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Agriculture in Transformation

Proceedings of the PSC Summer Schools 2014 and 2016

Zurich-Basel Plant Science Center
Melanie Paschke (ed.)

Concepts for agriculture production systems that are socially fair environmentally safe and economically viable

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edited by Melanie Paschke

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Zurich-Basel Plant Science Center
ETH Zurich
Tannenstrasse 1
8092 Zurich

www.plantsciences.ch

Editor
Melanie Paschke

With contributions of
Philipp Aerni, Gurbir Bhullar, Allan Buckwell, Markus Frank, Marcel van der Heijden, Hans Herren, John Ingram, François Meienberg, Michael Meissle, Melanie Paschke, Martin Schmid, Franziska Stössel, Raphael Wittmer and Gunda Züllich

PSC Summer School participants
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Proofreading and co-editing
Manuela Dahinden, Anett Hofmann, Karina Oborune, Carole Rapo and Liselotte Selter

Layout
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Preface

Future demand in agricultural output is supposed to match the needs of 9 billion people with less input of resources. Can we transform our agricultural practices and move behind existing paradigms to develop innovative and sustainable agriculture production systems?

A transformation of the regime is needed: a change in the socio-economic system through new narratives and diversification. Not driven by monopolising technologies but supported by innovation, knowledge and careful evaluation of sustainable technologies and farming practices.

What could be possible trajectories towards a sustainable agriculture and food system?

The Zurich-Basel Plant Science Center explored new concepts for sustainable agriculture and food security in its consecutive summer schools:
«Emerging Technologies» in 2014, and
«Concepts for an Agriculture that is Sustainable in all Three Dimensions of Sustainability» in2016.

These proceedings bring together the voices and contribution of internationally renowned speakers and case studies and fact sheets elaborated by participants of the summer schools.

Enjoy the proceedings!

Melanie Paschke
Zurich-Basel Plant Science Center

Agriculture in transformation: How perspectives on productivity and sufficiency shape debate and solutions?

Melanie Paschke

Agriculture is feeding 6.7 billion people worldwide. This incredible high number is one of the achievements of the green revolution. Through high-yielding crop varieties agricultural production tripled, however, also the use of fertilizers increased: external N flows also doubled and P flows tripled in terrestrial ecosystems (Tomich et al., 2011). Expectations that the world population will increase to 9.1 billion people in 2050 resulted in the call of raising overall food production by some 70% between 2007 and 2050 on the existing arable land (FAO, 2009).

Conventional and agro-industrial production, with its high productivity based on external inputs, is one of the major drivers of problems that risk our livelihood in the future. For example, agriculture in the European Union (EU) contributes to 10% of the total increase in 2011 worldwide CO_2 budget through the use of fertilizers (EU, 2013). Worldwide, agricultural production uses 70% of total available global water from rivers and aquifers (Beddington et al., 2012) and seriously threatens biodiversity.

Mankind has moved from an era of unlimited resources for agricultural production to scarcity of natural resources (land, water, nutrients, energy) and increasing environmental costs (related to the loss of biodiversity and climate change) that are accelerated by political, social, institutional and economic obstacles. Tipping points could be easily reached and many planetary boundaries are overstepped (Steffen et al., 2015). The high productivity of conventional agriculture will strongly decrease under predicted scarcity of external resources, environmental limits and climate change. Agriculture is vulnerable to the changes it drives. Fast adaption, for example, to climate change is necessary (Challinor et al., 2014; IPCC, 2014). We need to change agricultural production. Ecological sustainability must be our first and foremost objective.

The sustainability concept

The Brundtland report (WCED, 1987) suggested three main pillars of sustainable development: economic growth, environmental protection and social equality with emphasizing that all three pillars are interconnected and weighted equally (Ott, 2009). Suggested by Ang and van Passel (2012), the strong sustainability model has the ecological system («environmentally safe») as the fundament for the functioning of the social («socially fair») and economic («economically viable») sub-systems. While the link between food security and the demand to produce more with less resource and less environmental impact has been intensively discussed, we are still debating how sustainable agriculture can be successfully implemented.

Two conceptual frameworks: sustainable intensification and ecological intensification

Sustainable intensification serves as an overall term to describe efforts and approaches to increase yields of arable crop plants on the existing farmland with far less environmental impact and less external resources (e.g., fertilizers, pesticides and water) through the use of technologies, more resource-efficient crop varieties and increased quality of yields for human nutrition (e.g., through bio-fortification or orphan crop breeding) (FAO, 2009; Garnett, 2013; Pretty, 2013; Tomich et al., 2011).

Precision agriculture is one example of new technologies for sustainable intensification. It is optimizing rates of fertilizers, seeds and chemicals for the specific soil at a specific field and time by combining site-specific knowledge gained from sensors, satellites and big data management with site management for more resource efficiency. Precision farming can contribute to long-term sustainability of agricultural production by reduced chemical loading of fertilizers and pesticides in the soil and by reducing N applications (Bongiovanni & Lowenberg-Deboer, 2004). Field studies in which sensor-based N management systems were compared with common on-farm practices showed high increases in the N use efficiency (+368%), saved N fertilizers (10%–80% less N), and reduced residual N in the soil (30–50% less N), without reducing yields or grain quality (Diacono et al., 2012). Agriculture in general needs direct (fuels and electricity) and indirect energy input (fertilizer and pesticides), with the proportion of indirect energy being higher in conventional farming than direct energy (Beckman et al., 2013). Precision farming is thought to reduce the need for indirect energy by increased efficiency. However, the need for smart machinery, operating systems, server systems, and data storage might result in additional direct and indirect inputs to be carefully monitored for their sustainability.

Another course of practice comes with the term ecological intensification. Ecological intensification is defined as a set of farming practices that are based on internal inputs (e.g., organic fertilizer) and ecological processes (e.g., for provision and regeneration of soil fertility), such as multiple ecosystem services

(e.g., provision of food, water supply, pollination or pest control) and knowledge-driven systems (e.g., build on diversified crop rotations or intercropping systems) (Tomich et al., 2011, Wezel et al., 2014). How ecological intensification with low input can be achieved, needs also to be assessed case-by-case.

Two perspectives on productivity and sufficiency

With the two perspectives or narratives the different approaches for a sustainable agriculture can be explored for the underlying worldviews, norms and values. As the report of the Standing Committee on Agricultural Research (SCAR) (European Commission, 2011) states, the productivity perspective is the dominant one but challenged by the sufficiency perspective. In the following part the two narratives will be introduced to show exemplary how different argumentation and evidence arises from these. Examples will be: the different interpretation of the yield gap, combating chronic hunger and considerations about the food system approach.

The productivity narrative

To overcome the gap between agricultural production and the increasing demand of a growing world population the potential of science and innovation has to be developed with new crop varieties, breeds and technologies that produce high yields and are resource-extensive.

There are several assumptions linked to this narrative:

- Economic growth will continue to generate the necessary funding for massive investment in research and development.
- Removal of barriers such as trade barriers, regulation and access to markets will ease the adoption of the technologies through the farmers.
- The scale for the implementation needs to be global.
- Limited resources, environmental pollution as well as social inequalities could be overcome by more productivity and linked gains in economic return as well as through new technologies.
- Social impact of the new technologies and their global implementation are underestimated as well as long-term costs.

The sufficiency narrative

The sufficiency narrative points out that there are limits in growth due to our planetary boundaries and finite resources. Reducing demand through behavioral changes, knowledge-intensive agroecological innovation and changes in the food system will feed the world population in 2050.

Assumptions of this narrative are:

- The transition can start endogenous driven by human's changing behavior followed by contracts and policies.
- Innovation and knowledge about processes in the agroecosystem increase productivity.
- Resources for agricultural production as an endogenous component of the system and being renewable should be used.
- Regional short supply chains closely link productivity and demand, thus reducing wastefulness.
- Source of resilience is the diversity within the food system, of agroecological practices and of food patterns.

EXAMPLE 1

HOW ARE YIELD GAPS INTERPRETED UNDER THE TWO PERSPECTIVES?

Challenge

Organic farming systems have been found to have 20% lower crop yields compared to the conventional farming systems in a 21-year study in Central Europe (Maeder et al., 2002). Recent meta-studies have reported that multi-cropping and crop rotations substantially reduce the yield gap to below 10%, when the methods were applied in only organic systems. Thus, diversification in management practices can reduce the yield gap between organic and conventional production (Ponisio et al., 2014).

Under the productivity perspective

Critics of ecological intensification argue that currently lower productivity in organic farming systems will increase the demand for arable land, therefore, increasing the pressure on the environment. Voices arguing for ecological intensification emphasize the sharing perspective on arable land: under agroecological use, arable land could produce and as well offer multiple ecosystem services without compromising yield (Garnett, 2013).

Under the sufficiency perspective

The need for 70% higher yields in overall agricultural production to satisfy future demands of the global population is debated. If under the premises of demand restraint the expected increase in meat consumption due to changing dietary habits could be restricted this will have direct and large impact on agricultural production.

According to FAO (2009), meat production would have to grow by over 200 million tones to a total of 470 million tones to reach the 2050 food demands. Especially, the higher demand of meat is coming with an immense need for additional area, for example for 1 kg of pig meat: 9–12 m^2 for chicken meat: 8–10 m^2 and for beef meat: 27–49 m^2, while the area to produce 1 kg of wheat is only 4 m^2 (von Witzke et al., 2011).

EXAMPLE 2

DIFFERENT SOLUTIONS FOR COMBATING HUNGER

Challenge

Chronic hunger, reality still for some 795 million people in the world has been on the rise again in the last decade as a result of economic crisis and food price inflation but not of food scarcity (FAO, 2015). 2 billion people suffer from one or more micronutrient deficiencies and 1.4 billion people are overweight (FAO, 2013).

Under the productivity perspective

Policies suggested by the FAO (2013) to build a food system for better nutrition include sustainable intensification of yields, biotechnical approaches to increase nutrients (e.g., bio-fortification of food) and technical improvements in the (global) food supply chain (e.g., for nutrient-preserving processing, packaging, transport and storage). Changes are steered by global governance (taxes, regulations and labels), economic and public investment in research and development, as well as education of consumers to allow them to make more healthy choices. Economic and social developments lead to the gradual transformation of agriculture with less smallholders and subsistence farmers and declining shares of population working in agriculture while urbanization rises. This in turn will drive the demand for better nutrition.

Under the sufficiency perspective

Ecological intensification enables small-scale farmers to make a livelihood from their land. As ecological intensification is knowledge intensive rather than capital intensive it enables small farms with diversified production to maintain their economic viability. Ecological intensification emphasizes the ability of local communities to scale up innovation in successful and economic viable farming practices. However, it needs a strong political will to create an enabling environment (Holt-Gimenez & Altieri, 2013). Land tenure to make a livelihood on the land is a key issue and can be supported by egalitarian (democratic, participative) structures as well as by political governance. With a focus on regional production and consumption chains, ecological intensification is not neglecting the importance of well-functioning markets but it is in favor of short supply chains (for example, linking local producers with local consumers and retailers in a timely manner using the new information technologies) and increases the income and economic viability of small-scale farmers.

EXAMPLE 3

THE FOOD SYSTEM APPROACH

Challenge

The concept «food system» is a multilevel approach that starts at production (up to the farm gate) to the post-harvest supply chain (from the farm gate to the retailer) and spans to the consumers through dietary choices. The food system includes all processes and infrastructure involved in feeding a population in a certain region with the global food system composed of many regional food systems. The food system integrates several dimensions: (1) the policy environment and connected development priorities, (2) the economic, social, cultural and physical environment, (3) outcomes that affect or are affected by health and food safety, (4) education, gender roles, sanitation and infrastructure; and (5) the intended environmental sustainability.

It includes many factors that are determining the global food security situation: for example, constraints on dietary choice and diversity influenced by the set of activities in the food chain that determine the final food quantity and quality and the price to consumers. They can feedback to the food security as well as to the health of the consumers (Ingram, 2015). Under the two perspectives of productivity or sufficiency actions within the food system will be differently approached.

Under the productivity perspective

Food quality could be modified with technologies at the production level, for example, through crop varieties with increased nutrient content or increased qualities of crops for better food processing and storage (Ingram, 2015). Food waste at later levels of the supply chain could be mitigated through improvements of efficiency in technologies for processing and storage.

Under the sufficiency perspective

Food quality could be improved through ecological intensification. For example, increased food quality has been linked to organic farming: organic dairy products contain significantly higher omega-3 to omega-6 ratio than the conventional types (Palupi et al., 2012). Higher antioxidant and lower cadmium concentrations and lower incidence of pesticide residues were found in organically grown crops (Barański et al., 2014). Thus, ecological intensification could counteract the trend of consuming more calories with fewer nutrients content. This could feedback on calorie demands and might stabilize the need for higher yields in our main staple crops as well as lead to diversification of the food system. Further, sufficient calorie and nutrient intake by consumers depends on constraints that cannot be solved by productivity only, but are dependent on availability, access and distribution of nutritious food for all. For avoiding food waste major transformations could be done through short food supply chains with less retailers and shorter delays between production and consumption.

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I: Sustainability at the production level

How could we transform our agricultural production to become more sustainable? Environmental sustainability on the farm needs to integrate innovative farming practices with new technologies and knowledge systems. Chapter I brings together some of the current concepts and the research at the farm level.

Hans Herren
Millennium Institute, Washington, USA

The agroecology approach for a holistic transformation

Gurbir Bhullar
Research Institute of Organic Agriculture, Frick, Switzerland

Contribution of organic agriculture to sustainable development in the tropics

Michael Meissle
Agroscope, Zurich, Switzerland

Genetically engineered plants and integrated production

Marcel van der Heijden and Raphaël Wittwer
Agroscope, Zurich, Switzerland

A comparison of Swiss arable cropping systems: an agronomic, environmental and ecological evaluation

The agroecology approach for a holistic transformation

Hans Herren

Sustainable agriculture and food systems: the challenges

From the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD) report commissioned by six UN agencies and the World Bank (2009), it was clear that agriculture and food systems need a radical transformation to address the challenges ahead, from increased demand to climate change. In particular, the issues that the 400 authors of the global and five regional reports did highlight, covered the need to address agriculture and food system in all three dimensions of sustainable development: environment, society and economy. The main message was that «Business as Usual (BAU) is not an option». BAU in this context means both the green revolution / industrial high input agriculture and the traditional agriculture, none of these having the characteristics needed to satisfy the sustainability goals. What is wrong with our current food system? The push for more efficiency at the cost of resilience results in tremendous losses or risks for soil, biodiversity, and ecosystem services and in the accelerated speed of climate change. For example, between 47% to 52% of all greenhouse gas emissions come from the global industrialized food system: 15–18% from deforestation for agricultural production, 11–15% from farming, 5–6% from transport, 8–10% from processing and packaging, 2%–4% from freezing and retail and 3-4% from waste (Grain, 2014). We should be well aware that we have overstepped some of the planetary boundaries for nitrogen, phosphorus and the integrity of the biosphere (land degradation, loss of biodiversity) and for others, as climate change or land-system changes we are fast approaching the limits (Steffen et al., 2015).

Can we overcome the challenges? How, When, Who?

The IAASTD report (2009) recommended that new policies should be in support of agroecological and regenerative types of agriculture, with an emphasis being given to a systemic and holistic approach to the food system.

The report also stated that we need a fundamental shift in the agricultural knowledge that science and technology produces. Agri-food system policies with financial investment in institutions may guide the capacity development from farmers to decision makers, given that agroecology is complex and knowledge intensive. It also stated the need to transition the current agricultural systems (industrial, conventional and traditional) to agroecological systems. Finally, it recommended a two-fold paradigm change: the transition to a sustainable, ecological and regenerative agriculture that is addressing the multi-functionality and resilience needs of small-scale and family farmers and the adoption of a systemic and holistic approach.

What is a holistic system in agriculture?

According to IIED (Silici, 2014), agroecology – the application of ecological concepts and principles to the design and management of sustainable agro-ecosystems – has three facets. These are:

- a scientific discipline involving the holistic study of agro-ecosystems, including human and environmental elements;
- a set of principles and practices to enhance the resilience and ecological, socio-economic and cultural sustainability of farming systems; and
- a movement seeking a new way of considering agriculture and its relationships with society.

Agroecology makes sustainable use of the interactions between plants, animals, humans and the environment within agricultural systems. It relies on key ecosystem services (e.g., pollination, natural pest control, nutrient and water cycling) for production (UNEP, 2011; Gliessman, 2006).

For both systems-industrial agriculture and subsistence agriculture – a transformation to diversified agroecological farming is necessary through different pathways.

For subsistence farming the transformation can be reached through appropriate mechanization of agriculture to free human labour. The transition path should include the building of knowledge on agroecological farming (education, skill development and access to relevant and practical information), on the use of innovative practices generated through this knowledge and on the diversification of crops and farming practices to increase environmental and economic resilience and the access of the producers and their products to markets. For industrial agriculture the transformation can be done through building knowledge about the production system and not only the production of a crop, which should result in reduction of chemical inputs through taking advantage of the ecological services of the system, through diversification of crops and farm management practices to increase environmental and economic resilience (IAASTD, 2009).

Ecosystem services for productive agroecosystems

Recent evidence has shown that productivity of agroecological systems can be equal or overshooting the outcomes of the conventional systems (Badgley et al., 2007): In developed

countries it can be nearly doubled (180%) in the agroecological systems compared to the conventional systems (100%) in the same environment. In industrialized countries the productivity gaps are becoming closer and tolerable: 92% in agroecological systems vs. 100% in industrialized systems. Other evidence is supporting these numbers of a nearly closed productivity gap between agroecological farming and conventional agriculture (Holt-Giménez et al., 2012, Moore, 2016).

Agroecology and climate change

Just adopting renewable energy and stopping emission will not stop climate change: The world reached 400 ppm CO_2 in 2016 (Kahn 2016) which means that the 2 degree threshold of the Paris agreement has been reached. An on average 2 degree warming will translate into 3.5 to 5 degrees warming on a regional level (IPCC, 2014). We should aim to remain at and better under, 350 ppm of CO_2, a goal that looks out of reach now, but if we were to use agroecology's potential to sequester CO_2, we would be able to manage.

Soil is the second biggest reservoir of carbon on the planet, next to the oceans. But human activity like deforestation and industrial farming – with its intensive ploughing, monoculture and heavy use of chemical fertilizers and pesticides – is ruining our soils at breakneck speed, killing the organic materials that they contain. Now 40% of agricultural soil is classed as «degraded» or «seriously degraded». In fact, industrial farming has so damaged our soils that a third of the world's farmland has been destroyed in the past four decades (Gibbs & Salmon, 2014). As our soils degrade, they are losing their ability to hold carbon, releasing enormous plumes of CO_2 into the atmosphere.

There is a solution. Scientists and farmers around the world are pointing out that we can regenerate degraded soils by switching from intensive industrial farming to more ecological methods – not just organic fertilizers, but also no-tillage, composting, and crop rotation. Here's the brilliant part: as the soils recover, they not only regain their capacity to hold CO_2. They begin to actively pull additional CO_2 out of the atmosphere (Friedlander, 2015; Codur et al., 2017).

Recent studies showed rates between 3% (Gattinger et al., 2013) to 40% (Cohen, 2016) for regenerative farming in sequestering global carbon emissions. Jason Hickel (2016) argues that if we apply regenerative techniques to the world's pastureland as well, we could capture more than 100% of global emissions. In other words, regenerative farming may be our best shot at actually cooling the planet.

Additionally regenerative farming can increase crop yields over the long term by enhancing soil fertility and improving resilience against drought and flooding. So as climate change makes farming more difficult, this may be our best bet for food security (Lal, 2014).

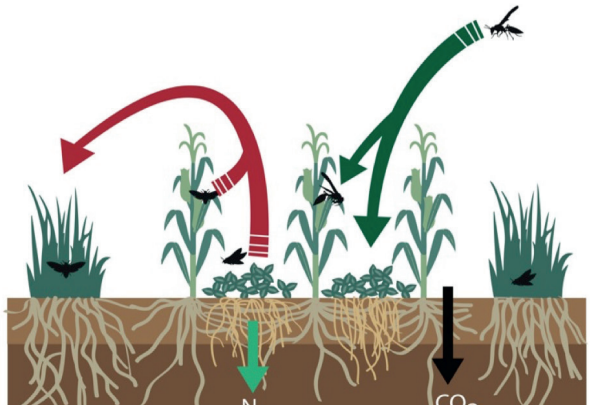

Figure 1. What is needed for the paradigm change? So(i)lutions (in green and black): Through the ecosystem services of fixing N and C into the soil the system can become self-regulated again. This can be combined with natural pest control (dark red and green).

The lock-ins of the current political economy

Why do we not see a major transition towards diversified agroecological systems, given the expanding evidence that they can deliver on all dimensions of sustainable food systems? The reasons are a number of roadblocks, or lock-ins, as were described in the IPES publication «From uniformity to diversity» (IPES, 2016). See Figure 2.

Could the transformation towards agroecology be done with decent investment?

UNEP (2011) was the first to show that a decent global investment of 0.2% of total GDP ($141 Billion/year) would result in a significant improvement in all underlying categories («green» scenario in table 1) compared to a «business as usual» (BAU) scenario. With predicted 2.524 calories for consumption per person and day in 2050 in the «green/agroecology» scenario the calories for consumption are increased compared to the «BAU» scenario. An average of 2.500 calories per day/person are sufficient for a healthy life, and so the switch to agroecology can satisfy the food security concerns voiced by many of its detractors. Also to be noted, that the total investment needed would be some 141 US$ Billion/year, roughly 1/3 of the global annual agricultural subsidies.

From our modeling work for the UNEP Green Economy, we can assert that implementing the IAASTD Report options for action, the world can enjoy food and nutrition security by 2050 and beyond.

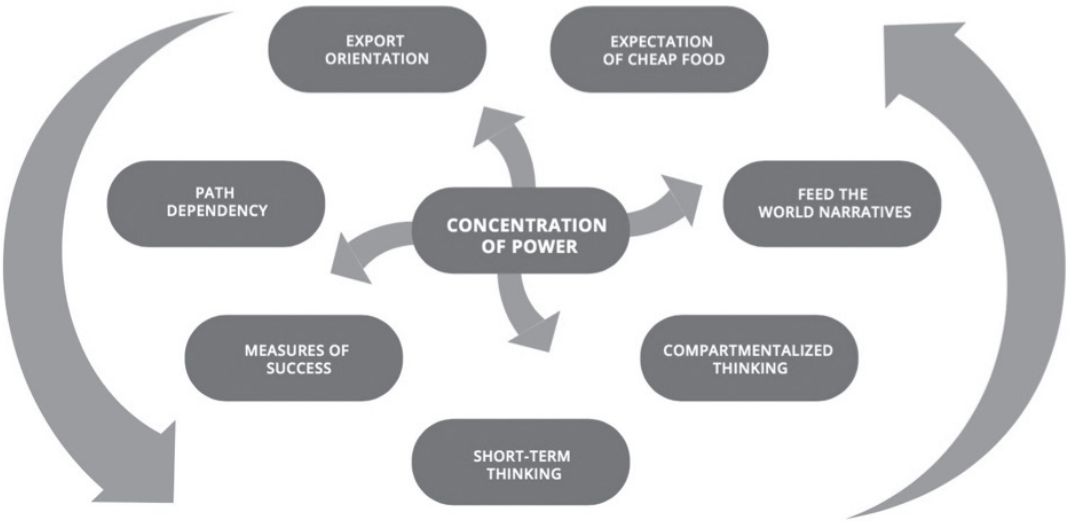

Figure 2. The political economy of food systems produces 8 lock-ins. Diagram is courtesy of: IPES, 2016, p. 45

INDICATOR	UNIT	BASELINE	GREEN	BAU
Agricultural production	Bn US$/year	1921	2582	2559
Crops	Bn US$/year	629	996	913
Employment	M people	1075	1703	1656
Soil quality	Dmnl	0.92	1.03	0.73
Water use	km^3/year	3389	3207	4878
Land	Bn ha	1.2	1.26	1.31
Deforestation	M ha/year	16	7	15
Calories for consumption	Kcal/person/day	2081	2524	2476

Table 1. Baseline scenario (this is the scenario in 2011), green scenario based on an investment of 0.2% of GBD, and business as usual (BAU) scenario (UNEP, 2011)

DISCUSSION

How can local and traditional farming systems cope with the issue of climate change and the possible introduction of new pests and pressures from the environment?
In his talk Prof. Herren pointed out that there are sufficient methods already present in today's organic agriculture to combat different plant pests. If the suggested natural protection system by nearby growing non-crop plants would still work after new disease migration due to climate change was subject of active discussion. The danger of overcoming the natural protection system by new locally arising pathogens due to changed climatic conditions was causing worries in the audience. Prof. Herren argued against it with an adaptation of the natural protection system as best solution.

Who must take the responsibility to induce the change needed to achieve the sustainable development goals?
The discussion concluded that it needs a less globalized system that concentrates on local foods, local knowledge and empowerment. There were arguments that distributing organizations like supermarkets must take the lead with their offers and reduce it to available and seasonal food. On the other hand, the opinion was represented that we should have our own choices to make, and with more education about how bad global food transport is for the environment, we would by ourselves stop to buy food that was brought from far away.

Markus C. Kolodziej and Alejandro Gimeno Sierra contributed to the reporting of the discussion

"«The transformation of the industrial/conventional food production, value adding and consumption system to one based on agroecological principles, is a must. We need to take care of the climate change problem, the self-destroying growing environmental degradation upon which agriculture depends, the human health time bomb and the social disruptions from food insecurity induced mass migration. From citizens to leaders, we all have to contribute to this transformation and there are many promising signs that the public, the youth in particular, is taking notice and starting voting with the wallet at the supermarket. The increasing demand for sustainably or organically produced food is a good sign, which has yet to be matched by an equal increase in the production. It will be important to reform our food system's institutions and subsidies policies, to support farmers by covering risks, providing R&D and introduce a full accounting pricing policy for both the positive and negative externalities. It's possible, it's needed and it will happen.»

Prof. HANS R. HERREN
Millennium Institute, USA

Hans Herren is a pioneer in the field of biological pest control and was the first Swiss to receive the World Food Price in 1995. He is the President and CEO of the Washington-based Millennium Institute and Co-Founder and President of the Swiss foundation Biovision. He is an outspoken proponent of agro-ecological farming systems, organic and other forms of sustainable agriculture.

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Contribution of organic agriculture to sustainable development in the tropics

Gurbir Bhullar

It is legitimate to question whether organic agriculture and other alternative farming practices can contribute to sustainable development as they are often based on an ideology. Studies conducted in Europe validated this hypothesis but few systematic studies were performed in the tropics. To address this, four long- term experiments were established in Kenya, India and Bolivia in 2006 to evaluate conventional and organic production systems. The systems are assessed regarding yield, product quality and storability, use and respect of environmental services, efficiency and economic viability. Along with this, each project site has a Participatory On-farm Research (POR) component to ensure that farmers' concerns were taken into account. Results from maize fields with high or low inputs in Kenya showed that conventional and organic systems were comparable in terms of yields. The high input organic system led to higher economic benefits after a few years as less inputs were required than for the conventional one and thanks to the contribution of the premium price. Also, high input organic systems improved soil fertility.

In Bolivia, five cocoa production systems were compared: monoculture-conventional and organic, agroforestry-conventional and organic, and successional agroforestry. The canopy openness was wider for the monoculture productions but there was no difference between organic or conventional systems. Conventional and organic agroforestry had very high productivity by producing various plant products and thus offered a better nutritional value. Moreover, farmers were less dependent on the weather conditions as they could rely on different cultivated species.

In India, cotton-based farming systems for which there is two years cotton-soybean-wheat crop rotation, are studied with four treatments: organic, biodynamic, conventional and conventional Bt-cotton. Organic cotton fields had lower yields but gross margins were comparable to the conventional production. Nonetheless, financial risks were lower compared to conventional agriculture, as the organic production system is less capital intensive. The project in India presents an excellent example of integration of research with sustainable agri-value chain. The farmers in the project area have contracts with a company that provides inputs and trainings to farmers as well as ensures that the organic cotton produced by the smallholders would be purchased and a premium price is offered. Organic and biodynamic systems produced the same yields as the conventional system for soybean production, slightly lower yields for cotton and significantly lower yields for wheat. Finally, biodynamic and organic fields had better soil organic carbon contents than the other fields. A study conducted on farmers' fields in the region showed that the grain zinc content was higher in organic wheat than conventionally produced wheat. In order to identify bottlenecks regarding organic cotton production in India, a survey was conducted among farmers. An interesting result was that for comparable yields, conventional farmers tend to oversupply their crops compared to organic farmers, resulting in a lower nutrient efficiency. Then, it appeared that premium prices are the main motivation for small and medium holding farmers to switch from conventional to organic agriculture, whereas contributing to healthy food production is the main motivation for farmers with large land holdings.

To conclude, the field trials established in FiBL's long-term farming systems comparison program (SysCom) demonstrate a successful cooperation between farmers, researchers and industry and contribute to finding solutions for a sustainable agriculture in the tropics.

DISCUSSION

What support for organic farmer pending the productive peak occurs?
There is currently no financial support available for organic farmers during these yield gap years, although most of them are aware of that and are able to overcome this drop in revenue. Some labels start to provide financial support but this is still very limited.

What are the part for exportation and the one for the local market?
It used to be 95 % for exportation and 5 % for local market, respectively. Now the trend seems to be more in favor of an increase of the local market's part.

Regarding these experiments, can we expect to have the same beneficial effects on a larger scale?
To scale-up these agricultural practices, it would be very important to consider availability of biomass to be used as manures. Green waste for instance offers a good opportunity: collect it from the vegetable markets, turn it into compost, bag it and sell it for people to use in their garden. Also, scaling-up would require additional labor force, which would not be an issue in the tropics as the population density is high. Improving mechanization would help as well, but it would come with additional costs.

How long do the trials last?
The trial carried out in Switzerland has now been running for nearly 40 years and the systems comparison trials in the tropics were initiated in 2006–07 with an idea of a 20-year period. Thanks to the sustained commitment of our donors, the project is now in its third phase – new funding needs to be secured every four years to maintain the trials.

Myriam Deshaies, Clémence Marchal and Ramal Cyrielle Ndougonna contributed to the reporting of the discussion

Dr. GURBIR BHULLAR

Research Institute of Organic Agriculture (FiBL), Switzerland

Gurbir Bhullar is a senior scientist at FiBL in Switzerland, where he is leading the «Long-term farming systems comparison in the Tropics-SysCom» program. His research focuses on development of sustainable farming practices, which are economically viable and practically adoptable. Engagement with important stakeholders using participatory on-farm research methods is of high importance in his research projects. In recognition of the innovativeness and research excellence in one of his projects, the Swiss Forum awarded Dr. Bhullar with the SFIAR Award 2014 for International Agricultural Research.

Genetically engineered plants and integrated production

Michael Meissle, Agroscope, Switzerland

Integrated production

During the green revolution in the 20th century, agricultural production, but also the use of chemical pesticides and fertilizers was increased dramatically (Aspelin, 2003). In addition to increased productivity, the sustainability of agricultural practices became increasingly important in the more recent years. This is for example reflected in the European Union's rules for the sustainable use of pesticides (Directive 2009/128/EC). The concept of Integrated Pest Management (IPM) as an important element of Integrated Production (IP) is an important attempt to comply with the principle pillars of sustainability, e.g., economic, social, and environmental sustainability. The International Organisation of Biological and Integrated Control (IOBC) has been a leading organization in the development of science based IPM and IP guidelines (Boller et al., 2004). The concept of IP is a systems approach making use of natural resources and an understanding of regulating mechanisms that can replace potentially harmful inputs while preserving and improving soil fertility, maintaining a diversified environment, and observing ethical and social criteria. The aim is to produce high-quality products in a sustainable way. In addition to the physical quality of the product itself, quality also comprises ecological, ethical, and socio-economic aspects (Boller et al., 2004). IPM is the careful selection and balance of preventive and responsive control measures. Preventive tactics include the use of natural resources, the optimization of farming practices, and the enhancement of natural enemies (Figure 1). When monitoring systems indicate that pest polulations reach economic threshold levels, responsive crop protection methods should focus on biological control agents, biotechnical methods, and physical measures. If pesticides are needed, selective pesticides with short persistence should be chosen (Boller et al., 2004).

Although some elements of IPM have been implemented in many agricultural systems worldwide, systems strictly fol-

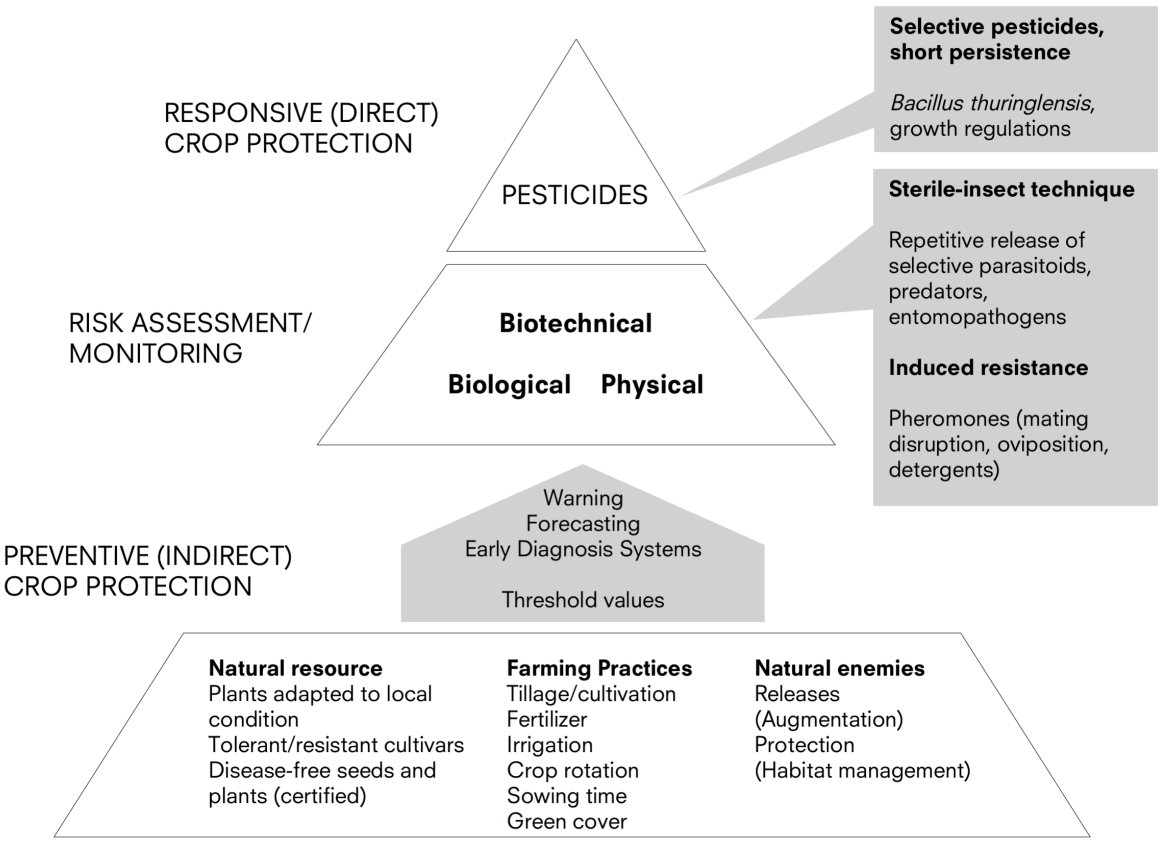

Figure 1. Principle of Integrated Pest Management. Adapted from Boller et al., 2004

lowing IPM principles are often limited to label production (e.g., organic) and scarce in conventional agriculture. Reasons include higher costs of IPM measures, lack of knowledge, and lack of efficient alternatives to chemical pesticides.

