BioSight: Strategic policy analysis for sustainable agricultural intensification at the intersection of food, water, land, energy, and the environment.

Draft report on literature review indicators and model/analytic tool evaluation (deliverable #2)

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I. Background and history of the term 'Sustainable Intensification'

Concern over global food security has increased dramatically as a result of rapid economic development rates and increased 'effective demand' for energy, grain, and livestock products in developing countries and slowing rates of yield increase for primary grains (Godfray et al. 2010; van Ittersum et al. 2013). Raising population and wealth have increased demand for food, energy and bio-products and so increased demand for land, water and inputs to a degree that will be unsustainable if growth is not guided by sound policy (Koning et al. 2009; Cassman et al. 2010). Such policy will need to contend with the challenges of climate change and globalization as it promotes productivity and food access while protecting natural resources from degradation (Godfray et al. 2011; Knoke et al., 2012). The growing consensus that increases in food access and productivity will need to be achieved using existing arable lands using methods that do not degrade the environment or contribute to climate change has led to calls for 'sustainable intensification (Foresight, 2011; Beddington et al. 2012). First coined by Pretty in the 1990s (Pretty 1997), the term '*sustainable intensification*' (SI) is increasingly used by authors who emphasize gains in productivity (eg; Cassman 1999) or food access/justice (De Schutter, 2010). There is broad agreement that increases in productivity must be achieved per unit area using practices that simultaneously protect the environment and human well-being by mitigating climate change, and conserving provisioning resources (soil and water), biodiversity, and cultural resources (Pretty et al. 2011; Tilman et al., 2002). Biologically based management that promotes nutrient recycling through diversification, incorporation of perennials where possible, and integration of livestock into systems, has been advocated as the primary method to be used to achieve SI (Swift, 1997; Snapp et al. 2010; Mapfumo et al. 2013); and, this is why the term '*ecological intensification*' is sometimes used as a synonym for SI. Others emphasize breeding and commodification of environment and social benefits as key dimensions of SI. Most agree that science-based approaches are needed to inform 'strategic investments to establish climate-resilient agricultural production systems, minimize greenhouse gas emissions, make efficient use of resources, develop low-waste supply chains, ensure adequate nutrition, encourage healthy eating choices and develop a global knowledge system for sustainability (Beddington et al. 2010).

II. Sustainable Development framing

IFPRI's existing strengths and approaches include tools that will support both SI and EI approaches. Efforts like the Outlook and Global Change program, The Climate Change research agenda, and the Science, Technology, and Innovation Policy research, will likely continue to draw on existing international indicators and data bases currently populated by global organizations (eg: the UN, FAO, and the OECD) whose work is informed by Millennium Development Goals (MDGs). The goals for indicator frameworks determine the outcomes assessed and so deserve particular attention. The recent Rio 20+ Outcomes document produced by the UN General Assembly reaffirmed its commitment to make every effort to accelerate the achievement of the MDGs by 2015 and recommitted to the principle that expansion of free trade will underpin growth (UN 2012). That document (The Future we Want) also added a call for expanded participation from the business and civic society sectors and emphasized that broad public participation and access to information and judicial and administrative proceedings are critical components of sustainable development. Organizations that have been highly influential include the World Bank (2010), which is committed to "sustainable globalization" that "enhances growth with care for the environment"; the International Monetary Fund (IMF, 2010), which is committed to "sustainable economic growth"; and the World Trade Organization (WTO, 2010) which seeks to advance sustainable development through the removal of barriers to trade. Sustainable development is also a prominent component of the Millennium Development Goals, which have been widely endorsed by national governments and the world's foremost development organizations since they were adopted at the Millennium Summit in 2000. The Organization for Economic Co-operation and Development (OECD), which was founded in 1961 to foster economic growth, employment and a rising standard of living for both member and non-member countries has been and continues to be a significant contributor to core metrics. Explicit concern for environment was added to the agenda at a OECD Ministerial Council meeting in 1989 that called for a more systematic and effective integration of environmental and economic decision making to promote sustainable development (OECD 1999b). A UN Commission on Sustainable Development asked countries to develop indicators to measure progress in reaching goals for sustainable development outlined in the 1992 United Nations Conference on Environment and Development held in Rio de Janeiro. That call included a mandate to develop indicators for agriculture. The OECD published its initial framework for Environmental Indicators for Agriculture in 1999 (OECD 1999a). Indicators were selected based on policy relevance, analytical soundness, measurability and the appropriate level of aggregation. That initial indicator set was developed to address thirteen agri-environmental issues (nutrient use; biodiversity; pesticide use; wildlife habitats; water use; landscape; land use and conservation; farm management; soil quality; farm financial resources; water quality; socio-cultural issues, greenhouse gasses).

