E-forum: **Examining Sustainable Intensification Research Priorities**

Background

Agriculture is at a defining moment: the effective demand for food is growing around the world, while at the same time severe constraints are faced from degraded soil resources and a changing climate (Beddington et al., 2012; Godfray et al., 2010). Agricultural intensification in recent decades has dramatically increased food production, in combination with extending production into new areas (the later is notable throughout sub-Saharan Africa). Widespread food insecurity remains, however, and negative environmental consequences of agricultural practices have put water and air quality at risk (Tilman et al. 2011). Sustainable intensification has been proposed as the means to address this difficult challenge, a way to feed the world, while protecting the resource base and environmental services. Sustainable Intensification (SI) was described by Pretty in the 1990s and has received increasing attention recently, particularly in the arena of international agricultural development (De Schutter, 2010; Pretty, 1997).

Pretty et al. (2011) define SI as follows: "Sustainable agricultural intensification is defined as producing more output from the same area of land while reducing the negative environmental impacts and at the same time increasing contributions to natural capital and the flow of environmental services". An important aspect of SI according to the same source is that: "As both agricultural and environmental outcomes are pre-eminent under sustainable intensification, such sustainable agricultural systems cannot be defined by the acceptability of any particular technologies or practices (there are no blueprints)." In summary, there are no blueprints because SI focuses on a goal, and there are different pathways to that goal.

In this paper we have undertaken a literature overview of SI that follows this same approach. We focus on how to support trajectories of SI, and put into practice agro-ecological principles, rather than on a specific set of technologies (Petersen & Snapp, in review). This was the rationale behind the SI research topics chosen for the e-Forum: farming systems, research rigor, integration and scaling out of science, and biologically-based management of natural resources as the foundation for SI technologies.

Farming systems analysis

Calls for systems-based approaches to understand farmers and their livelihoods have occurred intermittently since the 1970s yet component research has continued to dominate agricultural development, in conjunction with the linear research-extension model of technology transfer (Collison, 2000). It has been argued that the lack of farming systems analysis has been a key contributor to the agricultural stagnation that characterizes much of Sub-Saharan Africa (IAASTD, 2009). Although farmer participatory approaches and on-farm research are often mentioned as an important aspect of development projects, recent major investments have favored a 'silver bullet', component technology or technical package approach. In contrast, systems-based approaches offer a learner-centered alternative, where modeling and information is used to support opportunity analysis, participatory action learning, interdisciplinary research, and catalyze SI innovation.

The complexity of the challenges farmers and rural communities face include the uncertainty of a changing climate, and globalization transformations underway (Moore et al., 2012). Smallholders are particularly at risk to climatic variability such as poorly timed dry spells, extended drought and excess rainfall (Funk et al., 2008). In this complex and changing environment, technical solutions have failed, time after time. Participatory action research has provided notable exceptions, including introduction of crop varieties and integrated agricultural management that is tailored, and combined with attention to education to support local adaptation capacity (Snapp et al., 2010; Tittonell et al., 2012).

To support a SI trajectory, where production is intensified while the environment is conserved, it is clear that some form of systems analysis will be required. This will inform a thorough understanding of producer livelihoods and biophysical characteristics of crop, tree and livestock systems. A systematic systems analysis and co-learning approach with local communities has supported the identification and rapid adoption of best bet options, sometimes called plausible innovations (Giller et al., 2006, Mapfumo et al., 2013). How to scale out these innovations, and extend action research findings to multiple scenarios remains a challenge. Linkage with simulation modeling or participatory modeling has been proposed as one means, however, there are only a few examples of successful implementation of such linked approaches (CGIAR, 2012). This raises the question, what are the research priorities in farming systems analysis?

We pose the following as key areas for inquiry:

- What are the drivers of sustainable intensification and how can they best be identified?
- What are the important system boundaries within which farming systems research can most effectively produce scalable results?
- On which scales should sustainable intensification research be focused and how can they be determined?
- How can research move from system characterization to constraint identification and diagnosis and then to scalable solutions?