GE crops in integrated production

Genetically engineered (GE) crops have been grown on increasing areas worldwide since their commercial introduction in 1996 (James, 2015). The main traits of commercial GE plants are resistance against lepidopteran or coleopteran pests and tolerance to broad spectrum herbicides. To answer the question how a particular GE plant fits into an IP system, it is necessary to evaluate the plant carrying the novel trait(s) in the production system in which it will be introduced (Meissle, 2016).

Characteristics of the GE plant: Environmental risk assessment, as part of the regulatory approval process, ensures that GE plants are safe for the environment (EFSA, 2010). Regarding IPM, for example, insecticidal crops producing proteins from *Bacillus thuringiensis* (Bt) are highly resistant against specific target pests, while unrelated species remain unaffected. This trait thus fits well into the IPM concept, where resistant cultivars are part of the foundation of preventive crop protection measures (Meissle et al., 2011).

GE plants in the cropping system: As a system approach, the main dimension for IPM is the production system with the farm as the basic unit. New production systems should include sustainable solutions to existing problems without creating new problems. Therefore, production systems with GE crops should maintain management tactics in line with IPM principles and replace tactics problematic for IPM. Measures to ensure a long-term improvement of the system should be installed based on the identified risks. For example, less broad spectrum insecticides need to be applied when growing Bt crops (Coupe & Capel, 2016), which is beneficial to populations of natural enemies (Meissle et al., 2011). On the other hand, high selection pressure on target pests, which ultimately leads to the evolution of resistance, is the biggest threat to the durability of Bt crops. Countermeasures are the planting of non-Bt refuges and the pyramiding of several Bt toxins with different modes of action into one plant. The refuge strategy is successful when the plants express a high dose of toxin killing almost all target pest, when farmers comply with planting non-Bt refuge areas next to the Bt field, when target pests mate randomly between main crop and refuge, while larvae don't move between Bt and non-Bt plants, when resistance evolution is a rare event, and when resistance allelles are recessive. Pyramiding several toxins is only useful if no resistance to the individual toxins has evolved. When those prerequisites are met, resistance management can be successful, as demonstarted e.g., for Bt maize in Spain, or Bt cotton in Australia. However, resistance to Bt crops has evolved, eg. in corn rootworm in the USA, in African corn borers in South Africa, and in Lepidopteran pests in India. In those cases, the grown Bt crops did not produce a high toxin dose for the respective pests and the refuge requirements were often not implemented.

Socioeconomic context

An economically profitable and environmentally sustainable use of GE crops is only possible when all stakeholders see a benefit in growing, processing, and marketing them. Incentives for improvement of current production systems (with or without GE crops) can be provided by different stakeholders. Governments can impose regulation, subsidies, and ecological compensation schemes, and funding of training and research. Label organizations can market environmentally friendly and socially acceptable premium products. Growers can explore new crops, new production systems, and new markets, and grower associations can offer training and funding of research and can require implementation of IPM for their members. Finally, the seed and pesticide industry can contribute with product stewardship programmes. In the context of Bt crops, the Australian cotton system is a good example how the different stakeholders work together to implement the best possible system for both growers and the environment (Deutscher et al., 2005).

Conclusions and perspective

Several examples show that certain GE crops (e.g., Bt crops) fit well into the IPM concept and have contributed to the reduction of chemical pesticides in reality (Coupe & Capel, 2016). However, each particular GE crop in a particular production system is an individual case. In addition, the wider economic and societal context involving all stakeholders needs to be taken into account to predict if a GE crop could improve agricultural production of certain crops in a sustainable, e.g., environmentally friendly, economically viable, and socially acceptable way. With the knowledge that the earth's resources are over-exploited and the experience gained with chemical plant protection measures during the green revolution, increased efforts towards sustainability of agricultural systems are warranted. Commitment for sustainability is necessary from all stakeholders, including governments, production chain, retailers, and consumers with clear incentives to transform purely profit-oriented agricultural systems towards more sustainabile production systems. Such efforts are visible on a political level, e.g., in the sustainable development goals of the United Nations (UN, 2016), in the EU regulation on the sustainable use of pesticides (Directive 2009/128/EC), and in the Swiss system of minimal standards for ecological performance (Direktzahlungsverordnung), which are the basis for direct subsidy payments. The need for improved sustainability, integrated pest management, and longer durability of novel agricultural products is also on the agenda of the major seed and agrochemical companies. And finally, consumers have increasingly the possibility to buy label products with improved ecological and social responsibility, and the market for those products grows. However, the road to sustainability of conventional agricultural production on a global level will still be long.

«Government, farmers, agro-business and consumers need to incentivize the implementation of IP and have an open attitude towards new technologies, while ensuring that sustainability principles are followed.»

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Dr. MICHAEL MEISSLE
Agroscope, Switzerland

Michael Meissle is the deputy leader of the Biosafety research group at the Swiss Federal Research Institute, Agroscope. His research is focused on risks and benefits of genetically modified (GM) plants. He studied biology in Munich and conducted scientific researches throughout the world, including Germany, Switzerland, the UK and Australia.

A comparison of Swiss arable cropping systems: an agronomic, environmental and ecological evaluation

Marcel van der Heijden and Raphaël Wittwer

Sustainable arable cropping systems

One of the primary challenges of our time is to develop sustainable farming systems that can feed the world with minimal environmental impacts. Although the green revolution and the intensification of cropping systems have led to high productivity, it has a negative impact on the environment by decreasing biodiversity, causing pollution and eutrophication of water, and degrading soil quality (Stoate et al., 2001).

To mitigate this trend, ecological intensification has been proposed. Ecological intensification is defined as the environmentally friendly replacement of anthropogenic inputs and/or enhancement of crop productivity (Bender et al., 2016, Bommarco et al., 2013). Ideally, a sustainable system will have the right balance between external inputs (e.g., fertilization, pesticide application, energy use) and ecosystem service delivery (e.g., support of plant productivity, disease suppression, soil structure) to keep a high productivity but increase internal regulatory processes and resilience of the system (Bender et al., 2016) (Figure 1). This could be achieved by including agricultural practices that promote regulating and supporting ecosystem services, such as organic farming or conservation agriculture combined with ecological management practices such as improved crop rotation and the use of cover crops. Organic agriculture is defined as having no synthetic inputs (no synthetic pesticides, no mineral fertilizers), and it emphasizes rotating crops, managing pests naturally, diversifying crops and livestock, and improving the soil with compost additions and animal and green manures rotation of crops (Reganold & Wachter, 2016). Conservation agriculture represents a set of three crop management principles: (1) direct planting of crops with minimum soil disturbance (that is, no-till), (2) permanent soil cover by crop residues or cover crops, and (3) crop rotation (Pittelkow et al., 2015).

Some studies argue that organic farming systems are best because they have minimal impact on the environment and are positive for biodiversity (Mäder et al., 2002). Others argue that conservation agriculture (CA) systems are better because they save energy and preserve soil structure and quality (Hobbs et al., 2008). Despite clear ecological benefits, organic yields (Ponisio et al., 2015) and yields under conservation agriculture (Pittelkow et al., 2015) are often below yields in conventional systems. This yield gap can reduce the positive environmental footprint of organic farming and CA compared to conventional farming because more land is needed to produce the same

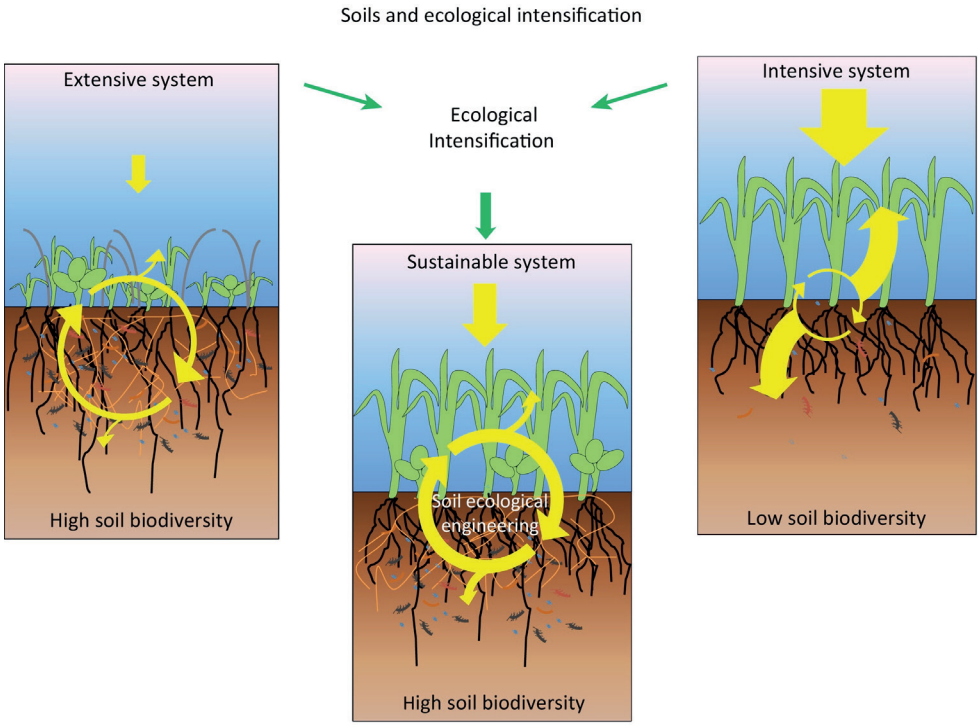

Figure 1. Ecological intensification ideally combines traits of intensive and extensive systems and leads to a sustainable system that has a rich soil life and is characterized by moderate resource inputs, a high rate of internal regulatory processes, low nutrient losses, and high productivity (Source: Bender et al., 2016; reprinted with permission, Trends in Ecology & Evolution, Elsevier).

amount of food. Thus, a third group argues that conventional farming systems are best because yield per hectare is highest.

However, so far, systematic comparisons of major arable cropping systems are rare and often it is difficult to compare the advantages and disadvantages of farming systems in a systematic way due to differences in soil/site characteristics and management.

Farming system and tillage experiment Agroscope

Here we present first data of the Swiss Farming Systems and Tillage Experiment (FAST), a long-term experiment where important European arable cropping systems (organic and conventional cropping system) with either intensive tillage (plough) or reduced tillage/no tillage are being compared using a factorial replicated design (Wittwer et al., 2017; Figure 2). The main aim of this experiment is to assess the impact of various arable cropping systems and specific management practices (the use of different cover crops) on productivity and the environment by evaluating, providing, regulating and supporting ecosystem services. A multidisciplinary team of researchers from various disciplines and organizations are involved in this experiment. So far, we collected data on productivity, life cycle analysis, global warming potential, soil quality, soil organisms, plant root microbiomes and above and below ground biodiversity.

First results show that integrating cover crops, as ecological management practice, can support ecological intensification of arable cropping systems by increasing overall productivity. But, the positive effects of cover crops were highest in organic cropping systems and decreased with higher land use intensity (Figure 3). Thus, our results show that cover crops are essential to maintaining a certain yield level when soil tillage intensity is reduced (e.g., conservation agriculture with no or minimum tillage), or when production is converted to organic agriculture and that the positive effects are best acknowledged when management intensity, also within conventional systems, is reduced (Wittwer et al., 2017).

Although the no tillage system (approximately -6% yield in average) and organic systems (approximately -25% yield in average) still have reduced productivity, they already present soil ecological benefits after one crop rotation. Soil erosion risk was lowest in the absence of tillage and in organic cropping systems (Seitz et al., in preparation). A life cycle assessment of the experiment further showed that organic systems have generally a lower global warming potential per area and that improving the N-efficiency is a crucial leverage-point to improve the environmental performance of arable farming systems (Prechsl et al., 2017).

Conclusions and perspective

Overall, our results indicate that no single cropping system performs best for all ecosystem services provided by agricultural production. However, we could demonstrate that ecological management practices that promote regulating and supporting ecosystem services can reduce this yield gap. Moreover, the long-term impact of preserved/increased soil quality and the resilience of the systems in a context of climate change still have to be

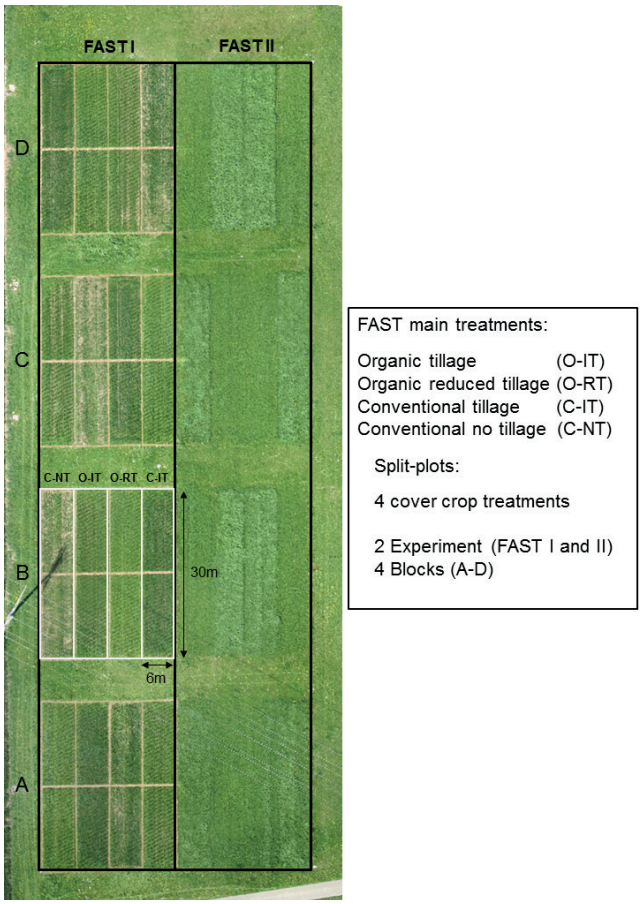

Figure 2. Aerial picture of the FAST experiment at Agroscope (Zurich, Switzerland). Left: FAST I (winter wheat crop) and right: FAST II (grass-clover). The four white boxes reflect four main treatments in FAST I. The four replicates/blocks are separate from each other by grassland strips. The four cover crop treatments (within a main treatment as split plot) are not shown.

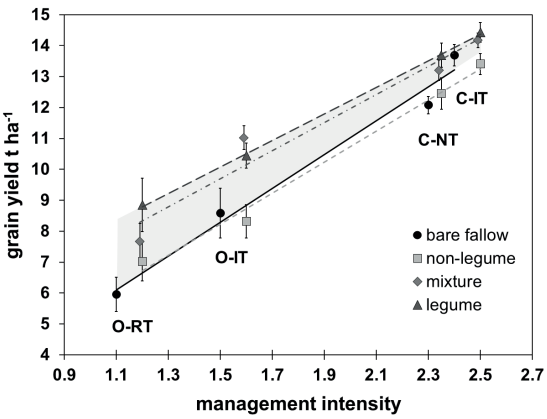

Figure 3. Grain yield (sum of wheat and maize) as a function of management intensity (cropping system) and cover crop treatments (Mean ± standard errors, n=8). Management intensity is derived from energy use, N fertilization and pesticide application. The grey area shows the potential of cover crops for ecological intensification for each of the four cropping systems as a function of decreasing management intensity (Wittwer et al., 2017). (C-IT: conventional intensive tillage, C-NT: conventional no tillage, O-IT: organic intensive tillage, O-RT: organic reduced tillage).

evaluated. Thus, long-term field experiments are precious and will play an important role, together with the many innovative farmers, in designing more sustainable cropping systems. Lastly, the choice of the «best» cropping system depends largely on economic, ecological and environmental priorities and involves exchange and discussion among producers, industry, politics and consumers.

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Prof. MARCEL VAN DER HEIJDEN

Agroscope, Switzerland

Marcel van der Heijden heads the Plant-Soil Interactions research group at the Swiss Federal Research Institute Agroscope and he is professor in Mycorrhizal Ecology at Utrecht University and guest professor at the Department of Evolutionary Biology and Environmental Sciences, University of Zurich. He obtained his PhD in 1999 at the Botanical Institute at the University of Basel studying the impact of mycorrhizal fungal diversity on plant diversity, nutrient cycling and ecosystem functioning. His current work focuses on the relationship between soil biodiversity and ecosystem services, beneficial plant symbionts (arbuscular mycorrhizal fungi), nutrient cycling and the development of sustainable farming systems.

RAPHAËL WITTWER

Agroscope, Switzerland

Raphaël Wittwer is the deputy leader of the Plant-Soil Interactions research group at Agroscope. His work focuses on the impact of cropping systems and field management practices on ecosystem services. He studied agricultural science at the ETH Zurich and he is currently absolving a PhD at the University of Zurich beside his position as project leader at Agroscope.

II: Sustainability from the farm gate to the consumer

The concept «food system» is a multilevel approach that starts at production (up to the farm gate) to the post-harvest supply chain (from the farm gate to the retailer) and spans to the consumers through for example dietary choices. Chapter 2 explains the concept of the food system in more detail with contributions on different methods and practices to assess and monitor the sustainability throughout the value chain. The emphasis of the assessment approaches and tools is on environmental sustainability.

John Ingram
University of Oxford, UK

Towards a resource-smart food system

Gurbir Bhullar
Research Institute of Organic Agriculture, Frick, Switzerland

Consumer choices for sustainable produce could transform production systems

Franziska Stössel
Institute for Environmental Engineering, ETH Zurich, Switzerland

Assessment of sustainability of agricultural production by using the Life Cycle Assessment

Markus Frank
BASF, Germany

Sustainability assessment in the agri-food value chain

Towards a resource-smart food system

John Ingram

Introduction

Food systems are complex. This complexity arises from the wide range of food system's activities, which are undertaken by a wide range of actors who have a wide range of motives and who are sensitive to a wide range of influences. This leads to a wide range of social, health, enterprise and environmental outcomes.

Thinking about food systems therefore necessitates an integrated systems approach that goes beyond food-chain concepts that only take into account the food system activities: producing, processing and packaging, storing, disposing and reusing, wholesaling, retailing and consuming. In this context, achieving the goal of sustainable food and nutrition security through a resource-smart food system involves adapting a two-way street: human activities related to food systems that impact the natural resources upon which food security depends; and the environmental, social, political and economic changes that impact the food system.

Smart resources-food systems

The outcomes of the food system actor's activities impact food security, or more specifically, the short and long-term stability of food utilization, availability and access. Food security-isachieved «when all people, at all times, have physical, economic and social access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active healthy life» (FAO, 1996). Food systems activities also influence environmental and socio-economic welfare (Table 1; Figure 1). Globally, increasing food production is not the main issue for food security at present, since enough food is currently produced to feed the actual world population of 7 billion people. The problem of food insecurity today relies in the availability and access to food for all and in the balance between under and over consumption.

Meeting the demands, especially in the face of global environmental changes (Ingram and Porter, 2015) will however need substantial changes food system as meeting anticipated demand through the current food system pushes the planetary boundaries, (the planet's biophysical subsystems or processes that determine the safe operating space for humanity) (Steffen et al., 2015). For instance, agriculture, one of the main food systems activities, has resulted in severe soil degradation, freshwater exploitation, biodiversity loss, and is a main contributor to greenhouse gas emissions.

A food systems approach, such as the model suggested by Ingram (2011), can be very useful in finding opportunities to

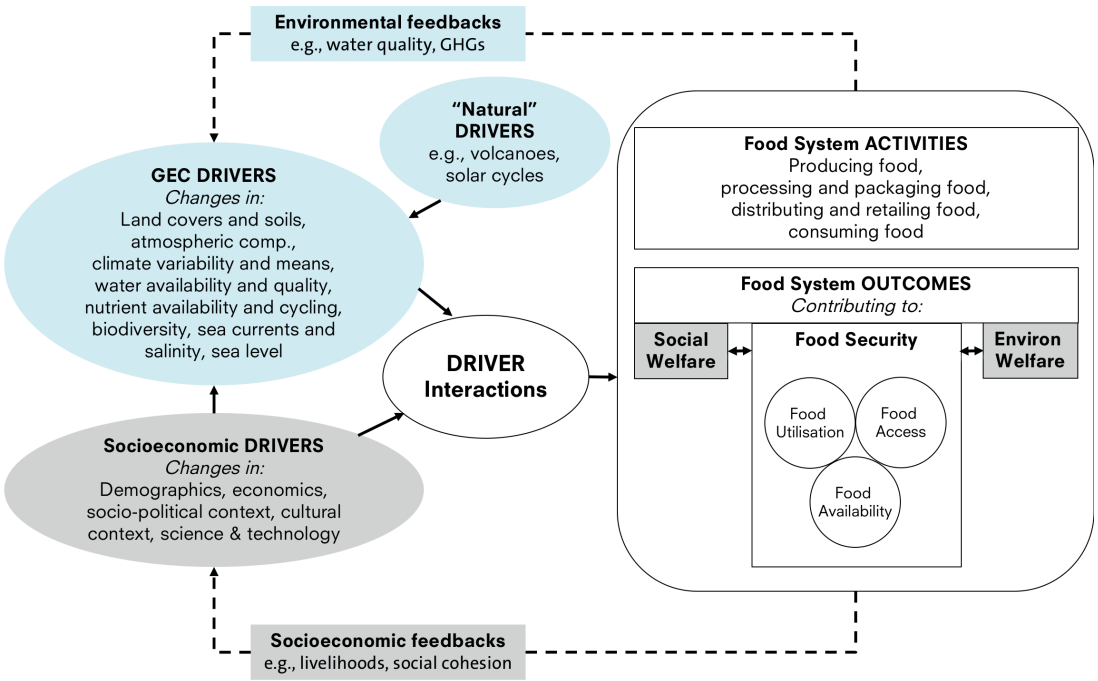

Figure 1. Food systems model: drivers, activities, outcomes and interactions. Adapted from Ingram, 2011

	PRODUCING FOOD	PROCESSING & PACKAGING FOOD	DISTRIBUTING & RETAILING FOOD	CONSUMING FOOD
Climate change	GHGs, albedo	Factory emissions	Emissions from transport and cold chain	GHGs from cooking
N cycle	eutrophic N, GHGs	Factory effluent	NOx from transport	Waste
P cycle	P reserves	Detergents		Waste
Fresh water use	Irrigation	Washing, heating, cool-	Cleaning food	Cooking, cleaning
Biodiversity loss	Deforestation, soil degradation	Paper/card, Al and Fe mining	Invasive species	Consumer's choices
Atmospheric aerosols	Dust		Shipping	Smoke from cooking
Chemical pollution	Pesticides	Factory effluent	Transport emissions	Cooking, cleaning

Table 1. Food system activities to planetary boundaries. Adapted from Ingram, 2011

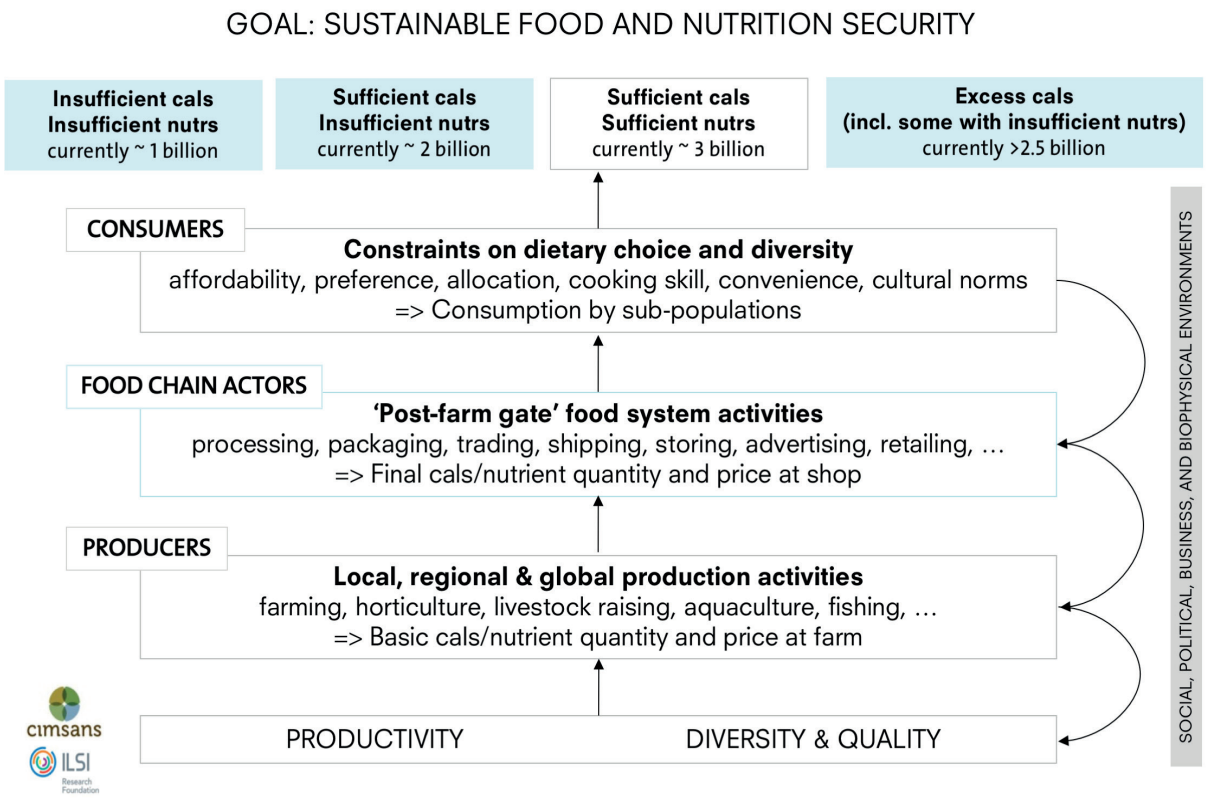

Figure 2. Global food security status and links with the food system

mitigate the contribution of food system activities to crossing planetary thresholds by identifying key limiting factors and feedbacks within the food system, and how they interact and influence global environmental changes (Figure 1).

In turn, crossing the planetary boundaries also destabilizes food systems. For instance, climate change can result in weather extremes that disrupt food storage and distribution systems, and can compromise food safety through potential increases or shifts in pathogen and pest pressure on staple crops, which would also require greater use of pest control agents (Porter et al., 2014). Vulnerable countries, with degraded soils, water scarcity, and other poor environmental and socioeconomic conditions, are particularly exposed to the negative effects of global environmental changes, especially climate change. To achieve the goal of sustainable food and nutrition security, in addition to taking account of the interactions of global environmental change with the food system, it is important to understand and bridge the gap of over- and under-consumption of food and nutrients. Currently, nearly one third of the population has excess calories, one third has sufficient calories and nutrients, and one third has insufficient nutrients and/or calories (IFPRI, 2016). Sufficient calorie and nutrient intake by consumers depends on constraints on dietary choice and diversity such as affordability, preference, allocation, and cultural norms. These are in turn affected by food chain actors, who process, package, store, advertise and retail the food that is produced by small and big farmers and fishers. Consumer feedback to food chain actors, and feedback from these actors to producers, also affects productivity, diversity and quality of food (Figure 2).

Current trends of global population growth, increasing urban population, and increasing middle class results in a greater food consumption over time, as the amount of disposable income is proportional to calorie intake (Tilman and Clark, 2014). Although increasing food consumption is important to meet global nutrition goals, future projections extrapolated from current trends show that while the number of people with insufficient calorie in the world remains the same, the number of people with excessive calorie consumption increases dramatically (Figure 3). At the same time, the well-known health burdens associated with obesity, which include non-communicable diseases such as Type 2 Diabetes, and their associated economic burden rise (Tilman and Clark, 2014).

Finally, to address current obstacles to achieving food and nutrition security, food systems must adapt to inevitable change and mitigate further change. Plant sciences can further contribute to increasing food productivity per unit land area by improving resistance to pests and diseases, modifying crop quality to address nutrient deficiencies and to increase the efficiency of activities such as food processing and storage (Ingram and Porter, 2015). In addition, recoupling of consumers with healthy diets and nutrients in the food system and avoiding waste within the agriculture sector is necessary. Numerous opportunities exist to reduce food losses on the farm and throughout the food chain, particularly those associated with consumption (Foley et al., 2011). Reallocation of food sources from animal feed and biofuel production could also result in higher food availability for people (Foley et al., 2011). The major constraints to these solutions are mainly of a political nature. Furthermore, a food systems approach can be of great aid in devising strategies to address sustainable development goals by identifying synergies among them.

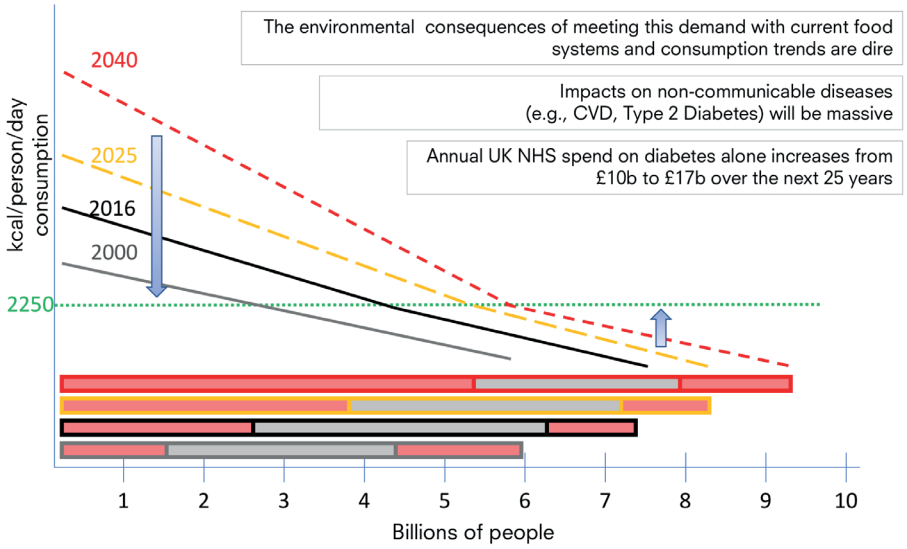

Figure 3. Extrapolated trends in consumption patterns. The figure indicates linearly-extrapolated changes in the number of people (x axis) against daily calorie consumption per person (y axis) for the years 2000 (grey), 2016 (black), 2025 (yellow) and 2040 (red), noting the recommended daily intake per person of 2250 kcal (green dotted line). The bars at the bottom represent approximate numbers of people over-consuming (left-hand section); appropriately consuming (middle section) and under-consuming (right-hand section) for the same color-coded years based on the historic, current and anticipated global populations for the respective years.

«Satisfying the world's current food demand in an equitable and sustainable way is proving difficult. But satisfying the world's anticipated food demand in an equitable and sustainable way given changes in population, wealth and climate will be far harder unless we see radical changes in how food systems operate. Food system thinking is needed to navigate the challenges ahead. It can help identify effective interventions in all food system activities from production to consumption to deliver better food system outcomes for health and environment, while maintaining vibrate enterprises.»

Dr. JOHN INGRAM
University of Oxford, UK

John Ingram's interests are: the conceptual framing of food systems, the interactions among the many actors involved and their varied activities, and the outcomes of their activities for food security, livelihoods and environment. He has designed and led regional research projects around the world on the links between food security and environment through the analysis of food systems.

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Consumer choices for sustainable produce could transform production systems

Gurbir Bhullar

Majority of the contemporary research on agricultural sustainability focuses on developing sustainable farming practices that could enhance productivity with minimal environmental footprint. A number of alternative approaches are thereby brought forward from time to time in different parts of the world, for instance, ecological, organic or biodynamic agriculture, natural farming, permaculture and agro-ecology, to name a few. Despite the demonstrated health and environment benefits, the large-scale adoption of these practices is many times challenged by socio-political and economic constraints. Therefore, the production-centered approach for transformation of our agricultural system has its limitations. In contrast the transformation of production practices driven by consumer demand would have greater chances of success. It is imaginable that the economic incentive could trigger transformation at a faster rate. However, to achieve this, science, policy and industry needs to make coordinated efforts.

Consumer-driven transformation of agricultural systems

To achieve a consumer driven transformation of agricultural systems, a number of different factors need to be considered. Since food choice and access engage a significant emotional component, the change in consumption behaviors could only be achieved by providing convincing evidence and information to the consumers or by offering comparative economic advantage.

Consumer awareness

When affordability is not a predominant constraint, a well-informed consumer is likely to make healthier and sustainable choices. Therefore, continued efforts are needed to inform and educate consumers about which products are sustainable and which are not. This also means that the first that we need to determine is which products originating from different type of production systems are more sustainable than others. Therefore, the sustainable products need to be available to the consumer in a clearly distinguishable form. Underlying sustainability standards and labels are a step in this direction. But, in the meantime there are too many sustainability labels each claiming to be more authentic than others. Many of these labels address only one or few of the sustainability focus areas and thus are not holistic. Sometimes, the regulatory requirements to obtain these labels – for instance in case of specialty commodities like coffee or cacao – could also promote specialization on farm leading to homogeneity of production systems, which works against the principles of diversity and sustainability (Meybeck & Redfern, 2014). Despite the questions on their authenticity and integrity, many of these sustainability standards have influenced the consumer choices, which indirectly translate to the choices made at the production end.

A clear evidence of the significance of consumer choices, for instance, comes from the case of organic agriculture: the demand for organic produce has surpassed its production in recent years (Willer & Lernoud, 2015). However, majority of this increase has happened in the prosperous societies of developed countries, where consumers can afford to purchase sustainable products at a premium price. Despite the substantial increase, organic and sustainable products still represent a niche market considering the total volume of trade.

True cost accounting

The consumer choices – particularly in developing countries (to some extent in developed countries as well) – are substantially influenced by product price. In low-income societies a large share of daily earnings has to be spent on securing sufficient food for the families. In this scenario it would be unrealistic to imagine a consumer paying premium price for sustainable products, which are apparently comparable to the conventional options available on the market. A plethora of evidence is available on the indirect costs of conventional production (e.g., on environment, health and natural resources), but none of these costs forms part of the retail price of the produce (Kimbrell, 2002). For instance, Pretty (2000), reported total indirect costs of UK agriculture in 1996 to be equivalent to £208/ha of arable and permanent pasture. A study in Switzerland concluded that the economic costs of pesticide use amount at least to 50-100 million Swiss Francs per year (Zandonella et al., 2014). Unless strategies are developed to incorporate these indirect costs into the retail price of the products, conventional products will continue to give false impression of being cheaper and the sustainable products will continue to be economically disadvantaged. Therefore, for mainstreaming of organic or sustainable production systems, true cost accounting could offer a significant breakthrough. Though the implementation of this concept is unsurprisingly challenging. Because of the inherent complexity of biological systems and the cascade of microbial and biogeochemical interactions lasting over extended periods, monitoring the influence of single factors over a determinate period of time and putting a justifiable price on it is a massive task. In this context, considerable knowledge gaps remain to be addressed. Moreover, the implementation of such a concept

needs careful planning as in the short term it might result into increase in food prices, which might have food security consequences, particularly for the underprivileged societies.

Role of science

Scientific evidence is of crucial importance in determining the sustainability of various production systems and farming practices. Research efforts need to be systematically coordinated across farming systems and value chains. To some extent, such efforts have been successfully undertaken largely in temperate environments of developed countries. For instance the long-term trial comparing biodynamic, organic and conventional systems (nicknamed DOK trial) in Therwil, Switzerland has made considerable contribution towards closing the knowledge gap since its beginning in 1978 (Fliessbach et al., 2007; Mäder et al., 2007). While in the tropical environments of developed countries research comparing agricultural systems for sustainability parameters is still lacking. In this regard, FiBL's long-term farming systems comparison program (SysCom) compares different farming systems for their economic, social and environmental sustainability in Kenya, India and Bolivia since 2006–07 (Adamtey et al., 2016; Schneider et al., 2016; Foster et al., 2013). Apart from comparing the production systems, sustainability aspects need to be studied throughout the agricultural value chains and the spillover effects e.g., on social wellbeing need also to be considered.

