PARTICIPATORY RESEARCH ON THE UPTAKE OF LEGUMES BY FARMERS

Marie-Hélène JEUFFROY

UMR Agronomie, INRA, AgroParisTech, Université Paris-Saclay, 78 850 Thiverval-Grignon, France, Email: Marie-Helene.Jeuffroy@grignon.inra.fr

Introduction

Legumes play a key role in the supply of ecosystem services, allowing new challenges in agriculture to be addressed (climate change, growing scarcity of non-renewable resource, frequent occurrence of abiotic and biotic stress, economic uncertainty) and thus improving the sustainability of the agro-ecosystems. Despite the huge range of species and crop management plans of legumes, they disappeared from French and European agricultural areas several decades ago. Several reasons exist and are linked around a lock-in of the agro-industrial system around a few major species, consistent with a high use of synthetic inputs, thus marginalizing legumes (Meynard *et al*., 2013). The analysis of the sociotechnical system shows that several levers should be combined to unlock the system: the improvement of the techniques for production and processing, the development of new outlets, and a stronger coordination between the actors. These targets open new avenues for research. As the combination of innovations require strong collaboration between the actors of the whole agrifood system, we conducted several participatory studies, it is essential for these questions to be studied, working at the different levels of the agrifood system.

Materials and Methods

Within several research projects, we used three scientific frameworks:

1. The framework of agroecological transition (Geels & Schot, 2007): it allowed us to study the sociotechnical system to understand the activities of the different stakeholders, with the aim of identifying the possibilities and the need for innovation, and the way to organize this process,
2. The framework of ecosystem services (MEA, 2005): in the scientific literature, the services supplied by legumes are available for a small range of species and growing conditions and should be quantified for a larger range. Moreover, the services vary according to the actors' requirements. To enhance innovation in legumes, we assumed that it would be essential to build a shared vision of these services.
3. The framework of cropping system design and assessment, which was assumed to be enlarged to the territorial scale.

Results and Discussion

We first identified the obstacles to the development of legumes, involving the actors from the value chains and the institutions. Interviews among stakeholders of the value chains showed that challenges around legumes are numerous, and sometimes opposing. This enlightened the difficulty of the actors in collaborating on a shared vision of legume development. They shared a vision on the obstacles: technical difficulties, low investment from R&D, low competitiveness compared to the major species, low availability for the industry…A diversity of levers are identified by the stakeholders: (a) combining public policies and private initiatives, (b) guiding more R&D activities on legumes, (c) combining organizational arrangements at the territorial scale. But few actors mentioned food as a lever.

Second, as it appeared as a lack of knowledge, we quantified the services supplied by various legumes in real agricultural conditions, from observations in farmers' fields, and shared these results with the actors of the territory.

Third, we co-designed cropping systems adapted to territories and assessed them taking into account the diversity of points of view of the stakeholders. Instead of building a consensus on the targets, which is often unsatisfactory for many of them, we showed that some cropping systems including legumes were satisfying for most of them, even all sometimes. We showed that the interest of legumes should always be assessed on crop succession. Yet, most available tools of the actors advising farmers (economic and environmental) do not allow this multi-year assessment.

Finally, as several surveys showed legume-based cropping systems implemented by farmers with good multi-criteria assessment, a study aiming at on-farm innovation tracking was implemented on intercrops. This allowed us to identify the targets of these farmers, and the links with the crop management plans they implemented on their intercrops. The results also showed large lacks of knowledge, research being concentrated on a small number of species and subjects.

Conclusions

As agronomists, our participatory research involved mainly farmers, advisors and agents from collective firms. Nevertheless, our investigations showed that the development of these legume crops require a combination of a large diversity of innovations, which can be economic, organizational, institutional, or concern processing and food, in strong interaction. This requires a strong need for design of coupled innovations, renewing the round table of actors to invite. This also leads for renewing the dynamics of knowledge production, with specific questions on expert knowledge.

Acknowledgements

This synthesis was derived from three studies, funded respectively by French National Research Agency as part of the ANR-13-AGRO-0004 project LEGITIMES, by the European Community's Seventh Framework Programme (FP7/ 2007–2013) under the grant agreement n°FP7-613551 (LEGATO project.), and the French Ministry in charge of Agriculture as part of the project Casdar 7–175.