Rigorous science and effective data management

Farming systems research requires the collection, analysis, and management of data from multiple scales, on a range of biophysical and socio-economic variables, and across a number of research organizations. Insuring relevance of research is the foundation for research rigor. Farmer preferences often value traits such as stability of production, meeting a diversity of requirements, labor and land saving traits, and locally-preferred taste and storage traits above metrics of productivity, such as high yield (Ceccarelli and Grando, 2007; Mugwe et al., 2009). This is the rationale for conducting research on-farm, and developing action research partnerships that enhance understanding, and catalyze innovation at multiple scales. Research involving such complex data is susceptible to being insufficiently focused and can result in unclear conclusions. This has been a major barrier to conducting farming systems research at farm level. The challenge of a changing climate highlights the urgent need to move beyond data collection and information gathering to knowledge, or what has been called actionable information (IRI, 2011). To ensure effective integration of the multiple disciplines involved in farming systems, research data must be shared across a wide range of disciplines, and transparency on how data were collected and at which scales.

To integrate spatial information, systems analysis over space and time, and understand inference zones requires improved data management capacity and utilization. Large volumes of quality data is a foundational requirement for the integration of simulation models operating at the field or farm level with GIS data bases, to make predictions and infer trends (Hartkamp et al., 1999). A wide range of modeling and decision support approaches to understanding rural livelihoods and support SI requires attention to, and improved management of, large quantities of farm data (CGIAR, 2012). The case has also been made for qualitative and quantitative data as a basis for group model building in a systems dynamics approach to understanding natural resource management, as shown by an intriguing case study from the Philippines (Schmitt Olabisi, 2010).

Farming systems research has too often relied on databases that document demonstrations, e.g., the location of technologies tested, and responses observed. This has often involved narrow sets of technologies that are supply driven, with little attention to documenting demand or adaptations. In contrast, data are needed that support participatory action research, and farmer-led innovations (O'Brein, 1998). Farmers often value traits such as stability of production, meeting a diversity of requirements, labor and land saving traits, locally-preferred taste, and storage traits above metrics of productivity, such as high yield (Ceccarelli & Grando, 2007; Mugwe et al., 2009). Data that is relevant to these objectives can provide a foundation for farming systems research hypotheses and objectives. It is crucial to develop these data platforms to help design experiments, document findings and synthesize the main drivers of productivity, livelihoods, health and a sustainable environment. Inference from research findings, across time and space requires improved management of these large data sets.

Key questions include:

- What are the necessary steps to ensuring that multi-scale, multi-disciplinary research is coherent, is relevant to a wide range of farm households, and leads to clear conclusions?
- What are the requirements for effective data set management and sharing amongst multiple organizations and across projects and programs?
- How can relevant, hypothesis-based experiments be designed to include spatial scales spanning plots, fields, farms and landscapes?

Scientific and local knowledge integration and scaling out

Farmer knowledge and input is a critical component of SI activities and farmers are often directly involved in priority setting, experiment management, and data collection. Their involvement can greatly increase the relevance of results but can also introduce ethical issues and bias and disrupt their livelihoods. Another challenge is how to integrate local knowledge with scientific knowledge (Huntington, 2000). In a rapidly changing world, local capacity and action research is fundamental to supporting resilience (Mapfumo et al., 2013). At the same time, scaling out to reach larger audiences requires new approaches to integration and dissemination (Snapp & Heong, 2003).

Key questions include:

- How can the testing or adoption by farmers of innovative SI strategies be supported in action research without risking livelihoods or biasing results?
- How can engagement with farmers and rural communities support research priority setting and scaling out of results?
- How can scientists capture how farmers adapt introduced innovations to real world and changing conditions and broaden options beyond narrowly focused technologies?

Integrating productivity and natural resource management

Increasing crop, livestock, and aquaculture productivity per unit land area or input—intensification—is critical for farmers to meet their economic and nutritional needs. Doing so in an environmentally sustainable manner is critical for long-term success (Pretty et al., 2011). Beyond conserving the resource base, sustainable intensification also pays attention to supporting production of a broad range of ecosystem services, conserving biodiversity and other benefits of nature (Tilman et al., 2002).

Successful SI strategies rely heavily on biologically based management to increase the productivity of soil and water resources. Crop diversification, recoupling of crop, livestock, and/or aquaculture nutrient cycles, agroforestry, and integration of perennial vegetation can play important roles in developing successful SI strategies. Principles put forward as the foundation for SI have included reduced disturbance and various forms of conservation agriculture, although this remains controversial in an African smallholder livelihood context (Giller et al., 2009). Coupled carbon and nitrogen cycling, and harnessing of plants and associated microbial communities to improve nutrient cycling are also key principles of SI (Drinkwater & Snapp, 2007). Diversification with livestock and legumes that combine food production with soil building properties has been shown to 'go to scale' and enhance farming system performance, and stability of production (Mapfumo et al., 2013; Snapp et al., 2010).