Role of policy

No sustainability initiative could fully succeed without appropriate policy support. Policies promoting the development and maintenance of sustainable agricultural value chains need to be put in place at regional, national and global scales. Current policies and market dynamics favor unsustainable production practices by stimulating the production of single agricultural commodities in large quantities which are sold at distortedly low prices at the cost of the environment and ultimately humankind. There is an urgent need for coordinated research and policy action to tackle this problem (Andres & Bhullar, 2016). Viable governance and regulatory frameworks need to be put in place that support in making context-dependent decisions (e.g., considering farm holdings, cropping systems, target markets and social organization of local populations). Experiences from the countries that were at the fore front of sustainability standards development (e.g., Austria and Switzerland, where 19.5% and 12.2% of the agricultural land is under certified organic agriculture, respectively (Willer & Lernoud, 2015) could serve as role models for development of appropriate governance and regulatory frame works.

Role of industry and civil society organizations

As responsible entities of our society, industry and civil society organizations can play significant role in bringing the desired changes in our food system. For instance, the adoption of voluntary sustainability standards (VSS), if done appropriately, by food industry could play a significant role in making the production systems not only economically viable, but could also potentially deliver the required ecological and social benefits. Similarly, the organizations active in various spheres of civic society (e.g., NGOs, media institutions and social associations) could contribute by raising consumer awareness about the health and environmental benefits of consuming sustainably produced products. Such awareness campaigns have the potential of delivering the needed impact on the consumption end of the agricultural value chains that will translate to the desired changes in production practices at the producer's end.

«The development of a healthy, affordable and sustainable food system is a priority of our times. As the scale of the challenge surpasses economic, political, social and geographical boundaries only a coordinated action could yield the desired effects. Majority of the research efforts have been focused on the production end of the agricultural value chains. Changes in the consumption patterns have substantial potential of triggering the necessary changes towards sustainable production systems at the production end. Therefore, capacitating the consumers to make informed decisions is highly important. European Parliamentary Research Services (EPRS) has recently published a study reviewing existing scientific evidence regarding the impact of organic food on human health from a EU perspective (EPRS, 2016). In this commendable effort by an important international think-tank, direct (health) and indirect (environmental) benefits of organic agriculture are summarized based on the available peer-reviewed research. It is important to bring the findings of such studies from scholastic spheres to common public in order to bring the desired transformation towards sustainable consumption patterns.»

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Introduction to Life Cycle Assessment for a sustainable food system

Franziska Stössel

The basics

The global supply chains, production technologies and consumption patterns are interconnected through complex interlinkages, which often result in negative impacts to the environment. Tools are required that facilitate the identification of improvement potentials in the life cycle of products. In this regard, Life Cycle Assessment (LCA) is a systematic method for analyzing environmental impacts of products, processes and services from cradle to grave allowing an assessment from a systems perspective. To do so, it is important to include all processes, to address trade-offs and avoid burden shifting from one environmental impact to another. Furthermore, LCA allows comparing the environmental impacts of various products, processes and activities with the same methodological framework. Therefore, LCA enables both to understand the consequences of human actions on the environment and to optimize economic performance through gaining efficiencies.

Steps of LCA

Conducting a LCA consists of a process with 4 steps: i) definition of goal and scope, ii) inventory analysis, iii) impact assessment and iv) interpretation. The first step requires detailed description of the purpose and system boundaries. The second step defines the relevant emissions and resources the system produces or consumes. The third step consists of grouping emissions and resources according to their impact categories and converting them to common impact units to make them comparable. In the final step the results of the inventory and impact assessment are interpreted in order to answer the objectives of the study (Figure 1).

Application of LCA

There are different uses where LCA can provide valuable decision-making support, namely as: i) LCA at the product level, ii) organizational LCA, iii) consumer/lifestyle LCA, and iv) country LCA. Typical examples to assess and improve specific product systems are for the eco-design of products (comparison of different products), process optimization, supply-chain management, and marketing and strategic decisions. Companies are using LCA to identify key drivers of their entire product portfolios and to report key environmental aspects on a corporate level. LCA can pinpoint crucial areas of consumption and drivers of environmental ramifications in the area of sustainable consumption and production. On a national level, it can be instrumental in policy-making providing information on environmental costs and benefits of specific projects before money.

Asparagus as a case study

One presented application of an agricultural LCA was the ranking of the global warming potential of fruit and vegetable products sold in a Swiss retailer. The inventory included, among others, seedling production, farm machinery use, fuels for the

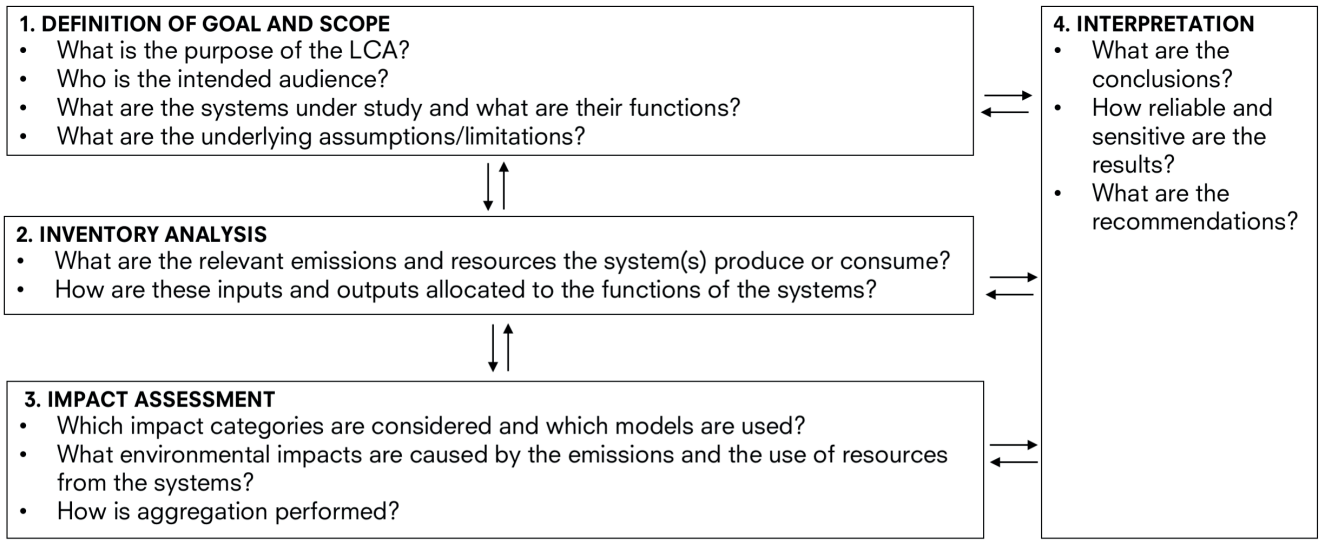

Figure 1. Stages of an LCA adapted from the International Standard 14040 (ISO 14040, 2006)

LCA in BRIEF

Why to use it
With LCA we are able to compare different production systems. We have a big reviewed database where we find inputs from nature and technosphere. With the discipline of consequential LCA we are able to quantify the consequences of changes in a system in order to avoid burden shifting.

Time needed for this activity
The time needed for an assessment very much depends on the access to the data for the establishment of the Life Cycle Inventory (LCI) and to which extent the detail has to be considered. In the first step of the analysis process the functional unit, the system boundaries and the allocation methods have to be chosen. Another important step is the choice of the impact categories and the assessment methods. If step 1 and 2 of a LCA are well elaborated, step 3 and 4 can be performed faster

Skills you will acquire
Doing a LCA generally trains you in system thinking. In the LCI step it is rather about understanding the processes in the technosphere. The quantification of the emissions from e.g., agricultural processes requires a profound understanding of the processes in the ecosphere. In doing a LCA, there is chance to learn about processes from fields outside of the habitual field because in a life cycle of a product or service different aspects play a role. This is challenging and sometimes it is suggested to take expert advices. Interdisciplinary working would enhance the quality.

Guideline and protocol
ISO 14040 considers the principles and framework for an LCA, while ISO 14044 specifies the requirements and guidelines for carrying out an LCA study. A European standard and extended guideline (the ILCD Handbook) is built on the base of these two standards (PRé, 2016).

What to do with the results
LCA studies are often conducted on behalf of persons or companies that are interested in the environmental performance of their products or services. The results have to be transferred to the client. The results of a study either serve to improve single production processes or company performances. Results of LCA studies can also serve governments to reduce environmental impacts on country level. Other results serve researchers to evaluate their findings (e.g., comparison of the environmental performance of a conventional variety and a genetically modified plant in agricultural production). New Life Cycle Impact Assessment methods are tested in case studies in order to prove the applicability and the results.

Supporting material
The use of databases (e.g., ecoinvent) and LCA software such as Brightway, SimaPro, OpenLCA, GaBi or Umberto are essential.

Best used for
- Comparisons of the environmental impacts of two or more products with the same functional unit and within the same system boundaries.
- The analysis of production processes in order to find the process steps with highest environmental impacts and the major improvement possibility.

heating of greenhouses, irrigation, fertilizers, pesticides, storage and transport to and within Switzerland. The study found that the largest reduction of environmental impacts could be achieved by reducing transports by airplane, followed by consuming seasonal fruits and vegetables. The retailer used the results to improve the supply chain management and made changes in purchasing decisions. The whole study is described in details in Stoessel et al., (2012).

Challenges of LCA
Although current LCA analyses have proved themselves as powerful tools, they bare a high uncertainty in terms of interpretation and discussion of the results, which is mainly due to reduction and simplification of complex cause-effect relationships. As a consequence, each outcome of a LCA raises the question: To what extent can the results be trusted and thus accepted? Although recent developments have brought forward new quantitative means to assess uncertainty in LCAs, uncertainty assessments are sometimes not addressed in practice (Gregory et al., 2013, Hellweg, & Canals, 2014).

Conclusion
Great potential is seen in LCA as a technique to assess the environmental impacts of products and services from cradle to grave, which makes it an indispensable tool for a sustainability analysis. It should not be expected that the outcomes of LCA always provide an ultimate answer to a particular problem. They rather provide an overall overview and comprehension of a system's problems and its potential solutions.

Eric Rahn and Tony Reyhanloo contributed to the reporting of Franziska Stössel's presentation.

«The possibility to use LCA in combination geographic information systems will improve the assessment possibilities substantially, because it allows to include referenced global environmental data either from remote sensing or national and international surveys. It also enables to develop regionalized methods for the Life Cycle Impact Assessment that is crucial for the LCA of agricultural products. As soon as we have this possibility, we have the chance to analyze effects of substantial transformations. In other words: we are able to model the consequences of the changes. Today it is possible to compare different systems in case studies.»

FRANZISKA STÖSSEL
ETH Zurich, Switzerland

Franziska Stössel presented the methodology of LCA on development and applications at the PSC Summer School 2016. She also gave a workshop allowing the participants to have first insights working with the SimaPro software. Franziska is currently a PhD candidate at the Institute of Environmental Engineering at ETH Zurich and has almost 10 years of experience working with LCA. Her main focus is the LCA of agricultural products and agricultural production methods, as well as Life Cycle Impact Assessment of soil quality aspects.

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Sustainability assessment in the agri-food value chain

Markus Frank

Sustainability in food production

A focus on sustainability in the food value chain has become a basic prerequisite for suppliers and consumers. There is no other industry with so many product marketed as «sustainable» as in food production. To what can the trend towards the introduction of higher sustainability standards be attributed? Although some observers believe that the later stages of the value chain drive the issue strongly (Giovannucci & Ponte, 2005), other authors consider the active role to lie with end consumers and their increasingly troubled trust in the food industry (Spaarge & Oosterveer, 2010; Willmroth, 2011), and others lean to the side of the food corporations and supermarket chains (Oosterveer & Sonnenfeld, 2010; Traill, 2006). This development certainly imposes increasing demands on all levels of the chain – from the supply of agricultural resources to plant and animal production to food processing and marketing.

Global mega-trends will bring increasing challenges with them. A dramatically increasing global population of approx. 9 billion people by 2050 (UNFPA, 2012) and a rapidly growing middle class in developing countries such as China and India with a demand for high-quality and nutritious food, with an additional increased appetite for meat and dairy produce (Oosterveer & Sonnenfeld, 2012; Gerosa & Skoet, 2012), mean further pressure on agricultural production, based on the poor energy conversion in the production of meat. In light of this, sustainable agriculture and a sustainable supply chain have become imperative. One stage in the chain is not sufficient on its own; a joint effort across all stages is required.

Systems to measure sustainability

The most widely accepted sustainability assessment schemes are either driven by multi-stakeholder initiatives or within a corporate environment. Among the group of multi-stakeholder initiatives, an important example of an initiative is the «Field to Market» program. In «Field to Market», a broad group of stakeholders – seed companies, agricultural producers, processors, trade and non-governmental organizations – joined in 2006 to establish sustainability standards in the American agricultural supply chains, particularly those of soybean, maize and cotton, and to make them measurable. The aim of «Field to Market» is to identify relevant sustainability criteria for the relevant supply chains, which acknowledge the potential role of diverse technologies (e.g., genetically modified seed stocks) and support farmers in aligning themselves with these criteria (cf. The Keystone Center, 2013; Constance, 2010; Field to Market, 2013a, b). The aim is to roll out widespread general minimum standards and raise the base line to some degree. The priority is heightening the sensitivity of farmers to central sustainability issues by comparison of their individual farm performance with a benchmark and facilitating their implementation in their businesses. The «Fieldprint Calculator» (Field to Market, 2013b) is a central tool of the «Keystone» initiative. Farmers can use it as an aid to check their overall sustainability in terms of energy, soil and water consumption and their effect on climate. In doing so, the «Fieldprint Calculator» compares the method and the performance of individual farmers with the average in their region and in their state.

In contrast to «Field to Market», the Response-Inducing Sustainability Evaluation (RISE) initiative and the Sustainable Agriculture Initiative (SAI) platform began with food companies, first and foremost with Nestlé. RISE is an indicator-based method for assessing the sustainability of an agricultural business. The Bern University of Applied Sciences has developed RISE since 2000 with strong support from Nestlé (HAFL Bern, 2012).

The model covers 12 indicators from the areas of economy, environment and society. The indicators are energy, water, soil, biodiversity, emissions, pesticides, waste, cash flow, profit, investments, local economy and the social situation of the business (Häni et al., 2003). Like «Field to Market», RISE is not a control method or certification. Users commit to complying with a code of conduct, where all collected and processed data is treated with strict confidentiality. The RISE method has already been implemented in over 1.200 companies in 36 countries. The types of businesses analyzed include dairy, vegetable and arable farms, mixed farms, coffee, cocoa and tea plantations, small African operations and nomadic herdsmen (HAFL Bern, 2012). Whilst the strength of RISE lies in its ability to create a truly detailed analysis of an agricultural business, one weakness is the high costs involved in data collection and the work carried out.

In order to be able to evaluate suppliers more quickly and economically, Nestlé, Unilever and Danone joined forces in 2002 to launch the SAI platform. SAI aims at simplifying and focusing the sustainability indicators to enable broader coverage of agricultural suppliers (Hamprecht et al., 2005; SAI Platform, 2010). Today the SAI platform has over 50 members from the food industry. In 2009 the SAI platform issued the first set of sustainability indicators, covering issues such as energy consumption, humus balance and greenhouse gas emissions, however in a purely qualitative way.

In addition to these initiatives driven primarily by commercial companies, there are further approaches, which deal with certain aspects of sustainable agriculture. This includes, for example, INDIGO (Bockstaller et al., 1997), KSNL, Association for Technology and Structures in Agriculture (KTBL, 2008), REPRO (Küstermann et al., 2008) and on a national and international level, IRENA (Indicator Reporting on the Integration of Environmental Concerns into Agriculture Policy System, European Environment Agency, 2005), and the OECD approach (OECD, 1993, 2001). These indicator systems generally focus on the practical applications for agricultural operations. In doing so, these methods do not make use of the life-cycle analysis, where the whole footprint of a product or a process can be mapped from the «cradle», e.g., the harvesting of the raw materials, potentially right to the «grave», namely the consumption of the food and the disposal of the packaging. As a result, they cannot create a realistic image of the share that various stages add to the value chain and tend to overestimate the influence of individual factors on the whole footprint (de Haes & de Snoo, 1997).

AgBalanceTM as a contribution towards a focus on sustainability

BASF started developing the «AgBalance» in 2011: a sustainability method, which guarantees implementation of the breadth and flexibility of a life-cycle analysis whilst involving an acceptable balance between data requirements and scientific depth.

The successful development and marketing of sustainable solutions is the core of the BASF company strategy and is a central theme for the Agricultural Solutions business segment. A fact-based sustainability analysis is indispensable to be able to achieve this goal, in order to critically assess BASF technologies and solution approaches on the one hand and on the other to support producers in their positioning towards their customers.

With AgBalance™, BASF has attempted to facilitate a realistic and precise depiction of the food value chain, in order to be able to derive specific recommendations for action from this. Against the backdrop of almost 20 years of experience in life-cycle analysis, this scientific approach was also selected for observing the agricultural chain. The result is a sustainability method that includes ecological, economic and social aspects in its analysis and which can – with simple adaptations to the local circumstances – be used around the world (Frank et al., 2012). Depending on the issue, it is equally possible to observe a certain technology or production system or an entire value chain. These methods make use of the so-called life-cycle analysis, where the whole footprint of a product or a process can be mapped from the «cradle to the grave». AgBalanceTM can be used to map an individual farm or the whole agricultural sector in one region. The focus can either be on the agricultural production system alone or on the processes that have been established downstream in the value chain, such as logistics or processing.

As agriculture is one of the world's most fully globalized markets, AgBalance must be broad enough to cover the most important sustainability concepts in all regions, whilst also promoting a practical application adapted to local conditions (Frank 2011). The project team at BASF developed 69 indicators in cooperation with academics, non-governmental organizations, political and consumer organizations in the EU, the USA and Brazil and gave them the appropriate weighting factors. That last step is necessary to be able to derive an overall statement from a multitude of indicators and therefore to offer simple representations on a scientific basis. In order to ensure the quality of the sustainability profiles from the outset, a broad range of stakeholder groups have participated in the development and weighting of these criteria. Amongst others, the representative consumer surveys on the significance of the individual factors in the society of multiple countries (including Germany, France, Great Britain and USA) influenced the weighting.

Using official statistics and established scientific data sources (e.g., the IUCN biodiversity indicators, FAO statistics, etc.) together with field studies, the 69 sustainability indicators are calculated and their results expressed in a relative form, in order to bring to light the specific differences between two production systems. AgBalance™ delivers results that should enable farmers, the food industry, regulators and society to objectively evaluate processes in terms of their sustainability profile. In doing so, a vast amount of information on individual factors can be ascertained in addition to overall statements on the sustainability of agricultural practices (e.g., ploughing).

Case study: comparing two Brazilian large-scale farms

A corresponding case study with the holding company SLC Agricola in Brazil involved an internal benchmarking of two large farms, each with over 1.000 hectares, to identify the central sustainability drivers for their crop rotation consisting of soya, maize and cotton and to derive follow-up opportunities for their continuous improvement from this (Frank et al., 2012). An average cultivated hectare for each of the two farms, Panorama (Bahia state) and Planalto (Mato Grosso do Sul state) were compared on the basis of the operation data from the 2009/2010 season. The indicators from all three sustainability dimensions – environment, economy and society – were investigated using a holistic approach over a section of the life cycle that starts with the raw materials used in the production (the «cradle» of the process, for example phosphorus extraction or oil production) and ends with the delivery of the harvested goods at the nearest port.

The analysis shows that the production at Planalto is substantially more sustainable than the Panorama farm. Planalto achieved a 40% better result in the relative sustainability index. This is largely due to better results in the economy. Figure 1 shows the overall comparison of the farms in terms of the three dimensions of sustainability. Figure 2 compares the individual indicator categories. Panorama achieved better results in two social indicator categories, namely in «Professional training» (in the category «Future Generations») and the «Working conditions in the upstream chain» (in the category «Employee/Farmer»).

Planalto proves to be the benchmark in all other categories. The most important drivers in terms of economy turned out to be an improved cost situation and an increased profit (in the category «Macroeconomy»). Both were partly due to a more efficient use of resources and a better logistical starting point (in contrast to Panorama, Planalto had a rail link). In terms of the environment, the most important driver turned out to be a slight in-balance for nitrogen and above all, phosphorous in the soil at Panorama. This increased use of fertilizer is reflected in the higher energy and resource consumptions, which is due to the production and transportation of the fertilizer and the higher emissions from production and the field. The «Soil Index» category also reflects the imbalanced nutrient content in the soil. A second important factor in the dimension «Environment» was the pesticide regime at Panorama. Despite the low volume, with not more than two percent of the total amount being from pesticides, the use of organophosphates as soil insecticides in the production of cotton leads to poorer results in the «Ecotoxicity» category.

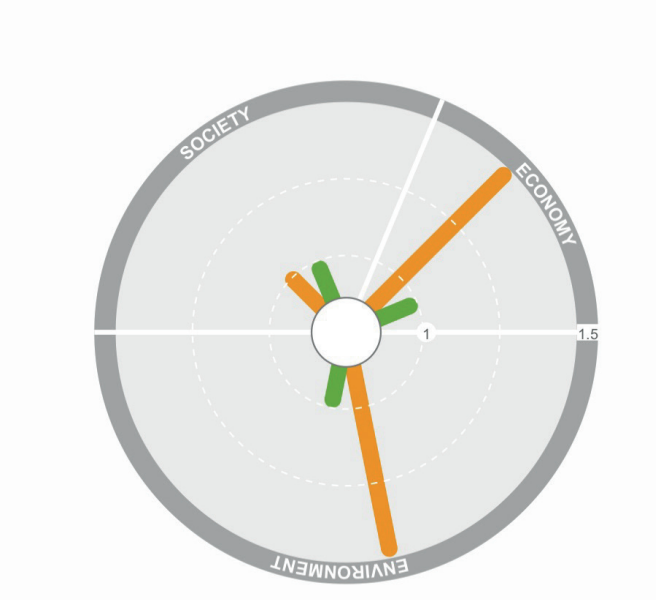

Figure 1. Representation of the sustainability index in terms of the three dimensions of sustainability. The length of the bar indicates higher sustainability. Green: Panorama, Orange: Planalto. Each time the worse alternative is normalized to the value 1. Source: BASF SE

According to initial calculations, the optimization of the fertilization regime in Panorama could lead to savings of almost 15 million kWh of energy (this corresponds to the energy use of roughly 2.000 households in Brazil) in addition to substantial cost savings. The CO_2 equivalents saved using AgBalance™ amount to almost 8.000 tons per year. These results, together with the additional findings on pesticides, can serve as the starting point for a continuous improvement program at SLC Agricola. With its knowledge base, BASF supports a suitable product portfolio throughout the whole life cycle and works towards creating common solutions towards greater sustainability.

Sustainability of shared value creation in agriculture – where is the trend heading?

Measuring sustainability can be a central key to improvements towards more sustainable agriculture. The essential prerequisite for this is its success in translating results from complicated life-cycle analyses into farmer's everyday reality for farmers and to derive specific recommendations for better farm management from this.

The central requirement of the measurement systems destined for implementation into agriculture, such as «Field to Market», SAI or AgBalance, is to maintain the correct balance between requirements regarding data and scientific depth on the one hand and practical relevance on the other. Acceptance by farmers ultimately decides the success or failure of such systems, with the aim of establishing a basis for shared value creation. Furthermore, there is a demand to be able to map the whole value chain. Through interfacing of on-farm production data deposited in electronics field documentation systems with the software carrying out the sustainability assessment, acceptance by farmers will be substantially improved and at the same time, data quality will strongly benefit.

The limitations of the different methodologies must not be disregarded. Careful quality assurance and continuous improvement of the methodologies is essential. With the broad and consistent inclusion of stakeholders in the creation of the studies – from further stages of the chain, associations, non-governmental organizations and academics to regulators and politics – the relevance of the results depends on the sustaina-

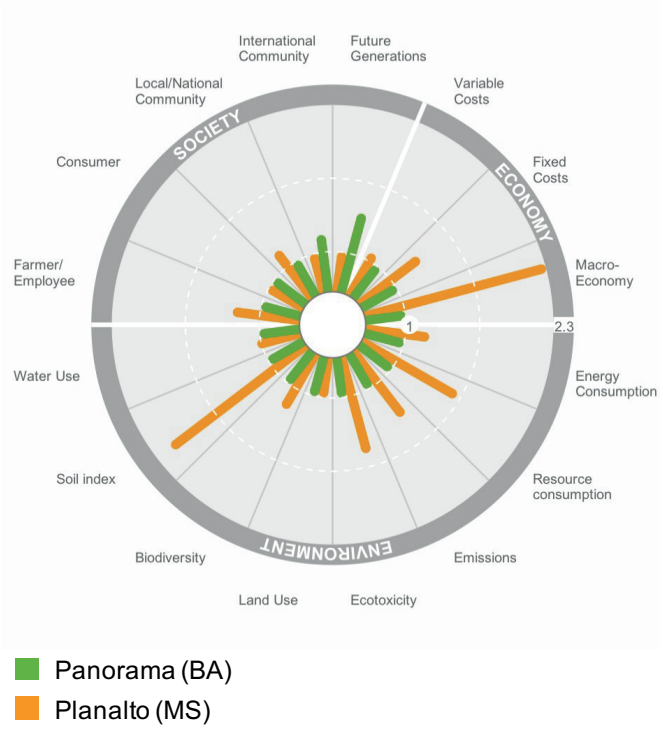

Figure 2. Representation of the sustainability index in terms of the individual indicator categories in AgBalance™. Source: BASF SE

bility measurements for shared value creation along the supply chain. Moreover, not all aspects can be easily integrated into a life-cycle analysis. This particularly includes ethical and some social aspects such as the protection of indigenous rights or safeguarding against child labor. These aspects cannot be treated as one conflicting goal among many, given that they are unacceptable or even illegal practices. These topics should be evaluated separately and assessed by relevant stakeholders and, if possible, a solution or certain countermeasures should be introduced. Finally, the topic of sustainability in agriculture has an increasingly strong regional character, despite global supply chains. Implementation in the agricultural business takes place solely on a local level. Both the assessment method and the subsequent implementation plan must therefore be flexible enough to facilitate local solutions. Taking all these limitations into account, it can be expected that quantitative sustainability assessment will more and more guide management decisions of the actors all along the agro-food and agro-feed value chains.

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III: Food and agriculture policy

How can policy help in implementing sustainable agriculture? Chapter 3 gives insight in sustainable policy directions of the EU's Common Agricultural Policy (CAP). It introduces scenario-playing as a tool for developing options for agricultural policies sustaining the Sustainable Development Goals (SDS).

Allan Buckwell
Institute for European Environmental Policy, London, UK

EU agricultural policy as a tool to encourage sustainable intensification

Gunda Züllich
Millenium Institute, Washington, USA

Practical scenario playing and policy analysis

EU agricultural policy as a tool to encourage sustainable intensification

Allan Buckwell

There is no problem in principle in utilizing the EU's Common Agricultural Policy (CAP) to help steer EU rural land management onto a path of sustainable intensification. However, this slogan has not been adopted by the EU. The Treaty based objectives of the policy have always been concerned with improving the productivity of agriculture. This can be consistent with improving resource efficiency; this often goes hand in hand with increasing intensity of production as measured by inputs per hectare and outputs per hectare. Although some aspects of narrowly focused productivity improvement can be, and have been environmentally damaging, generally, higher yields mean that less land has to be diverted from forest, natural grasslands and wetlands to feed the growing population than would otherwise be the case. More recently all EU policies have been set the goal of moving to sustainable development, and progressively since the 1980s the CAP has explicitly embraced objectives and measures to improve the environmental sustainability of agriculture. Together there is a desire to ensure that agricultural output growth does not destroy natural capital, is associated with less pollution and with greater delivery of environmental and cultural landscape services. These general goals are widely accepted; however, the seriously difficult challenge is to translate them into measurable progress through practical policy measures agreed at EU level but which can be sensibly adapted to the diversity of European farming systems and natural conditions. This is especially challenging given the very low margins in agricultural production.

Sustainable agriculture and policy-making

Sustainable intensification appears in the context of world food security and land scarcity. The rationale is that if more food has to be produced it is preferable that this be done by intensifying existing agricultural land. Bringing any new lands into cultivation will cause more biodiversity loss and climate damage. However, its definition is not straightforward. It is regarded as the simultaneous improvement of productivity and environmental management of agricultural land. While intensification is well defined, intensity is a measurable ratio of inputs and outputs per hectare of land, the meaning of the term «sustainable» is not as clear. Since sustainability has environmental, social and economic dimensions, there is no agreement on how it may be measured with precision. However, there is a general consensus that the highly-productive European systems should emphasize improving their sustainability. Agricultural production is associated with pervasive positive externalities (e.g., conservation of ecosystem services) and negative externalities (e.g., pollution and contamination). Encouraging the production of positive externalities and depressing the negative ones are the principal rationale for agricultural policy.

The sustainability dimensions targeted

Europe's CAP has quite explicitly during this century tried to embrace all three dimensions of sustainability. For example, the most recent reform of the CAP negotiated during the period 2010–2013 and now implemented for the period 2014–2020, explicitly set out to achieve viable competitive agriculture (the economic dimension), which provided sustainable management of natural resources (the environmental dimension) whilst maintaining territorial balance (this is generally taken as ensuring the continuation of farming in the remoter and marginal areas which introduces a social dimension).

All three aspects create challenges. The system of direct payments grew out of compensation for the change from commodity price supports, which had been the basis of the CAP from its formation in the 1960s until the mid-1990s. The scaling and distribution of these payments is easy to explain but very hard to justify. This was significantly complicated by the accession of the newer Member States from Central and Eastern Europe in 2004 and 2007. These payments are not well directed as income supports, nor as a risk management tool, and not as a payment for environmental services either. Despite, by international standards, very generous support for farming through an elaborate system of direct payments to individual farmers, there are still many farming households living at low material standards, and at the same time highly dependent on public payments.

There has been general agreement that the deployment of a significant part of the CAP budget to encourage farmers to improve their environmental performance is a correct approach. On the face of it substantial progress has been made in this direction with approximately 30% of CAP funds allocated for this purpose. There are many imaginative and worthwhile environmental schemes across the EU, and some signs that some indicators are moving in preferred directions. However, there are many challenges to ensure that these funds are well targeted and used. Many of the schemes – not least the three so-called «Greening Actions» introduced in the 2013 reform – are claimed to involve few farmers having to change their management at all, and therefore judged unlikely to result in observable improvement in environmental indicators. These schemes are often expensive for administrators, cumbersome

and thus unpopular with farmers, and may not be operated at sufficient scale with the necessary continuity and connectivity to make a difference to fragile, and isolated ecosystems. Perhaps unsurprisingly there is a long way to go, a lot of learning by doing, to improve the uptake and outcomes of these schemes.

Two particularly difficult areas of EU agricultural and rural policy are: (i) dealing with the several million micro farmers, subsistence and semi-subsistence farmers, and (ii) managing the remoter and marginal areas. The first of these issues is mostly found in some southern EU Member States and in the new Member States particularly Bulgaria and Romania. Most of these micro farmers are simply too small to be captured by the administration of CAP schemes. Collectively they manage a significant area of land and are sometimes associated with valued semi-natural habitats. The farmers in marginal areas generally can only survive by diversifying their economic base. Policy measures try to assist this in a number of ways. For example, it can provide training and skills enhancement, encourage imaginative marketing to embrace landscape and local traditions in higher quality food products, assist rural tourism, farm catering, accommodation and retailing, and by improving rural services such as telecoms and broadband.

The Rural Development programs to provide such assistance require investment in social capital to bring together farmers, other land managers, and civil society groups to devise actions needed for the specific challenges in each locality. In the EU this is done through the LEADER program. There are many successful programs, but the overall challenge remains. Generation renewal in these areas is often difficult as younger people move out. Much wider policy than the relatively small resources mobilized thought the rural development arm of the CAP are required.

In short, collective action through agricultural and other policies is needed to help agriculture onto a path that could be called sustainable intensification. Devising and implementing such policies, especially across the whole EU, turns out to be a slow process. The different Member States and regions have their own mix of economic, environmental and social challenges, and are at different stages of economic development. The institutions of the EU struggle to reconcile the different interests engaged in all this. Food consumers generally want good quality food, which is affordable. Citizens vote for high environmental standards to be maintained. Farmers are squeezed between highly concentrated suppliers of their major inputs (e.g., fertilisers, machines, credit) and equally concentrated processors and distributers who buy their products, and therefore operate with very small margins. If higher environmental standards mean higher costs farmers are reluctant to take them on. The overall challenge is to internalize these environmental costs – but in fact none of the parties in the food chain is particularly eager to pick up these costs. International competition adds to the complexity of the task. The sheer complexity and multi-faceted nature of the task, combined with the diversity of conditions in the EU and conflicting interests of key groups, plus the nature of European political institutions (Council, Parliament and Commission) conspire to make it very difficult to achieve transformative change in the EU. Incremental change is the result – and this may prove inadequate to meet the challenges faced.

The institutions in the EU and policy decision process

Stakeholders such as farmers, landowners, consumers, environmentalists and academics are allowed to participate in the discussions of EU institutions. They can provide their inputs to the discussion through direct lobby, use of media and public demonstrations.

The legislative procedure makes CAP reforms a bureaucratic and slow process that goes through many different organisations and requires enormous amount of discussions to reach a final modification. Likewise, the conservative nature of the agricultural work makes farmers more reluctant to change practices than any other productive sector.

Prof. em. ALLAN BUCKWELL
Institute of European Environmental Policy (IEEP), UK

Allan Buckwell is a Senior Research Fellow. He is an agricultural economist specializing in agricultural and rural policy. His topics of interest are CAP, agriculture and environmental land management.

Practical scenario playing and policy analysis

Gunda Züllich

Transformation of agriculture and the SDGs

On 25 September 2015, the 193 Member States of the United Nations adopted the 2030 Agenda for Sustainable Development – including 17 Sustainable Development Goals (SDGs) and 169 targets – committing the international community to achieve sustainable development over the next 15 years (2016–2030) (UN, 2015). The SDGs include very diverse goals from various different sectors and it is Goal 2 («End hunger, achieve food security and improved nutrition and promote sustainable agriculture») that is directly targeted towards agriculture. However, since all the goals are interconnected, it is important to realize that «food and agriculture are key to achieving the entire set of SDGs» (FAO, 2016) and actions on several other goals will also have an impact on agriculture and Goal 2. For example, the way agriculture is done affects Goal 1 (no poverty), Goal 8 (good jobs and economic growth), Goal 2 (responsible consumption), Goal 13 (climate action), Goal 14 (life below water) or Goal 15 (life on land). On the other hand, health (Goal 3), education (Goal 4), gender equality (Goal 5) or infrastructure (Goal 9) are key for the development of agriculture (Blanc, 2015). Hence, the 2030 Agenda forces the international community to take a more holistic and integrated perspective on development, the goals and the policies how to achieve them.