The Millennium Assessment (MA) deserves attention as it provides the basis for many core metrics currently supplied by international organizations. These can be usefully employed in modeling and analytic frames that embrace the dominant view of SI wherein, governments and businesses assume sustainable development is achieved through continued economic growth made more environmentally sensitive in order to raise living standards globally and decouple poverty and environmental degradation (Hopwood et al. 2005). The Millennium Ecosystem Assessment pursued nine goals (identifying and categorizing ecosystems and their services; identifying links between human societies and ecosystem services; identifying the direct and indirect drivers of change; selecting indicators of ecosystem conditions, services, human wellbeing, and drivers; assessing historical trends and the current state of ecosystems, services, and drivers; evaluating the impact of a change in services on human well-being; developing scenarios of ecosystems, services, and drivers; evaluating response options to deal with ecosystem changes and human wellbeing; analyzing and communicating uncertainty). It divided the effort into five categories (core data sets, data and indicators for assessment, indicators for summary and reporting, new data, and metadata). It delineated 'State' indicators that were useful to describe ecosystem services (provisioning, regulating, cultural, and supporting); 'Service' indicators describing human wellbeing (health, livelihood, culture, and equity) affected by trends (population growth, consumption, and governance) and indicators that described direct and indirect drivers of change. Table 1 summarizes the environmental indicators of most relevance to regulation and policy related to SI developed for the MA. This was adapted from a recent review of the MA indicator set conducted by the World Resources Institute (Layke, 2009) which notes core data and associated global assessments will benefit substantially from new synoptic data sets (eg: remote sensing). Incomplete and inconsistent spatial and temporal data coverage, contradictory definitions of types of data, and the mismatch of ecological, geographic, and political boundaries remain challenges.

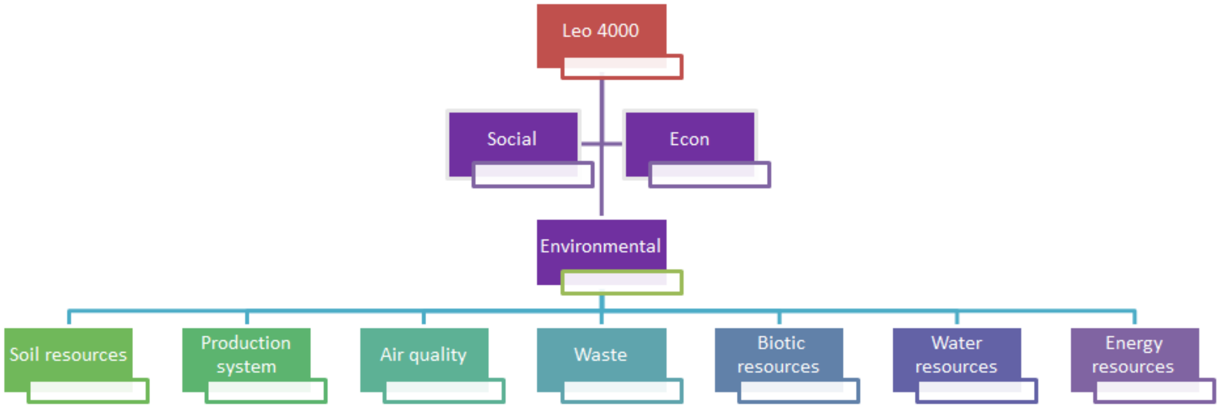
Table 1. Data and Indicators most relevant to EI from MA; Note, indicators describing some services (Provisioning, Capture fisheries; Regulating =Air and Climate, Natural Hazards;Cultural- recreation and ethical) were not included.

Service	Sub-category	# indicators	Data quality (clarity and availability)	Data sources
Provisioning service	Crops (4)	Crop production (Mt) Dietary energy supply (kcal) Employment prod processing (#people) Value of production (Currency)	High Med Low Med Low Med Med Low	FAO
Food	Livestock	Livestock production (Mt) Livestock products (Mt) Value of products (currency)	Med Med Med Med Med Med	FAO
	Aquaculture	Fish prod (Mt) Total prod from aq including products (Mt)	Med Med Med Med	FAO
	Wild foods	Number of species	High and Low	FAO?
Bio Raw materials	Timber wood	Employment in forest sector (#people) Forest biomass prod (Cubic m, tons) Roundwood prod (Cubic m, tons) Value forest prod (Currency) Volume for local craft (Mt) Wood pulp prod (Mt)	Med Med High Med Med Med Med Med Med Med Med Med	
	Fiber and resin, Animal skin, Ornamental	Employment in fiber (# people) Fiber prod (Mt) Wildlife-derived skin, wool, feather (Mt) Value of fibers (Currency)	High and Med	FAO
Biomass fuel	Plant animal materials used for energy	Charcoal (Cubic meter) Fuelwood (Cu m) Industrial energy forest sys (Twatts) Value of fuel (Currency)	High and Med	FAO
Freshwater	Inland water sources used for agriculture and other	Population served by water res (# people) Renewable H2O supply (Cu kilo) Renewable supply avail to hum (Cuk) Storage capacity (Day of river dis)	High and Med	FAO
Genetic resources	Genetic info materials used for breeding, plant animal improvement	Inv. bio prospecting (Currency) Number improved species commercialized (#) Value of genetic resources (Currency)	Low Low	None listed
Biochemical, natural medicine, pharm	Medicine, food additives, natural pesticides	Number organisms from which prod derived (#) Value of pharmeceutical prod derived (currency)	Low	None listed