Including all possibilities in all places, though, can result in overly complex systems that aren't easily adopted by farmers and are difficult to design effective research around.

Key questions include:

- Have robust and practical methods for determining the suitability of biologically based interventions been developed that can help prioritize research interventions?
- What is the interaction of these strategies with industrial or purchased inputs?

- Which are key biological principles to support SI, such as increased vegetative cover for soil conservation and capture of sunlight, judiciously targeted disturbance, or coupling of carbon with nutrient cycling?

Future direction

There is an increased recognition that systems analysis, which identifies drivers of productivity and opportunities for farmer-led SI, can help meet the challenges presented by highly heterogeneous and complex farming systems where adoption has been almost nil to date (McCown et al., 2009). Successful examples of SI trajectories include introduction and adoption of improved legume genetics, targeted and judicious use of integrated nutrient management technologies, and climate-smart forms of agriculture that integrate perennials (Glover et al., 2012). For example, participatory action research, modeling and nutrition education has helped drive agricultural intensification in a manner that supports local resilience and measurable improvements in child nutrition in Northern Malawi, Ekwendeni region (Snapp et al., 2010; Bezner Kerr et al., 2010). 'Plausible bet' technology options have been identified that show promise as means to improve soil moisture holding capacity and drought resilience and support farmer innovation, but these options need to be tested and scaled out over space and time, especially in light of an often risky climate and marginal production environment (Tittonell et al., 2012). Rigorous, evidence based research that links the best science to local knowledge is urgently needed. This can support the innovation, experimentation and information sharing that leads to adoption, and more resilient, sustainably intensified, farming techniques (O'Brien, 1998).

References

Beddington , J. , Asaduzzaman, M., Clark, M., Fernández, A., Guillou, M., Jahn, M., Erda, L., Mamo, T., Van Bo, N., Nobre, C.A., Scholes, R., Sharma, R., & Wakhungu, J. (2012). Achieving food security in the face of climate change: Final report from the Commission on Sustainable Agriculture and Climate Change. *CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).* Copenhagen, Denmark. Available online at: www.ccafs.cgiar.org/commission.

Bezner Kerr, R., Berti, P.R., & Shumba, L. (2010). Effects of a participatory agriculture and nutrition education project on child growth in Northern Malawi. *Public Health Nutrition, 14*(8), 1466-1472.

Ceccarelli, S., & Grando, S. (2007). Decentralized-participatory plant breeding: an example of demand driven research. *Euphytica, 155*, 349–360.

Collinson, M. (2000). Introduction. In M. Collinson (Ed.) A History of Farming Systems Research. (1-5). Rome, Italy: Food and Agriculture Organization of the United Nations, and Oxon, UK: CABI Publishing.

Consultative Group on International Agricultural Research. (2012*). A review on farm household modelling with a focus on climate change adaptation and mitigation.* (Working Paper No. 20.) Copenhagen, Denmark: van Wijk, M.T., M.C. Ruffo, D. Enahoro, D. Parsons, S. Silvestri, R.O. Valdivia, and M. Herrero.

Drinkwater, L., & Snapp, S. (2007). Nutrients in Agroecosystems: Rethinking the Management Paradigm. *Advances in Agronomy, 97,* 163-186.

De Schutter, O. (2010). Proceedings from the United Nations General Assembly*: The Right to Food.* (65th session, Item 69 (b), Promotion and protection of human rights: human rights questions including alternative approaches for improving the effective enjoyment of human rights and fundamental freedoms), 21.

Funk, C., Dettinger, M.D., Michaelsen, J.C., Verdin, J.P., Brown, M.E., Barlow, M., & Hoell, A. (2008). Warming of the Indian Ocean threatens eastern and southern African food security but could be mitigated by agricultural development. *Proceedings of the National Academy of Sciences of the United States of America, 105,* 11081-11086.

Giller, K.E.,Rowe, E.C., de Ridder, N., & van Keulen, H. (2006). Resource use dynamics and interactions in the tropics: Scaling up in space and time. *Agricultural System*s, 88, 8-27.

Giller,K.E., Witter, E., Corbeels, M., & Tittonell, P. (2009). Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crop Research, 114,* 23-34.

Glover, J., Regan, J., & Cox, C. (2012). Agriculture: Plant perennials to save Africa's soils. *Nature*, 489, 359-361.