SDGs: a great achievement, an opportunity and a challenge at the same time

The adaptation of the SDGs by the international community is a great achievement, especially, considering that it is the result after decades of advocating for a sustainable development agenda. Milestones were, for example, the UN Conference on the Human Environment in Sweden in 1972, the first UN Conference on Environment and Development in 1992 in Rio, the Rio+20 Conference twenty years later, and the parallel establishment of the Millennium Development Goals at the Millennium Summit of the UN in 2000. Now, the world has an agenda for sustainable development that accomplishes two important insights. First, it establishes the agenda and its goals as universal for «all countries and stakeholders» and secondly, it emphasizes that the SDGs «are integrated and indivisible and balance the three dimensions of sustainable development: the economic, social and environmental» (UN, 2015). In other words, it is acknowledged that the goals are all interconnected, so that it is important to analyze and plan development in a comprehensive way, leaving behind the silo perspective.

The fact that these goals are internationally acknowledged is a great opportunity because it sensitizes the very different actors around the globe in very diverse countries for a same vision and the need to act. So, it gives the world the opportunity to direct efforts and resources towards their achievement.

However, to achieve those goals is at the same time a big challenge because of their ambitious, multi-disciplinary, interconnected and long-term nature. Therefore, it is imperative that the strategies developed to achieve the goals are based on comprehensive and sound analyses addressing their key dimensions in an integrated manner (UN, 1992; UN, 2000; UN, 2014a; UN, 2014b). In addition, we need tools to experiment without real consequences to improve our understanding and learn which strategies and policies avoid undesired consequences and are better able to achieve the goals.

iSDG model as a tool to support the achievement of the SDGs, including the transformation of agriculture

The Integrated Sustainable Development Goals (iSDG) Model, developed by the Millennium Institute (MI) is such a comprehensive simulation tool that can generate country-specific development scenarios to show the implications of policy on a country's progress towards the SDGs (Pedercini et al., 2016). Being the only simulation tool that incorporates the 17 SDGs into a single, integrated framework, the iSDG and its predecessor, the Threshold21 (T21) model, have been evaluated as one of the best analysis and planning tool for the SDGs at the national level (UNEP, 2014; Allen et al., 2016; OECD, 2016,;UN, 2016). Taking into account the interdependency between the sectors and goals, its holistic, multi-sectorial and systems approach helps achieve policy coherence and integration at both policy design and evaluation stages. Hence, the iSDG Model gives policymakers and other stakeholders involved in policy planning the capacity to:

- visualize progress towards each of the SDGs, highlighting specific areas requiring more attention or resources;
- evaluate the likely benefits of proposed policies and strategies, and reduce undesired long-term impacts (up to 2050);
- ensure policy coherence across areas of interventions and facilitate the alignment of SDG strategies with other national development plans; and
- define an efficient policy implementation schedule that facilitates high-impact results and monitors progress towards achieving policy objectives.

For more information on the model, please refer to its homepage (www.isdgs.org), where it is possible to check the documentation for more details on the model itself and to download a demo version of the user interface of the model to test it and play out scenarios.

Once a government or other stakeholders involved in policy planning are interested in MI identifies with its collaboration partner the policies to test, adjusts the model to the country specific circumstances, conducts on-the-spot simulations in multi-stakeholder consultation processes and performs complex policy analyses to support the development of coherent, synergetic strategies to achieve the SDGs.

If requested, the projects can focus on certain sectors, without losing the integrated perspective. For example, the Changing Course in Global Agriculture (CCGA) project that MI implements together with Biovision (see http://changingcourse-agriculture.com), aims at supporting effective, comprehensive and long-term planning of sustainable agricultural development and poverty reduction. Results of our analyses showed that investment in knowledge intensive agriculture has better long-term and multi-sectoral impacts, for example, on social and ecological indicators than investing, for example, in subsidies for fertilizer and pesticides that are also more resilient (MI, 2014; Züllich et al., 2015a, b, c). Such analyses assess the ability of alternative policies to achieve given socio-economic goals, and support the realization of paradigm shifts by providing decision makers with critical information on the long-term multi-sectoral impacts of proposed policies and strategies.

Taking a broader perspective, the iSDG was used in Ivory Coast to analyze the progress of all 17 SDGs by 2030 in three scenarios: the Business as Usual (BAU) scenario (e.g., no policy changes); National Prospective Study (NPS) scenario, reflecting the policies included in the NPS «Cote d'Ivoire 2040»; and SDG scenario, based on the NPS scenario, but including a series of additional interventions for critical aspects that are not sufficiently covered in the NPS (Figure 1, Millennium Institute, 2016). Here, our analysis helped to identify areas that need further improvement and policies that could contribute to a higher achievement of the SDGs, taking into account positive and negative side effects, feedback loops and interactions between policies, sectors and goals.

Gunda Züllich is a Senior Modeller/Policy Analyst at Millennium Institute, Washington, USA.

«I think it is a great achievement and opportunity that the world agreed on a joint vision: the achievement of the SDGs. Now, we have to bear the challenge to find ways how to achieve them. For this, it is essential to better understand the interconnections between different sectors, goals and policies and to learn to take a holistic perspective.»

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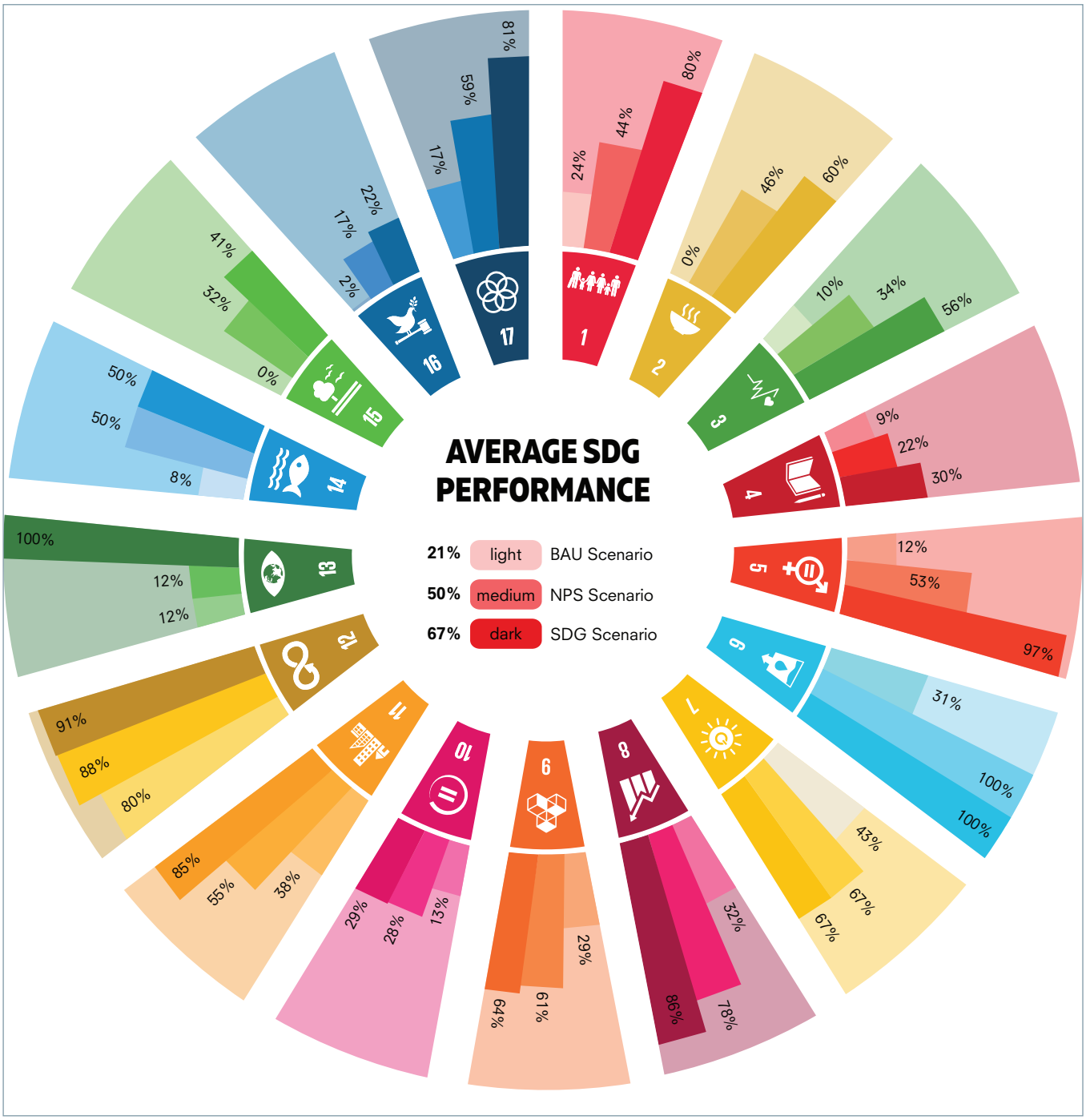

Figure 1. SDG wheel for Ivory Coast: progress on the SDGs in a snapshot in three different scenarios with additional investment (% of GDP) in BAU = 0%; NPS = 4.5%; SDG = 15%. Figure is courtesy of Millennium Institute, 2016

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IV: Socio-economic challenges in sustainable agriculture

The major constraints of transforming into sustainable agriculture are socio-economic causes rather than a lack of possible solutions. Why? Underlying values and norms are sometimes in conflict with the solutions, generating narratives that are shared within communities and imprinted in our behavior. Chapter 4 explores the different normative values and the ethical discourse that is behind different perspectives of a sustainable agriculture.

François Meienberg
Public Eye, Bern, Switzerland

Sustainable access to plant breeding material

Martin Schmid
HEKS/EPER, Swiss Church Aid, Zurich, Switzerland

Access to land: laying the groundwork for development

Philipp Aerni
Center for Corporate Responsibility and Sustainability, University of Zurich, Switzerland

Attitudes towards the role of innovation in promoting sustainable agriculture

Melanie Paschke
Zurich-Basel Plant Science Center, Zurich, Switzerland

Ethical considerations on the two narratives: productivity and sufficiency

Sustainable access to plant breeding material

François Meienberg

Various international regulations govern the access to seeds today: the International Treaty on Plant Genetic Resources for Food and Agriculture, the TRIPS Agreement of the WTO, the Acts of the International Union for the Protection of New Varieties of Plants (UPOV). This chapter will discuss in which way these regulations do support or are in contradiction with human rights obligations, the sustainable development of plant genetic resources and the promotion of innovation and development. The presentation of specific patent cases will help to better understand the current patent policy in Europe and its possible impact on the breeding sector, farmers and consumers.

Farmer's rights are legally confirmed rights to save, use, exchange and sell farm-saved seeds and propagation materials.

When are farmer's rights endangered?

All regulations that strongly protect breeders can put pressure on farmer's rights, e.g., private companies that protect their biotechnologically or conventionally developed seeds through contracts and intellectual property rights as well as international free trade agreements promoting these rights. Not discussed in this article, but also a potential threat to farmer's rights, are seed marketing laws restricting the use farmer bred varieties or landraces or seeds that do not allow the multiplication by farmers.

Why are farmer's rights important?

Today 90% of all farms are defined as «small», holding an average of 2.2 hectares. They occupy just s quarter of the global farmland but are the major food producers in the world (GRAIN, 2014). For these smallholders, owning seeds and propagating them on farm is necessary for accessing food: several field studies revealed that the informal seed system, based on farm-saved seeds and the exchange and sale of seeds by farmers, is the most important system for these smallholder farmers to access seeds (including improved and protected varieties) (Berne Declaration, 2014). The informal seed sector guarantees access to affordable seed for small-scale, resource-poor farmers and protects them from the uncertainties of the formal seed supply (uncertainty in price, availability and quantity) and from the risks associated with high-input agriculture. However, there is interaction between the formal and informal sectors. At one hand, the formal sector is using the agricultural biodiversity developed by the informal seed sector as a basis for its breeding activities. On the other hand, the informal seed sector integrates modern varieties developed by the formal seed sector in its system and further adapts them to local circumstances.

The introduction of legislation or other measures, which creates obstacles to the reliance of farmers on informal seed systems, may violate the obligation of states to respect existing access to adequate food, since it would deprive farmers from a means of achieving their livelihood (UN, 2009; de Schutter, 2009).

Crop diversity and its underlying genetic diversity adapted to local conditions is the treasure that allows to feed the world under environmental change and that produces the diversified diet that prevents malnutrition (Berne Declaration, 2014).

Experts believe that the prevailing policy framework favors «centralized crop breeding and the creation of uniform environmental conditions and discourages agro-ecological research or local breeding tailored to local conditions» (UNDP, 2008). Especially UPOV 1991 (see below) tends to favor commercial breeders and has promoted genetic uniformity in crop varieties. Crop diversity that we have lost we cannot restore.

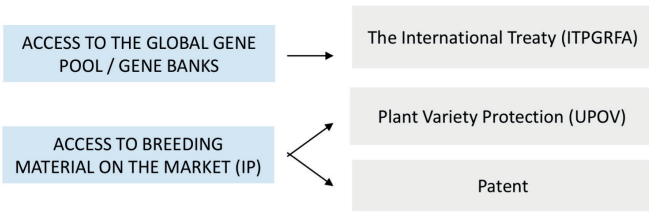

Figure 1. Access to plant breeding material and international regulations

Towards a balanced «sui generis» plant variety regime

New FAO Voluntary Guide for National Seed Policy Formulation (FAO, 2015) has highlighted some key factors to balance farmer's and breeder's rights:

- *«In most developing countries, the informal sector is the main source of seed. The ability to easily access, exchange and use seeds underpins the informal sector and is a crucial practice for facilitating access to seeds.» (FAO 2015: 29)*
- *«The seed policy should address the respective roles of the formal (public and private) and informal sectors in meeting its objectives, ways in which each could be improved, as well as the need for coordination between both components of the seed system.» (Ibid: 31)*

Louwaars and de Boef (2012) suggested that countries develop integrated approaches that strengthen both the formal and informal seed systems and the connections between them, in order to ensure the production of the seeds of crop varieties that are useful for diverse and evolving farming systems.

The International Treaty for Plant Genetic Resources for Food and Agriculture (ITPGRFA)

In 1992 the Convention on Biological Diversity was adopted giving the sovereign rights over plant genetic resources to the countries of origin (United Nations, 1992). Nonetheless, for food crops it can be difficult to determine one clear land of origin for a particular variety. Sometimes plants have even been domesticated at the same time in different parts of the world. In fact, some varieties have been moved across continents and have been used for breeding for several hundred years. An example of this is the «8-Wuchä-Nüdeli» which is an ancient popular Swiss potato cultivar. The potato is originally domesticated in Peru, however, a lot of breeding activity has gone into making the «8-Wuchä-Nüdeli» exactly to the Swiss growing conditions in high altitudes.

As it can be very difficult or even impossible to find the origin of a variety, International Treaty for Plant Genetic Resources for Food and Agriculture (ITPGRFA) was negotiated with the goal to implement the objectives of the Convention on Biological Diversity (conservation, sustainable use and benefit-sharing) in the case of plant genetic resources for food and agriculture (FAO, 2016).

The International Union for the Protection of New Varieties of Plants (UPOV)

The International Union for the Protection of New Varieties of Plants (UPOV) is an intergovernmental organization, which was established in 1961 and is based on the International Convention for the Protection of New Varieties of Plants (UPOV Lex, 2017). The UPOV Convention should strengthen breeder's rights by protecting new plant varieties trough intellectual property rights for breeders. It was adopted in 1961 and revised in 1972, 1978 and 1991. While the two adjustments of the convention in the 1980s did not substantially alter the original system of plant variety protection (PVP), the revision in 1991 expanded and strengthened the breeder's right tremendously by limiting the farmer's rights at the same time. The most important alteration of the convention in 1991 was the scope of the protection of plant varieties as well as of the breeder's rights. Since 1991 the multiplication (production and reproduction) of protected plant varieties have been limited and thus the free use of farm saved seeds and propagation material has been restricted. This has led to a growing dependency on seeds from formal breeders. Although some kind of farmer privileges was established, the alteration of the convention in 1991 had drastic consequences for farmer's rights. Since the adjustment in 1991 farmers are not allowed to exchange seeds. Furthermore, farmers are also not entitled to use propagation material from protected plants that are not the product of the harvested. This means that farmers can multiplicate potatoes harvested in their fields, but they cannot do this with carrots as the seeds used for multiplication are not the product of the harvest (in this case the carrots) (Correa, 2015).

Initially (in 1961), only European countries and the US were part of UPOV. Today UPOV has 72 members of which 24 are developing countries. Whereby, several developing countries are only members due to bilateral pressure from US and European free trade agreements. In contrast, there are also major developing countries like India, Thailand and Malaysia, which are not part of the UPOV and which have their own PVP system.

In general, the UPOV membership and the UPOV convention could have a negative impact on human rights. Especially, in developing countries, where almost 90% of the seeds are not bought on the seed market but breed and developed by local farmers. The UPOV convention causes tremendous problems regarding the accessibility of seeds:

- UPOV–1991 restrictions on the use, exchange and sale of farm-saved PVP seeds will make it harder for resource poor farmers to access improved seeds originating from the formal sector.
- With the restriction to sell protected varieties farmers will lose an important source of income.

UPOV–1991 restrictions on the use, exchange and sale of farm-saved PVP seeds, could negatively impact the functioning of the informal seed system, as the beneficial interlinkages between the formal and the informal seed system will be cut-off.

- All of this could contribute to increased food insecurity (Correa, 2015; Berne Declaration, 2014).

Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS)

All members of the World Trade Organization (162 countries) were obliged to sign the Agreement on Trade-Related Aspects of Intellectual Property Right (TRIPS) which was adopted in 1994 (WTO, 1994). TRIPS should ensure minimal protection standards by Intellectual Property Rights. Thus, any invention (product or process) that is new, innovative and useful (capable of industrial application) should be patentable. However, each ratifying country can individually decide whether it will exclude «[…] plants and animals other than micro-organisms, and essentially biological processes for the production of plants or animals other than non-biological and microbiological processes.» from patentability.

Patents on seeds

While European Countries in the European Patent Convention (38 member countries) do not accept to be patentable «plant or animal varieties or essentially biological processes for the production of plants or animals; this provision shall not apply to microbiological processes or the products thereof» (Art. 53), the implementation regulation, Rule 27 allows: «Biotechnological inventions shall also be patentable if they concern: (b) plants or

ITPGRFA in brief
Adopted: 2001
In force since: 2004
143 Contracting Parties

Comment: The ITPGRFA regulates the access to the global gene bank's resources. The objective of the treaty is to facilitate the use of plant genetic resources for food and agriculture, and to make sure that the benefits are distributed sustainably. This treaty was adopted in 2001, and is in force since 2004. The ITPGRFA includes 140 contracting parties. The United States will join the Treaty in March 2017. Countries, which ratify the ITPGRFA, agree to make their genetic diversity and related information available about crops stored in their gene banks.
In this treaty farmer's rights are very well recognized in paragraph 9 while benefit sharing is regulated in the chapter on the multilateral system. However, it has to be noted that so far (after more than 10 years) no mandatory user-based payments (benefit-sharing) have been made. Therefore, in 2013 the Governing Body of the Treaty decided to review the multilateral system in order to increase user-based payments in a sustainable and predictable long-term manner. The review is still going on.

From the text of ITOGRFA
1.1 The objectives of this Treaty are the conservation and sustainable use of plant genetic resources for food and agriculture and the fair and equitable sharing of the benefits arising out of their use, in harmony with the Convention on Biological Diversity, for sustainable agriculture and food security.

9.1 The Contracting Parties recognize the enormous contribution that the local and indigenous communities and farmers of all regions of the world, particularly those in the centres of origin and crop diversity, have made and will continue to make for the conservation and development of plant genetic resources which constitute the basis of food and agriculture production throughout the world.

9.2 […] each Contracting Party should, […] take measures to protect and promote Farmer's Rights, including:
(a) protection of traditional knowledge relevant to plant genetic resources for food and agriculture
(b) the right to equitably participate in sharing benefits arising from the utilization of plant genetic resources for food and agriculture; and
(c) the right to participate in making decisions, at the national level, on matters related to the conservation and sustainable use of plant genetic resources for food and agriculture.

9.3 Nothing in this Article shall be interpreted to limit any rights that farmers have to save, use, exchange and sell farm-saved seed/propagating material, subject to national law and as appropriate.

10.2 […] the Contracting Parties agree to establish a multilateral system, […] both to facilitate access to plant genetic resources for food and agriculture, and to share, in a fair and equitable way, the benefits arising from the utilization of these resources, […].

13.2.d) (ii) […] a recipient who commercializes a product that is a plant genetic resource for food and agriculture and that incorporates material accessed from the Multilateral System, shall pay …, an equitable share of the benefits arising from the commercialization of that product, except whenever such a product is available without restriction to others for further research and breeding, […]

UPOV in brief (UPOV Lex, 2017)
Adopted: 1961 (only European countries and the US)
Revised (with stronger IP Rights): 1972,1978, 1991
73 members. About 24 are developing countries (14 are members of UPOV–1978 and 10 are members of UPOV–1991). In addition, also the African Intellectual Property Organization (OAPI) is a member – including 16 francophone African countries.

Comment: It is a well-known fact that several of the developing countries that joined UPOV–1991 e.g., Morocco, Peru, Dominican Republic, Costa Rica, Jordan, Oman, Panama have done so due to bilateral pressure from US/EU free trade agreements. In UPOV farmers` rights are inexistent (with exception of a farmer's privilege, see Art. 15.2), e.g., the objective of the Convention is the protection of new varieties of plants by an intellectual property right (=breeder's rights). Some major developing economies (e.g., Argentina, China, Brazil) continue to be members of UPOV–1978. Some developed countries (e.g., Norway are still members of UPOV–1978). Other major developing economies e.g., India, Thailand, Malaysia have not joined UPOV but have developed alternative sui-generis plant variety protection systems, differing in a smaller or bigger extend from the framework developed by UPOV. Today for new members wishing to join UPOV the only possibility is to join UPOV–1991. The option of acceding to UPOV–1978 is no longer available.

From the text of UPOV
UPOV –1991 Art. 14 (a) Subject to Article 15 and Article 16, the following acts in respect of the propagating material of the protected variety shall require the authorization of the breeder:
(i) production or reproduction (multiplication),
(ii) conditioning for the purpose of propagation,
(iii) offering for sale,
(iv) selling or other marketing,
(v) exporting,
(vi) importing,
(vii) stocking for any of the purposes mentioned in (i) to (vi), above.
(b) The breeder may make his authorization subject to conditions and limitations.
Art. 15.2 (Optional Exception):
Each contracting Party may, within the reasonable limits and subject to the safeguarding of the legitimate interest of the breeder, restrict the breeder's right in relation to any variety in order to permit farmers to use for propagating purposes, on their own holdings the product of the harvest which they have obtained by planting, on their own holdings the protected variety.

TRIPS in brief (WTO, 1994)
Adopted: 1994
162 Parties (all WTO Members – extended transition period for Least Developed Countries)

Comment: Some member countries use the flexibility enshrined in paragraph 27.3b, for example India, Indonesia or Brazil, to exclude plants, animals and essentially biological processes for the production of plants or animals from patentability, while the Philippines or South Africa only exclude patents on plant varieties (but not on plants in general). The US, but not Europe, grant also patents for plant varieties.
From the text of TRIPS
27.1
1. Subject to the provisions of paragraphs 2 and 3, patents shall be available for any inventions, whether products or processes, in all fields of technology, provided that they are new, involve an inventive step and are capable of industrial application.
27.3.
Members may also exclude from patentability:
b) plants and animals other than micro-organisms, and essentially biological processes for the production of plants or animals other than non-biological and microbiological processes. However, Members shall provide for the protection of plant varieties either by patents or by an effective sui generis system or by any combination thereof. […]

animals if the technical feasibility of the invention is not confined to a particular plant or animal variety» (European Patent Office, 2016).

Rule 27b is an extremely important exception to what Europe has seen as patentable or non-patentable until now and resulted in an increase of patens on conventional-bred seed and varieties since 1995.

Opposition against patents on native traits

The European Parliament (EP) in its Resolution of 10 May 2012 on the patenting of essential biological processes (2012/2623(RSP)) «Calls on the EP also to exclude from patenting products derived from conventional breeding and all conventional breeding methods, including SMART breeding (precision breeding) and breeding material used for conventional breeding» (EP, 2012). The German government, The European Seed Association (ESA), NGOs and farmers organizations are against patents on conventional bred plants and 2 million citizens signed a petition by Avaaz against patents on seeds (Meienberg et al., 2013).

From natural pepper to a patented plant

An example for a patent on a conventional plant is Syngenta's capsicum patent. Syngenta found a quantitative trait loci (QTL), responsible for the resistance against thrips and whiteflies in a wild peeper plant form Jamaica, and breed it into a common capsicum variety by conventional breeding methods. Finally, Syngenta could patent the new plants.

An opposition was filed by Public Eye in 2016 and other NGOs based on the following consideration:

- plant varieties are not patentable: The patent claims plant varieties that are not patentable according to the European Patent Convention (EPC) Art. 53(b);
- discoveries are not patentable: according to (EPC) Art. 52 (2) (a), discoveries are not considered as inventions and are thus not patentable;
- lack of novelty: the patent lacks novelty. In the literature, several pepper plants have already been reported as being resistant to bemisia; and
- lack of inventive step: as the product claims are essentially characterized by the manufacturing process (product-by-process claims) and this manufacturing process is not considered an inventive step according to (EPC) Art. 56, the product claims themselves do not present an inventive step either.

Patents enforce concentration

The International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD, 2009) identified the following problems arising from concentration:

- concentration to a handful of suppliers leads to concentration in research, and the development of only a few varieties of seeds;
- concentration impedes market entry for new companies;
- the anti-competitive effect can lead to a massive increase of seed prices. For example, prices for cotton seed have increased by three or four times since genetically modified (GM) cotton was introduced in the United States and there was a substantial increase in prices in developing countries as well (Berne Declaration, 2013).

Conclusion

Patents on genes or plants, as well as Plant Variety Protection laws without any balance between farmer's and breeder's rights have huge interlinked impacts on (1) the income and the access to plant breeding material for breeders, (2) farmer's rights, costs and choice, (3) the choice of the consumers, (4) the quality and price of agricultural products, as well as (5) impacts on biodiversity. Thus, these IPRs and their interlinkage area between farmer's and breeder's rights are big political and social issues of modern society and directly or indirectly linked to food insecurity, social inequality and environmental problems.

On a global scale only a few seed companies control the market and these are often also big players in the pesticide production. This oligopoly leads to reduced diversity in the varieties sold, farmer dependency, food insecurity and new questionable (unsustainable) breeding goals. The tipping point where patents support innovation has been reached a long time ago. Nowadays, patents on plant breeding material are inhibiting the innovation process of the breeders (Berne Declaration, 2013).

However, there is light at the end of the tunnel regarding the patent policy in Europe. A powerful opposition coalition is arising which includes the German, Dutch and French government, ESA, NGO's, and farmer organizations, as well as citizen groups.

DISCUSSION

How do patents work on a free market?
Plant patents are granted on country or regional level, and are a tool to control the market of the patented plant. François Meienberg described a case where Monsanto tried to file for a patent on herbicide resistant (genetically modified) soy in Argentina. The patent was rejected in Argentina. In reaction to this, Monsanto tried to stop all import of Argentinian soy flour to Europe. Monsanto claimed that import would be violating their patent rights within Europe. In the end, the European Court of Justice refused the claim with the explanation that the Monsanto Patent import of soy flour would not limit the company's possibility of selling GM soy seeds in Europe.

How many patents are known? Is it a significant amount and thus a very relevant issue?
There are more than thousand varieties covered by patents on food plants and seeds in Europe to date. But more important is that the varieties covered by one patent are often unknown. For breeders and breeding companies this can be rather problematic because if they breed with a protected variety (even without their knowledge), the new variety with the protected gene sequence or characteristic, will fall into the hands of the patent owner. For example, today more than 500 lettuce varieties (probably most of the varieties for sale) are covered by one patent.

Milena Wiget, Anna Kaja Hoeyer, Karolina Slominska and Melanie Paschke contributed to the reporting of François Meienberg's presentation.

«The seed policy of the future should promote the farmer-led seed system and the commercial company led seed-system. Intellectual Property Rights promoting the development of new varieties adapted to ecological agriculture will be designed to not be in contradiction with farmers' rights and will not hamper the right to food. Thus Intellectual Property Rights will safeguard biodiversity and promote innovation.
The ones who commercially benefit from the use of agricultural biodiversity will contribute to the conservation and sustainable use of genetic resources.»

FRANÇOIS MEIENBERG
Public Eye, Switzerland

François Meienberg is a specialist in intellectual property rights of seeds. For 18 years he has worked for Public Eye (formerly known as the Berne Declaration). Public Eye is a Swiss non-governmental organisation (NGO) with 25.000 members, which fights against injustice in poorer countries due to companies and regulations in Switzerland.

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Access to land: laying the groundwork for development

Martin Schmid

Restricted and endangered access to land and resources has proven to be one of the major obstacles to the development of rural communities, which are in the center of HEKS/EPER's work. As a consequence of the urgent needs to secure access to land and HEKS/EPER's longstanding experience in development work, a substantial number of HEKS/EPER projects have focused and are focusing on enhancing access to land and resources for rural communities.

The reasons why access to land is crucial for the development of rural communities is manifold: agriculture is the predominant source of income for rural communities and a secured access to land and resources is the basis for any agricultural production and the development of agricultural based market systems. Beyond the classical crop cultivation, a secured access to land is required for other basic livelihood strategies, for example access to pasture land, possibilities for collecting fruit and firewood, the fulfillment of housing requirements. Furthermore, secured access to land is important for the spiritual attachment of a group and thus the maintenance of a feeling of belonging and cultural identity as well: over 90% of the 570 million farms in the world are run by individuals or families and 72% of the farms on global scale are smaller than 1 hectare, but control only 1% of the global agricultural land (FAO, 2014).

Access to land and resources means, in the view of HEKS/EPER, that people have secured rights to land ownership and/or land use, and that they can control, manage and use the land and affiliated resources in the long term. Depending on the context, HEKS/EPER's work focuses on four aspects:

- Supporting people and communities in their legitimate endeavors to have secured access to land and resources.
- Enhancement of processes and institutions resolving land conflicts and harmonization of rules and laws.
- Assisting populations that have access to land and that use its resources in safeguarding it against outside interests on the basis of the laws in force.
- Supporting people and communities in investing in land and in managing their land more productively and sustainably in order to secure access to land in the long-term (sustainable agricultural production and development of inclusive market systems).

Since 2009 HEKS/EPER has been actively involved in analyzing the interplay between access to land and development endeavors.

It seems that population growth, possibilities of quick gains through global financial investments, changing food consumption habits in new emerging economies as well as environmental stresses among other factors have exacerbated violent conflicts over land. The current literature dealing with the subject of «land grabbing» predominantly assesses the situation from a global perspective. HEKS/EPER's analysis goes beyond the land grabbing discourse and proposes an analysis that starts at the local level and examines triggers, key causes and amplifiers that constitute and enforce land conflicts. Based upon the analysis an appropriate intervention, strategy can be defined (HEKS/EPER, 2015).

From local to international: key issues around access to land

In the international development discourse on access to land, three different perspectives may be distinguished: a) rural development; b) human rights; c) economic policies underlining the cross-sectorial nature of access to land. Although problems around access to land are mostly accompanied by open or latent conflicts the conflict perspective as a fourth perspective is under-represented in the current literature (HEKS/EPER, 2015).

Access to land is a highly complex issue not only discussed in many different thematic contexts, but also on many different levels. However, the different perspectives add to the understanding of the complexity around securing access to land for the poor and marginalized, as well as dealing with the sources and consequences of land conflicts. Summarizing the different processes of the development discourse, the following main issues are divided in local, national and global level.

Local level: among the most common conflicts are disputes over land between different groups of users (e.g., farmers versus pastoralists) and communities losing their land to investors due to land leases or purchases for agricultural production, natural resource extraction, or financial investments. Yet land is the central resource, which smallholder farmers need to have access to in order to be able to make their living through agriculture. Local land conflicts arise especially where national legislation does not consider predominant, traditional forms of land tenure sufficiently (communal, well-negotiated norms). Unfortunately, the modern legislation rarely protects the communal rights, with a consequent increase of inequity in land distribution.

National level: national food security and poverty reduction strategies are interlinked closely to the issue of land. Unequal

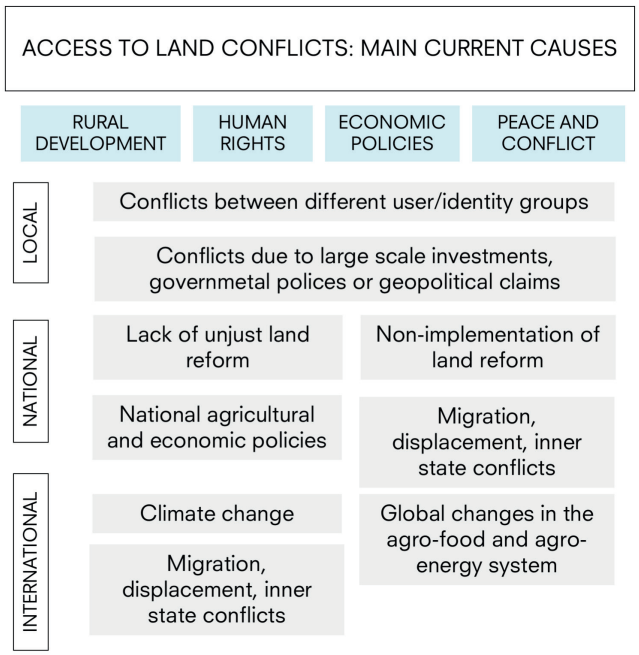

Figure 1. Illustration of different approaches with regards to access to land and the key issues at different levels

land distribution is a problem in many developing countries and agrarian reforms by national governments, which take up issues related to access to land, are crucial. Depending on the existence and quality of respective national policies, this covers the demand for the implementation of agrarian reforms. In addition, agricultural, economic and other policies also have an impact on access to land, depending on the incentives set by national governments.

Global level: in recent years, the impacts of global developments and policies have been in the focus of the debate around access to land, with the most prominent issue being land grabbing in developing countries. Most of the debate focuses on the consequences of investment in land in the context of agriculture and energy supply in developing countries. For example, since 2006, between 500 and 1.200 large-scale land grabs have taken place, which cover between 30 and 42 million hectares of land in 78 countries (GRAIN, 2016; Nolte et al., 2016). In addition, land degradation due to climate change (e.g., UN Convention to Combat Desertification) and the consequences of global environmental policies (e.g., REDD+) have also been a focus.

Due to the crosscutting nature and high complexity of access to land, many projects and programs in developing countries tend to focus on specific aspects and neglect other important aspects. HEKS/EPER therefore tries to take all the different perspectives and levels into account in his work related to access to land.

HEKS/EPER analytical framework: causes of restricted access to land

Having a clear picture of the main points of a land related conflict, be it latent or violent, an analysis of the causes is necessary. In 2014, HEKS/EPER developed an analytical framework, which allows distinguishing different clusters of causes of restricted access to land. This includes socio-political as well as economic drivers that amplify or exacerbate existing land conflicts. These may be clustered in two categories: in prevailing conditions, which describe social, political, historical, economic and environmental challenges from a macro perspective; and in governance and enabling environment, which cover land related governmental, juridical issues and deal with the communities' ability to claim their rights on access to land and resources. These two clusters are based on HEKS/EPER's experience in addressing land related conflicts in its projects over the last couple of years. Figure 3 summarizes these different core problems of causes, which are at stake across HEKS/EPER projects and programs.

After the status of a conflict has been framed, the causes and drivers are identified. Customized intervention strategies can be developed, which help the local population to achieve the set goals.