References

Meynard J.M. – Messéan A. – Charlier A. – Charrier F. – Fares M. – Le Bail M. – Magrini M.B. – Savini I. – Rechauchère O.: 2014. *La diversification des cultures. Lever les obstacles agronomiques et économiques*. Versailles: Editions QUAE.

Geels F. – Schot J.: 2007. Typology of sociotechnical transition pathways. *Research Policy*, **36**: 399–417.

Millennium Ecosystem Assessment.: 2005. *Ecosystems and Human Well-Being*. Synthesis, Island Press. 155 pp. http://www.millenniumassessment.org/documents/document.356.aspx.pdf.

CHALLENGES OF FOOD SECURITY

Professor Molly JAHN [1, 2, 3]

[1] Department of Agronomy, Center for Sustainability and the Global Environment, Global Health Institute, Discovery Fellow, Wisconsin Institutes of Discovery, University of Wisconsin-Madison, One Gifford Pinchot Dr., Madison, WI 53726 USA, Email: molly.jahn@wisc.edu
[2] Joint Faculty, Oak Ridge National Laboratory, Oak Ridge, TN
[3] Senior Adjunct Research Scientist, Earth Institute, Columbia University

Abstract
In recent years, the FAO released a report that claimed that in order to feed the world in 2050 with growing population and growing affluence, food production (net of food used for biofuels) must increase by 70 percent. Annual cereal production will need to rise to about 3 billion tonnes from 2.1 billion today and annual meat production will need to rise by over 200 million tonnes to reach 470 million tonnes. In short, this does not add up. Various powerful stakeholders are interested in developing improved methods to reflect risk and uncertainty that originate in or amply through our global food systems. Some estimate that the 9B expected by mid-century could be fed today by our current agriculture especially if we employed at scale a number of agricultural, agronomic, information technology, business and social innovations already known. There is particular interest in more dynamic and integrated reflections of the condition of food security, the current status of food systems and more dynamic and integrated reflections of the condition of soil with respect to soil “health,” agriculturally relevant reflections of soil carbon and soil moisture.

Continued globalization of food networks has introduced unprecedented levels of uncharacterized complexity into the global food system. Climate change and extreme weather events are already affecting food availability, food accessibility, utilization, and food systems stability. As pressure on our globalizing food systems currently optimized for globalized trade regimes, stable environmental conditions, and peace-time mounts from growing populations, civil unrest, consolidation and migration, so does its vulnerability to sudden acute disruptions that could reduce global food supply and trigger food price increases. Such scenarios can in turn create cascading effects for businesses, governments and societies around the world. Various powerful stakeholders on both the public and private sectors are now interested in developing improved methods to reflect risk and uncertainty that originate in or could be amplified through global food systems. There is intensifying demand for more probabilistic reflections of both risks and threats for humanitarian concerns, capital and human security. Professor Jahn will examine how to improve decision-making on the complex issue of feeding the world, looking at collaborative work aimed at improving knowledge systems that better dynamically reflect food, water, and energy flows that will lie at the heart of changing course at scale toward sustainability for human beings and all other living things.

Acknowledgements
The author acknowledges support from the US Department of Agriculture, the Oak Ridge National Laboratory, the Skoll Global Threats Fund, Thomson Reuters, Lloyd’s of London and an anonymous philanthropist.

CHALLENGES AND OPPORTUNITIES TO LAND USE AND FOOD PRODUCTION, A TROPICAL PERSPECTIVE

Ingrid ÖBORN [1, 2]

[1] World Agroforestry Center (ICRAF), Southeast Asia Region, CIFOR P.O. Box 161, Bogor 16001, Jawa Barat, Indonesia, Email i.oborn@cgiar.org
[2] Department of Crop Production Ecology, Faculty of Natural Resources and Agricultural Sciences, Swedish University of Agricultural Sciences, P.O. Box 7043, SE-750 07 Uppsala, Sweden. ingrid.oborn@slu.se

Introduction – Global Challenges And Agreements

Globally, the demand for food, fibre and fuel is increasing due to a growing world population, urbanization and raising living standard in many low and middle income countries. This is putting high pressure on land, fresh water, biodiversity and other natural resources. With high growth rates in many emerging economies the market for livestock and dairy products is developing quickly further enhancing the pressure on natural resources. Climate change with increasing weather variability and occurrence of extreme events is adding to this pressure, and is in particular hitting vulnerable groups of people in dry areas and coastal zones. In order to meet these challenges a lot of discussions and activities are going on at international, regional and national policy levels, in the private and public sectors, within research, among development actors, in farmer communities, in the civil society and non-government organisations.

