with Malawi Government Extension. What is needed next is for the curriculum to be taught in university courses, and used as the basis for extension education material that is disseminated through cell phone technical cards, farmer field school 'training of trainers', to reach agro-input dealers and farmers through country-wide extension demonstrations. This is critical for training the next generation of agricultural scientists, educators and farmer-to-farmer capacity building.◆

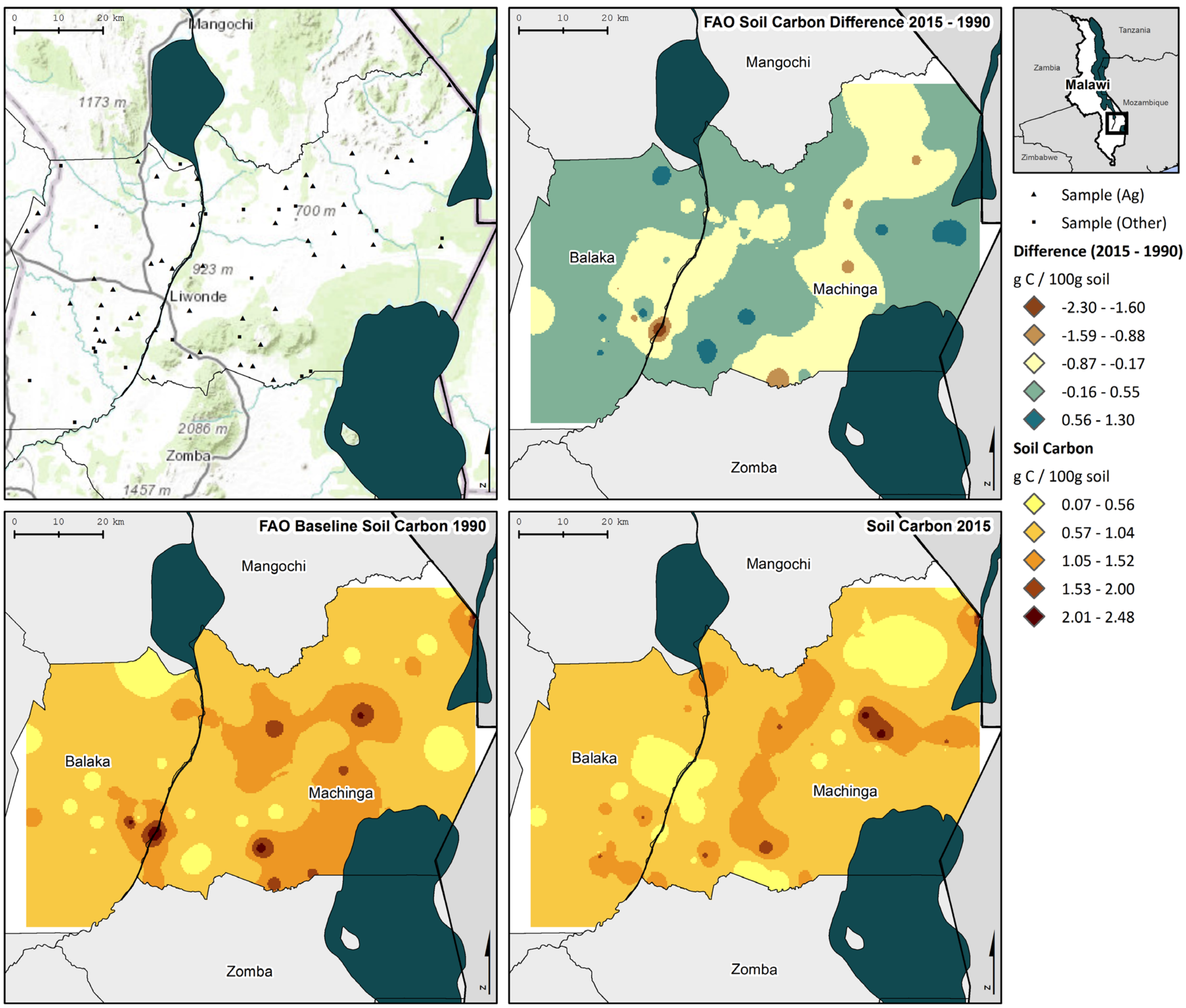

FIGURE 2. Soil carbon status over twenty-three years (1989 - 1990 FAO soil characterization pits revisited and soil sampled in 2013-2014), at sites that vary in land use from natural vegetation to continuous cropping.

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