Regulating Services				
Water regulation	Influence ecosystem on water cycle, rate and pattern of movement and storage within landscape	Soil water infiltration (no units) Soil water storage (no units)	High and Low	None listed
Erosion regulation	Vegetation protects soil	Not assessed in global MA – no indicators identified		None listed
Water purification and waste treatment	Filtration and decay of organic and inorganic wastes and pollutants, detoxification in soil	Amount of waste processed by ecosys (amt of waste) Capacity to process (amt waste potentially processed) Value of waste treatment and purification (currency	High and Low	None listed
Disease regulation	Influence on incidence and abundance of pathogens	Disease vector pred pop (#) Est change in disease burden die to change in ecosys (# disease cases) Popln inc in disease vectors mosquitoes post change (Mosq popln)	Low and Low	None listed
Soil quality regulation	Influence on biological activity, diversity and productivity; partitioning of water, store and recycle nutrients	No indicators		None listed
Pest regulation	Influence on crop and livestock pests	Not assessed	NA	NA
Pollination	Influence on effective transfer of pollen	Not assessed	NA	NA
Supporting services			NA	NA
Nutrient cycling	Flow of nutrients (N.P,K,S, C)	Not assessed	NA	NA
Primary production	Growth of plants and biomass (NPP?)	Not assessed	NA	NA
Water cycling	Flow of water	Not assessed	NA	NA

III. Emerging voluntary business indicators and frameworks

The indicator sets and data-bases being developed to back sustainable agriculture standards and business practices will likely rely on these data, especially during their early developmental phase, but will likely be in a position to contribute valuable data and indicators as their standards and voluntary certification systems evolve. The UN Global Compact, which includes business, civic society organizations, and experts working to develop sustainable agriculture business principles (SABPs), is a good example of the kind of consortium that will have the potential to provide extremely valuable information about agriculture and the global food system. Once developed, SABPs will articulate a common understanding and agreement on the resources, ecosystem services and socio-economic impacts needed to build resilience into agricultural supply systems and the markets they serve, provide a way for responsible businesses to satisfy the goals of the UN articulated in the Rio+20 outcome document (UN, 2012) and, provide a framework to further good practices and foster effective private and public sector policies and partnerships (UNGCO 2013). That effort uses the ISO 14001 Environmental Management System Standard that provides the basis for managing corporate sustainability globally (MacDonald 2005). Accordingly, SABPs will include commitments to pollution prevention, continual improvement in environmental performance, and compliance with all applicable statutory and regulatory requirements; and, will be highly compatible with (easily harmonized with) any sustainable agriculture standard that is ISO certified.



Environmental indicators and data sources being used by some of the leading groups developing sustainable agriculture standards including the draft standard being developed for the American National Standards Institute will be summarized in in the final report (Leonardo Academy, 2012). It will summarize some of the key players, indictor frameworks and modeling and analytic tools they are using and note how these rely on government data and tools at present. The Leo 4000 draft standard is typical of emerging business frameworks in that it uses a much simpler framework for indicators and goals (Social, Environmental, and Economic) than government-backed tools addressing MDGs. Subsets of indicators are applied within these three areas to account for the so-called triple bottom line. The environmental indicator set is currently divided into seven areas (Figure 1). At present, most efforts are in development and pilot phases that are developing both the approach and metrics to be used. The data needed to support such assessments is and will expand rapidly. Whether or how data might be made publically available is unclear. Many of the organizations currently working to develop business standards and tools to support them (eg: the Keystone Center (Field to Market, 2012), the Sustainability Consortium (TSC, 2012) have committed to developing transparent methodologies, tools, and strategies to promote creation and use of products and supply networks that address environmental, social, and economic imperatives. The Sustainability Consortium's Food Beverage and Agriculture Sector is focused on developing a Sustainability Measurement and Reporting System along with Category Sustainability Profiles (CSP) using life cycle methods and Key Performance Indicators (KPI) for product categories related to grains, beef, milk, packaged cereal, beer, bread, farmed salmon, wine, and cotton. The KPIs are intended to target regions and opportunities for improvement of the performance of individual product categories using scientific methods. The resulting tools are intended to foster communication between the buyer and supplier that will improve product sustainability across the value chain. Once created, TSC's 'Knowledge Products' are to be used by member organizations which include large multinationals like Walmart and PepsiCo (TSP's website, 2013).

IV. Reliance on government resources and tools

In the US, Government backed assessment tools are also influencing and enabling indicator use. Among these of high relevance to SI are tools developed by the USDA and EPA. The USDA Natural Resources Conservation Service (NRCS) has already adopted a framework that relates changes in resource status to anticipated change in ecosystem services in the form of the 'Conservation Measurement Tool' or "CMT" which was developed to implement the 2008 farm Bill. The CMT was deployed in 2009 to streamline eligibility to participate in Conservation Stewardship Program and evaluates conservation performance in crop-, pasture-, range-, and forest-lands. It is a comprehensive tool that evaluates operational conservation performance by recording the management practices applied using a spread sheet interface before scoring their performance in terms of air, soil and water quality, soil and water quantity, plant health, wildlife habitat and energy conservation using an expert system developed by NRCS staff (USDA, 2010). The CMT is an example of a practice based standard as scores are entirely driven by the management practices.