In the last year real progress have been made to address the global challenges. The Heads of State meeting at the United Nations in New York, 25–27 September 2015, agreed on 17 Sustainable Development Goals (SDGs) to be fulfilled by 2030 (http://www.un.org/sustainabledevelopment/summit). They are building on the Millennium Development Goals (MDGs) and complete what these did not achieve. New in the SDGs are the inclusion of the whole globe (previous focus was on the developing world) and the focus on sustainable development. The 17 goals are integrated and indivisible and they balance the three dimensions of sustainable development: the economic, social and environmental. Other global agreements of major importance for land use and food production are the Paris agreement and the United Nations Framework Convention for Climate Change in December 2015 (https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf) and the Bonn Challenge on land restoration (http://www.bonnchallenge.org/content/challenge).

Several of the SDGs are of particular importance for the theme of this lecture and will be dealt with in more detail such as 'End hunger, achieve food security and improved nutrition and promote sustainable agriculture' (SDG #2)', 'Ensure sustainable consumption and production pattern, (#12), 'Take urgent action to combat climate change and its impacts' (#13), and 'Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss (SDG#15). The CGIAR -a global research partnership for a food-secure future - have aligned their work with the SDGs and formulated four higher level goals which agricultural research can address (i) reducing rural poverty, (ii) increasing food security, (iii) improving human nutrition and health, and (iv) more sustainable management of natural resources. These goals are integrating not only increased productivity and natural resource management but also poverty reduction, i.e. increased income, and human nutrition and health.

Research On Sustainable Land Use And Food Production

Multifunctional landscapes, sustainable intensification and diversification, and climate smart agriculture are general concepts being put forward in the debate but also being implemented on the ground. The overall question is *how to integrate increased production and productivity with natural resource management in order to achieve economic, ecological and social sustainable and fair development* for all (women, men and children). There will probably not be one solution or model that fits everywhere ('silver bullet'), the way forward might rather be innovations and adaptions to the local context building on existing potentials and resources and meeting the short- and longer-term demands. For example, there is a debate whether farmers should be sharing land *with* nature or sparing land *for* nature, e.g. integrate tree, crop and livestock production producing and using ecosystem services, or cultivate some land very intensively leaving other areas for conservation. The way forward might not be either or, but a combination of the two approaches depending on the local context. In the lecture I will share some experiences from agriculture and food system research in Sub-Saharan Africa and Southeast Asia in order to address and illustrate the overall question. This will include research on (i) nutrient and trace element flows and balances in agricultural systems and an assessment of element balances as sustainability tool, (2) agroforestry practices - trees on farms and in agricultural landscapes – in relation to climate change mitigation, adaptation and species diversity, and (3) sustainable intensification and diversification, e.g. through mixed crop livestock-systems and introduction of multi-purpose legumes.

Agricultural productivity in sub-Saharan Africa is stagnant or declining and the rural population is increasing which has resulted in land shortage and food insecurity. Increased pressure on natural resources is also increasing vulnerability to climate change. Although Africa accounts for only 3–4% of global carbon dioxide emissions, it will be among the regions of the world to be hardest hit by climate change. To be able to enhance productivity and improve the livelihood in the long-term the declining trend in soil fertility and tree cover has to be reversed and the resilience of farming systems enhanced. The Kenya Agricultural Carbon Project has been promoting sustainable agricultural management practices including agroforestry through training of farmer groups in since 2009 and is combining climate change mitigation and adaptation. The changes in management practices have increased the maize yield by 50% (1st harvest) and 30% (2nd harvest) as compared to control farms. Also the food-self-sufficiency and household savings have increased. In addition the farmers have received payment for CO_2 emission reduction from the voluntary carbon market.