Two case studies illustrating HEKS/EPER endeavors related to access to land

Claiming access to land in Brazil

The Cerrado region, the biologically richest savanna ecosystem in the world is under threat from expanding large-scale cultivation of soybean, sugarcane and eucalyptus, extensive cattle ranching, as well as major mining projects. HEKS/EPER works with different population groups in the Cerrado who have either lost or risk losing their territory. The HEKS/EPER partner organization Centro de Agricultura Alternativa (CAA), is supporting these population groups in their struggle for the recognition and securing of their territorial rights, as well as the formulation of sustainable development plans for the use of their regions.

Different strategies such as information and legal advice on land rights, boosting organizational capacities and negotiation skills, networking of groups and sharing of experiences, informing and sensitizing the domestic and international public, and building and strengthening of producer groups and marketing networks led to the recognition and demarcation of about 200.000 hectares of land between 2009 and 2016, the recognition of traditional communities and the building of a culture of community organization and citizen participation and formation of a growing role of local actors in the struggle to defend rights.

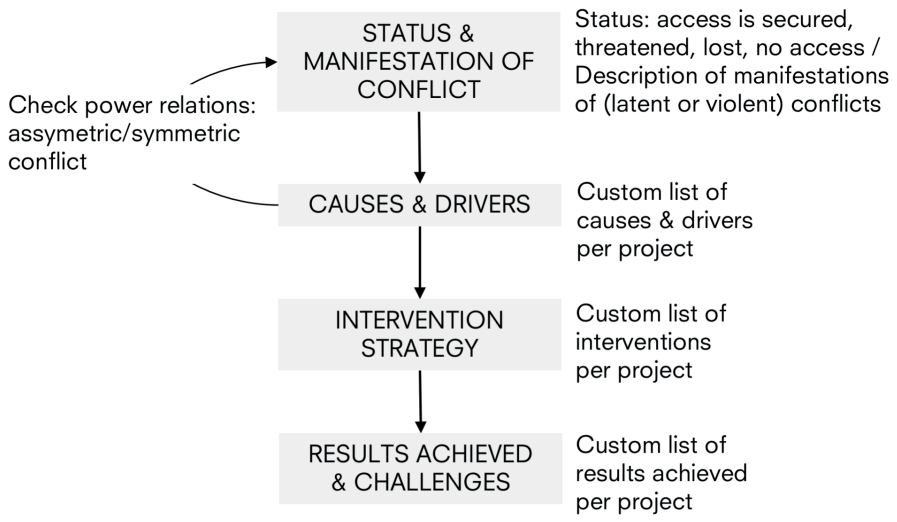

Figure 2. Methodological approach of HEKS framework of analysis

Access to land for pastoralists in Niger

To adapt to the climatic conditions in the Sahel region, dominated by dry and rainy seasons, the pastoralists in Niger follow a century old pattern of mobility. With their herds they migrate in a yearly cycle from the North to the South of the country and back, in search for adequate pasture and water to raise their animals and in order to guarantee a balanced use of the scarce resources in the whole region. More than 80% of the population of Niger is dependent from agriculture and livestock. A transhumant system is applied for about 70% of the droves in Niger.

The South of Niger is dominated by sedentary agriculture. Recurrent drought and population growth have led to increasing pressure on natural resources, which brought the sedentary population to cultivate their crops in the passage corridors, where the pastoralists traditionally used to pass through. This has led to conflicts between the two population groups.

In order to countervail the different problems and conflicts arising between pastoralists and sedentary farmers and to foster a sustainable use of natural resources, the Government of Niger put in place in 1993 the «Code Rural», a law that regulates the land use of the sedentary population, but also guarantees right of use of passage routes for the pastoralists. The idea of the law is to set up «land user commissions», involving government officials, traditional authorities and representatives of both user groups as well as the civil society, on all administrative levels, who will negotiate and agree the use of the contested land. The setting up of the commissions, however, has so far only proceeded slowly.

With the Zamtapo project, which started in 2011, HEKS/EPER facilitated the forming of the required land user commissions in the Southern district of Mayayi and supports them in their process to negotiate and agree on land user rights for sedentary farmers and pastoralists.

An important instrument to reconcile the conflict potential between the two groups is the clear demarcation of passage corridors for the pastoralists and their herds. The land user commissions are in charge to lead these negotiations between all parties involved, as well as to monitor the compliance with the agreed rules and to mediate in case of conflict.

Between 2011 and early 2016, 61 inter-communal forums have been conducted, 971 km of corridors have been established and mapped, 19 mediations have been conducted by the established structures of the Rural Code, 200 acts of land tenure transactions have been facilitated, 37 pastoral wells have been built, the pastoral corridors are frequently used by transhumant and there is clear evidence of a reduction of conflicts between cattle breeders and sedentary farmers within the project zone.

Carole Epper and Johanna Rüegg
contributed to the reporting of Martin Schmid's presentation.

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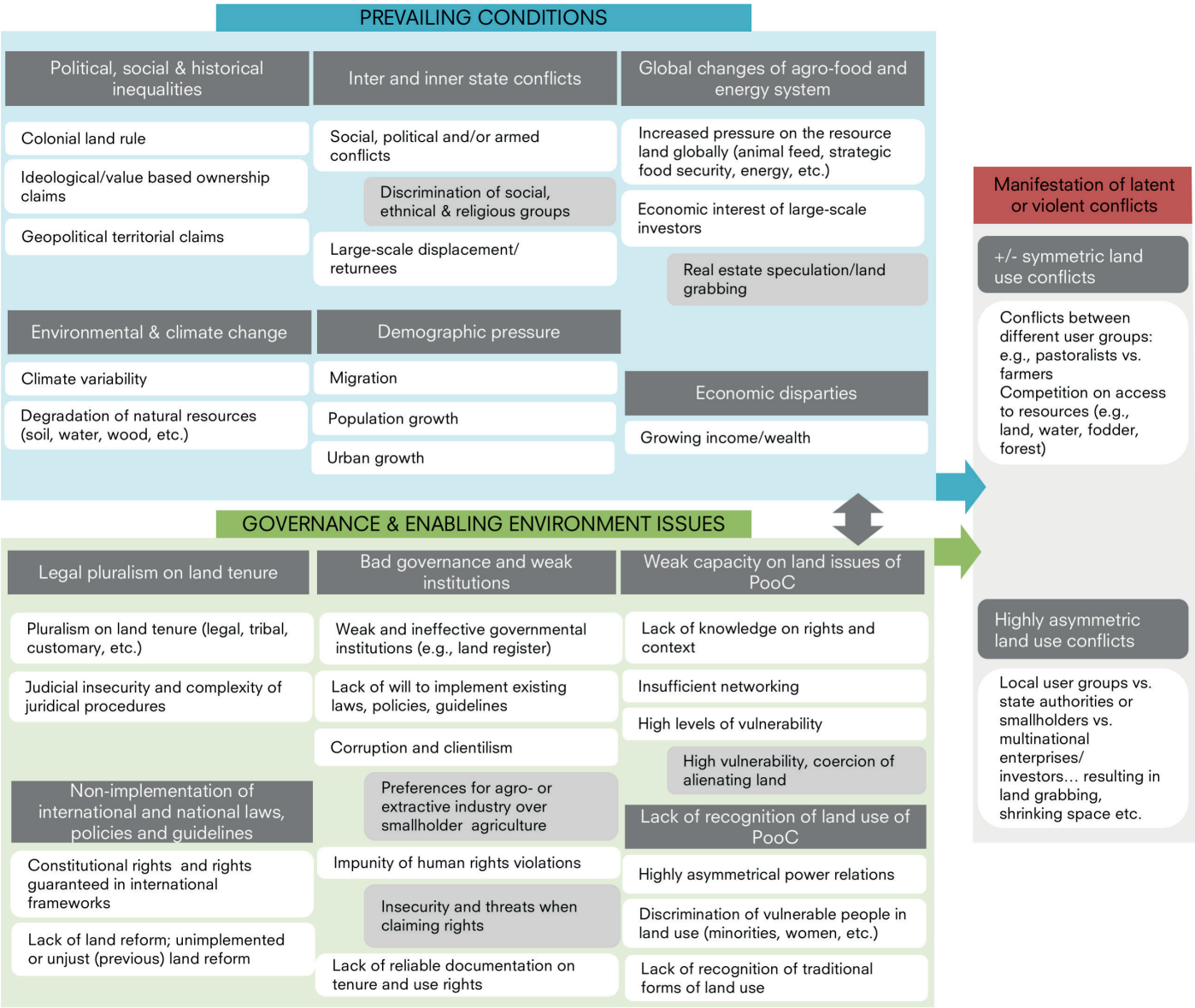

Figure 3. Cluster of causes of restricted access to land and land conflicts

MARTIN SCHMID
HEKS/EPER, Switzerland

Martin Schmid is the head of the HEKS/EPER`s Thematic Advisory Team. HEKS/EPER is the aid organization of the Swiss Protestant Churches and promotes and works towards a more humane and more equitable world, assisting people and communities to overcome economic, social or humanitarian disparities in order to gain autonomy and to live in dignity. Its International Division is based in Zurich (headquarters) and Lausanne. In 2016, HEKS/EPER delivers its results with 140 international and 38 headquarters staff members together with more than 100 partner organizations in more than 200 projects in 30 countries.

Attitudes towards the role of innovation in promoting sustainable agriculture

Philipp Aerni

This apparent global consensus on the main objectives of sustainable development as expressed in the Sustainable Development Goals, approved by the United Nations General Assembly in September 2015 cannot conceal the disagreement on how to achieve these objectives.

The disagreement on the «right» approach to achieve sustainable development is particularly strong in the field of agriculture. The divide is not just characterized by the dissent on the use of agricultural biotechnology but also reflects a trend in the growing non-farming urban population in More Developed Countries (MDCs) to regard agriculture as a life-style that needs to be preserved rather than a business that needs to grow.

This stands in contrast to the needs of many Less Developed Countries (LDCs) that must invest in the process of structural change in agriculture through entrepreneurship and innovation in order to cope with the growing demand for more and better food.

Depending on whether a country finds itself at the beginning or at the end of structural change, different strategies, technologies and policy instruments may be relevant to achieve sustainable agriculture. But this differentiation is often difficult to communicate in public, and political stakeholders involved in the national and global debates on sustainable agriculture may often have their particular constituency in mind rather than the public interest at large.

What do we mean with sustainable development in general and sustainable agriculture in particular?

According to the 1987 report of the World Commission on Environment and Development, sustainable development must «meet the needs of the present generation without compromising the ability of future generations to meet their needs» (Brundtland Report, WCED, 1987). In view of population growth and increasing affluence, this also means that sustainability is not just about preserving the environment for the next generation but also investing in innovation that allows us to produce for more people without the need to further deplete our natural resource base.

The UN Conference on Environment and Development (UNCED) in 1992 was based on the idea of intergenerational responsibility. The 27 principles of the UNCED's final declaration (Rio Declaration) have been reaffirmed in the Sustainable Development Goals (SDGs), passed by the UN General Assembly in September 2015. The SDGs combine the objectives of the Rio Declaration with the ones of the Millennium Development (MDGs) and aim at meeting its 17 goals by 2030 (Agenda 2030).

However, despite the general agreement on the principles and objectives of sustainable development, disagreement on how to implement them in an effective way remains widespread among influential stakeholders involved in national and international debates on sustainable development as well as between MDCs and LDCs. The official document of the Rio+20 Summit «The Future We Want» in 2012 confirmed indirectly that there is no «We» in the sense that «…there are different approaches, visions, models and tools available to each country, in accordance with its national circumstances and priorities, to achieve sustainable development in its three dimensions which is our overarching goal» (Paragraph 56). This statement has to be respected because different stages of economic development require different policies to promote sustainable development. In an early stage of economic development, poverty may be the biggest enemy of sustainable development, in the period of rapid catch-up growth it may be affluence that poses the biggest threat to social and environmental sustainability. But, finally, affluence may become means to fulfill the ends of sustainable development in the post-material stage of economic development (Turner & Fischer-Kowalski, 2011).

A problem may however emerge when sustainability policies designed for MDCs are adopted by LDCs that are still in a very early stage of economic development. This applies to the agriculture in particular. Recent international reports (Interagency Report, 2012; World Bank, 2012) and an extensive needs assessment on capacity development for agricultural innovation in tropical countries conducted on behalf of the Tropical Agriculture Platform (TAP) secretariat at FAO (Aerni et al., 2013) revealed that investment in capacity development for agricultural innovation in tropical countries tends to suffer from a misalignment between the priorities of Overseas Development Assistance (ODA) and the priorities expressed by national stakeholders in LDCs in the tropics. This misalignment is primarily rooted in the preference for individual capacity development in donor countries and the preference for institutional capacity development in recipient countries. The misalignment is also the result of the belief of many stakeholders in ODA that sustainability policies that apparently work in developed countries may also work for developing countries. Preferences of donor in MDCs tend to prevail in development assistance since development organizations are primarily accountable to those who pay (the donor in developed countries),

not those who receive (the poor in developing countries). It is the classic principal-agent problem that remains unresolved in development assistance (Aerni, 2006).

The Paris Declaration on Aid Effectiveness, passed in 2005 by OECD donors, was the last effort to address this misalignment. In this declaration donors commit themselves to align their foreign aid program to the development priorities set by national governments in developing countries. The commitment was reaffirmed in the Busan Partnership for Effective Development Co-operation in 2011 (Fourth High Level Forum on Aid Effectiveness). However, none of this has resulted in any binding agreement or international treaty so far.

Sustainable technological change and the precautionary principle

The recommended means of implementation in the «Future We Want», the official document of Rio+20, were focused on mobilizing finance, investment, youth, science & technology, capacity and trade for sustainable development (Paragraphs 252–282) for the purpose of eventually creating a global «green economy». The SDGs largely follow this insight that change is necessary to make the world more sustainable in view of population growth and growing affluence.

However, behind this apparent affirmation of sustainable change there is considerable disagreement on the proper understanding of the term. Different parties have very different conceptions of sustainable finance, investment, science and technology, capacity development and trade. For example, the repeated emphasis on clean and environmentally sound technologies in the document implies for some stakeholders that this would exclude an important platform technology such as biotechnology while others consider it to be an essential part of it. The controversy over the role of biotechnology in general and genetic engineering in particular is strong when it comes to the definition of sustainable agriculture and sustainable intensification in particular. Opposition to agricultural biotechnology is mainly related to the claim that the long-term risks of this technology may be potentially irreversible and therefore harm humankind and the environment rather than benefit it. In return, supporters claim that excluding an important technology such as biotechnology to address unresolved sustainability problems is not conducive to sustainable change. In this context, both sides make use of the Precautionary Principle (PP) to justify their stance in the name of sustainable development (Aerni et al., 2016). According to Principle 15 in the Rio Declaration, the PP says that scientific uncertainty regarding potential sustainability risks shall not prevent us from taking action now. The opponents of agricultural biotechnology interpret it as a justification of banning the use of genetic engineering in agriculture despite the lack of scientific evidence of harm to society and the environment. Supporters instead argue that we face many global environmental and socioeconomic challenges, such as mitigating man-made climate change and ensuring global food security. Even though we still face some scientific uncertainty about the effects of climate change, we should take action now by making use of all technologies available. This must include the techniques of modern biotechnology, so they argue.

Current public opinion and regulation of genetically modified (GM) crops in Europe and elsewhere suggest that the interpretation of the PP by the opponents of agricultural biotechnology has prevailed in the political decision making process. The PP may have become a political instrument to promote a particular version of sustainable agriculture that excludes the use of agricultural biotechnology in order to appease a constituency that perceives the technology to be a major threat to humankind (Paarlberg, 2001). It makes the public prone to a culture of fear and heteronomy in moral judgment (Furedi, 2002, Sunstein, 2005). Despite all that, GM crops have been cultivated and consumed for more than 15 years and adoption rates are growing particularly fast in developing countries (Aerni et al., 2016).

A north-south divide in the perception of sustainable agriculture?

It is difficult to keep controversies in the public debates on sustainable agriculture in affluent and developing societies strictly apart because the globally organized stakeholders that shape the international public debate on sustainable agriculture are also widely represented in the national debates. Nevertheless, the sustainability challenges in countries that are at the beginning of structural change in agriculture may be quite different from the challenges in countries that have already reached a mature stage in the agricultural structural transformation process. For example, small-scale farming in LDCs is not considered to be a sustainable life-style as in developed countries; but rather a harsh destiny with little future prospects (Gilbert, 2012) – and whereas the major concern in developed countries is that farms are becoming bigger, the major threat in LDCs is that farm sizes are shrinking continuously (due to high population growth and lack of off-farm employment) to a level that makes it impossible to even feed a household, no matter if it embraces sustainable agricultural practices or not (Hollander, 2003).

Global concerns framed in the local context

In MDCs and LDCs, national discussions revolve around the importance of local culture and traditions in national agriculture for the well-being of its farmers and consumers, as well as agricultural sustainability. This discussion tends to be actively shaped by global stakeholders originating from the global North who tend to frame global technological and economic change as a threat to such local cultures and traditions (Cochrane, 2008). This position is popular on the right and the left wing of the political spectrum, even in the global South, because it tends to address the national fears of colonialization and dependence as well as of foreign-induced environmental contamination with potentially irreversible effects (Nanda, 2003). This defensive and identity-oriented point of view ignores that the evolution of agriculture and its practices are largely based on exchange and

trade rather than protection of agricultural resources (Kingsbury, 2009). Historically, the popularity of the protective and conservationist perspective, as it is expressed by the global cultural and political elite, has always had a significant impact on future agricultural and environmental policies, as well as corporate investments not in MDCs but also in LDCs (Kingsbury, 2009).

Sustainable agriculture in developing countries in tropical countries

Agriculture is increasingly at the core of efforts to make the planet more sustainable, but, at the same time, agriculture may also be most affected by global environmental change. Especially tropical agriculture is likely to suffer most from the possible adverse consequences of global climate change (FAO, 2011). Moreover, tropical agriculture also faces most of the challenges regarding the sustainable management of ecosystem services, the conservation and sustainable use of biodiversity, and the economic empowerment of rural people, especially indigenous people and women.

Finally, tropical agriculture is also in great need to become more productive in order to secure the needs of its own growing population for food, fiber and fuel, and eventually to also grow through an export-oriented agricultural sector that takes advantage of the growing demand for high value agricultural products in Asia where a large middle-class is emerging. The changing diet of the Asian middle-class in terms of quantity (calories / capita) and quality (animal proteins / capita) will be an opportunity for tropical agriculture, as well as a challenge that needs to be addressed through innovative forms of sustainable intensification (Foresight, 2011).

Nevertheless, the national public debates on sustainable agriculture in African countries tend to be defensive rather than progressive, which explains why most African countries have banned the commercial use of agricultural biotechnology or face a popular resistance movement that has stalled the approval process of GM crops. This stands in contrast to the Comprehensive African Agricultural Development Program (CAADP) that has been approved by the African Union (AU) and the New Partnership of African Development (NEPAD). The main purpose of pillar 4 of the CAADP framework is to improve agricultural research and agricultural systems in order to disseminate new technologies in a sustainable way. The ambitious and comprehensive vision of this Africa-led and Africa-owned initiative is to achieve an average annual growth rate of 6 percent in agriculture. However, so far only few countries in Africa have been able to revive their national agricultural innovation systems to achieve the desired growth rates through endogenous development. According to the synthesis report of the Tropical Agriculture Platform (TAP) based at FAO in Rome (Aerni, 2013), this failure is strongly related to donor agendas that have a defensive understanding of sustainable agriculture. Yet, this defensive agenda is not respecting the progressive goals of the CAADP (Ojijo, 2013), and, as a consequence, it fails to respect the principles of the Paris Declaration of Aid Effectiveness.

Fighting new agricultural technologies and more opposing global agricultural trade in the name of national self-defense chimes well with popular movements such as the food sovereignty movement in MDCs, mostly based in Europe, as well as in LDCs, mostly based large emerging economies such as India, China and Mexico (Mittelman, 2000, Aerni, 2011). These LDCs identify agricultural modernization with increased dependence of farmers on large US-based multinational corporations and loss of local culture, as it is portrayed by anti-globalization activists (Castells, 2011). At the same time, all these large emerging economies invest heavily in the build-up of their own agricultural research capacity, especially in the area of agricultural biotechnology. Their bold industrial policies in agriculture also explain why they have already achieved a major transformation in agricultural development with all its desirable (reduction of poverty, emergence of an empowered middle class) and undesirable (dislocation of the rural poor, environmental problems, unsustainable urbanization) side effects (Liu et al., 2011).

Sustainable agriculture in MDCs in temperate zones

Unlike in LDCs in tropical regions, where poverty is widely considered to be the biggest enemy of sustainable development, people in the MDCs of temperate zones tend to see affluence and industrial, agricultural as the drivers of unsustainable consumption and production of food (Pollan, 2006). As a result, agricultural and environmental policies in affluent countries are mainly designed to protect farmers against the potential risks attributed to the negative impact of technological change and global trade. In Europe, a complex system of direct payments and eco-payments has been designed by the European Union to compensate farmers for the provision of environmental services and other positive externalities that result from extensive sustainable agricultural practices. These policies are based on the concept of multifunctional agriculture that aims at addressing the non-trade concerns of agriculture. This concept is based on the assumption that farming provides public services (e.g., environmental stewardship, decentralized settlement, etc.) that are not valued by the market. Yet, since taxpayers value these public services, the government feels authorized to pay farmers for providing them (van Huylenbroeck & Durand, 2003). This system is however implicitly based on the assumption that entrepreneurship and innovation, the major drivers of structural change, are part of the problem, rather than part of the solution (Aerni, 2009). This may also help explain the popularity of organic agriculture, which is also linked to a way of life before industrial agriculture took root. In this context, advocates of multifunctional agriculture in Europe may have a lot in common with those who see agriculture as an expression of cultural identity in the South (Aerni, 2011).

The political economy of sustainable agriculture

The clash of belief systems we observe in public debates on sustainable agriculture may reflect a divide between countries with different socioeconomic conditions as well as a divide between

stakeholders within particular countries who expect to be either beneficiaries or victims of technological and economic change in agriculture. But there is also a wider divide within stakeholder groups themselves. It can be observed within academia, business, civil society, the legislature and government. Many of the university institutes, company branches, NGOs and government departments that are part of a larger umbrella organization may have more in common with their globally organized topic-related networks than with the local actors within their stakeholder group. They have their own transboundary agendas and their different national and international constituencies with different views and expectations (Aerni et al., 2016). What unites them is often like-mindedness as well as political opportunism. Stakeholder representatives may share the belief system of their particular constituency, be they called customers, members, believers, donors or investors, but they also have a vested interest in moving the public debate in a direction that increases their particular material (increasing revenues from products, services, donations, membership fees, investments etc.) and immaterial benefits (e.g., public trust, loyalty, social prestige, identity and media attention) (Luhmann, 1993, Akerlof & Kranton, 2011). This has been particularly obvious in the businesses of retailing and gastronomy that have co-opted many of the alternative food movements (organic agriculture, ethical food, slow food and terroir), converted them into sustainability labels and signaled through their procurement policies their commitment to complying with the demand of the popular food movements. Some scholars argue that many global retailers are therefore no more primarily selling goods but «goodness» to consumers (Freidberg, 2007).

The importance of framing: from descriptive claims to proscriptive action

The combination of firm belief systems that are linked to a particular social identity combined with vested interests that aim to propagate such belief systems as marketing strategies may explain why collaborative efforts to promote sustainable agriculture face a lot of opposition in society. Public debates on sustainable agriculture are largely dominated by the fear of stakeholders of being denounced as stooges of the corporate agroindustry. This again has consequences with regard to public attitudes towards public-private partnerships in agriculture. They may perform well in improving the overall sustainability by combining the competences and skills in the private and the public sector, but they face a reputation problem in public. Involvement of the private sector must shift the focus from people and the environment to profits. Why do people tend to this in this binary mode of presumed «good» and «bad» motives

Generally, people tend to frame a problem contingent upon their mental representations of options rather than the objective states of the world (Kahneman & Tversky, 2000); yet, this mental representation of options can also be deliberately shaped by stakeholders who are keen to influence the media discourse in a way that best serves their political agenda (Luhmann, 1993, Fairclough, 2003). In the case of national agricultural policy, stakeholders who fear the loss of influence and access to scarce public resources as a result of structural change are likely to frame the national situation in a descriptive way (e.g., small-scale farmers form part of our national identity and are the guardians of sustainable agriculture) and the global situation in a prescriptive way (e.g., economic globalization should be curbed in order to preserve national sustainable agriculture). The reverse would be the case for stakeholders who are likely to benefit from structural change in agriculture; they would argue that economic globalization is an inevitable process (descriptive) and farmers must focus on the opportunities rather than the challenges in order to ensure sustainable change in agriculture (prescriptive) (Fairclough, 2003).

Concluding remarks

This article highlighted the diverging views towards sustainable agriculture and how they often prevent coherent collective action to address the global sustainability problems in agriculture. The UN SDGs reflect this dilemma by how containing as many calls to preserve, maintain and defend agro-ecosystems as calls to invest in agricultural productivity and structural change. Yet, compared to prior efforts to promote global sustainability, the SDGs put indeed more emphasis on private sector involvement and the role of entrepreneurship and innovation for sustainable development.

The Third International Conference on Financing for Development (Addis Ababa, 13–16 July 2015) highlighted already the importance of Public-Private Partnerships (PPPs) to achieve the SDGs as well as the need to «build capacity to enter into PPPs, including as regards planning, contract negotiation, management, accounting and budgeting for contingent liabilities (UN-DESA, 2016). The UN Conference on Trade and Development (UNCTAD) held a multi-year expert meeting on investment, innovation and entrepreneurship for productive capacity-building and sustainable development in March 2016. The conclusion of the meeting was that there is still a limited degree of real integration of science, technology and innovation into development policies and strategies in most developing countries. The communication paper warns that this will undermine progress towards meeting the SDGs within the short time frame set under the new development architecture (UNCTAD, 2016).

Despite this warning about the insufficient consideration of entrepreneurship and innovation in sustainable development policies, it is encouraging that the voices representing the interests of LDCs within the UN have becoming more assertive in their demand to mobilize PPPs, entrepreneurship and innovation for agricultural development.

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Dr. PHILIPP AERNI

University of Zurich, Switzerland

Philipp Aerni is Director of the Centre for Corporate Responsibility and Sustainability (CCRS) at the University of Zurich. While holding a PhD in Agricultural Economics, he is an interdisciplinary social scientist with a particular interest in the role of science, technology, and innovation for sustainable development. Philipp Aerni examines Public-Private Partnerships and their potential to drive sustainable innovations.

Ethical considerations on the two narratives: productivity and sufficiency

Melanie Paschke

Why one needs to reflect the two narratives of «productivity» and «sufficiency» under ethical lenses? Ethics refers to principles and standards that define if our behavior and our actions are considered as good, proper and right. Ethical discourse allows deliberating perspectives: why do we think that a certain course of action ought to be right or wrong? Within both narratives one might deal with different ethical questions.

In ethical discourse three different ethical principles can complement each other:

Consequentialism

Decisions should be made on the basis of the expected outcomes or consequences of the action. An action is right if its impact is increasing well being of men. An action is right if it provides the greatest benefits for the greatest number of people while avoiding harms. In its utilitarian interpretation the assumption is that the benefits associated with consequences can be quantified. Benefit-cost accounting can be used for ranking systems for all possible courses of options to produce a class of optima.

Rights ethics

An action is right if it follows a principle whatever the consequences are. Persons must be treated as ends in their own right and should not be instrumentialized as means (categorical imperative by Immanuel Kant). Rights imply duties.

Virtue ethics

An action is right if in accordance to the way that a virtuous person would act. A virtue person avoids vices.

The productivity narrative under different ethical lenses

Under a perspective of productivity, higher yields will be possible through technological progress and resource efficiency to overcome environmental limitations. Based on utilitarian argumentation the focus on the increase in production has been criticized for its benefit-cost accounting: through maximizing for short-term benefits (more production) long-term costs are systematically underestimated (for example, less resilience of the agricultural production system as a consequence).

The tragedy of the commons (Hardin, 1968) have been described as an ethical dilemma arising from the increase in productivity: if fish resources will serve the growing demand of world population and through fishing increases the wealth and livelihood of fishermen, the overexploitation of the fish population might be acceptable in the short-term. Finally, the fish population will collapse and generate a new situation when the harms of continuing the fishing will exceed the benefits.

Rights ethics challenges the productivity narrative. Intensification of production for example in tropical areas is not justified if it results in conflicts that are forcing small-holders or subsistence farmers from the land and in a position where their rights to food and shelter are not met. Imbalances in power and neglecting duties towards minorities for benefits of majorities are a violation of important human rights (FAO, 2004).

Justice based on the principle of rights ethics is implemented through negotiation between representatives of all stakeholder groups: Are conflicts for limited resources or constraints arising from the needs of majorities imposing on the rights of minorities? How to use and distribute land? How is the fair and just distribution of limited environmental resources? Could a dialogue be guaranteed where subsistence farmers, women, indigenous people, races, investors and governmental representatives are on equal power levels?

EXAMPLE 1

URBAN FARMING IN DETROIT FROM A RIGHT-BASED APPROACH

Since 2000 Detroit became an example for urban farming initiatives that spread all over the place. Following World War II, the auto industry boomed and the area witnessed suburban expansion making Detroit metropolitan area to one of the largest of US. Since 1958 auto industry moved away with negative economic consequences. In 2011 population has fallen to 700.000 (most of these from black population) and the lowest level in 100 years. In 2013 Detroit had to file bankruptcy.

Town municipalities came up with a new development plan in 2010: regrowth – concentrate funding and municipal services in selected areas of the city. Town population started to grew independent to the situation through urban farming: growing food as an act of resilience. The number of farms increased from 80 farms in 2.000 to 1.400 farms in 2016.

Still, many farmers squatter on land without ownership. Farmers describe years of agitating for land ownership and land tenure without success. The puzzle of recent and previous ownerships is not easy to solve for administration, which might serve as an explanation. The city continues to seek large development projects and arguments that they need investment and taxes to rebuild public services to their citizen.

What are the moral conflicts in this case?

- Can the small subsistence farmer continue to flourish in neighborhood to these big initiatives?
- Small-scale farmers fear to be driven from land. They argument that their investment has shrunken into the land but helped to improve the quality and property values of the neighborhoods.
- Are their ways to integrate their needs in city's policy?
- How can the right for making a livelihood through farming on town's land be guaranteed?

Background information

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The sufficiency narrative under an ethical lens

We cannot solve the tragedy of the commons if it is concentrated on individual's self-interest: if man has a right to choose how to make a livelihood, commoners could choose to overconsume the fish population they own. It was Thomas Hobbes who said rationality of persons would bound them to live in accordance with certain rights and duties if everybody else is doing the same. Therefore, the commoners ought agree on a social contract to sustainable use of their fish population. This could be seen as the ethical basis for the «sufficiency» narrative where limitations in resources could be overcome through social agreement on demand restrain.

In the «sufficiency» narrative the individuals are willing to self-determine their demand through behavioural changes based on the virtue-principle. Currently operating in a niche, what will be the challenges, when would be implemented on the large scale, for example, how should the system operate with vices?

EXAMPLE 2
ETHICAL EATING

Manuel living in a western town, 42 years, is working in a creative profession. He consumes a lot of fresh products mainly for health reasons. He is avoiding meat and animal-based products. His diet is gluten-free and includes imported grains for example from South America (amaranth), Ethiopia (tef). He is choosing his food also as an alternative to the industrial food system and its environmental illnesses.

What could be the moral conflicts of his «ethical» eating?

On one hand, this example deals with questions of food justice. Exclusionary aspects of eating as summarized in Bradley and Galt (2014): scarce availability of healthy and affordable food in low-income and minority populations is not due to a problem of scarcity but to a problem of distribution. Everybody should have the right to eat enough, to eat high-quality food and to enjoy food due to their cultural traditions, habits and individual preferences. Everybody should have the right to choose from diversity in food and food preparations.

On the other hand, the example deals with inequalities in the distribution of costs and benefits in a globalized word. Since beginning of 2016 Ethiopia is exporting limited amounts of teff flour to the United States and other foreign markets to gain profit from the growing demand for gluten-free grain products. Annual totals the first year expected to reach between 6.000–8.000 Mt (United States Department Agriculture, 2015). Tef harvests have failed to keep pace with Ethiopia's increasing population, driving prices for Ethiopian's population, while other crops need to be imported (Jeffrey, 2015).

What are the consequences of importing food from poor countries to the wealthy countries for individual food preferences?

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Bio-centric argumentation

Discourse on the two narratives «productivity» and «sufficiency» could also integrate the bio-centric argumentation that considers nature as moral subjects with an intrinsic value but threatened by human beings. This argumentation gives nature the role of a party, which rights have to be respected (Becker, 2007). Under this argumentation the «productivity» narrative will get criticized because it focuses on unlimited benefits taken from nature, diminishing costs and imposion on nature.

«Moral positions are important to reflect and justify our decisions. Ethical discourse enables students to think behind the dominant narratives but also to engage in an emphatic way with the different perspectives and values of people. Training in ethical discourse is a necessity in education about sustainability.»

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Dr. MELANIE PASCHKE
Zurich-Basel Plant Science Center, Switzerland

Melanie Paschke is director in education of the Zurich-Basel Plant Science Center. She has a PhD in Ecology and Environmental Sciences and a track record as educator in all areas of academic professional conduct with more than 30 training workshops, summer schools and seminars taught in previous years. Her focus is on ethics in plant sciences and sustainability.

Case Studies 2014

Sustainable intensification in tropical agriculture: example of Africa

A focus on locally adapted methods and stakeholder participation should be regarded as key to the adaptation of the sustainable intensification concept in the context of smallholder farmers.

Irina Bregenzer, Susan Hanisch, Abiel Rindisbacher and Hao Xu

Introduction

Technological progress in agriculture has seen some success in the past decades, but according to the United Nations (UN) Food and Agriculture Organization (FAO), 795 million people are still suffering from hunger in the world today. Half of those are smallholder farmers living on marginal lands and sub-Saharan Africa has the highest prevalence of hunger, with 25% of the population under-nourished. This forms part of the rationale for a particular focus on smallholders in tropical contexts. The innovations brought by the Green Revolution (GR) were able to tackle food shortage and famines in the second half of the 20th century in Asia and Latin-America through the development of high-yielding and pest-resistant rice and wheat varieties, chemical fertilizers and irrigation infrastructure. However, technologies were often not appropriate for marginal lands and, therefore, tended to neglect the poorest, as well as women farmers (FAO, 1996). The adoption of Green Revolution technologies (GR technologies) in Africa was particularly low as many farmers depend on orphan crops such as sorghum and cassava which did not play a role in breeding efforts. GR technologies were also not appropriate to address issues such as recurring droughts, extremely poor soils and a variety of pests and diseases that African farmers have to cope with. Poor infrastructure and low education levels further hampered farmers access to new technologies.

In Africa more than 60% of the population depends on agriculture, and smallholders provide 70–80% of the food supply. Smallholder farmers depend to a large degree on well-functioning ecosystems to provide services such as soil fertility and nutrient cycling, water delivery and plant protection. Smallholders also tend to have various interacting interests besides yield maximization for income, such as the reduction of risks and increase in long-term resilience, diversification, household food security and social and cultural aspects of farming. Additionally, as 97% of agricultural land in Africa is rain-fed, climate change is projected to put further stress on African food production. Efforts to improve agricultural systems in the past prioritized yield maximization with off-farm inputs and focused on a few crops and varieties, which created various ecological problems that only became apparent in recent decades as increasing environmental costs to society.