Several of the domestic sustainable ag business standards include greenhouse gas accounting that refers to or utilizes EPA data and/or modeling methods that parallel national efforts. For example, the Keystone group's Cool Farm Tool is being piloted internationally. The inventorying tool now under development by USDA combines biochemical process modeling with statistical weighting to estimate direct and indirect N_2O emissions for croplands and grazing lands (USEPA 2013). That tool uses DayCent, a version of the CENTURY soil organic matter (SOM) model (Parton et al. 1998) to derive expected emission rates for dominant fertilization and rotation practices, soil types and climate regimes for all USDA Land Resource Regions and adjusts these results using factors generated through meta-analysis of empirical studies (USEPA 2013). DayCent was also used to develop the Carbon Management Evaluation Tool (COMET-VR and COMET-FARM), for voluntary reporting of GHG emissions for EPA in the US (COMET-VR, USDA-NRCS, 2009). The widespread use and established capability of CENTURY have led to the modeling of N_2O emissions which are tightly coupled to SOC. This is a modification that grew out of adaptations of DayCent (Del Grosso et al. 2000) to assess the effect of agricultural land use activities on N_2O emissions. Data and modeling expectations will grow as greenhouse accounting bodies are shifting towards a more comprehensive inventory of greenhouse gas emissions that include CO_2, CH_4 and N_2O sources. For agricultural systems this means that inventories will focus on N_2O production because activities designed to address fertility and cropping practices contribute to 70.9 percent of the N_2O emissions in the US, which represented about 7.2 percent of the total US greenhouse emission inventory for 2011 (USEPA, 2013).

V. Transparency

There are many ongoing efforts to develop sustainability indicators and interpretive frameworks for policy making and communication of information about the performance of programs, countries, industries or practices. Sustainability assessment tools provide perspective by allowing users to visualize phenomena, highlight trends, index dimensions of sustainability, quantify, simplify and analyze complex information (Singh et al. 2009). Our ability to use technical information to assess and inform SI efforts will depend upon the: 1) quality and character of the data used, 2) models used to extrapolate and synthesize that data 3) metrics or results derived from tools, 4) and the interpretation frameworks that have been developed for use by 5) various decision makers (individuals, businesses, policy makers, regulators).

To establish the kind of trust needed to build consumer confidence the framework and data used to assess sustainability will need to be shared with the public. The State of Sustainability Initiatives review, which was developed by the United Nations Conference on Trade and Development (UNCTAD) and the International Institute for Sustainable Development (IISD) under the auspices of the Sustainable Commodity Initiative (SCI), emphasizes that transparency is fundamental to the success of any voluntary sustainability initiative and that a more refined and developed information collection and dissemination process is needed to support this (Potts et al. 2010). The nearly universal adoption of sustainable development as a guiding principle for international institutions, governments, businesses, and civil society is, in part, due to the flexibility of indicator sets and frameworks. Unless data quality and outcomes instill confidence in the public, critics will continue to see sustainable development as a way to green-wash environmentally and socially destructive practices (Munshi and Kurian 2005). Several well-known critics of our contemporary agricultural system are skeptical about techno-social solutions to problems in sustainability. Some argue science-based approaches are arrogant and foolish (eg: Vitek and Jackson, 2005).

Hybrid systems of governance involving multiple organizations and extensive oversight to provide transparency in both standards setting and standards enforcement are emerging to fill the need for a participatory and globally integrated approach to ensure sustainable development (eg: Hatanaka, et al. 2012.). This type of standard making process has proliferated in response to advocates for sustainable agriculture that have shifted their efforts to focus on public-private governance after reforms of the 1980s and 1990s effectively limited the scope of government. As a formalized science–policy dialogue, the standards making process may provide a way to bring about needed structural changes by engaging civil society in a discourse that allows them to define constituents and targets of sustainability, well-being and quality of life and the actions needed to move towards these targets (Pinter et al. 2012). Frameworks to support standards and indicator systems require organizational capacity in that they are based on coordinated monitoring, statistical data collection and reporting systems to enable assessments.

V. Indicators, data bases and assessment tools

Data quality, data access and governance structures will play a large role in determining the relative success or failure of technocratic solutions. Ideally a common data gathering and reporting system will be devised that would allow various players including the public to assess market trends and the impacts of different initiatives. Indicators being used by some of these voluntary initiatives are reviewed along with core metrics as they might ultimately contribute to the kind of high-quality decision tools, data, and evidence that the *BioSight* project seeks to inform efforts to expand the capabilities for integrated bioeconomic modeling and tools that use micro-level data that is spatially-explicit. Future review will consider IFPRI's criteria for indicator selection which are that data have a high potential to: (1) improve calibration of existing models, (2) extend their analysis to address alternative policies for scaling up of sustainable and ecological intensification, and, (3) generate actionable policy recommendations on ecological intensification.

The World Resources Institute (WRI) reviewed MDG indicators and associated data sources (WRI, 2008). That comparisons of global to sub-global assessments found that indicators for provisioning services are far better developed and supported than are indicators related to regulating and cultural services, which they found to be weak overall. The WRI noted that indicator sets that were tailored for local application better reflected population priorities. Indicators of regulating services are weaker (less well developed) at the sub-global scale. For example, soil infiltration and soil water storage are potentially useful indicators of water regulating services, but are not broadly supported by available databases. They note data are heterogeneous, and that data available for some sub-global assessments are not available for global application. This is quite common for cultural service and biodiversity indicators and for data on households, including consumption, population density, and agricultural needs and production. That report suggests that monitoring systems need to gather data at sufficient temporal and special scales and that disaggregated data that retains spatial information is of particular value. They note that: use of an ecosystem services framework requires information to be available at multiple spatial and temporal scales, the frequency of indicator measurement needs to be able to track flow of services , data must be made available in appropriate, ideally digital, formats and, be disaggregated and permit indicators to be normalized in ways that inform analysis and possible policy actions.