Future Perspectives Of Land Use And Food Production

In the Future Agriculture programme five future scenarios for 2050 were developed and used as a basis for stakeholder discussions to identify knowledge gaps and research issues to be addressed by agricultural research institutions and scientists (https://www.slu.se/en/Collaborative-Centres-and-Projects/future-agriculture/). The outcome was a number of research questions that were more cross-cutting that the present agricultural research, indicating a need for more integration between socio-economic and biophysical science, including consumer demand, ethical issues and policy aspects, e.g. rural-urban conflicts on land and resource use and wildlife, or production methods. In my experience research for development projects are many times more integrated than traditional research projects, with research teams working across disciplines and often together with different stakeholders and we can learn from that.

References

Hoang M.H. – Namirembe S. – van Noordwijk M. – Catacutan D. – Öborn I.: 2014. Farmer portfolios, strategic diversity management and climate change vulnerability - comparative studies in Vietnam and Kenya. *Climate and Development,* 6:216–225.

Khai N.M. – Ha P.Q. – Öborn I.: 2007. Nutrient flows in small-scale peri-urban vegetable farming systems in Southeast Asia – A case study in Hanoi. *Agriculture, Ecosystems and Environment,* 122:192–202.

Kuyah S. – Öborn I. – Jonsson M. – Dahlin A.S. – Barrios E. – Muthuri C. – Malmer A. – Nyaga J. – Magaju C. – Namirembe S. – Nyberg Y. – Sinclair F.L.: 2016. Trees in agricultural landscapes enhance provision of ecosystem services in Sub-Saharan Africa. *International Journal of Biodiversity Science, Ecosystem Services & Management,* (in press).

Minang P.A. – van Noordwijk M. – Freeman O.E. – Mbow C. – de Leeuw J. – Catacutan D. (Eds): 2015. *Climate-Smart Landscapes: Multifunctionality in Practice.* Nairobi, Kenya: World Agroforestry Centre (ICRAF). http://asb.cgiar.org/climate-smart-landscapes/index.html.

Nguyen Q.H. – Hoang M.H. – Öborn I. – van Noordwijk M.: 2013. Multipurpose agroforestry as a climate change adaptation option for farmers - an example of local adaptation in Vietnam. *Climatic Change,* 117:241–257

Nyaga J. – Barrios E. – Muthuri C.W. – Öborn I. – Matiru V. – Sinclair F.L.: 2015. Evaluating heterogeneity in agroforestry adoption and practices within small-holder farms in Kenya. *Agriculture, Ecosystem and Environment,* 212:106–118.

Nyberg G. – Knutsson P. – Ostwald M. – Öborn I. *et al*.: 2015. Enclosures in West Pokot, Kenya: Transforming land, livestock and livelihoods in drylands. *Pastoralism,* 5:25.

Öborn I. – Magnusson U. – Bengtsson J. – Vrede K. – Fahlbeck E. – Jensen E.S. – Westin C. – Jansson T. – Hedenus F. – Lindholm Schulz H. – Stenström M. – Jansson B. – Rydhmer L.: 2011. *Five Scenarios for 2050 – Conditions for Agriculture and Land Use*. Uppsala: SLU.

Öborn I. – Bengtsson J. – Hedenus F. – Rydhmer L. – Stenström M. – Vrede K. – Westin C. – Magnusson U.: 2013. Scenario Development as a Basis for Formulating a Research Program on Future Agriculture: A Methodological Approach. *Ambio,* 42:823–839.

Öborn I. – Vanlauwe B. – Phillips M. – Thomas R. – Brooijmans W. – Atta-Krah K. (Eds).: 2016. *Sustainable Intensification in Smallholder Agriculture. An integrated systems research approach* (In Press). *Earthscan from Routhledge, London: Earthscan Food and Agriculture.*

Öborn I. – Kuyah S. – Jonsson M. – Dahlin A.S. – Mwangi Hosea – De Leeuw J.: 2015. Landscape-level constraints and opportunities for sustainable intensification in smallholder systems in the tropics. In *Climate-Smart Landscapes: Multifunctionality in Practice*, pp. 163–177. Eds P.A. Minang, M. van Noordwijk, O.E. Freeman, C. Mbow, J de Leeuw and D. Catacutan. Nairobi, Kenya: World Agroforestry Centre (ICRAF). http://asb.cgiar.org/climate-smart-landscapes/index.html.

van Noordwijk M. – Hoang M.H. – Neufeldt H. – Öborn I. – Yatich T. (Eds).: 2011. *How trees and people can co-adapt to climate change: Reducing vulnerability through multifunctional agroforestry landscapes.* Nairobi: World Agroforestry Centre (ICRAF). 134 pp. http://www.worldagroforestry.org/sea/publication?do=view_pub_detail& pub_no=BK0149-11.