Godfray, H.C.J., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M., & Toulmin, C., 2010. Food Security: The Challenge of Feeding 9 Billion People. *Science, 327*, 812-818.

Hartkamp, A.D., White, J.W., & Hoongenboom, G. (1999). Interfacing geographic information systems with agronomic modeling: A review. *Agronomy Journal, 91,* 761-772.

Huntington, H. P. (2000). Using traditional ecological knowledge in science: methods and applications. *Ecological Applications, 10,* 1270–1274.

International Assessment of Agricultural Knowledge, Science and Technology for Development. (2009). *Sub Saharan Africa Summary for Decision Makers*, 24. Island Press, Washington D.C.: Markwei, C., Ndlovu, L., Robinson, E., & Shah, W.

International Research Institute for Climate and Society (2011). *Agro-climate tools for a new climate-smart agriculture*. New York: Hansen, J., Coffey, K., Hansen, J., Asseng, S., Whung, P., Baethgen, W., &Fraisse, C. Retrieved from http://r4d.dfid.gov.uk/PDF/Outputs/CCAFS/iri_agro-climate_tools_brief-web.pdf

Mapfumo, P., Adjei-Nsiah, S., Mtambanengwe, F., Chikowo, R., & Giller, K.E. (2013). Participatory action research (PAR) as an entry point for supporting climate change adaptation by smallholder farmers in Africa. *Environmental Development, 5,* 6-22.

McCown, R.L., Carberry, P.S., Hochman, Z., Dalgliesh, N.P., & Foale, M.A. (2009). Re-inventing model-based decision support with Australian dryland farmers. 1. Changing intervention concepts during 17 years of action research. *Crop & Pasture Science, 60*, 1017-1030.

Moore, N., G. Alagarswamy, B. Pijanowski, P. Thornton, B. Lofgren, J. Olson, J. Andresen, P. Yanda, and J.G. Qi. (2012). East African food security as influenced by future climate change and land use change at local to regional scales. *Climate Change, 110*, 823-844.

Mugwe, J., D. Mugendi, M. Mucheru-Muna, R. Merckx, J. Chianu, and B. Vanlauwe. (2009). Determinants of the decision to adopt integrated soil fertility management practices by smallholder farmers in the central highlands of Kenya. *Experimental Agriculture, 45*, 61-75.

O'Brien, R. (1998). An Overview of the Methodological Approach of Action Research. In R. Richardson, ed. *Theory and Practice of Action Research*. João Pessoa, Brazil: Universidade Federal da Paraíba.

Olabisi, L.S. (2010). The system dynamics of forest cover in the developing world: Researcher versus community perspectives. *Sustainability, 2*(6), 1523-1535.

Petersen, B. and S.S. Snapp. What is Sustainable Intensification: Views from Experts. Agriculture and Human Values, (Manuscript in review).

Pretty, J. (1997). The sustainable intensification of agriculture. *Natural Resources Forum, 21*, 247-256.

Pretty, J., Toulmin, C., Williams, S. (2011). Sustainable intensification in African agriculture. I*nternational Journal of Agricultural Sustainability, 9,* 5-24.

Snapp, S.S., and K.L. Heong. (2003). Scaling up: participatory research and extension to reach more farmers. In B. Pound, et al., eds. *Uniting Science and Participation: Managing natural resources for sustainable livelihoods.* (67-87) IRDC, Canada.

Snapp, S.S., M.J. Blackie, R.A. Gilbert, R. Bezner-Kerr, and G.Y. Kanyama-Phiri. (2010). Biodiversity can support a greener revolution in Africa. *Proceedings of the National Academy of Sciences of the United States of America, 107,* 20840-20845.

Tilman, D., Balzer, C., Hill, J., Befort, B.L., (2011). Global food demand and the sustainable intensification of agriculture. *Proceedings of the National Academy of Sciences of the United States of America, 108,* 20260-20264.

Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R., & S. Polasky. (2002). Agricultural Sustainability and Intensive production practices. *Nature. 418*, 671-677.

Tittonell, P., E. Scopel, N. Andrieu, H. Posthumus, P. Mapfumo, M. Corbeels, …, and S. Mkomwa. (2012). Agroecology-based aggradation-conservation agriculture (ABACO): Targeting innovations to combat soil degradation and food insecurity in semi-arid Africa. *Field Crops Research, 132*, 168-174.