The H. John Heinz III Center for Science, Economics and the Environment reviewed environmental indicators in two ‘State of The Nation's Ecosystems’ reports designed to provide an impartial and comprehensive understanding of ecosystem state of and trends. By advancing indicator science, the effort sought to shift environmental disputes from arguments over data accuracy or appropriateness to policy debates based on mutually accepted data. These were managed reviews engaging hundreds of scientific experts (150 in 2002 and 300 in 2008) who identified a set of 108 indicators to tack the wellbeing of distinct U.S. ecosystems at national, regional and local scales. That review focused on condition and trends (outcomes) and policy relevance and noted data must meet high standards for quality and coverage across the nation and through time and be updated periodically as scientific understanding and applications evolve. Their indicators were divided into four main categories (Extent and pattern (24 indicators) Chemical and physical characteristics (30 indicators) Biological components (32 indicators) and, Goods and services (22 indictors). Table 2 summarizes indicators and data sources that have high utility for evaluation of sustainable intensification. That effort considered data sufficiency and assumed credible data would be National in scale and likely to be available in the future. Additional unstated assumptions were that data will be collected in the public interest and that National and State governments would be primary data holders/suppliers.

Table 2. Farmland indicators relevant to EI identified in the State of the Nations Ecosystems.

Category	Characteristic	Farmland Indicators	Data sources
Extent and pattern	Extent	1. Total Cropland* 2. The Farmland Landscape	Multi-Resolution Land Characterization Consortium and ESRI
	Pattern	3. Proximity of Cropland to 4. Residences† 5. Patches of “Natural” Land in the Farmland Landscape†	Multi-Resolution Land Characterization Consortium and ESRI
Chemical and physical characteristics	**Nutrients, Carbon, and Oxygen**	6. Nitrate in Farmland Streams a. and Groundwater* 7. Phosphorus in Farmland a. Streams* 8. Soil Organic Matter*	USGS, National Water Quality Assessment and National Stream Quality Accounting Network. SOC: Natural Resource Ecology Laboratory, Colorado State University.)
	Chemical Contamination	9. Chemical Contamination	U.S. Geological Survey, National Water Quality Assessment Program.)
	Physical	10. Potential Soil Erosion 11. Soil Salinity 12. Stream Habitat Quality†	*USDA Natural Resources Conservation Service. Coverage data cover cropland and Conservation Reserve Program lands, but not pasture. Technical details: data are based on an index that combines information on soil characteristics, topography, and management*

			activities *such as tillage practices and whether crop residue is left on the field or not.*
Biological components	Plants and animals	13. Status of Animal Species in Farmland Areas 14. Established Non-native Plant Cover in the Farmland Landscape† †	
	Communities	15. Soil biological condition	U.S. Environmental Protection Agency, Wadeable Streams Assessment 2006. *stream biota
	Ecological Productivity	*They had nothing for farmland but this is critical- why and cite the 'plant growth index'	*[NASA analysis by Terrestrial Observation and Prediction System (TOPS) / Ames Research Center, NASA]. Coverage: lower 48 states. Technical details: Data for 1982–2003*
Goods and services	Food, Fiber Water	16. Major Crop Yields 17. Agricultural Inputs and Outputs* 18. Monetary Value of Agricultural Production	USDA Economic Research Service
	Recreation and Other	19. Recreation in Farmland Areas	

** Indicator refined since the 2002 State of the Nation's Ecosystems Report (original metric or metrics retained)*
† Indicator redesigned since the 2002 State of the Nation's Ecosystems Report
‡ New indicator since the 2002 State of the Nation's Ecosystems Report

VI. Process based approach to developing data and tools

Efforts like those being developed in association with USAID's 'Feed the Future' initiative that engage with country-led development programs that are tie to locally-important value chains are well positioned to improve agricultural productivity, expand markets and trade, and increase the economic resilience of vulnerable rural communities. Such strategic alliances are intended to ensure that 'research outputs – new technologies, management practices, varieties, and other tools – are locally relevant and reach farmers at scale'. The kinds of indicators and frameworks that will emerge to support these efforts are a good fit with IFPRI's Harvest Choice project, Collective Action and Property Rights, and Natural Resource Policies efforts and are likely to be of greater value to the Biosight effort. Promising indicators, frameworks and data sources that are being used or discussed in the primary literature will be reviewed for the final report. We will concentrate on indicators that have high utility to small holder agriculture, many of which have been identified through participatory efforts as metrics that have meaning to small farms and localized contexts. Development and use of such indicators might reduce the concern that some have about sustainable intensification, which ultimately pits the economy against the environment with the environment ultimately and inevitably losing out (Caccia, 2001). These indicators will support alternative conceptions of SI which place a higher value on natural capitol, recognizing it to be finite and a public good, wherein increases in production are achieved by 'ecological intensification' (EI) through adoption of biologically based management and increased diversification. While EI is not anti-global, it would constrain 'unecomomic' growth to sustain provisioning services and focus efforts to expand production to satisfy the basic needs of the poor. They might also address the critique of SI suggesting that its champions have promoted a neoliberal, free trade agenda to strengthen industrialized agriculture without regard for the people or places where food is produced, processed or consumed (Koc 2011, Patel 2009). The EI approach is a better fit with food sovereignty efforts which have been proposed as a way to provide for long-term food security wherein food is seen as a basic human right and nations are encouraged to maintain and develop the capacity to meet their productive and cultural food needs (Via Campesina 1996; Schanbacher 2010; Rossett and Martinez, 2010). The food sovereignty movement is a transnational agrarian movement that has grown rapidly to oppose the expansion of corporate food regimes and allow farmers and consumers to determine their own food system destinies (McMichael 2009, Claeys, 2012). Accordingly, EI tactics and indicators are compatible with civic movements like the food sovereignty movement that would shift the goal of development from growth to well-being. This distinction between SI and EI approaches to indicator development may be of use because indicator frameworks are organized around principles, goals and desired outcomes. This presents a significant challenge it is in the lesser developed countries where fine-scale data is most lacking. Mueller et al. (2012) identified resource endowment, nutrient management, water use and climatic factors as those determining productivity on the global scale noting the relative importance of each factor varies based on the spatial characteristics under evaluation.