INFORMATION NEEDS FOR SUSTAINABLE LAND MANAGEMENT DECISIONS

Paolo BÀRBERI

Institute of Life Sciences, Scuola Superiore Sant'Anna, Piazza Martiri della Libertà 33, 56127 Pisa PI, Italy, Email: p.barberi@sssup.it

Introduction

Agriculture (cropland + grassland) is the major land use type in much of the world, reaching a 44.4% share in Europe (Eurostat, 2012). As such, any major changes in the amount of land devoted to agriculture and/or in the way agriculture is practiced are likely to have important consequences on the global scale.

Starting from the analysis of the most recent data on food production, consumption and trade and on agricultural land use, this paper aims to shed some light on the following issues: (i) Can present agricultural and food systems be considered sustainable?; (ii) How can we make them more sustainable?; (iii) What kind of information and knowledge is needed to increase sustainability?; (iv) What kind of decisions are needed to increase sustainability? By whom? A worldwide and a European perspective are taken into account.

Are Present Agricultural and Food Systems Sustainable?

A commonly cited mantra is that a 70% increase in food production is needed to sustain a projected 9.1 billion world population by 2050 (FAO, 2009). The general plea for 'sustainable intensification', mainly referring to the need of increasing yields while optimizing resource use and reducing or avoiding further conversion of natural land to agriculture stems from this mantra. However, if we look at the worldwide yields of cereals – the most important group of food crops – we realize that in the period 2000–2012 they increased by *c*. 18% (FAO, 2015). By projecting the same yield increase rate in the future, we can estimate that by 2050 cereals will produce an average 5.9 t ha^{-1} of grain, which is 64–94% more than yield values in 2012 and 2000, respectively. In addition, the malnutrition rate is diminishing and the average per capita energy intake with food is increasing (FAO, 2015). Therefore, there is a positive trend in the status of worldwide food and nutrition and it seems that boosting yields to meet the 2050 goal may not be needed. Nevertheless, it remains to be seen whether this already ongoing intensification is impinging on the state of natural resources, i.e. if it is sustainable. There are worldwide trends towards increased conversion of natural land to agriculture and increased fertilizer use. These suggest a potential reduction in the overall environmental sustainability of agriculture but it is difficult to draw general conclusions from aggregated data. Concurrently, the per capita amount of food lost or wasted has reached intolerable amounts, ranging from *c*. 125 kg $year^{-1}$ in South and South East Asia to nearly 300 kg $year^{-1}$ in North America and Oceania (FAO, 2013). The issues are different in developed and developing countries, with much higher wastages at the consumer level in the former and relatively higher losses from production to retailing – especially post-harvest – in the latter. It is clear that resource use optimization cannot solely focus on the production level and that reorganization and adjustment of the whole food system (including better access to land and food) is imperative if we want to achieve true sustainability. If we could achieve significant reductions in food losses and wastage the need to increase yields would likely not be a priority.

Where does Europe stand? European agricultural land use is basically stable, with cropland and grassland in the EU set at 24% and 20.4% of total land use in 2012 (Eurostat, 2012). However, a detailed look reveals some changes, e.g. a reduction in cereal-grown and managed grassland areas from 2009 to 2012, compensated by an increase in areas of fodder crops, dry pulses, vegetables and flowers. Most of the older EU member states (EU 15) show a trend towards extensification (input reduction), contrary to most of the newer EU member states. The number of agricultural holdings, with or without livestock, is diminishing and there are regions – especially in the Mediterranean and the Baltic – at high risk of farmland abandonment. Despite this, the EU agri-food sector is economically healthy, showing a positive export/import balance of nearly 20,000 Mio €, due especially to export of high added value processed food and beverages (European Commission, 2016). Commodities, instead, show a negative balance. On the side of food wastage and losses Europe is not doing well, showing an average loss of 280 kg $year^{-1}$ $person^{-1}$, of which 32% is wastage at the consumer level (FAO, 2013). In a nutshell, Europe seems to be excellent in producing quality food using raw materials grown elsewhere in enough quantity to generate substantial food wastage within the continent. There is no doubt that there is room for improving sustainability of the European agricultural and food system.