Any success that did take place in improving agricultural yields in Africa was offset by population growth rates of more than 2% on the continent. While expansion of arable land has taken place at a rate of 0.7% per year in the last 50 years and is expected to grow at a similar rate until 2030 (FAO, 2014), intensification of crop and livestock production are needed to conserve ecosystem services that farmers depend on.

Soil fertility

No successful and sustainable agriculture is possible without healthy soils. But with the help of conventional agricultural methods this capital is being continuously compromised. The already poor soil fertility in many African regions is deteriorated because of overexploitation to feed an ever growing population, and low availability of and access to fertilizers. This loss of fertility does not only impair productivity and health, but also has strong impacts on natural resources as ecosystems are destroyed in traditional slash-and-burn methods to gain more ground, and depleted soils are left to erosion. For a more environmentally and economically sustainable way of addressing these challenges, new strategies are needed to allow farmers easy access to organic fertilizers. Promising methods to address these challenges are intercropping (N-binding crops), crop-livestock integration (manure) or agroforestry (leaf residues), or for example biofertilizers using mycorrhizal fungi. At the same time, low-till strategies like conservation agriculture can help build up soil structure and reduce gas emissions and erosion.

Water availability

As water resources worldwide suffer strongly under the pressure of agriculture and industry, together with pollution and climate change, there is a strong need for farming systems with low water input and high water use efficiency. In Africa, where pressure of industry and large-scale farming is relatively small, other factors impair the availability of and access to water. Two thirds of sub-saharan Africa are arid or semi-arid, and one third of the population live in regions with high risks of drought. Poverty, ongoing population growth and climate change threaten further decrease of the already insufficient availability of water resources to ensure human health and productivity, as precipitation patterns are predicted to change strongly in the

SUSTAINABLE INTENSIFICATION

«To increase food production from existing farmland in ways that place far less pressure on the environment and that do not undermine our capacity to continue producing food in the future.»

Garnett et al., 2013

«To produce 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»

Pretty et al., 2011

According to the FAO, sustainability also means «ensuring human well-being (and achieving global food security) without depleting or diminishing the capacity of the earth's ecosystems to support life or at the expense of others' well-being» (FAO, 2013). Thus, sustainable crop production also needs to take into consideration the potential and/or real social, political and economic impacts besides environmental aspects. A variety of traditional and innovative approaches and methods in farming systems have been shown to successfully tackle the key constraints to cropping intensification in Africa (e.g., soil fertility, water availability and crop disease pressure) without the necessity for external inputs, and are therefore promoted to be able to sustainably increase crop production. Social and economic aspects of crop production from the local to the national level are also more and more considered as key to well functioning production systems, while adaptation of methods to local needs is achieved by stakeholder participation; a stronger focus on bottom-up and away from top-down approaches.

TEF QUNCHO PROJEKT

Tef (*Eragrostis tef)* is a cereal crop grown for human consumption only in Ethiopia, where it is also an important part of the primarily culture. It is an so called «orphan crop», because until recently it has been neglected by research. In a participatory approach, the Debre Zeit Agricultural Research Centre has developed a new tef variety called «Quncho». The line was bred by crossing of a parental line with very white seeds to another parent with high-yield. The first trait is preferred by consumers, while the second is important for farmers. The involvement of all stakeholders (from consumers and farmers to researchers and policy makers) into the process ensured a broad acceptance and fast adoption. On-farm demonstration helped to convince farmers of the benefits of the new variety. The use of «seed loan» (farmers pay for the seeds with a part of the first harvest) enabled a fast multiplication. Delivering the new variety as part of a technology package provided the simultaneous spread of new management practices. Training and regular follow-up supervision ensures sustainability of the efforts.

Source: Assefa et al., 2011

Figure 1. Quncho tef. Source: https://www.flickr.com/photos/ilri/6237034208/in/photostream/

near future. Therefore, the development of water-extensive farming systems is of high priority to prepare African smallholder agriculture for future challenges. Possible solutions include water-efficient crop and livestock varieties, intercropping/agroforestry and water harvesting among others, and could not only restrain water consumption but also mitigate secondary effects like erosion and salinisation.

Plant variety diversification

The objective of Sustainable Intensification (SI) requires crops that can efficiently utilize the available resources. Thus, breeding new varieties and bringing them to the farmers will be of paramount importance for success. To meet this challenge three major areas need to be considered: genetic resources, new varieties and seed supply. Plant genetic resources can be used to develop varieties with new traits. It is also important to conserve these resources for possible future use in breeding and to maintain biodiversity of crop plants. Developing varieties with new, specifically adapted traits will be crucial for the success of the new management strategies implemented in the context of SI. They have to be more productive under nonoptimal conditions and use water and nutrients effectively, in contrast to the current high-input dependent lines. They have to be more tolerant to different biotic (pests and diseases) and abiotic (drought, flood, frost and heat) stresses. Maintaining and improving nutritional value, while breeding for these desired traits will also be necessary to provide balanced nourishment. Utilizing many different crops, including neglected and underused crops (see Quncho tef project), instead of only a few can also help to improve food diversity. There will be a constant need for breeding new varieties adapted to the changing management practices and climate, and seed production and delivery systems will be

necessary to supply the farmers with high-quality seeds. Establishment of local seed companies can help, but it is likely that farmer-saved seeds will remain important too. The development of these new varieties will be an enormous task and can be only achieved in a participatory approach.

Plant protection

Plant protection aims to manage invertebrate pests and vertebrate pests, plant disease, weeds and other pest organisms that damage agricultural crops. Conventional plant protection strategies have strong environmental impacts, are expensive and often have negative health effects, especially if used by inexperienced farmers. Although, the agricultural development of Africa has lagged behind in the green revolution during the middle of 20th century, the tropical agriculture, nowadays, is trying to adopt some approaches of sustainable development like Integrated Weed Management (IWM) and integrated Pest Management (IPM). Among the adopted strategies are line transplanting in Nigerian rice fields, efficient herbicide application, and intercropping systems like the push-and-pull-system.

Importance of knowledge

Many of the agricultural methods require more knowledge and farming capacity to adapt techniques to their local ecological and socio-economic conditions. Hence, compared to traditional «top-down» approaches, more participation of farmers and other stakeholders is necessary to make the most of locally available ecosystem services and to avoid conflicts that inhibit effective adoption.

Participatory research that explicitly involves farmers in the technology development process has gained more and more attention in research and development. For example, participatory plant breeding addresses the necessity for the selection of cultivars that are adapted to farmers conditions and correspond to their needs and preferences.

Farmer field schools, first introduced in 1989 in Indonesia, have been successfully used in many countries to train farmers not only in more knowledge-intensive methods such as integrated pest management, conservation agriculture, livestock hygiene but also in social and health issues.

Ownership has to be more strongly handed over from the researcher and extensionist to the farmer and the community. Furthermore, agroecological methods often tackle landscape-scale problems such as rainwater harvesting and irrigation infrastructure, which require innovative organizational approaches within the community and strong governance.

AGROFORESTRY

Agroforestry is a cropping system combining trees with other crops or grassland. It can increase soil fertility by using legume tree species, or secure water supply with deep-rooting trees. At the same time it usually increases yield of the main crop by means of shade and protection of pests and weather, and generates additional yield from timber or fruit trees, which also contributes to increase nutritional diversity and consumer's health.

CONSERVATION AGRICULTURE

Conservation Agriculture (CA) is characterized by three linked principles:

1. Continuous minimum mechanical soil disturbance (reduced, minimum or zero tillage).
2. Permanent soil cover with cover crops, crop residues or other types of organic materials.
3. Diversification of crop species grown in sequences (crop rotation) and/or associations.

While CA techniques have been successful in North- and South-American countries, in Africa adoption by small-holders remains very low. Constraints for the smallholder are often the time lag until yield increases can be observed, competing use of crop residues for livestock fodder and the lack of access to herbicides and pesticides which are often necessary in such systems. Hence there is a need to adapt this approach to African smallholders constraints and priorities, and a need to define CA less narrowly.

WATER CONSERVATION

Rainwater harvesting techniques have been traditionally used in semi-arid areas to increase water availability for crops, animals and people. Terracing, contour bunds, half-moon circles and pits such as the Zaï have been improved and promoted to increase rainwater infiltration and groundwater recharge, reduce erosion through run-off, concentrate organic matter for nutrient availability and thus enhance yields and biomass production. These farmer-led innovative techniques led to the «re-greening» and rehabilitation of more than 200.000 ha of degraded land in the Sahel for food production.

AQUACULTURE

Aquaculture is the farming of aquatic organisms (fish). It can be integrated into an agricultural setting to support SI trough water cycling and using the waste of the fish as fertilizer. Two types have emerged in sub-Saharan Africa: small ponds integrated on farms with small-scale fish production mainly for subsistence, using own products and wastes as feed. In some countries aquaculture has increased to commercial scale production of fish in concrete tanks using high-quality fry and feed. The advantage of these approaches, besides improved recycling of wastes and water, is a diversified diet. Limitations to potential up-scaling are the lack of skilled fish farmers, potential harms to the environment like eutrophication and in some places limited access to markets.

Figure 2. Aquaculture. Source: https://www.flickr.com/photos/theworldfishcenter/6339596836/in/photostream/

INTEGRATED PEST MANAGEMENT

Integrated Pest Management (IPM) aims at minimizing pesticide use while keeping pests or weed populations at economically supportable levels. It relies on a combination of practices like improvement of diversity in fields, monitoring pest populations, mechanical and biological control. An example is the push-pull-strategy to control weed striga (*Orobanchaceae*) (Hassanali et. al., 2008). This intercropping system uses so-called «trapping plants» or «pull-plants» like Napier grass (*Pennisetum purpureum*) or Sudan grass (*Sorghum vulgare sudanense*) to attract and trap pests to the outer borders of crop fields, thereby reducing the damage to the main crop. In addition, so called «push-plants» between crop rows (often low growing plants of the genus Desmodium) release pest-repelling chemicals without interfering with crop growth. This method has been widely tested in maize and cereals field in central Africa and effectively suppresses striga weeds. Additionally, Desmodium also maintains soil stability, improves soil fertility and serves as highly nutritious animal feed.

CROP-LIVESTOCK INTEGRATION

Crop-livestock integration is a combination of traditional cropping systems with livestock management, which intends to recycle nutrients in a sustainable way. The manure increases soil fertility and yield, while the livestock can be fed on straw or other plant residues, so the two parts of the system support each other. This approach can decrease input costs and labour while at the same time improving nutrition by adding animal proteins.

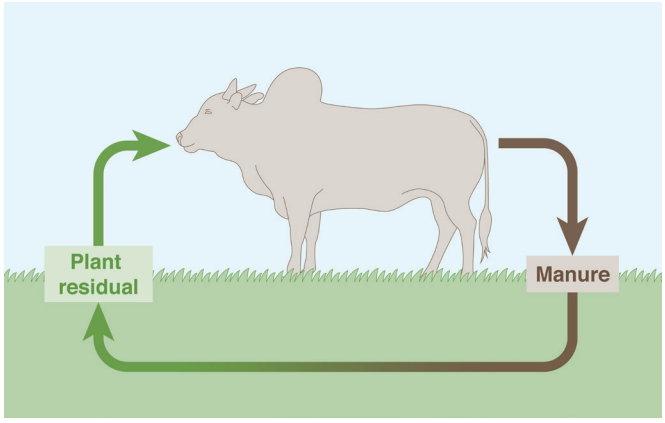

Figure 3. Scheme of crop-livestock Integration. Illustration by Gaia Codoni, based on draft by Irina Bregenzer

METHOD	SOIL FERTILITY	WATER PRODUCTIVITY	DIVERSIFICATION / CROP VARIETIES	PLANT PROTECTION
Agroforestry	xx	x	xx	x
Conservation Agriculture	xx	xx	xx	xx
Water Conservation		xx	x	x
Aquaculture	x	x	xx	
Crop-livestock Integration	xx		xx	x
Integrated Pest Managment			x	xx
Participatory Plant Breeding			xx	xx

Table 1. Effects on natural and agricultural resources of different management strategies connected to sustainable Intensification in Africa. «xx» represents a strong impact, «x» a weak or potential impact.

Position statement

The intensification concept addresses the challenge of decreasing availability of arable land to feed a growing population and declining availability of resources more generally. Due to increasing environmental problems and societal costs of intensified agriculture in the past, the sustainability concept has gained attention in research and policy making. Nevertheless, sustainability as a term is often causing misunderstandings and controversy. While some researchers put more emphasis on ecological aspects of sustainability, social and economic aspects are often neglected. The diversity of methods shows that there is not one single solution for a specific context and, therefore, local adaptation should be a priority. Often there is a danger to regard certain methods in the context of SI as «silver bullets», and not enough attention is being paid to the agro-ecological and socio-economic situation. Slow adoption rates of conservation agriculture or agroforestry techniques are the result. Similarly, the focus on yield increase inherent in the intensification concept may distract from important constraints such as post-harvest losses, long-term system resilience and low access to markets. While these can also be understood as part of sustainable intensification, e.g., to make more food and income available from the same amount of inputs, focus on ecologically sustainable solutions might distract from methods that primarily tackle economic shortcomings or human capacity constraints. Hence, the focus on locally adapted methods and stakeholder participation should be regarded as key to the sustainable intensification concept.

Overall, more research efforts and funding should be channeled towards long-term investment, farmer participation and capacity building, as these present an opportunity for more lasting impacts than traditional top-down approaches that often failed in the context of African smallholder agriculture. One principal message of sustainable intensification approaches is that it is possible to overcome trade-offs between economic and ecological goals, while also regarding socio-political innovations as an asset for lasting implementation.

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Sustainable intensification in temperate agriculture

To reach the overarching goal of sustainable intensification, the diversity of agricultural systems must be taken into account and thus appropriate strategies and opportunities have to be combined on a local, individual scale.

Federica Assenza, Dustin Eirdosh, Juliane Hirte, Verena Säle and Tina Schreier

Introduction

In the coming decades, the global food system will face major challenges. The world population will expand to approximately 9.6 billion people by 2050, and the absolute demand for food will rise dramatically. To feed this growing population, we have to intensify food production. However, the competition for land, water, energy, and other production inputs will increase, while the effect of climate change is becoming more and more apparent (Godfray et al., 2010).

According to the Food and Agriculture Organization (FAO) of the United Nations (UN), today's croplands already cover 1.53 billion hectares, and pastures cover another 3.38 billion hectares (FAO, 2011). Together, agriculture occupies about 38% of the Earth's terrestrial surface, which represents the largest land use category on the planet (Foley et al., 2011). The expansion potential is therefore limited, and the FAO stated that «the present paradigm of intensive crop production cannot meet the challenge of the new millennium. In order to grow, agriculture must learn to save» (FAO, 2011).

There is increasing focus on intensification in a sustainable manner to respond to these pressures (Royal Society, 2009). Opportunities for agricultural intensification are monitored by yield gaps – the difference between the actual crop yield and the attainable crop yield for a given region (Licker et al., 2010). Closing those yield gaps would increase the supply of food (Mueller et al., 2012). In our fact sheet, we will mainly focus on the intensification opportunities in the US and Europe, as examples of the temperate zone. Although, the productivity is already extremely high in those continents, there is still potential to increase yields, while simultaneously decreasing the environmental impacts of agricultural systems (Figure 1).

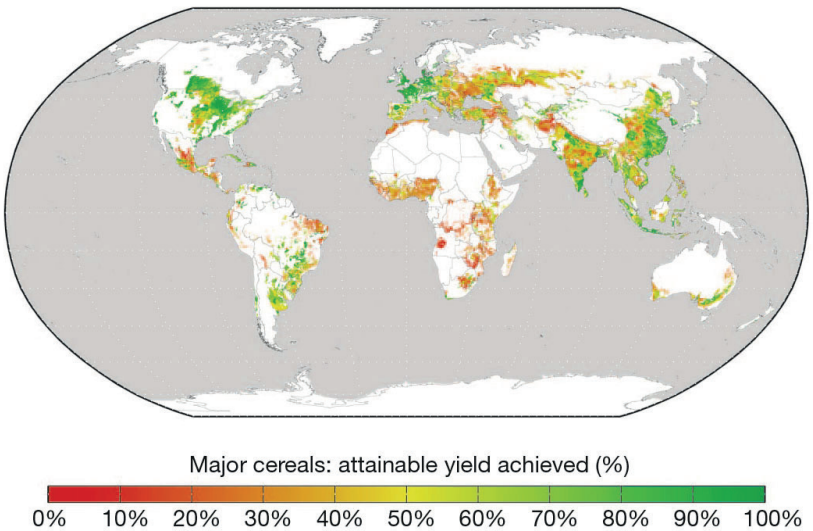

Figure 1. Average yield gaps for major cereals (maize, wheat, and rice). These were measured as a percentage of the attainable yield achieved in the year 2000 (Mueller et al., 2012).

Defining sustainable intensification

While there are clear arguments for the sustainable intensification (SI) of agriculture in a general sense, there is still much debate regarding how this term might be defined more specifically. Garnett and Godfray (2012) frame this discourse as focusing on SI as either a description or an aspiration for agricultural development. In this regard, they note the origins of SI thinking as coming from agronomists focused on African smallholder farmers, and viewed as an aspiration for the improvement of agro-ecological systems. In contrast, they note that modernized high input, high output agricultural industry has adopted SI terminology as a description of current industry practice with emphasis on adapting such systems to close global yield gaps and meet future challenges.

Finding common ground

While perspectives on the aims, methods and value of SI remain diverse, there exists a way to explore common ground underlying the core concept. The four premises of sustainable intensification (to the right) outline the key points with which many food systems development experts are likely to agree. It is not controversial to claim that SI approaches must utilize multiple metrics to gauge exactly what is to be intensified (e.g., production, ecosystems services, human health, etc.). Controversy and diversity of opinions emerge as the specifics of what is to be measured are clarified. As with all elements of community de-

velopment, SI of agricultural systems is inherently linked to human values. Therefore, SI is also critically linked to the democratic processes that enable groups with diverse values to achieve public policy agreements supporting effective development strategies. When exploring literature on SI, it is helpful to understand the diverse perspectives that shape the meaning of this term now, and into the future.

PREMISES OF SUSTAINABLE INTENSIFICATION

1. There is a need to increase production.
2. Increased production must be met through higher yields because increased land-use for agriculture carries high environmental costs.
3. Food security requires as much attention to environmental security as to increasing production.
4. Sustainable intensification is a goal, not a specific method or set of techniques.

Adapted from Garnett et al., 2013

High tech approaches: precision agriculture

Traditionally, soil and crop quality have been monitored by coarse-grid sampling and lab analyses (Oliver, 2013). The time lag between data generation and implementation and the imprecise estimate of field heterogeneity often led to partial under- or overuse of agricultural inputs resulting in yield loss or unnecessarily high expenses and environmental pollution. This was especially true for large farms as management units were mostly defined on field or even farm level. The demand for farm-resource efficiency on the one hand and upcoming political instruments for environmental protection on the other (e.g., in Europe: Nitrates Directive 1991 (91/676/EEC)) was answered by the emergence of new technologies on the market in the early 1990s. By means of yield sensors and global positioning systems (GPS) it became possible to record and map small-scale yield variability for large acreages (Oliver, 2013). This was the first step towards demand-oriented crop management called Precision Agriculture (PA). PA is a strategy that combines the large-scale use of high-tech positioning, imaging and/or sensor techniques with spatially variable, demand-oriented crop management (Rösch et al., 2005). Techniques have been constantly developed and refined from both the economic and scientific perspective. Three broad types of technologies are now applied to variable extents: satellite navigation, aerial imagery and sensor technology . All three technologies can be directly combined with variable rate applications of seeds or inputs (Figure 2), which reduces the time between data generation, analysis, and implementation considerably (Rösch et al., 2005). Although satellite navigation is already widely applied in practice – one third of North Dakota farmers (Bora et al., 2012) and one fifth of English farmers (DEFRA, 2013a) use this technology – the utilization of aerial imagery and sensor techniques is still in its infancy. The probability that a farmer adopts PA techniques is closely related to the farm size (Rösch et al., 2005). While the percentage of farms larger than 100 ha is 19% and 34% in the UK and US, respectively, there are virtually no farms in that size class in Switzerland (Figure 3). However, small fields could especially profit from guidance systems and auto steering since a considerable amount (up to 50%) of machine time is spent with turning manoeuvres. Small unmanned machines equipped with automated seeding, variable rate input application or demand-oriented weeding systems could be the future in regions with large field heterogeneities on small areas, as it is the case in Switzerland (Prof. Dr. B. Streit, School of Agriculture, Forest and Food Sciences HAFL, personal communication, 14 Oct. 2014).

TECHNOLOGIES APPLIED IN PRECISION AGRICULTURE

Satellite navigation: is the fundament of GPS-based guidance systems of agricultural machineries and auto steering. By reducing the overlap of tractor passes the farmer saves a significant amount of machine time and fuel and minimizes soil compaction (Bora et al., 2012).

Aerial imagery: comprises the use of satellites or drones to generate spectral data in a wide range of bands. Spectral indices (Figure 2) provide sub-meter accurate information about biophysical (e.g., water supply), biochemical (e.g., nutrition), and stress (e.g., pests) characteristics of the crop even up to several times during the vegetation period (Mulla, 2013).

Sensor technology: Optoelectronic sensors are hand-held or tractor-mounted devices that measure optical, mechanical or biochemical properties of plants and give information about e.g., the nutritional status of the crop or weed infestation.

Low-tech approaches: soil and crop management

One of the main issues linked to modern agriculture in temperate developed regions is soil degradation that ultimately leads to decreased fertility. In croplands, this phenomenon arises from a variety of agricultural practices such as the use of heavy machinery causing soil compaction, irrigation with high-salt water and application of large amounts of fertilizers causing salinization, and tillage that increases erosion due to wind and water (European Commission, 2009). Soil and crop management practices typical of sustainable intensification regimes aim at restoring long-term fertility. Many of them were in use before the 1940s, but were abandoned in the course of the last 70 years as a consequence of the adoption of mechanisation and high input agriculture (Machado, 2009).

Among these agronomic practices, minimum and no-tillage, collectively called conservation tillage, are of great importance. Seedbeds are prepared placing the seeds in un-

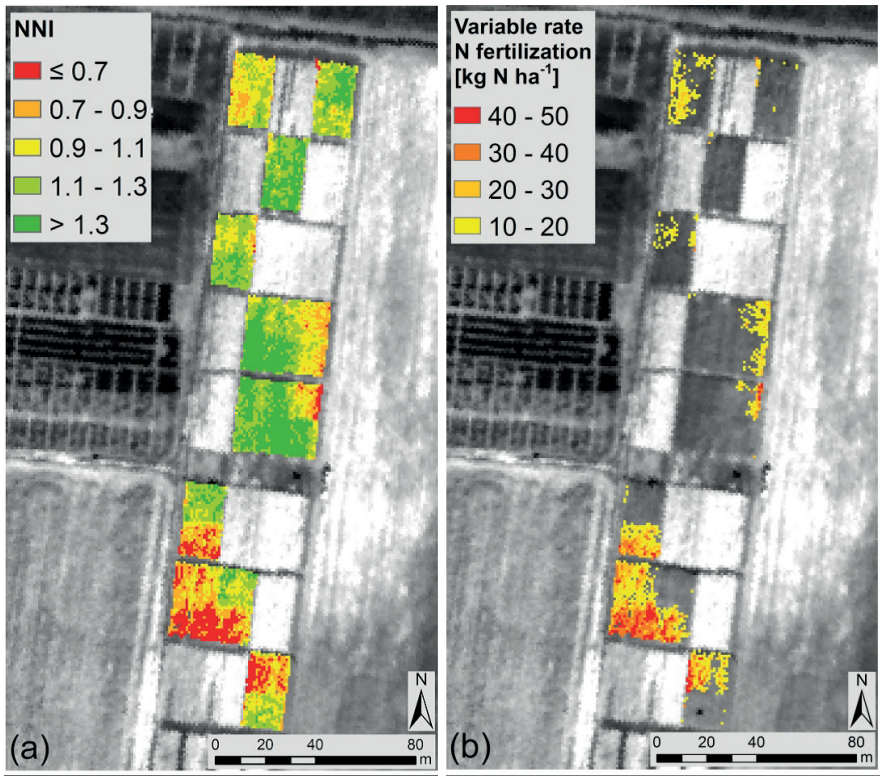

Figure 2. a) Nitrogen status assessment as Nitrogen Nutrition Index (NNI) and b) variable rate nitrogen fertilization on a field trial in Italy cropped with maize in 2010. With permission from: Cilia et al., 2014

disturbed soil among vegetation residuals. These techniques reduce soil erosion and increase water retention (Brown, 2009). However, reduced tillage poses challenges to the control of weeds and diseases. Weed seeds or rhizomes are not eliminated by ploughing and thus weeds will compete with the crop for nutrients, water and light (Peigné et al., 2007). To control weed development an even higher amount of herbicides compared to conventional tillage might be utilized at times. As an alternative, mechanical methods have been devised, for example in organic agriculture. These are applied both before sowing and after crop establishment. In all cases the effectiveness of each method depends on the weed and crop species, on climatic and soil conditions, and they can be labour and resource intensive to an extent that limits their sustainability.

In conservation tillage regimes soil moisture is increased. This condition favours the outbreak of diseases caused by soil-borne plant pathogens that thrive in humid environments (Bockus and Shroyer, 1998). The spores present on the vegetation residues from the previous year can swim in the water retained by the soil and spread, causing severe losses. This is the case of *Pythium*, a root-infecting wheat pathogen. On the other hand, reduced tillage can protect crops from fungi that infect plants upon drought stress.

In addition to soil management strategies, the choice of crop species and varieties can significantly reduce the negative environmental impacts of agriculture. Yield is influenced by climatic conditions and water and nutrient availability. Furthermore, the susceptibility to pathogens and pests plays an important role in determining productivity. The adoption of the appropriate crop, adapted to specific regional conditions, will reduce the need for irrigation and fertilization as well as the use of pesticides.

Beneficial effects on yield can be obtained by crop rotation and intercropping. Crop rotation is usually carried out growing a grain crop followed by a legume. The second species will increase the nitrogen levels in the soil that will be exploited by the cereal. The legume species can be itself a cash crop or be a cover crop planted to limit soil erosion and improve fertility after the harvest and before the successive growing season.

SOIL AND CROP MANAGEMENT PRACTICES

Conservation tillage: due to low or no disturbance of the topsoil, soil erosion can be reduced and water retention increased.
Choice of crop species and varieties: the cultivation of adapted crops to regional climatic and soil conditions can reduce fertilizer, pesticide, and irrigation input.
Crop rotation: cultivating grain crops and legumes in regular succession reduces soil erosion and enhances soil fertility.
Intercropping: growing two or more crops in alternating rows increases nutrient cycling and soil biodiversity and, at the same time, reduces crop susceptibility to pests, diseases, and weed infestation.

Commonly, in the European and North American agro-ecosystems, corn, wheat, and barley are rotated with soybean (Gaudin et al., 2013). In these cases, both harvests are relevant sources of income for the farmers.

Intercropping refers to the agricultural practise of growing two or more crops in alternating rows during the same growing season. This practice increases nutrient cycling and soil biodiversity, while promoting resilience against pests, diseases, and weeds above ground (Machado, 2009). The choice of plants to be grown side by side is difficult and depends on the resource utilization by the intercropped species. Its success depends on the equilibrium between competition and facilitation effects between the two plant species and the impact on the yield has to be determined empirically in each case. Intercropping is especially suited for organic farming because the use of synthetic pesticides and oil-based fertilizers is restricted in this management practice, but it can find applications also in conventional farming (Machado, 2009). Experiments have been conducted in organically managed fields throughout Western Europe to compare the effect of different pea-barley intercropping designs with the growth of a sole plant species (Hauggaard-Nielsen et al., 2009). The results show that pea-barley intercropping improved plant resource utilization to grain nitrogen yield irrespective of the setup and geographical location. However, intercropping did not improve soil mineral nitrogen content that was mostly impacted by local climatic conditions and long-term cropping history. The authors concluded that additional studies on rotational approaches in organic farming are needed in order to evaluate the effects of subsequent crops since changes can occur over long periods of time. Furthermore they pointed out that results derived from studies on conventional farming cannot be directly applied to organic farming and that evaluations need to be conducted for each management practice.

The success of crop production depends on the interplay of all the factors mentioned above. The impact of changes of one or several of them on yield and overall economic performance of a farm is scarcely predictable. Hence direct assessments are required to identify the most suited management parameters given the geography of the field and the crop being produced.

Position statement

The future will face us with challenges like increasing world population and climate change. Therefore, we have to deal with a need for higher food production and stable yields while at the same time the impact on the environment has to be reduced, e.g., we have to aim at sustainable intensification in agricultural farming. However the term «sustainable intensification» is not clearly defined and used in multiple ways. As it was shown above, a multi-metric approach has to be taken into account, also including that there is no single way to a sustainable intensification but rather a combination of individually adapted strategies. Since in temperate zones the yield gap is already small compared to other climates, it is more important to reduce the environmental impact rather than increasing the yield in those areas. Multiple technologies of precision agriculture (e.g., tractor GPS-guidance, precise fertilization based on aerial imagery and sensor technology) are certainly a good way to follow. But since these are expensive technologies, their application is limited to large scale farming. However, smaller farms that cannot afford costly investment can gain by optimizing management practices, including soil management and choice of crop varieties. Hence, the diversity of agricultural systems must be taken into account and thus appropriate strategies and opportunities have to be combined individually to reach the overarching goal of sustainable intensification.

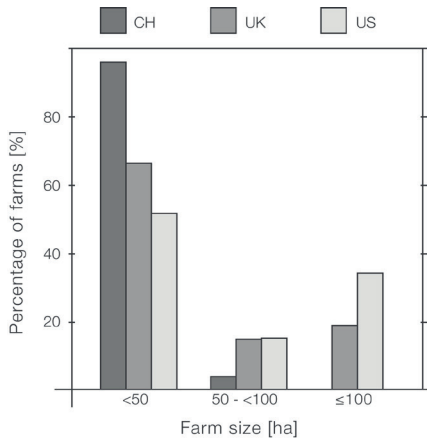

Figure 3. Percentage of total numbers of farms in Switzerland, the UK, and the US in different size classes (data from DEFRA, 2013b; USDA, 2013).

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Climate smart agriculture

The introduction of climate smart agriculture has received quick and widespread support and application, because global awareness about the urgency of climate change mitigation is increasing.

Lara Maspoli, Noemi Peter and Seraina Vonzun

Introduction

The global population and its demands are continuously rising and the FAO estimates an increase in need for food and feed of plus 60% by 2050. Coping with this need will not be easier considering climate change. The FAO has come up with several goals, for example, food security through sustainable production, adaptability to climate change, decreased greenhouse gas (GHG) emissions per output. An important aspect is that a program should not only concern large industrial producers, but rather focus on small scale farmers, which are often more exposed and sensitive to unpredictable climate change. This is mostly the case because of lack of knowledge and no access to support and financing for adaptive measures. The FAO is focusing globally in order to enhance productivity, efficiency, sustainability and food security. These aspects must be achieved by decreasing factors for climate change and pressure on the natural resources; this requires changes not only at the farm level, but more importantly in governance, legislation, policies and financial mechanisms.

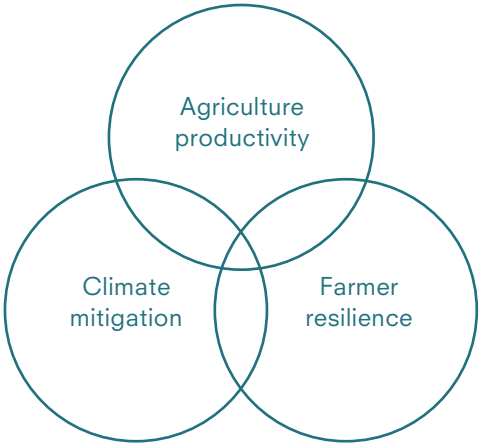

Figure 1. The concept of CSA includes agricultural productivity, climate mitigation and farmer resilience. Cross-cutting initiatives require monitoring and analysis of the local conditions, collaboration with farmers and governmental institutions. CSA aims to provide a tool to increase productivity, food security and income while being more resilient towards climate shocks, more efficient concerning input and contribute to climate mitigation. Adapted from awhere.com

Climate smart agriculture

In 2013, the FAO presented the Climate Smart Agriculture (CSA) program, which includes social, economic and environmental aspects, as a contribution to sustainable development goals. CSA is based on three main pillars:

- Sustainably increasing agricultural productivity and incomes.
- Adapting and building resilience to climate change.
- Reducing and/or removing greenhouse gases emissions, where possible.

CSA is an approach to develop the technical, policy and investment conditions towards sustainable agriculture for food security under climate change.

For practical application, CSA requires appropriate institutional and governance mechanisms to spread information and ensure broad participation. Priorities have to be evaluated, since not all goals can be reached at once. This requires a site-specific assessment to identify suitable agricultural technologies and practices. As an example, the European program AgriClimateChange, which aims to reduce GHG emissions of farms, will be introduced later in this report.

The FAO acts as guide to create an environment which enables a productive, resilient and sustainable agricultural sector by connecting practices, technologies, policies and financing. As further implementation of CSA, a partnership with UN agencies and other organizations has been created.

The components of CSA are not new, but it combines many aspects to a new approach, focussing on small scale producers. By including social, policy and financing aspects, it seeks to holistically and simultaneously address multiple challenges to avoid counter-productive obstacles.

Since the Rio Convention in 1992, mitigation and adaptation of climate change became some of the most important issues in international policy development. Within the United Nations Convention Framework on Climate Change (UNFCCC) sectorial strategies are developed that integrated the latest findings of the International Panel on Cimate Change (IPCC). Ecosystem-based approaches are currently getting more and more attention. This is mostly based on the fact that they are a «no regret» option, meaning that they are both cost efficient and flexible in dealing with a constantly changing climate and its associated risks. They are developed to promote the synergies between mitigation and adaptation strategies and therefore provide a holistic and systematic approach.

With appropriate technical, institutional, socio-economic and policy infrastructure in place, there is a huge potential for approaches to mitigate and adapt to climate change. Relevant areas to mitigate GHG emission are livestock farming, landuse change, tillage management and biomass energy production. Mitigation measures should be implemented in concert with assessments of climate vulnerability (e.g., changes in rainfall patterns, pest pressure, heat stress) and economic vulnerability assessments (e.g., market access, price volatility).

An example of ecosystem based approaches within the agriculture sector is Short Rotation Coppice (SRC). This is a combination of fast growing tree species such as popper and willows that are grown on agriculture fields between other annual crops. Positive outcomes for climate protection with mitigation, for example, are:

- enhanced carbon content in soils;
- substitution of fossil burning; and
- less energy input through relative extensive cultivation.

An advantage of SRC in comparison to only changing tillage practice as an adaptive measure, is that SRC also reduces erosion, as well as:

- less wind erosion, which would lead to soil loss; and
- less wind minimizes direct damage to the crop (violation, uprooting or total crop loss).

Both, mitigation and adaptation, aim to increase the efficiency and resilience of ecosystems and thus to stabilize the provisioning of important ecosystem based services.

Focus on Europe

The AgriClimateChange (ACC) project was developed in 2010 in four European countries. Its purpose is to assess GHG emissions on farms, and to create action plans to reduce them and to raise awareness of stakeholders in the agricultural sector. Agriculture in Europe represents the 10% of total GHG emissions and non-CO_2 emissions have already decreased by one quarter between 1990 and 2005 because of the decreased livestock production. In 2010 the ACC Tool software was developed and used to assess GHG emissions on more than 120 farms that participated in this program. With this software every farm was analysed and the sources of GHG and energy waste were identified. Subsequently, an action plan was designed to specifically reduce emissions in each farm and the measures have been taken in agreement with the farmer. These case studies have provided the necessary information to make a global proposal applicable to all the farms in EU. This proposal also mentions feasibility and costs of each action.