In the complex and heterogeneous conditions that characterize much tropical smallholder agriculture, some argue for participatory approaches in designing indicator systems. Proponents claim that substantial participation from knowledgeable end-users is required if systems are to be relevant and usable. Approaches can be divided into those whose goal is designing and assessing potential impacts of new technologies and those whose goal is monitoring and evaluation of current systems.

On the one hand, indicators are relevant in designing targeted approaches for distinct niches. A 2008 e-debate sponsored by the Future Agricultures Consortium between experts on SI in Africa revealed a near universal condemnation of "blanket" approaches and recommendations. In the highly heterogeneous world of African agriculture, the one-size-fits-all approach has failed (Scoones, 2008). Important and linked farm differences which have been cited are: soil responsiveness to inputs as affected by inherent soil quality, management and climactic factors, regional population density, livestock presence and type, cash or subsistence crop production orientation, access to inputs such as organic materials, fertilizers, improved seeds and labor, wealth of the farm household, access to markets and storage facilities and preferred crops (e.g. Tittonell et al., 2005; Sileshi et al., 2010; Giller et al., 2011,Vanlauwe et al., 2011). Integrated Soil Fertility Management (ISFM) is a paradigm promoted by the Institute for Tropical Soil Biology and Fertility (TSBF) which has gained wide currency. The ISFM concept is based on the idea of maximizing input efficiency by blending use of inorganic and organic fertilizers and improved germplasm in a way that makes sense for local soil needs and input constraints (Vanlauwe et al., 2011). Giller et al. (2011) have designed a conceptual framework called "Nutrient Use in Animal and Cropping systems – Efficiencies and Scales" (NUANCES) which aims to model farming system complexities in order to identify what they term "best-fit" technologies in the ISFM paradigm. This framework, formed around the authors' work chiefly in highly populated areas with reliable rainfall and high agricultural potential, involves a detailed description of the local context, data from which is used to group farms into typologies, through qualitative (key informants, local experts) or quantitative (multivariate statistics) means. A small number of "typical" farms from each class are selected for in-depth analysis of nutrient flows, the data from is used to produce "virtual farms" in which different allocation scenarios can be tested. This testing is done with the input of farmers and the virtual farms are altered iteratively based on farmers' input. The refined models and different resource allocation scenarios are used in farmer groups to discuss intensification approaches (Giller et al., 2011). Using this "participatory modeling" approach research teams can collaboratively identify niches for suitable improved technologies, predict important tradeoffs (i.e. Rufino et al., 2011), assess technology feasibility to various types of farmers and identify areas where government support will be needed (i.e. Vayssieres et al., 2011).

A similar approach involves using the process of indicator selection as a tool for building consensus between farmers and researchers, a necessary precondition to the collective action needed in real integrated farming system change (Barrios et al., 2006). The goal is the creation of a common language between stakeholders of what "sustainable" consists of and is identified by, as in countries with overstretched extension services and few soil analysis labs most monitoring and evaluation will likely be done by the farmers themselves. Proponents of a participatory process of indicator selection reason that this will be more effective if indicators grow out of and are stream-lined with local soil knowledge (Barrios et al., 2006). In addition, often traditionally used indicators are highly adapted to the complex system they were developed in (Altieri, 1991). The process borrows methods from ethnopedology to inventory soil knowledge and identify important local indicators of soil quality (LISQ) such as soil color and indicator plants and integrate them with scientific indicators such as pH, CEC or total soil C (e.g. Erkossa et al., 2004; Mairura et al., 2006; Barrios et al., 2006; Dawoe et al., 2011). There is no standardized process, but the method developed by Barrios et al. (2006) is representative of most approaches. The method, developed in Latin America and also introduced into East Africa, involves two steps. Firstly, scientists along with farmers and extension agents work to identify relevant soil quality indicators for an area, define critical levels and get the main limitations of the system in question. Secondly, researchers then form this information into a local soil-quality monitoring system, which is critiqued by users and revised until it is accepted. Chosen indicators are ranked as to how quick they are likely to change, helping farmers to see when to look for results and to have an idea what will change and what won't. The overall goal is to have a locally-adapted soil quality monitoring system, accepted and usable both by farmers and researchers, that can be used as decision support tool. The system is presented at "soils fairs" around the area, in which a larger group of farmers is trained to use the system and encouraged to comment on its accuracy and relevance. Barrios et al. (2006) find that the general framework was easily adaptable to both Latin American and East African smallholder conditions, where it was useful for quickly helping farmers learn to monitor their soils.