How Can We Increase Agricultural and Food Systems Sustainability?

There is only one way to ensure long-term sustainability and resilience of agricultural and food systems anywhere: to increase their *diversity*. This is true at any level of the food system. At the field level, application of agroecological approaches and functional biodiversity targeting priority agroecosystem services (Moonen & Bàrberi, 2008) can substantially improve resource use efficiency, adaptation to climate change, and yield stability. At the farm level, diverse, multifunctional agriculture can expand business opportunities, increase jobs and minimize risks posed by global trade. At the landscape level, partnerships engaging different stakeholders in participatory activities around goals of common interest through an Integrated Landscape Management approach (Sayer *et al*., 2013) can improve and maintain sustainability. At the regional or superregional level, diversity through e.g. optimum combination of land sharing and land sparing and food and non food objectives may turn in more sustainable land use than when either approaches are used in isolation.

What Kind Of Information and Knowledge Is Needed To Increase Sustainability?

To fully exploit the potential of diversity to improve sustainable land use different sources of information and knowledge are required. On the research side, one gap that is important to fill in is the quantification of agroecosystem services as driven by diversity across different spatial and temporal scales. Recent EU-funded projects are trying to unravel this issue, with promising results (www.quessa.eu). Big Data may help reveal hidden (un)sustainability patterns, but the objectives of using such large amount of data should be clearly stated. Recognition of knowledge from stakeholders other than scientists (e.g. farmers) on sustainability issues is gaining pace, but more should be done to strengthen this trend (Knickel *et al*., 2013). Along this line of thought, an interesting novelty is European Commission's engagement in Collective Awareness Platforms embracing sustainability views from the civil society. An example of this is the transdisciplinary and transboundary Horizon 2020 project CAPSELLA (www.capsella.eu), bringing together stakeholders communities/networks and Information and Communication Technologies experts to develop new tools to foster agrobiodiversity.

What Kind Of Decisions Are Needed To Increase Sustainability and By Whom?

Action is required by researchers, farmers and policy makers to foster sustainability of agricultural and food systems through diversity. Researchers should realize that their resilience can only be increased if they engage in transdisciplinary and participatory research. Farmers should fully acknowledge that their survival in uncertainty times resides in getting away from specialized, globalized, locked in technology-based systems. Policy-makers should take the courage to move from farm-based subsidies to subsidies promoting stakeholders aggregation around common sustainability objectives that can be more easily met by implementing higher diversity at landscape scale. Signs that change in this direction is possible are already visible in the EU.

Conclusions and Perspectives

Agricultural and food systems may be more sustainable than is commonly thought but action is needed to improve and pinpoint their sustainability in the long-term. Diversity is key to achieve these goals. Diversity is also a fantastic opportunity for agronomists to regain a core position in sustainability research and debate, provided they fully re-acknowledge the original, cross-cutting spirit of Agronomy in the light of new evidence.

Acknowledgements

I wish to thank Prof. Elisa Marraccini (Université La Salle-Beauvais, France) and Dr Davide Rizzo (Scuola Superiore Sant'Anna, Pisa, Italy) for constructive discussion and for suggestions on key references and online resources on Integrated Landscape Management.

References

European Commission: 2016. *Agricultural and rural development*. Trade statistics. http://ec.europa.eu/agriculture/trade-analysis/statistics/index_en.htm. Accessed 23 July 2016.

Eurostat: 2012. Land cover/use statistics (LUCAS). http://ec.europa.eu/eurostat/web/lucas/statistics-illustrated. Accessed 23 July 2016.

FAO: 2009. Harvesting agriculture's multiple benefits: mitigation, adaptation, development and food security. *Policy Brief.* Rome: FAO.