In the proposal three main categories are considered in order to decrease emission and energy consumption by 10–40%. These are: agronomy, livestock and energy. Agronomy and livestock have the highest potential for reduction. For the first one, the measures suggested include a limited use of nitrogen (N) through a better N balance and the use of leguminous plants and cover crops. For the livestock more attention should be focused on the management of manure and in the development of biogas production facilities. Energy is the third category where some savings can be done, by using more efficient machines and reducing tillage, fertilization, etc.

GREENHOUSE GASES

Agriculture contributes a significant amount of greenhouse gases (GHG) like CO_2, CH_4 and N_2O to the atmosphere. This is largely caused by decay of organic matter, changes in land use or tillage and fertilization practices, leaving a large potential for mitigation. Therefore, methods for increasing sequestration of carbon in the soil or changing fertilizer management (e.g., rate, timing, placement) in order to reduce emissions of GHG, have received widespread attention globally.

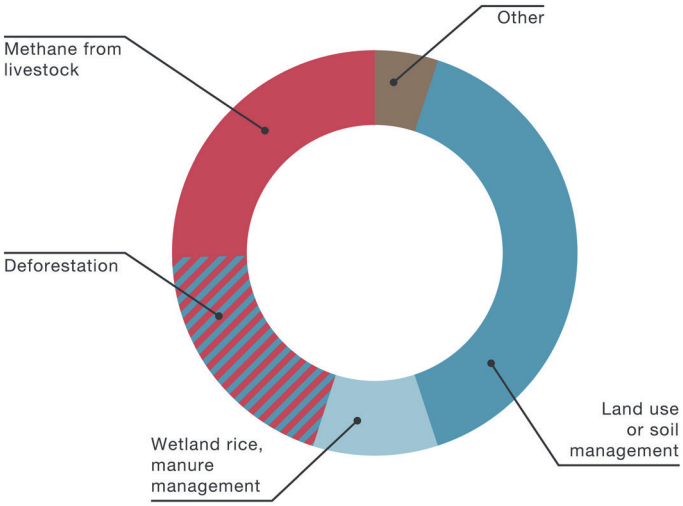

Figure 2. GHG from agricultural land use and soil management contributes a large part of GHG to the atmosphere. Adapted from Smith et al., 2014

Summary of the ACC measures

For the category agronomy the three aspects mentioned are all related to the consumption of N (Figure 3). An N balance calculated over an entire year is designed to avoid the overuse of fertilizer. The calculation considers the intake of N by the soil through fertilizers and leguminous plants and the outtake summing the yields of the crops. Leaving a soil without cultivation may generate many problems, for example, soil erosion, as well as loss of organic matter, loss of important elements (soil leaching) and water in deeper layers. Planting cover crops is one of the solutions proposed to prevent these problems. Furthermore they provide biodiversity supplying corridors and pest controls. If the cover crops are leguminous plants, which is often the case, we can also benefit from an extra source of N for the soil. That helps saving chemical fertilizers, avoiding all the costs and emissions of production, transport and purchase of the latter. Cover crops are also extra forage that is neither purchased nor transported.

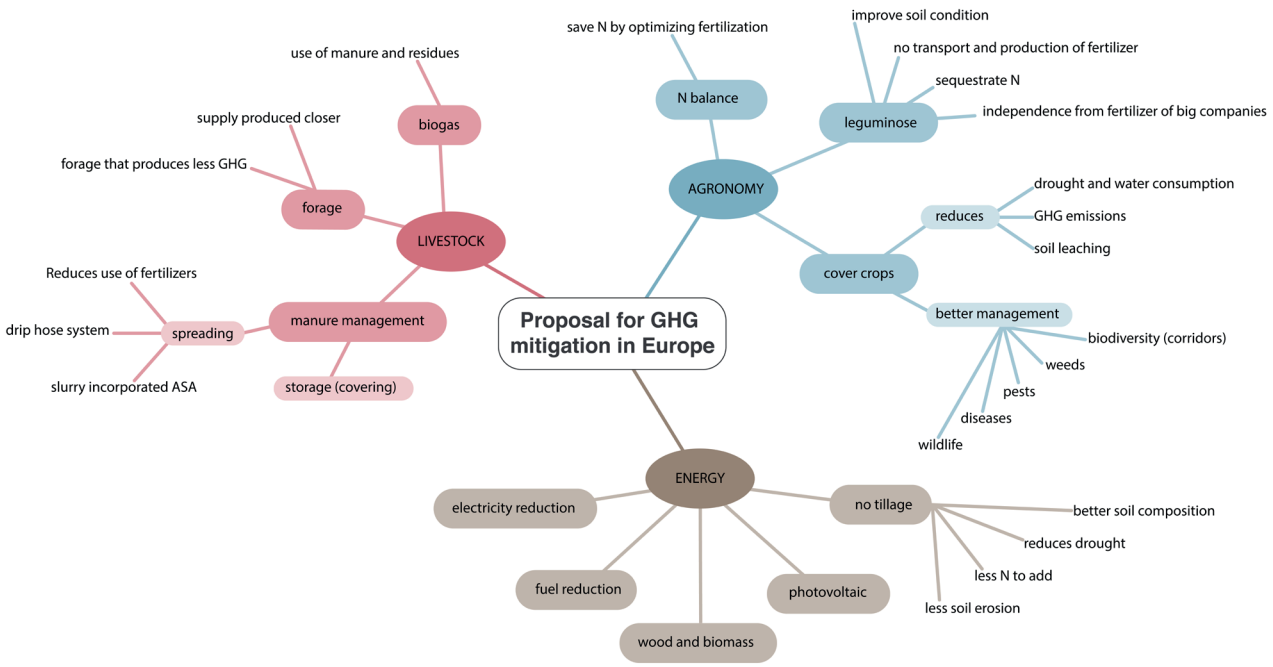

Figure 3. Map of measures and effects in the AgriClimateChange proposals (2013). Three main categories where a reduction of GHG and energy is possible: agronomy, livestock and energy.

The biggest emissions in livestock are due to manure. Very simple measures like covering the slurry storage can decrease NH_3 emission by 70–90%. If solid manure is incorporated in the soil four hours after its spreading, the emission of ammonia can be decreased by 80%. The production of biogas, thoughhaving a high initial cost, avoids the emissions due to manure management as the latter with other residues, are completely used in this process. Another strategy is to vary ruminant feed nutrition, which can reduce the emission of methane.

The last category concerns energy saving. It is suggested to install a plant for biogas and photovoltaic panels and to check and optimize the efficiency of the engines used; this could reduce fuel supply by 10 to 15%. Also no-tillage is listed as an activity that can save up to 50% of fuel, compared to a conventional farming.

Position statement

Since CSA is intertwined in a global network of large organisations, which have power and financial resources, the possibility of its success and application seem more probable than ever, especially concerning policy and governance. However, even though the program has been received well, there are critical voices which are mainly concerned with the aim of CSA to include agriculture in the global carbon market, meaning revenues from an offset market for reducing carbon emissions. This would bias the system against smallholders, who this approach claims to focus its efforts on. The opponents also state that, for example, the no-till soil-management (one proposal of CSA to reduce GHG emissions) involves application of herbicides which makes the farmer again dependent on large companies. Similarly, carbon offsets would put small scale farmers in debt by undermining their capacity to adopt and adapt. The other paradox is that some measures listed to reduce GHG emissions can actually be sources of GHG in some cases. For example no-tillage in places with abundant precipitation can cause stagnation of the water in the soil which can increase the emission of nitrous oxides to the atmosphere. Also the use of leguminous plants in nutrient rich soil can be a source of emission instead of sequestration. There are no general solutions that can be applied everywhere, every location should be studied separately in order to find a specific solution. CSA is an ambitious, young and dynamic program which might be well received. There is hope that its strong and powerful backbone (the FAO) might enable its success, without endangering the independence of smallholders.

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Biofertilizers open up new perspectives for sustainable crop production

Biofertilizers are a promising and low risk technology to increase plant growth and to enhance crop yield and quality, especially in low input systems.

Adele Ferrari, Daniel Maag, Christopher Mikita and Lukas Schütz

Introduction

Healthy and stable plant growth requires proper plant nutrition. Typical farm practices supplement naturally abundant macro- and micronutrients with fertilizers. Adequate nutrient management remains a formidable challenge to organic systems that are restricted from mineral fertilizers. Sufficient fertilizer application is so important that conventional high-input systems often choose over-application of nutrients to minimize risk of deficiency. This inherent inefficiency, however, can lead to waste as mineral fertilizers can volatize into the atmosphere, be leached into groundwater or be taken up by microbes and weeds. Additionally, a major portion of the global greenhouse gas emission, attributed to the agricultural sector, derives from metabolization of excessive nutrients by soil microorganisms. Further, natural sources of, for instance, phosphate (P) are finite and will soon become limiting. Therefore, reduction in mineral fertilizers availability and pressure for reducing environmental impacts of agriculture, may drive towards improving the efficiency of agricultural systems. During the last years biofertilizers received more and more attention as an alternative or complement to chemical fertilizers. Although their application showed promising results in terms of crop yield and quality, their effect is still highly variable depending on environmental conditions and agricultural management. The application and production of biofertilizers is yet under intensive investigation.

Mechanism and effect of biofertilizers

Microorganisms used as biofertilizers belong to a wide array of bacteria and fungi, which support plants by several distinct mechanisms (for an overview see Table 1). A first group are N_2-fixing bacteria, which are able to convert atmospheric nitrogen in plant usable ammonium. They are generally divided into two groups. Nodulating N_2-fixing bacteria can be used only to inoculate legumes, as other crop families would fail to form associations with these symbionts. Non-nodulating N_2-fixing bacteria are either obligate symbionts living at the root surface, or free-living symbionts. Inoculation with non-nodulating N_2-fixing bacteria can benefit all kind of crops, especially in conditions of low N availability. Another group of microorganisms used as biofertilizers are phosphate solubilizing bacteria and fungi which excrete low molecular weight organic acids that solubilize phosphate from organic and mineral sources. Phosphate solubilizing bacteria can as well be co-applied to enhance the efficiency of rock phosphate as fertilizer. Similarly some

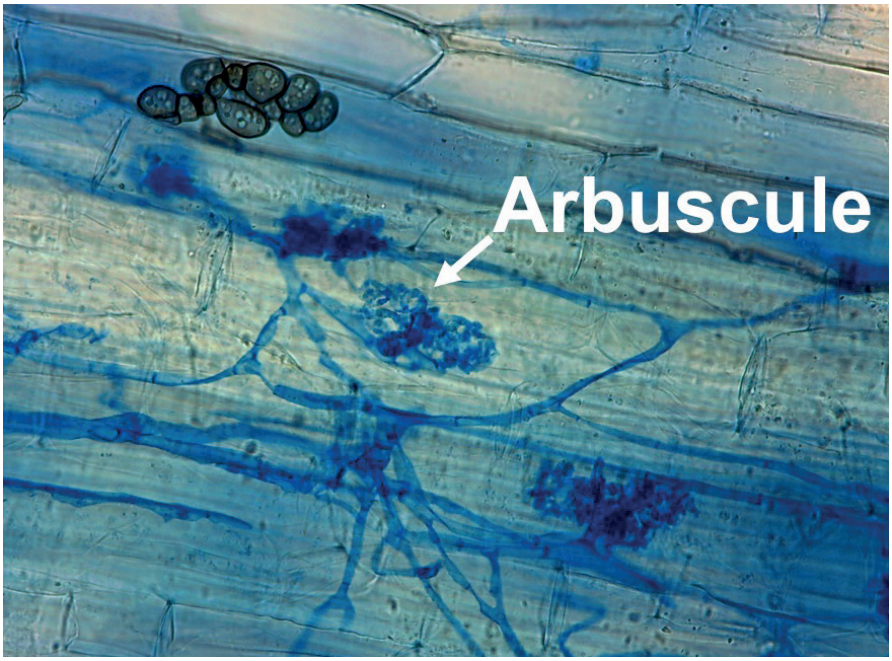

Figure 1. Stained arbuscular myccorhizal fungi in a plant cell. Photo by Luise Olbrecht

«Biofertilizers are microbial inoculants that have the ability to improve soil fertility and increase crop productivity. Commercially available products are formulated based on naturally occurring microorganisms and applied similarly to conventional fertilizers.»

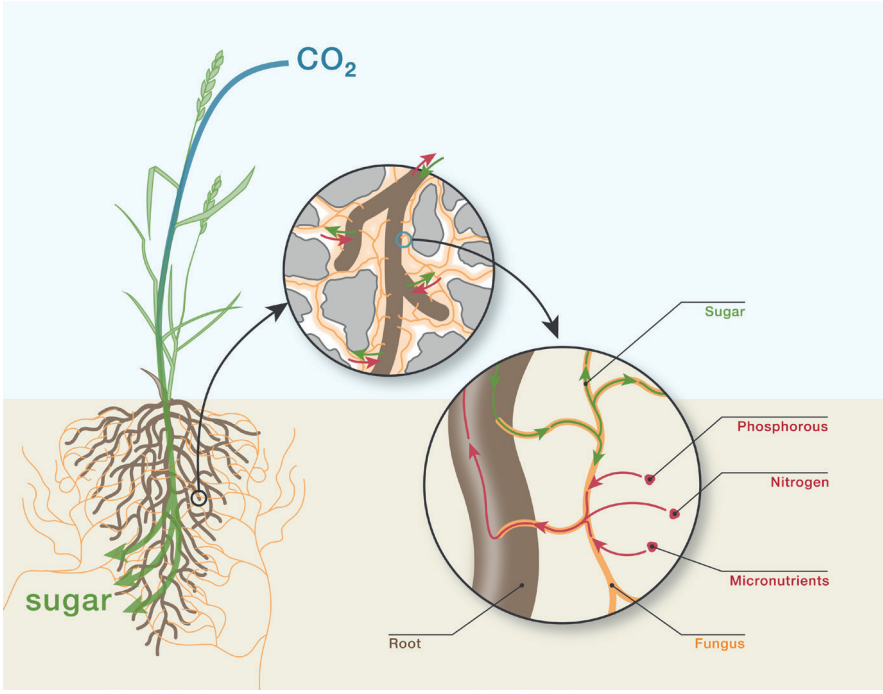

Figure 2. Nutrient exchange during arbuscular mycorrhiza is a two-way route. While the plant benefits from enhanced nutrient supply (e.g., nitrogen and phosphorus) mediated by the fungal partner, it provides organically bound carbon, produced by photosynthesis, that is excreted into the rhizosphere in the form of sugar. In addition, the fungi can solubilize otherwise unavailable nutrients (e.g., from rock phosphate), thereby increasing the nutrient availability in the soil.

Source: Zurich-Basel Plant Science Center (2014). Sustainable plant systems: Online learning material.

fungi have the same capability and are therefore as well used as biofertilizers. Both, N_2-fixing bacteria and phosphate solubilizing microorganisms improve plant nutrition by increasing nutrient availability in the soil. A third group of biofertilizers include arbuscular mycorrhizal and ectomycorrhizal fungi (AMF and EMF, respectively). The mycorrhizal mycelium absorbs and transfers nutrients from the soil to the plant, thus increasing the volume of soil exploitable by the roots and as a consequence improving plant nutrition. AMF species can be used with most agri- and horticultural plants, while inoculation with EMF can help establishing tree cultivation on former arable soils. The last group of biofertilizers is formed by plant growth-promoting rhizobacteria (PGPRs) which support crop plants by favoring seed germination, suppressing plant diseases and producing phytohormones (e.g., plant and root growth stimulants). Many PGPRs belong to groups of N_2-fixing bacteria or to phosphate solubilizing microorganisms. More biofertilizer agents can be applied in combination to favor the synergetic action of their functions. Phosphate solubilizing bacteria, for instance, can be combined with AMF to improve plant access to the solubilized phosphate.

Potential of biofertilizers

It is widely recognized that biofertilizers can replace substantial amounts of chemical fertilizers and thus increase the income of the farmers and simultaneously reduce negative impacts on the environment. In regions with fertile soils it may increase the profitability of low input systems such as organic agriculture, whereas in regions with a low level of soil fertility as in many tropical areas the use of biofertilizers is a promising technology to raise food production and increase food security. Besides its effect on plant growth, it has also been shown that biofertilizers are able to raise the micronutrient content like Zinc in harvested grain (see below for case study 2). Zinc deficiency ranks fifth among the most important risk factors for illnesses and death in developing countries according to the WHO and hence biofertilizers may reduce this malady. Currently studied is the suspected effect of biofertilizers on crop health. By changing the soil community, they are predicted to diminish soil pathogen populations. Biofertilizers are yet an emerging technology and legislation and registration for use and trade are still under discussion. As well the quality of biofertilizers needs to be addressed in this context and product labelling controlled. For a wider adoption and to gain the trust of the practitioner, information about the density of infective propagules, its shelf life time and its testing conditions has to be available besides others.

Conditions

Plants invest energy into beneficial soil biota. If nutrients are sufficiently available, there is less need for the plant to sustain them as they can access them by themselves. Hence, any biofertilizer is more effective in soils with low fertility, where their enzymes and transport abilities help to access nutrients. However, benefits can be expected under both conditions. Especially in low input systems, even though the base fertility may be high, biofertilizers can increase the use-efficiency of added nutrients and speed up the breakup of organically bound nutrients. There is a threshold of fertility, where biofertilizers will not show an effect anymore. The fertility is managed by the farmer and he needs to know about the fertility status of his field to use biofertilizers appropriately.

Limitations

Although, biofertilizers show positive effects in many different agricultural systems, they still show some specificity and are not generally applicable to the global agricultural system.

N_2-fixing biofertilizers	
Non-nodulating	*Azotobacter chrooccocum, Azotobacter brasilense, Beijerinckia indica, Klebsiella pneumoniae, strains of Bacillus megaterium, Anabaena cylindrica, Anabaena variabilis, Aulosira fertilissima, Nostoc muscorum and Tolypothrix tenuis, Gloeotrichia, Nostoc, Calothrix, Aphanothece spp., Anabaena oscillaroides, Brevundimonas diminuta, Azospirillum brasilense, Azospirillum lipoferum*
Nodulating	*Rhizobium, Frankia, Mesorhizobium, Bradyrhizobium*
P-solubilizing biofertilizers	
Bacteria	*Pseudomonas sp., Burkholderia caryophylli, Bacillus firmus*
Fungi	*Penicillium bilaii, Aspergillus niger, Aspergillus tubingensis, Penicillium brevicompactum, Penicillium solitum, Piriformopora indica, Trichoderma atroviride, Trichoderma harzianum*
P-mobilizing biofertilizers	
Arbuscular mycorrhiza	*Glomus* sp., *Gigaspora* sp., *Acaulospora* sp., *Scutellospora* sp.,*Sclerocystis* sp.
Ectomycorrhiza	*Laccaria* sp., *Pisolithus* sp., *Boletus* sp., *Amanita* sp.
Plant growth promoting Rhizobacteria	
many bacteria from different phyla	*Gluconacetobacter, Rhodobacter capsulatus, Paenibacillus polymixa, Burkholderia vietnamensis, Burkholderia tropica, Bacillus megaterium, Bacillus subtilis, Variovorax paradoxus, Bacillus circulans, Rhodotorula glutinis, Ochrobactrum anthropi*

Table 1. The most common biofertilizers

Soils already harbor their own and specific community of soil microbiota, which influences the establishment and longevity of newly introduced microorganisms. The existence of adverse or supporting microfauna and also the availability of nutrients and micronutrients depends highly on the soil type. Thus, if the source of the biofertilizer is not of local origin, the success of an inoculation is not guaranteed. Another important fact is that biofertilizers cannot replace completely organic or chemical fertilizers. Additional fertilization is always necessary, but biofertilizers help to make previously unavailable nutrients available.

Risks

Overall, risks related to this technology are rather low, especially in comparison to conventional fertilizing practices. One potential risk may be alterations of the indigenous microbial soil communities due to the application of biofertilizers. Such non-target effects are poorly studied, however, partly due to the high complexity of soil ecosystems and partly due to a lack of appropriate methods. An example would be the change of biogeochemical cycles which are affected by changes of the composition of the microfauna. Further research is needed to fully understand the complex interactions occurring in soil.

Production and application of biofertilizers

Production cost is an important constraint, as the price of a biofertilizer should not exceed that of conventional ones to assure a market potential. Bacteria strains selected as biofertilizers are multiplied as pure cultures in bioreactors. To contain the costs, cheap organic substrates (such as whey, sludge, composts, etc.) are used as growth media. For what concerns symbiotic fungi, EMF inoculants can be easily produced with bioreactors. The production of AMF, however, poses several difficulties due to the necessity of a plant host for the propagation of the fungus. AMF spores can be produced in-vitro using genetically transformed carrot roots. However, this procedure is still very costly and mainly used for laboratory or small field trials. Commercial AMF inoculants for large scale application are produced in propagation cultures. This consists in inoculating the selected mycorrhiza species to suitable host plants in a sterile substrate and cultivating the plants under controlled conditions. The substrate used for plant growth, containing spores, hyphae and fragments of the mycorrhized root is then used as inoculum.

The carrier helps to apply the biofertilizer in a suitable amount and in good physiological conditions. It should as well provide a suitable microenvironment to the microorganism, assure a sufficient shelf-life and allow an easy dispersion in the field. Additionally, it should be cheap, easy to sterilize, biodegradable and non-polluting. The kind of carrier utilized defines the physical form of the biofertilizer. Dry inoculants can be produced using different types of organic or mineral materials (peat, compost, sawdust, lapillus and perlite). Liquid inoculants are based on broth, oils in water emulsions. Additionally, polymer-based carriers appear very promising for increasing shelf-life of the biofertilizer. Some organic polymers, like alginates or carrageenans, may be applied to encapsulate the microorganisms in a protective matrix and release them gradually in the soil while degrading.

The application method or the biofertilizer varies depending on the crop. One possibility consists in spreading the inoculant over the field surface or in the furrows.To avoid additional costs to the farmers, formulated inoculants need to be simple to apply or to rely the farming machinery, which are already available. It is also possible to dress / coat the seeds prior to sowing. Therefore, the inoculant is dissolved in a solution (e.g., starchy water from rice cooking) to create a slurry in which seeds are mixed to be uniformly coated, and sown quickly after. For those crops

that are transplanted at a certain point of the cultivation stage (e.g., rice) it is also possible to dip the roots of seedlings in a biofertilizer solution.

Position statement

Biofertilizers are a promising and a low-risk technology to increase plant growth and to enhance crop yield and quality, especially in low input systems. In highly managed agricultural systems biofertilizers can be an effective tool to improve the use-efficiency of chemical fertilizers, thereby reducing their application. Increasing economic pressure and concerns about greenhouse gas emission trigger the need of new tools in agriculture. Biofertilizers do have the potential to be a real and good complement to chemical fertilizers, especially for an environment friendly agriculture.

CASE STUDY 1: BIOFERTILIZERS CAN REDUCE THE USE OF MINERAL FERTILIZERS

Data collected from more than 500 field trials in the US demonstrates the growth-promoting effect of the fungal biofertilizer Trichoderma. Application of this fungus to maize kernels as a seed treatment led to an average yield increase of around 5%.
However, under heavily managed agricultural conditions, these growth-promoting effects are expected to be rather low due to a high supply of agricultural fields with mineral fertilizers. Yet, the application of biofertilizers may help to reduce the amount of mineral fertilizers that is needed to obtain high yields (see graph below). This is achieved through increased nutrient uptake efficiencies of the plant caused by the association of the fungus with the plant's root. Additionally, Trichoderma has beneficial effects on plant health, which may also contribute to the observed growth enhancement.

Source: Harman, 2000

CASE STUDY 2: AMF AND PGPR INOCULATION IMPROVE WHEAT GROWTH AND YIELD

In this study, which was performed over two years in India, the growth response of wheat, rice and black gram was tested after inoculation with AMF or with PGPR, or with a combination of both. The effect of the applied biofertilizers was most notable in wheat, where the mean grain yield was increased up to 41% when a combination of AMF and PGPR was applied. This effect has been observed in both years of application. Different traits were analyzed and surprisingly, the positive effect is mainly due to increased numbers of tillers, whereas seed weight played a minor role. The AMF + PGPR treatment not only influenced yield, but it also had a positive effect on grain quality. Contents of nitrogen, macro- and micronutrients were significantly increased in wheat. The study concludes that AMF and PGPR inoculation is an effective strategy towards food security and resource preservation.

Source: Mäder et.al., 2011

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Use of genetic diversity to increase fungal resistance of small grain crops

Resistance breeding offers the potential to produce durable resistance to fungal diseases in small grain crops. A large spectrum of genetic diversity is available, and can be exploited by novel knowledge and techniques.

Guillaume Lacavé, Linda Lüthi, Coraline Praz, Morgane Roth and Luisa Schäfer

Introduction

Small grain crops or cereals with small kernels and short plants, such as wheat, barley, rye, triticale, oat and rice are important in the global food system. Especially rice and wheat, since they are the second and the third most produced crops worldwide after maize.

To meet the increasing demand for food, yields increased tremendously during the last decades. For example, the world wide wheat production increased from an average of 1 ton/ha in 1961 to more than 3 ton/ha in 2012. To reach these higher yields, agricultural practices were further developed and new crop varieties (cultivars) were bred. Unfortunately, a higher yield potential is often combined with a higher vulnerability to pest attack (Oerke, 2006). Pests reduce crop productivity in various ways (Boote et al., 1983) and cause losses in both product yield and product quality (Oerke, 2006). Five of the most important fungal plant pathogens infecting small grain crops are *Magnaporthe oryzae, Puccinia* spp., *Fusarium* spp., *Blumeria graminis* and *Zymoseptoria tritici* (Dean et al., 2014). Various strategies such as growing resistant varieties, use of fungicides or agricultural practices can be used in fungal disease management (Roelfs et al., 1992). To develop resistant varieties, both classical resistance breeding and GM technology can be used. Here we discuss two different breeding strategies, both aimed at reducing yield losses to fungal pathogens and both using natural genetic variation to do so.

Resistance breeding

Development of resistant varieties is the most sustainable way to prevent yield losses caused by fungal pathogens. Furthermore, modern agriculture consisting of extensive monocultures and other practices that favor pathogen proliferation, increases the need for durable resistance (Michelmore et al., 2013). Nevertheless, resistance breeding must be viewed within the context of a range of strategies to control diseases, such as crop rotations and the deployment of chemicals. Since breeding is an expensive and time consuming process, it is only economically feasible to breed for resistance to major pests and diseases, causing large crop losses. It is also important to note that resistance to pests and diseases is only part of a set of desirable traits that are considered in breeding programs.

Many factors determine the amount of emphasis placed on disease resistance, among traits such as yield, product quality and resistance to abiotic stress. For example, in organic agriculture disease resistance is more important than in conventional agriculture, since chemical disease management is restricted, and therefore receives more attention in breeding.

Resistance breeding is aimed at improving host resistance, which has a genetic basis and can therefore be improved by breeding. The disease resistance of most commercial cultivars relies on a gene-for-gene interaction between plant and pathogen. Major resistance (R) genes are often used because they provide effective resistance and are easy to breed for. However, fungal pathogens are evolving rapidly and can quickly overcome such resistance (Bhullar et al., 2010). The durability of R genes is therefore often regarded as problematic. Polygenic resistance, although often conferring lower levels of protection against disease, is considered more durable, but is more difficult to breed for since more genes are involved.

Genetic variation is used in breeding as a source of desirable traits. Resistance breeding makes use of the gene pools accessible for the species in question. Resistance is introduced into breeding material either by backcross or by transgenic method (see Figure 1). In backcrosses, an initial cross between the resistant donor and the susceptible recipient is followed by a series of crosses to elite material. Since the donor of the resistance is often of low agricultural value, or even a wild relative of a crop species (see below), these backcrosses over several generations are necessary to eliminate the undesirable donor genome, only keeping the resistance gene(s) (see Figure 3). Selection of the resistant plants can be either done by giving it a visual resistance score following a natural or artificial infection with the pathogen, or by using molecular markers associated with the resistance gene. The latter can be done at a very early stage of growth and without the need for infection, making it cheaper, more reliable and faster. To achieve more durable resistance, different approaches could be used in order to deploy more than one resistant gene in the same cultivar. Here we will focus on two of them: multilines or cultivars mixtures and cultivars with pyramided major resistance genes (McDonald & Linde, 2002; Brunner et al., 2012; Liu et al., 2000).

Cultivar mixtures and multilines

Protection against disease can be achieved by using a designed mixture of cultivars or lines, within which each genotype is resistant to a different strain of a pathogen. In an environment with disease pressure from pathogens with different races and varying incidence, the use of multilines or cultivar mixtures should result in a more stable yield compared to using a pure line cultivar. The effective amount of spores of the pathogen is reduced because susceptible plants are interspersed with resistant plants in a field so that the growth of the pathogen population is delayed. Multilines and cultivar mixtures thus have a damping effect on epidemics, as well as reducing the speed at which pathogens overcome host resistance. Mixture composition can be adjusted annually, based on data on disease spread of the previous year.

Multilines are often composed of so-called isolines, which share a common genetic background but differ in one disease-resistance conferring location in the genome. These lines are laborious to create, requiring multiple cycles of backcrosses for every line to be included in the mixture. Cultivar mixtures on the other hand are relatively simple to obtain through composing the best combination of commercially available cultivars. The mixture can include different genetic backgrounds, as long as the components are uniform or compatible for traits of agronomic importance, such as height, maturity and daylight sensitivity. Cultivar mixtures are able to buffer genotype by environment effect to a larger degree than multilines.

Examples of successful deployment of multilines or cultivar mixtures have been reported. Barley cultivar mixtures reduced powdery mildew infection by 80% in Germany (Wolfe, 1992) and stem rust in wheat was controlled blending varying combinations of multilines every season (Browning and Frey, 1969). More recently, rice blast was shown to be effectively controlled by multilines (Ishizaki et al., 2005).

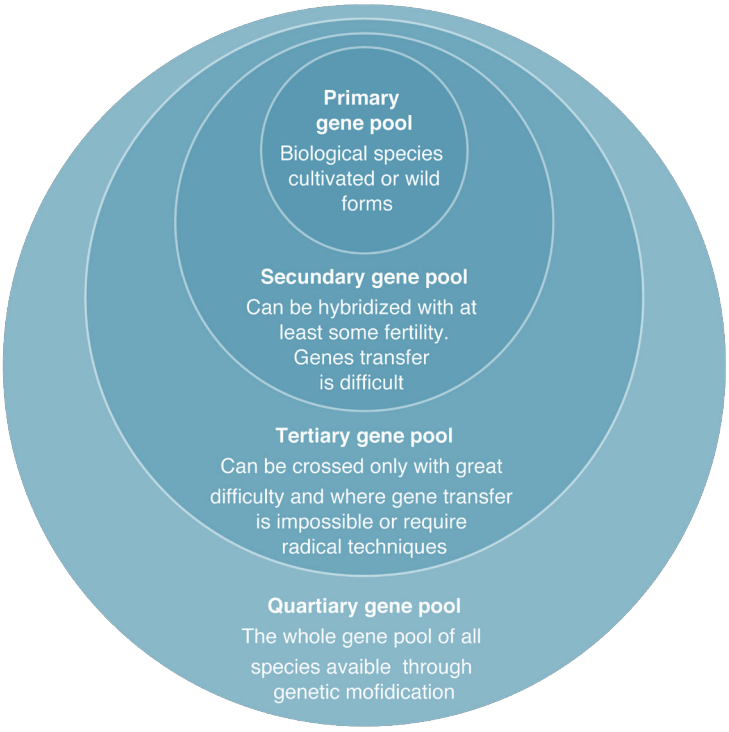
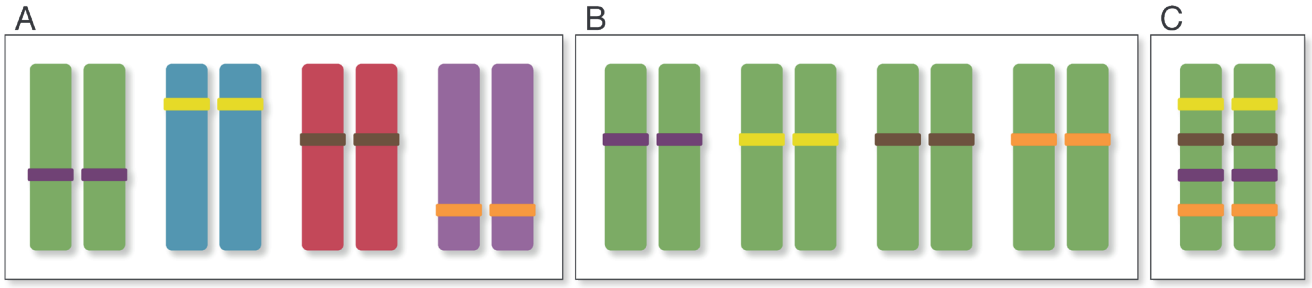


Figure 1. Gene pool concept. Adapted from Harland and de Wet, 1971

GENETIC DIVERSITY

The total genetic diversity found within a population or a species is often defined as the gene pool. The gene pool concept divides the total gene pool of cultivated plant species in three different gene pools. This classification is based on the possibility to make crosses between them. The primary gene pool contains cultivated and wild forms of a species which can be crossed together and gene transfer is therefore simple and direct. The secondary gene pool contains species that have reproductive barriers between them, but can still be artificially crossed. All species that can be crossed only with great difficulty and where gene transfer is impossible or requires radical techniques belong to the tertiary gene pool (Harlan & de Wet, 1971). More recently, a fourth gene pool was added to the classification system to include gene transfer using genetic modification technologies (Spillane & Gepts, 2001). The different gene pools can serve as tremendous source for genes and gene variants to improve cultivated crops. Gene banks all over the world safeguard this precious genetic diversity by storing seeds of a huge number of plant species.



A: Cultivar mix, B: Multilines, C: Gene pyramiding

Figure 2. Making use of diversity for the sustainability of the introgressed resistance

Gene pyramiding or gene stacking

Gene pyramiding or gene stacking is the combination of multiple R genes within the same plant (see Figure 2). They can confer resistance against one or multiple pathogens. Stacking of multiple R genes against the same pathogen is generally thought to lead to the best possible resistance.

The level of resistance conferred by gene pyramiding can be predicted using a probabilistic approach. If we assume that mutations within the pathogen to overcome different R genes are independent, the probability of all necessary mutations to overcome several different R genes occurring simultaneously would be very low. Therefore, only a few resistance genes would provide stable resistance for centuries (Mundt, 1990). However, data from Canada showed that there is no correlation between the number of stacked R genes and durability of resistance in stem rust resistant wheat cultivars (Mundt, 1990). There are two reasons for this: firstly, a lack of organisation and management of R gene deployment in the field, and secondly, a lack of in-depth knowledge on the function and interactions of R genes within the plant as well as on the corresponding processes in the pathogen.

R gene management in the field is difficult. It is important to keep broken and unbroken R genes apart, since a cultivar containing an arbitrary number of broken R genes and one unbroken R gene is not a valid case of R gene stacking. Also, whether an R gene is considered broken strongly depends on location and time. It happens that during cultivar development the situation changes, so that unbroken R genes are stacked on top of broken R genes. Also, many cultivars contain stacked R genes that are used as well in cultivars containing single R genes. This is highly problematic, since it allows step-by-step breakdown of the resistance by the pathogen, undermining the whole strategy of R gene stacking. Although it is known that R genes used for stacking should theoretically be functionnal, meaning not exposed to a pathogen population on their own elsewhere, traditional breeding often relies on introgression of R genes from wild plant populations or resistant landraces. Thus, these R genes can have been exposed to a pathogen population.