VII. Dominant environmental indicators related to food, water, land and energy

Food (Provisioning Services)

As has been noted, data and indicators related to provisioning services, or more commonly ‘goods and services’ including food production are the best developed metrics for SI. These are supported by numerous global entities and being strengthened by remote sensing. Advocates for SI methods argue that we must be able to quantify food production capacity on every hectare of current farmland in a consistent and transparent manner to guide policy and management (Cassman et al, 2013). At present, important data bases (eg: OECD environmental indicators) report cropped area devoted to major crops or livestock (often reported as area or extend of ag land), and crop demands for inputs (Tables 1 and 2).

Both yield potential and water-limited yield potential have been proposed indicators for use under irrigated and rainfed conditions where the differences between these theoretical yield levels and those achieved in farm fields define ‘yield gaps’ where SI efforts might pay off. Cassman et al. used empirical methods to estimate yield potential from 90 to 95th percentiles of farmers’ yields, maximum yields from experiment stations, growers’ yield contests or boundary functions in three countries and compared these with estimates of potential or water-limited yields derived from models. They outline a tiered approach that employed crop growth simulation models to fill data gaps within homogenous climate zones. Their methods are consistent with others performing simulations for dominant soils and cropping systems and is fully consistent with case study methods that can adapt accounting frameworks to describe situational dynamics. Critics of this approach (Titonell and Giller, 2013) suggest that a paradigm of ecological intensification focused on yield potential, soil quality and precision agriculture may not benefit smallholder farmers. They argue that continued cropping without sufficient inputs of nutrients and organic matter will degrade soils and that after leveraging increased fertilizer and labor without reward would be worse off than before such interventions.

Water

Dominant metrics for water track quantity and quality which is important for agriculture as it relies on and impacts both of these factors. Water quality and quantity indicators and water cycle indicators are needed to evaluate the ecological impact of agriculture. Agriculture depends on water as plants have high water content and require it for growth and as a result water use by agriculture impacts stocks and flows directly through water removal. Agriculture also impacts the water cycle by influencing water flow as the majority of water consumed by society percolates through the soil. Water movement into and through the soil is important contributor to filtration and water store. Agriculture can have negative effects on water by reducing water quantity and quality, and water holding and filtering capacities. These negative effects on water are connected to soil erosion, nutrient depletion, and pesticides inputs, and are strongly correlated with the high ratio of world land degradation, estimated to be around 40% of the agriculture land (Bossio, et al. 2009). The World Bank (1995) and FAO (1994) have produced documents to guide societal actions to improve water quality in agricultural and other systems. Many of the current set of agri-environmental indicators recommended by OECD (2004) are linked to water quality and quantity. Most emerging Business standards consider water used to produced crops (irrigation), some include indicators of quality and water cycle function (infiltration and filtration). Of promise are management-based indicators that can be related to water protection. If these are fast and easy to measure on farm using simple and cheap tests, important properties like water holding capacity, resistance to soil erosion, prevention of nutrient, and water runoff, can be tracked. The water quality indicators for SI may be monitored by measuring pH, phosphate, turbidity, dissolved oxygen, chlorine, ammonia, and coliforms.

Land and Soil Quality

After food production, indicators tracking arable land available for production are the next most-tracked factor of sustainability. Area and status (potential for erosion or salinization, nitrogen and phosphorus inputs) are commonly tracked in international databases. Emerging business standards also include soil quality and place an emphasis on biotic health because soil biodiversity has been cited as an essential contributor to sustainable intensification from the concepts inception (see Swift, 1997 and contents therein).

Indicators of soil health provide some of the core metrics for public and private entities seeking to monitor sustainability because soil lies at the heart of the Earth's life, sustaining the 'Critical Zone' where the pedosphere provides the fragile interface between the atmosphere, lithosphere and hydrosphere (Dietrich and Perron, 2006; Wilding and Lin, 2006). As a relatively non-renewable resource, soil contributes uniquely to the earth's provisioning services (Millennium Ecosystems Assessment, 2005) and is currently threatened by soil acidification, salinization, desertification, organic matter depletion, compaction, nutrient loss, chemical contamination, landslides, and erosion (Batjes, 1996; Millennium Ecosystems Assessment, 2005; UNEP, 2007). Concern for the soil has increased interest in monitoring and management to protect this vital resource. Areas in need of research include the development of: 1) indicators of soil health that quantify resource stocks, fluxes, and transformations, 2) methods to relate indicators of soils' 'natural capital' to ecosystem services, and 3) integrative tools that draw on data, standards and indicators to allow decision makers to better steward the soil (Yaalon and Yaron, 1966; Tugel et al. 2006; Robinson et al. 2011). Efforts to develop effective decision making frameworks will vary with the amount and quality of soils information that is available, the institutional and organization capacity of information producers and suppliers and, with the context and scale for decision making.

Several of the groups working on voluntary sustainable agriculture standards are looking at the Soil Management Assessment Framework or 'SMAF' as one way to quantify soil quality (Andrews et al., 1994). The SMAF relates measured indicators to anticipated ecosystem services and so could satisfy desires to document benefits. The SMAF uses soil physical, chemical and biological indicator data to assess management effects on soil function using a three-step process for (1) indicator selection, (2) indicator interpretation and (3) integration into an index. Proposed methods for indicator development and calibration are being used to refine relationships between indicators and outcomes (eg: Weinhold et al. 2009; Stott et al. 2012). This is fortunate as non-government organizations have expressed interest in using the SMAF to backstop business-backed sustainable agriculture standards. To achieve their potential soil health indicators and assessment frameworks like SMAF they will need to relate changes in indicator state to outcomes including changes in soil productivity, water quality, air quality and biodiversity.