FAO: 2013. Factsheet. *Food wastage footprint*. Rome: FAO.

FAO: 2015. Statistical pocketbook. *World food and agriculture*. Rome: FAO.

Knickel K. – Zemeckis R. – Tisenkopfs T.: 2013. A critical reflection of the meaning of agricultural modernization in a world of increasing demands and finite resources. In *Proceedings Rural Development 2013: Innovations and Sustainability*, pp. 561–567. Ed. Aleksandras Stulginskis University

Moonen A.C. – Bàrberi P.: 2008. Functional biodiversity: an agroecosystem approach. *Agriculture, Ecosystems & Environment*, **127**:7–21.

Sayer J. – Sunderland T. – Ghazoul J. – Pfund J.-L. – Sheil D. – Meijaard E. – Venter M. – Boedhihartono A. K. – Day M. – Garcia C. – van Oosten C. – Buck L. E.: 2013. Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land uses. *Proceedings of the National Academy of Sciences of the United States of America*, **110**:8349–-8356.

INFORMATION NEEDS FOR SUSTAINABLE AGRICULTURAL SYSTEMS

Ian CRUTE

Agriculture and Horticulture Development Board, Stoneleigh Park, Kenilworth, Warwickshire, CV8 2TL, UK, Email: ian.crute@ahdb.org.uk

Introduction

The purpose of this paper is to stimulate discussion. This discussion is about the data requirements to ensure the *indefinite* maintenance of levels of agricultural production necessary to deliver, from within any prescribed boundary, both a good living for farmers and, at least, the proportion of nutrients (required to provide a healthy diet for a specified population) that is currently supplied. The prescribed boundary that has been selected is Great Britain (GB). Within this boundary, the majority of land is classified as agricultural but the population has been predominantly urban for over 100 years. The high natural geodiversity of GB is reflected in the diversity of its soils. This has resulted in a high level of "agri-diversity" when coupled with geographically variable weather patterns (particularly rainfall).

The sustainability of agricultural systems cannot be measured in years, or even decades, but only in terms of human generations. Unlike less favoured regions of the world, the farms of southern Britain have kept pace with the need to feed an ever-increasing population since the introduction of agriculture during the Neolithic period (at least 200 generations). The increases in production necessary have been founded on resilient soils, a benign climate, plentiful water and, critically, continuous innovation. However, the past is no predictor of the future. GB produces approximately 60% of its own food (when non-indigenous products are taken account of) and about 70% if non-indigenous products are excluded. A key question for GB (and others regions) to address is: will we still be able to meet the same proportion of the population's nutritional needs from within the region's boundaries even just 20 generations hence? Addressed only tangentially in this paper is: over the same time period, will we still be able to secure the same proportion of the population's nutritional needs that are currently sourced from outside the region's boundaries?

The answer to the first question above lies in understanding, and permanently securing, the attributes that enable agricultural systems to deliver what is demanded of them, not just season after season, but generation after generation. Such understanding can only be provided by long time-series of meaningful measurements and this poses several additional questions. Do we, and indeed can we, measure the right things, at the right scale for sufficiently long? Who should be responsible for the collection, organisation, curation, analysis and dissemination of such data? More informed decision-making is the common motivation for a diversity of different potential providers and users of data. However, the time-horizons and types of decisions that need to be taken differ greatly between, for example: farmers and growers; input and service suppliers; food manufacturers and retailers; government and its agencies; research funders and providers. Nevertheless, at scales from international/national, through regional and business level to individual farmer's fields there is a need for meaningful metrics that not only enable sound decision-making but also ensure well-founded assessment of the sustainability and resilience of production systems.