Assessments of soil status will also increasingly rely on inventories of soil organic carbon (SOC), which is a core metric of soil condition that is also important for climate change modeling as it is one of the main components of greenhouse gas (GHG) accounting frameworks. Global estimates of soil organic C stocks have been guided by the Intergovernmental Panel on Climate Change (IPCC, 2006). The IPCC methods to estimate soil organic C stocks are ranked in Tiers, from which Tier 1 estimates are based on Land Use Change factors multiplied by a reference SOC stock (eg: IPCC, 2006), but the spatial resolution is limited and thus their contribution to local decision making. For global spatial layers on soil parameters, the most recent and complete dataset is available as the Harmonized World Soil Database (HWSD) (FAO/IIASA/ISRIC/ISSCAS/JRC, 2009). The HWSD provides the most recent and complete dataset for global soil layers. It was developed through partnership between the Land Use Change and Agriculture Program of the *International Institute for Applied Systems Analysis* (IIASA) and the *Food and Agriculture Organization of the United Nations* (FAO) in collaboration with the *International Soil Reference and Information Centre* ISRIC) -World Soil Information, the European Commission Joint Research Centre (JRC) and the *Institute of Soil Science, Chinese Academy of Sciences* (ISSCAS). The amended dataset provides the organic C density (t ha^{-1}) for the topsoil (0-30 and 30-100cm depth) at the 1km and 10km scales. The evaluation of estimates based on the HWSD Version 1.1 revealed that bulk density is the most influential variable for estimating C stocks and mainly responsible for the differences between estimates. Most affected from the variability in bulk density are SOC stocks in areas with soils which are high in organic C. For more on this consult Hiederer and Kochy, 2011. Tier 2 methods estimate C stocks based on local soil and weather conditions under specific management practices; Tier 3 methods use modeling techniques which describe local soil and climate conditions in their subroutines (Smith et al. 2012a).

Agricultural systems are responsible for the large amounts of reactive N that enters the global N cycle (Smith et al 2012b) and derived from industrial synthetic N fixation. Estimates of global N stocks and fluxes are important to determine the productive capacity of soils and to design tools to monitor and mitigate its negative effect on greenhouse gas emissions and water quality. Efficient N management will involve the coupling of the C and N cycle as their processes are interrelated. Major global indicator frames do not at present account for N use as effectively as they need to.

The importance of animal and green manures to improve physical, chemical and biological soil properties is largely acknowledged. The limited access to industrial-based inputs in developing countries forces the integration of livestock-based operations that recycle nutrients within the system. Often, the long-term use of animal manure and when applications are excessive, soil P accumulation or build-up occurs leading to P runoff and water quality problems (Edmeades 2003). The use of inorganic P sources is generally guided through soil testing, this becomes more of a challenge with it comes to P management in livestock-based systems. International indicator frames do not track this but many of the management-based assessment tools (eg: the NRCS CMT and emerging business standards do). Our ability to estimate credits with any kind of spatial precision will depend upon development of modeling tools. Efforts to do this using process models like Century, RUSLE2 and EPIC are ongoing.

To support spatially explicit modeling we will need to disaggregate soil maps or collect local data. Within the United States, federally supported soil protection and soil mapping efforts have established a strong basis for soil conservation and management founded on soil classification. The United States Department of Agriculture (USDA) soil classification system (Keys to Soil Taxonomy, 2006) relies on taxonomy that emphasizes pedogenesis where a soil type or reference group is related to the climate and substrates contributing to soil formation. Taxa can be weakly related to function through this information but only at a relatively coarse (great group level) (Mueller et al. 2010). This is why individual properties (texture, organic matter, pH) are frequently used as indicators of soil function and why Tugel et al. (2005) have proposed that national efforts should focus on developing methods to map and manage 'dynamic soil properties.' That work outlined the data and information systems that would be needed to backstop an indicators framework based on soil health that answers Robinson et al.'s (2011) call for indicators that can track changes in natural capitol and soil-dependent services. Related efforts will greatly enable indicator-based frameworks by providing needed benchmarks and interpretations.

Energy and Climate

Energy related metrics for agriculture are becoming more common and more important. The MA tracked fuel but emphasized renewable sources. Raising costs and awareness of energy have prompted business standards to include energy as a way to normalize production. For example the Field to Market calculator considers BTU/bu corn and greenhouse gas emissions derived from seed, fertilizer, lime, tillage, etc. Use of renewable sources of energy is essential for EI. Agriculture has become increasingly dependent on direct and indirect uses of fossil resources to increase food production since the 1960s. The relationship between energy input and energy output in yields is non linear (Woods, et al. 2010), and there is high inconsistency in the calculations of output/input energy balance in the literature (Zegada-Lizarazu, et al. 2010). At present, there us 'un-economic' use of fossil fuels promoted largely by government's subsidies for energy particularly in developed nations. Ideally, appropriate SI indicators for agri-energy relations would support policy to maximize energy return on investment (EROI).

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