Realistically, there is only a relatively narrow time boundary within which individuals and organisations can appraise, plan and act. We can delve into the distant past and try to vision the distant future but it is probably only information relating to an 80–100 year "sliding window" on the immediate past and immediate future that will be both available to us and directly relevant to the decisions we need to make and choose to take. The "ingredients" for agricultural sustainability span the bio-physical (soils, topography, weather, nutrients, genetic resources, pests, pathogens etc.) and the cultural (policies, investment, trade, land tenure, skills, research, markets, innovation etc.). By way of illustration, since the 16th century, China has experienced 45 years of famine (most recently in 1961) in contrast to just 4 years in England (most recently in 1728). This past occurrence of famine is a retrospective indicator of agricultural sustainability regardless of whether the cause was due to bio-physical factors such as adverse weather and crop disease or socio-political factors such as land tenure and trade policies (or a combination of both). Attributing the cause of past catastrophic agricultural production failure may have some limited value but, in addition, some useful time-series of data derived from national statistics (FAOStat, 2016) and long-term field experiments (Leigh & Johnston, 1994) do exist. Such time-series provide insights into the sources of spatial and temporal variation in agricultural production. However, their ability to inform prospective production system sustainability has been limited.

Materials and Methods

All data referred to below derives from Defra (2015) and FAOStat (2016).

Results and Discussion

I define agricultural sustainability throughout the period from generation g_0 to g_n by the equation: [AO g_n - RO g_n] ≅ [AO g_0 - RO g_0] ≅ 0 (where AO = actual output and RO = required output). This equation emphasises that stability and predictability of output (i.e. resilience) are as important as magnitude. The value of AO at time t is provided by the equation: $AO_t = LA_t(f\ G_t \times E_t)$ where LA is the land area deployed. Yield and environmental impact are a function of the interaction between the potential of the genotype deployed (G) and two environmental components: E_O and E_L (respectively - management to achieve genetic potential and management to minimise loss through waste). Balancing RO and AO by removing or increasing LA is not an option compatible with sustainability. The latter can only be achieved by modification of G × E where E embraces E_I (environmental impact). However there are some important constraints:

- Components of E_O utilise non-renewable resources (e.g. fossil fuel) or influence E_I (e.g. GHG emissions);
- Climate change, influencing weather impacts on E_O and E_I;
- Evolution is a potent force impacting on G (e.g. pathogen virulence);

Management practices aimed at optimisation of E_O, E_L and E_I interact and "win-wins" are rare so it is necessary to quantify trade-offs.

Analysis of recent production data indicates that LA devoted to crops in GB would need to increase by about 730KHa (12%) to meet an increase in RO of arable and horticultural crop products by 2050 if this is proportionate to a projected population increase of 20%. This rather simplistic analysis assumes, unrealistically, that there is no increase or decrease in current yields and neither is there any change in availability or affordability of imported products. Important information for sustainable systems will have to be the establishment of realistic targets for AO, E_L and E_I. Such targets must be based on product (and nutrient-specific) models that are founded on realistic spatial and temporal quantification of genetic potential (G) and its achievement through system optimisation (E_O) and resource use efficiency (E_L and E_I). There is also a requirement for metrics that enable meaningful comparisons (benchmarking) over time (measurement of progress) between the efficiency of production systems and/or products and/or enterprises and/or businesses to deliver RO in terms of macro-nutrients for the GB population.

Preliminary analyses have led me to conclude that an Efficiency Ratio (ER) that quantifies the ratio between readily measurable agricultural output and environmental impact best defines system sustainability. More work will be required on the statistical properties of a range of possible ERs but I particularly favour an output numerator of "person-years of macro-nutrient requirement" (PYN) produced per hectare and an environmental impact denominator of KgN + m^3 extracted H_2O per hectare. This enables comparisons between different crops that are irrigated or rain-fed and grown to produce one or more macro-nutrients (oils, starch, sugar or protein).

Conclusions

Information for sustainable agricultural systems is required at national and regional levels. Specifically, there is a requirement for spatial and temporal quantification of RO, AO, E_L and E_I as defined above. In addition, information is required at the level of business and field operation. Specifically, this is a requirement for development of a readily measurable ER that takes account of local edaphic and climatic factors but enables the identification of opportunities for improvement through modification of G × E as defined above.

Acknowledgements

I am grateful to Simon Oxley for provision of of data from UK Recommended List wheat trials.

References

Defra.: 2015. *Agriculture in the United Kingdom 2014.* 99 pp.

FAOStat.: 2016. http://faostat3.fao.org

Leigh R.A. – Johnston,A.E. (Eds): 1994. *Long-tem experiments in agricultural and ecological sciences.* Wallingford, UK: CAB International. 428 pp.