One unanswered questions in gene stacking theory is why some R gene combinations succeed while others are quickly broken. To answer this question, deeper mechanistic understanding of R gene function on a molecular level is needed. A recent study yielded new insights into the molecular interaction of stacked R genes. It found that pairwise stacked alleles of the wheat powdery mildew resistance protein Pm3 suppress each other (Stirnweis, 2014). In conclusion, the situation is complex and each R gene and R gene combination has to be carefully assessed on the genomic, proteomic and phenotypic level in the lab and field to make any predictions about the strength or duration of the resistance conferred.

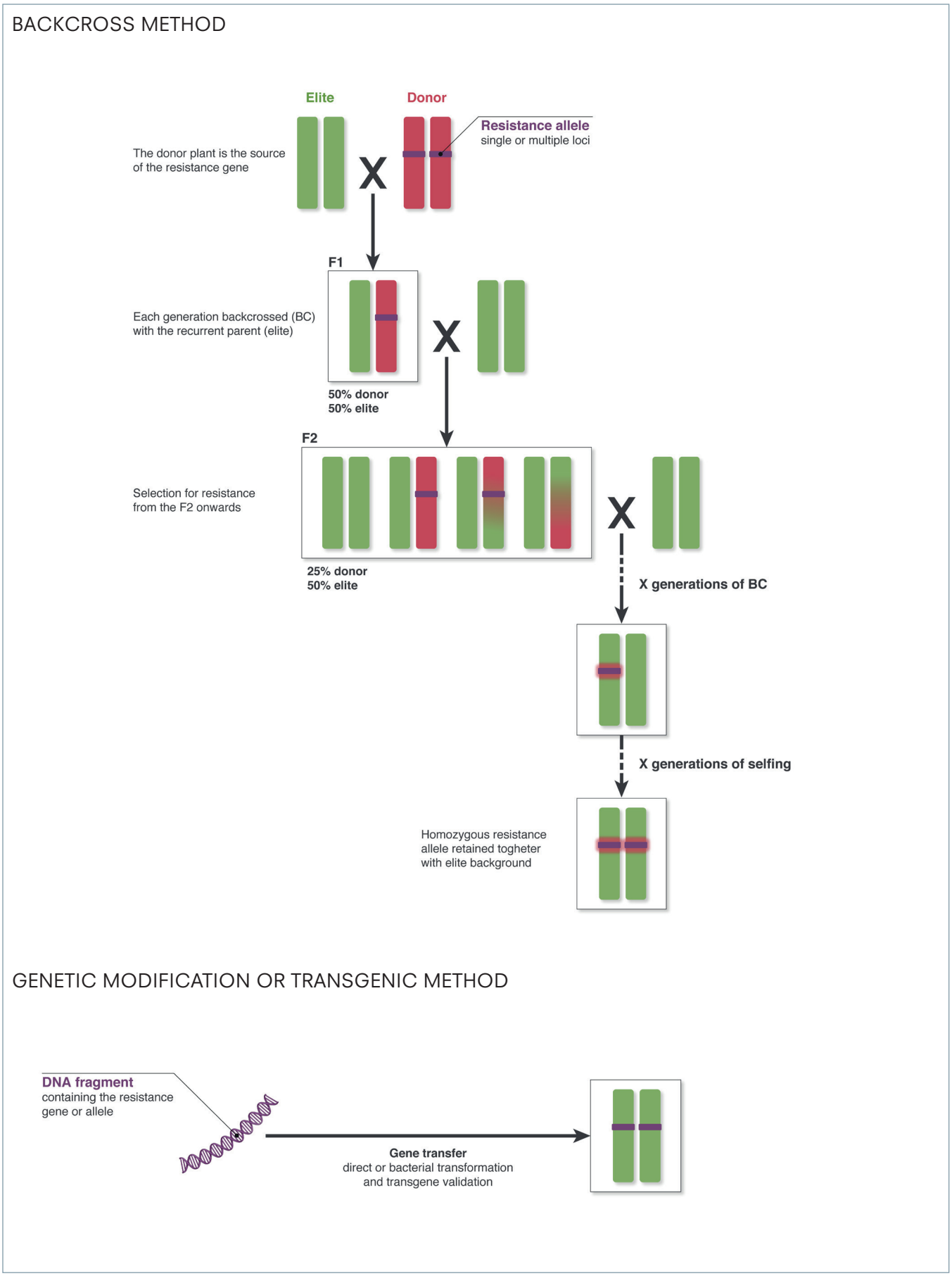


Figure 3. Methods for resistance breeding in autogamous plants. Introgression of resistance genes in elite cultivars using genetic diversity: backcross method and genetic modification or transgenic method.

MARKET REQUIREMENTS FOR A VARIETY

Bringing a new variety on the market implies meeting several levels of requirements, which can be analysed through the prism of regulation and market player's needs (e.g., seeds companies, farmers, retailers, industries). At the regulation level, in the European Union, several aspects of a new variety are evaluated before it can be registered. To do so, the DUS criteria (Distinctiveness, Uniformity, Stability) are used. Each new variety must be clearly distinguishable (different) from any other variety on the market. Uniformity refers to the ability of the variety to produce homogeneous plants on the field, with same characteristics and aspects. Finally, the stability criterion refers to the obligation of the seed company to supply the same genetics, without variation, every year and therefore to provide a product that is guaranteed to be the same year after year, meaning homogeneous through time. Some countries have additional requirements for new varieties to be allowed on the market. In France for instance, new technical and agronomical value must be added to the pre-existent varieties. With respect to each new variety coming to the market, the expectations and needs of the different market players are very diverse, and sometimes contradictory. For example, consumers' taste for innovation can often be opposed to the need of stability for industrial purposes. In conclusion, innovation in the field of small grain crops for targeting resistance to pests, diseases, and also for other traits, must be holistically developed. The process must integrate national and international regulation (present and prospective), the needs of the direct clients (farmers), and additionally the demands of all the market players that will be in contact with the product throughout the whole value chain (industries, retailers, consumers…). Neglecting to take these differents requirements into account can be a major pitfall in the deployment of a new variety.

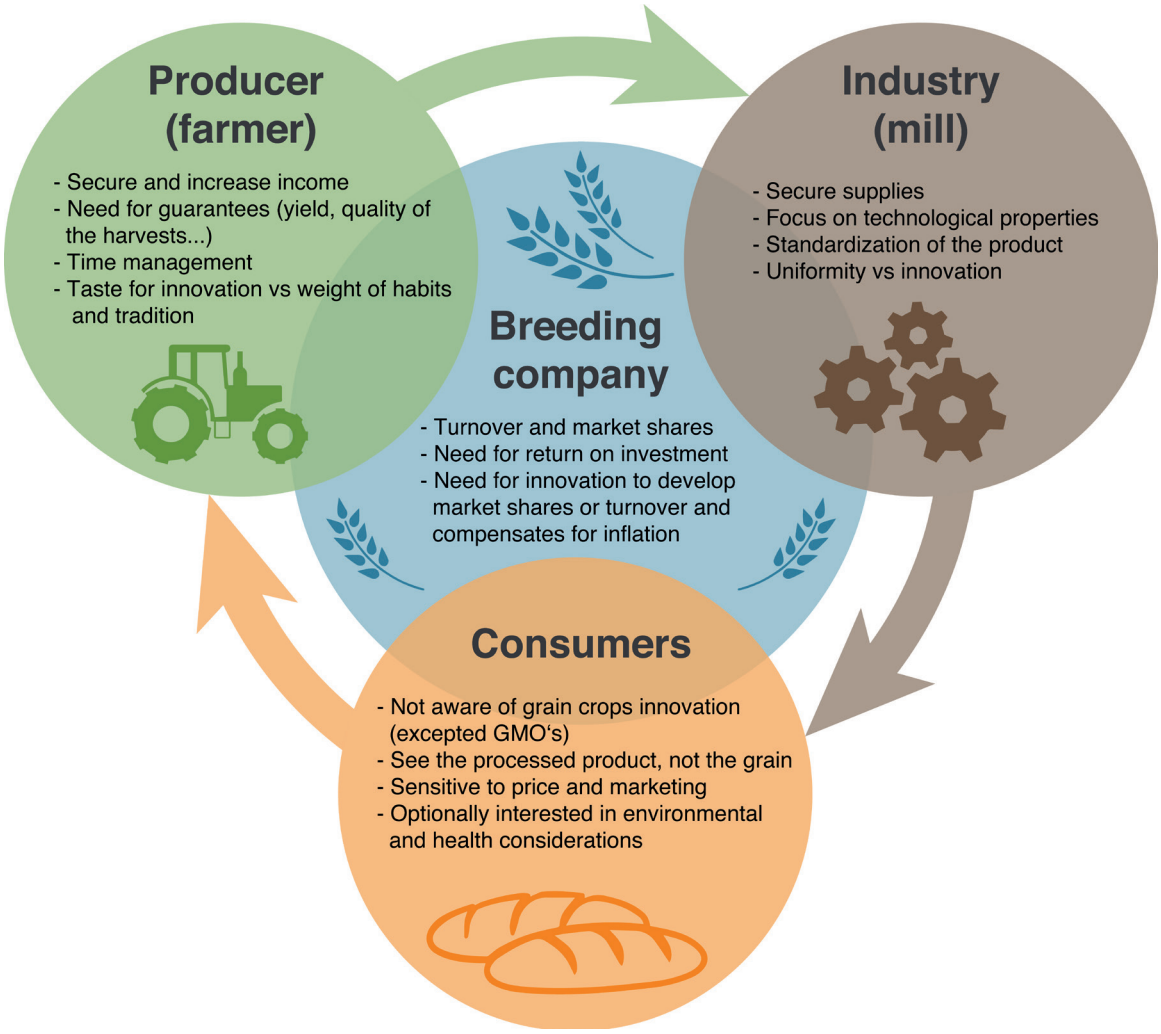


Figure 4. Main needs and constraints of market players concerning varietal innovation in small grain crops

Position statement

Resistance breeding offers the potential to produce durable resistance to fungal diseases in small grain crops. A large spectrum of genetic diversity is available, and can be exploited by novel knowledge and techniques. Creating commercial cultivars with a long-lasting and broad resistance against major pathogens, is therefore easier nowadays. Multilines, cultivar mixing and pyramiding appear to be promising ways toward this objective, but their use has not yet been deployed at a large scale. Resistance genes can be combined in order to limit the chances of adaptation of the pathogens. A long term strategy should be implemented to manage these resistance genes in a sustainable way. Managing this diversity would allow for recycling known resistance genes while discovering new ones with a systematic approach. Next, the possibility of introgressing a new resistance, whether with a low or with a high-tech approach (e.g., crossing vs. transgenic methods), should also be regarded as a part of the breeding strategy. Eventually, implementing a new resistance has to be achieved in an efficient and affordable way. To develop successfully, the new variety must also match the market requirements and the user and consumers acceptance. The sustainability of the resistance displayed by a given grain crop does not expressly bring added value to all the market players. Therefore, this characteristic may not be prioritized by breeding companies, because of important development costs. The use of resistance genes is only determined by a resistant behaviour in the field for the breeding time scale and is not assessed or predicted for the long term. To serve sustainability, important reflexion and decisions need to be made at the political level. A broader diversity management could be implemented that would allow to inventory the spread of resistance genes, to monitor them for a long term efficiency and to regulate their use depending on the populations of pathogens, as it is already studied for the resistance from pests to pesticides. In parallel, research on disease mechanism will enable to identify resistance with increasing accuracy. As we have seen, the technical ways to achieve a sustainable resistance to fungal disease in small grains are made available by current progress. However their benefits rely on their effective implementation that could be facilitated if a clear policy is drawn to achieve this goal.

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Case Studies 2016

Phytophthora-resistant potato: contribution to sustainable agriculture in Switzerland?

Markus C. Kolodziej[1], Sujit J. Karki[2], Keshav B. Malla[3] and Silvia Zanini[4]

[1] Department of Plant and Microbial Biology, University of Zurich, Switzerland
[2] UCD School of Agriculture and Food Science, UCD Earth Institute, Dublin, Ireland
[3] UCD School of Biology and Environmental Science, UCD Earth Institute, Dublin, Ireland
[4] Institute for Phytopathology, Centre for BioSystems, Land Use and Nutrition, Justus Liebig University, Giessen, Germany

Introduction

In the years between 1845 and 1951 the «Great Potato Famine» caused approximately one million hunger deaths in Ireland (Yoshida et al., 2013). Nowadays, it is known that the failures of this crop were caused by a disease called Potato Late Blight. One single strand of a fungal/algae-like organism, called *Phytophthora infestans*, was spread from North America to Europe. *P. infestans* is able to replicate itself asexually, as well as sexually. The two mating types of *P. infestans* (A1 and A2) originally came from Mexico, like the strain causing the «Great Potato Famine». The A1 mating type spread around the world in the 20th century, while the A2 phenotype started to spread in the 1990s (Dyer et al., 1993). The presence of both mating types started new *Phytophthora* problems in modern times. Sexual reproduction enables them to be genetically flexible, which allows a rapid development of resistance against commonly used fungicides, as well as the development of new virulences.

Nowadays, potato late blight does not cause millions of famine deaths in Europe, but it causes an estimated loss of one billion euro every year. These costs are generated not only by loss of production but also by additional costs for counteracting the disease (VIB, 2015). Switzerland produces approximately 447.000 Mt potatoes per year, which are worth almost 55 Million Euro (FAO, 2011). To perpetuate this production, potato fields in Europe are sprayed about 15 times with fungicides in a normal dry summer, and up to 25 times in a humid summer (VIB, 2015).

Integrated crop management practice

The definition of Integrated Pest Management (IPM) principle is centered on the management of crop with limited use of pesticides. The idea is to use selective pesticides only if other non-chemical preventive measures do not provide sufficient crop protection. In Switzerland, IPM was introduced as part of integrated crop production and has become the mainstream production scheme. At present, approximately 85% of the usable agricultural area is managed according to IPM requirements, as compared to the 12.7% farmed according to the «Organic Production Program» (Mouron et al., 2016).

Late blight (*P. infestans*) is one of the most damaging crop disease with the ability to spread rapidly in favourable conditions. Blight control is currently achieved in Switzerland through planting early varieties, e.g., potatoes planted earlier tolerate blight infection better than those planted late. Planting healthy, blight-free seed and varieties with high blight resistance. Internet based network support systems mainly PhytoPRE for information regarding disease forecast and appropriate recommendation of control measures. Synthetic fungicides in conventional and fungicides based on copper in organic agriculture have been most effective. However, restrictions on the amount of copper pesticides followed by lack of other alternatives creates a serious concern on managing damage caused by late blight in organic agriculture.

Resistance breeding and genetic modification

Traditional plant breeding introduces new beneficial alleles or gene from crossable species. However, due to crossing barriers and linkage drag, it is time consuming and requires several generations of breeding and selection. Another possible way to improve the potato farming could be the incorporation of a genetically modified late blight resistant potato. In transgenic breeding, the gene of interest is directly transformed to the recipient genome. However, crops generated from transgenic technique have brought considerable concerns about the safety and impact on health and the environment because genes from other species such as bacteria are transferred to plant genomes using a selection marker.

Cisgenesis is a genetic modification to transfer beneficial alleles or genes from crossable species into a recipient plant (Hou et al., 2014). This is better solution than traditional breeding techniques because several R-genes can be inserted into one step without integration of unwanted genes that one closely associated with target gene. Van Der Vossen et al. (2003) applied the cisgenesis approach and successfully cloned and introduced three late-blight resistance genes from *S. bulbocastanum* to cultivated potato. Cisgenic strategy was initiated in 2006 by Wageningen University to develop resistant potato against late blight. In the Durable Resistance against Phytophthora (DuRPh) program, R-genes, including their native promoters and terminators, are subsequently transferred into commercially grown potato varieties leaf cells through *Agrobacterium tumefaciens* transformation. For the fast determination of the R-gene combination a marker was used and after that step the

desired potatoes with these genes were modified in a marker-free way method (de Vetten et al., 2003). The resistance cisgenic potatoes are grown to maturity and only the plants showing the same characteristics as the original variety are selected (Haverkort et al., 2009).

Possible integration of genetically modified crops into integrated food system

20th century marked the green revolution in agriculture with breeding of high yielding crop varieties and use of chemical pesticides and fertilizers. Due to higher dependency on chemical pesticides, fertilizers and their potential negative impact on environment the concept of IPM was developed. IPM can be broadly defined as method or way to control pest through integration of several practices, so that it will have less or minimum effect on the environment. It is important to understand how a genetically modified (GM) crop could improve agricultural production in sustainable, environmentally friendly, economically viable and socially acceptable way. The introduced trait and the production system of the crop in a certain region, and the socio-economic context need to be considered (Meissle, 2016).

Cisgenic potato in the Swiss context

Despite the potential usefulness of a cisgenic late blight resistant potato, there are also concerns against introducing it in Switzerland. There is an ongoing debate in Switzerland about the regulation of GM and New Breeding Techniques (NBT) plants and products: the current ban on GMO (in place since 2005) is expected to be extended after 2017. Despite recent report by the Zurich Office of Waste, Water, Energy and Air (WWEA)/Federal Office for the Environment (FOEN) working group which concluded that many NBTs should not be subject to GMO laws, policymakers are following a precautionary approach and are probably not planning on differentiating between the various technologies/methodologies (Schuttelaar & Partners, 2015). As a result, cisgenic plants in this overview will be considered as GMOs to assess their socio-economic and environmental sustainability.

Environmental impact

The establishment of potato varieties Phytophthora-resistant in conventional farming systems will decrease by half the number of applications of pesticide that have deleterious effects on beneficial fungi and other non-intended targets (Speiser et al., 2012). Furthermore, the introduced genes are already present in wild species and conventionally bred varieties, and, as such, their effects on the ecosystems are already known: no reported impacts on non-target organisms has been found for fungal resistance (FR) (Vogler et al., 2010).

Finally, given the absence of wild potatoes in Switzerland, FR potatoes can only cross with other cultivated varieties, which are mostly self-fertile or almost sterile, averting the risk of gene flow (Schuttelaar & Partners, 2015). As a result of a less labor-intensive management and less pressure on resources, FR potatoes are predicted to improve soil quality (Wohlfender-Bühler et al., 2016).

Reduction of pesticide applications will likely reduce CO_2 emissions and lower the pesticide runoff risks, but implementing the required measures of co-existence has been predicted to increase CO_2 emissions and affect the environmental sustainability of the system (Wohlfender-Bühler et al., 2016). Deregulation of cisgenic crops will circumvent the need to observe these measures, and the use of FR potatoes will result in an improvement of the environment quality.

Socio-economic impact

One of the major obstacles to the introduction of cisgenic technology in the fields is the low public acceptance of GM products. Swiss consumers are reluctant to embrace this technology over environmental and health concerns, notwithstanding the scientific community agreement that GM and conventionally bred varieties entail equivalent risks (Scott et al., 2016).

Consequently, farmers and agribusiness are not likely to benefit economically from the use of GM crops in the current situation. Seeds are generally more expensive and, «while the management advantages could compensate the additional costs for implementing coexistence measures, low acceptance from the consumers will likely lead to overall decreased profits» (Wohlfender-Bühler et al., 2016).

Conclusion

The costs incurred by losses and chemical control of *P. infestans* on potato alone is estimated to be around € 5.2 billion globally, urging the institution of efficient control measures against late blight (Haverkort et al., 2009). One of the possible courses of action is the use of cisgenic potato that is resistant against late blight. Integration of cisgenic potatoes into the integrated production systems would allow reduced chemical sprays and lesser impact on biodiversity. In Switzerland, field trials of FR potatoes have been approved in 2015 by Swiss Expert Committee for Biosafety on the Agroscope Protected site and will assess the sustainability of these new varieties in the Swiss context. However, without a change in consumer's attitude toward GM and NBT crops, it is unlikely in our opinion that the FR potatoes will be introduced successfully in a Swiss agro-system.

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Agroecological practices and ecological intensification in tropical agriculture: the push-and-pull-approach

Carole Epper*[1], Vanathy Erambamoorty*[1], Annelle Mendez Gutierrez*[2] and Milena Wiget*[3]

* shared first authors contributed equally in this report
[1] Institute of Agricultural Sciences, ETH Zurich, Switzerland
[2] Safety and Environmental Technology Group, ETH Zurich, Switzerland
[3] Institute of Environmental Sciences, ETH Zurich, Switzerland

Introduction

The industrialization of agriculture and the green revolution have greatly increased global food production, but have simultaneously resulted in enormous environmental problems (IPES, 2016). Current industrial agriculture requires massive resource inputs (water, land, fertilizer, pesticides and energy) and has negative impacts, such as eutrophication, land degradation, biodiversity loss and greenhouse gas emissions (IAASTD, 2009). The current ecological, food, and energy crises have led to a transformation of the green revolution mentality of «increasing production» into a new mindset of «increasing sustainability» (Horlings & Marsden, 2011; IPES, 2016). This concept evolution can be captured by the term «ecological intensification», which describes an agricultural production with a high ecological value and a sustainable basis, while ensuring food security by maintaining a high productivity (UNEP, 2011; Garnett et al., 2013). Ecological intensification could be done by using agroecological practices that reduce environmental, social and economic costs and increase yield especially in tropical areas (UNEP, 2011; Wezel et al., 2014).

Tropical areas span different continents, climates, vegetation zones and altitudes; thus, ecological intensification requires local adaptation of a diversity of farming systems. Ecological intensification in tropical latitudes is important for several reasons. First, unsustainable agricultural practices are often linked to poor socioeconomic conditions, which apply to the majority of tropical countries (Sachs et al., 2001). As a result of compromised socio-economic conditions, vicious circles emerge, which are often manifested in the tropics by increasing deforestation and land degradation due to soil fertility loss, soil erosion, decreasing agroecological functions and land abandonment (IAASTD, 2009). Environmental degradation – particularly soil degradation – and poverty in the tropics could be addressed through ecological intensification (Pretty et al., 2003; UNEP, 2011). In addition, incorporating agroecological practices might help to adapt to climate change and to increase resilience against food insecurity (CCAFS, 2011). As current agricultural production within tropical latitudes does not keep up with population growth and suffers from negative climatic changes (De Groote et al., 2010; Reynolds, 2010), agroecological practices have a huge potential by increasing the yield sustainably (De Groote et al., 2010; UNEP, 2011).

In the following, the push-pull approach is described as an opportunity to ecologically intensify agriculture in tropical regions, with focus on eastern Africa. The benefits, challenges, and future potential of this approach are also discussed.

The push-and-pull-approach

In eastern Africa, stemborer *Chilia partellus* can cause up to 30–40% yield losses of maize (*Zea mays*) and other cash crops (Amudavi et al., 2007; Hassanali et al., 2008). Thus, researchers from the international center of insect physiology and ecology (ICIPE) from Kenya did several field observations and chemical analyses and devised an integrated pest management strategy against the stemborer, the push-pull approach (ICIPE, 2015). This approach is composed of three main plants: the cash crop (e.g., maize), Napier grass (*Pennisetum purpureum*) and a Desmodium species (silverleaf, *D. uncinatium* or Greenleaf desmodium, *D. intortum*) (Figure 1). Napier grass is a perennial plant with low water and nutrient requirements that is already highly used as fodder for goats and cows (Orodho, 2006). Particularly one variety of Napier grass attracts the stemborer moths by producing volatile chemicals that attract the insects, as well as a sticky exudate that traps them (Hassanali et al., 2008; ICIPE, 2015). By growing Napier grass on the edges of the field, the moths are «pulled» out of the field and lay their eggs on the grass. Contrary to maize, Napier grass has developed a good self-defense mechanism against the stemborer larvae (ICIPE, 2015; Khan et al., 2016).

The Desmodium species produce a number of volatile compounds that «push» the stemborer moths away from the field (ICIPE, 2015). They also have the ability to control the maize parasite Striga (e.g., *Striga hermontica*), which also causes yield losses of about 30–50% (Amudavi et al., 2007), by producing different C-glycosylated flavonoids that have an allelopathic effect and induce suicidal germination (Hassanali et al., 2008; ICIPE, 2015). In addition, species from the Desmodium genus

are leguminous plants that can fix atmospheric nitrogen (Hassanali et al., 2008) and cover the soil to prevent further soil erosion.

The push-and-pull approach was first introduced in the two Kenyan regions Suba and Trans Nzoia in 1997 and by 2004 approximately 68.800 smallholder farmers were using the push-and-pull technology in Kenya, Uganda, Tanzania and Ethiopia (Khan et al., 2014). As local farmers need to produce as much food as possible on the small parcels, the push-and-pull approach has been slightly adapted and changed in some regions. For example, beans like *Phaseolus vulgaris L.*, cowpea *Vigna unguiculata L.*, and groundnuts *Arachis hypogaea L.* were integrated among the single maize plants or even in the same holes (Khan et al., 2008, 2009). Also the integration of sorghum (*Sorghum bicolor*) instead of maize is being studied (Khan et al., 2006).

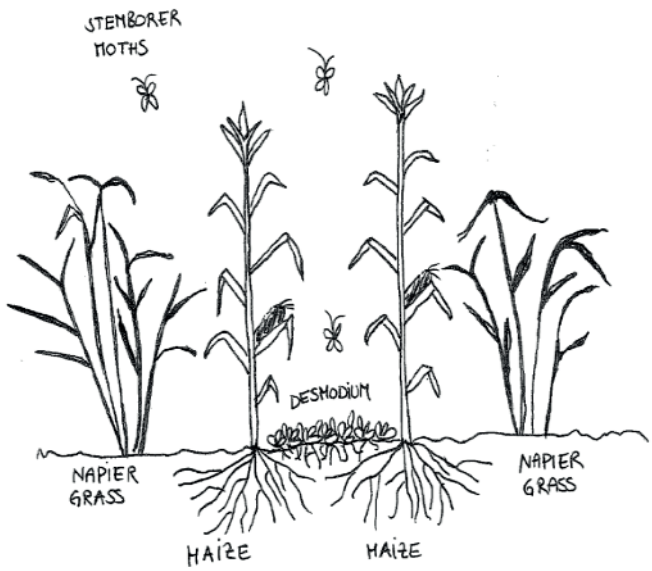

Figure 1. The push-and-pull approach on the field. Aadapted from foodsecurity.ac.uk

Benefits

A wide range of economic, environmental and social benefits stem from the adoption of the push-pull approach in Eastern Africa. First, by reducing Striga and stemborer damage to crops, two to three-fold yield increases for maize (Hassanali et al., 2008; ICIPE, 2010; Khan et al., 2014; ICIPE, 2015) and sorghum (Khan et al., 2014) have been achieved. The push-pull approach also provides supplementary income-generating opportunities. Napier grass and Desmodium can be harvested all year long, so they can be sold when the cash crop is not yet available for sale (De Groote et al., 2010). The availability of fodder has also allowed farmers to establish their own dairy farming (ICIPE, 2010, 2015). By producing their own forage or obtaining it from neighbors, farmers also save time in gathering forage and herding animals (ICIPE, 2015). Moreover, crop residues, previously used to feed animals, can be returned to the soil and animal manure can be used as fertilizer.

The push-pull approach also has several positive effects on the environment. It reduces the use of synthetic pesticides by capitalizing on semiochemical responses, allelopathy and inorganic fertilizers by improving soil fertility (ICIPE, 2010; Khan et al., 2014; ICIPE, 2015). Moreover, the Desmodium cover crop conserves soil moisture, decreases soil temperature and prevents loss of top soil (ICIPE, 2010), while Napier border rows reduce soil erosion and protect maize from wind damage (ICIPE, 2015). By having a mixture of crops and grasses agro-biodiversity, as well as biodiversity in beneficial soil microorganisms are increased (ICIPE, 2010, 2015). All of these benefits also enhance resilience of smallholder farms to changing climatic conditions (Khan et al., 2014). Another advantage of the push-pull approach is its adaptability and flexibility to meet needs. The «push» or the «pull» aspect can be strengthened depending on the degree of Striga or stemborer infestation, or soil fertility issues (ICIPE, 2015). Also, the cash crop, cover crop or grass can be successfully replaced by more drought-tolerant species (Khan et al., 2014). Finally, increasing productivity of small farms reduces pressure on the land and migration (ICIPE, 2010, 2015).

Furthermore, adaptation of the push-pull approach has valuable impacts on numerous social dimensions. First, it improves all food security outcomes: food availability through greater food production, food access through increased purchasing power throughout the year, and food utilization through a more balanced and varied diet as a larger variety of crops and milk become available. Second, the extra income generated allows a greater access to education (ICIPE, 2010). Third, capacity building through mass media, local agricultural extension services, farmer field schools and farmer-to-farmer exchanges has increased the knowledge and skill base of smallholders on successful sustainable farming practices (Khan et al., 2014; ICIPE, 2015). It also strengthened safety nets in the communities (ICIPE, 2010) and enhanced their organizational skills (UN, 2010) by making them more attractive for funding agencies (ICIPE, 2015). In addition, as farmers regain the feeling of wanting to be a farmer instead of being forced to do so in the absence of other opportunities, their pride and social status is bolstered, which in turn contributes to reduced migration and stronger family ties (ICIPE, 2015). Finally, the integration of women, particularly in Desmodium seed production activities, has resulted in greater gender equality (Hassanali et al., 2008).

Challenges

Despite promising ecological and affordable agricultural intensification method in eastern Africa, the push-and-pull approach brings also several challenges. Before implementing the push-and-pull method, it is important to get rid of stemborers in the field because their larvae can remain dormant and can thus hinder the desirable effect of the push-pull system (Polosky, 2015). Practicing crop rotation in the fields can help to tackle this (Chabi-Olaye et al., 2005). However, the perennial nature of Desmodium and Napier grass and their success as cash crops can be a limitation (ICIPE, 2010). Khan et al., (2007)

discovered that only a variety called bana Napier grass significantly attracts female stem borer moths for egg placement over maize and decreases survival rates. Relying on only one variety of «pull» plants could decrease biodiversity and further promote spread of diseases such as Phytoplasma, spread by leafhopper in Napier grass (Amudavi et al., 2007). Other problems such as pollen beetle attacks on Desmodium (Lebesa et al., 2012) also need to be solved (Amudavi et al., 2007).

In addition, farmers find that planting, trimming and weeding the slow-establishing Desmodium at initial stages is work-intensive and they usually cannot afford hiring helpers (ICIPE, 2010). In addition to labor costs, purchasing Desmodium seeds and Napier cuttings contribute to high initial costs (De Groote et al., 2010). Besides, this method requires larger plots than monocropping to grow non-food crops (Desmodium and Napier grass), which dilutes the overall cash crop yield improvements and presents an additional challenge due to insecurity in land ownership. Hence, the incentive to invest in push-pull systems can be relatively low (ICIPE, 2010).

The farmer's acceptance of push-and-pull system is sometimes hindered because it is perceived by few farmers as a «scientific experiment» that is managed by outsiders (ICIPE, 2010). Older and more experienced farmers, who are more knowledgeable on various traditional practices, are often less willing to adopt new ideas than younger farmers (Amudavi et al., 2009), who are technically more open-minded (Ike & Inoni, 2006; Speelman et al., 2008).

Conclusion

The analysis of the push-and-pull approach as an agroecological approach to intensify tropical agriculture ecologically has shown that it has many environmental, social and economic benefits, but also faces several challenges such as the high initial costs that are negative in the short-term, but decrease over time. As long as externalities are not included in economic benefit calculations, the costs of push-and-pull approach will always be higher and less competitive compared to the costs of commercial approaches. To successfully implement and expand the push-and-pull approach strategies and to overcome the mentioned challenges (especially motivation challenge), they must be devised to ensure the long-term sustainability of the approach.

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Genetically modified organisms as an option for crop management for disease and pest resistance

Ngoni Kangara*[1], Clemence Marchal*[1], Cyrielle Ndougonna*[1] and Karolina Słomińska-Durdasiak*[2]

* shared first authors contributed equally in this report

[1] John Innes Centre, Norwich Research Park, Norwich, UK

[2] Leibniz Institute of Plant Genetics and Crop Plant Research, Pathogen-Stress Genomics, Stadt Seeland, Germany

Introduction

Food security is defined as the «availability at all times of adequate world food supplies of basic foodstuffs to sustain a steady expansion of food consumption and to offset fluctuations in production and prices» (UN, 1975). With increased population growth, access to food may be limited in some parts of the world. It is assumed that the world population will exceed 9 billion people by 2050. To be able to feed all those people some scientists reckon that we have to produce larger amounts of food without impacting the quality (Herrera-Estrella & Alvarez-Morales, 2001). For food demand to be satisfied, it is estimated that crop production should increase by 50% by 2050 (Khush, 2001).

For thousands of years, agriculture has relied upon plant breeding as a tool to improve plant-derived products in order to feed people and domesticated animals. The aim of resistance breeding is developing plant material, which is protected from biotic or abiotic stresses. In conventional breeding improved resistance is done through crossing superior plants to compatible plants carrying traits of interest. Because of random DNA recombination in offspring, linkage drags may occur and selection for traits of interest is impeded. Hence, conventional breeding often takes decades to develop a new variety with improved traits and its success in the field is highly environment-dependent (Barrows et al., 2014). Mutagenesis by irradiation or chemical compounds application is widely used to circumvent this issue: a mutagenized population is developed in the cultivar of interest and then screened to identify desirable traits. This method is very non-specific as thousands of genes may be mutated. Reports from the National Academy of Sciences of the United States acknowledged that the risk of creating some unintended health effects using mutagenesis is greater than with any other technique, including genetic modification (Kaskey, 2013).

Genetic approaches in breeding

Genetic approaches were implemented in the mid-1990s with the aim to accelerate the breeding process by artificially modifying the genetic material of an organism to give it a new property (Hartung & Schiemann, 2014). Materials produced through these approaches are known as Genetically Modified Organisms (GMOs). Several methods can be used to edit plant genomes. For instance, DNA from another organism can be incorporated into the genome of the targeted plant to produce a new protein. This approach is called transgenesis and Bt crops, which will be discussed in the following sections, are the best-known examples regarding insect resistance traits. As opposed to transgenesis, we refer to cisgenesis, when the transgene comes from the same species or a crossable, sexually compatible species. Using this method, it is possible to obtain highly similar progeny to the one, which could be obtained also by conventional breeding. Gene expression can also be altered in the plant using RNA interference (Sinha, 2010). More recently, target modification tools were developed. One of them is the CRISPR-Cas9 technology, allowing for precise editing of genomes without leaving any signs of such edition, apart from the edition itself (Wang et al., 2016). This lead to a huge debate regarding their regulation, as the derived plant material cannot be traced without prior knowledge of the edition.

What we have learned from the deployment of the Bt-crops

The following section aims to give a broad view of what has been learnt from the deployment of these plant materials in conventional agriculture and, thus, illustrates the benefits, but also non-intended effects that have been shown through a wide range of studies. We focus here on the Bt-crops as they are the most known example of first generation GM crops and have been commercially accepted for decades. The first generation GM crops is defined as plants, which have been engineered to improve input traits such as pest resistance and herbicide

THE TWO MAIN BT CROPS IN THE US

Bt maize and cotton represent 80% and 84% of the maize and cotton grown in the US in 2014 (US Department of Agriculture, National Agricultural Statistics Service, 2015). These crops have been engineered to produce insecticidal toxins (Cry proteins) from *Bacillus thuringiensis* with the aim to reduce the use of pesticides and limit pest damages on cultures. Providing the transgene comes from a different species, these plant materials have been produced by transgenesis techniques.

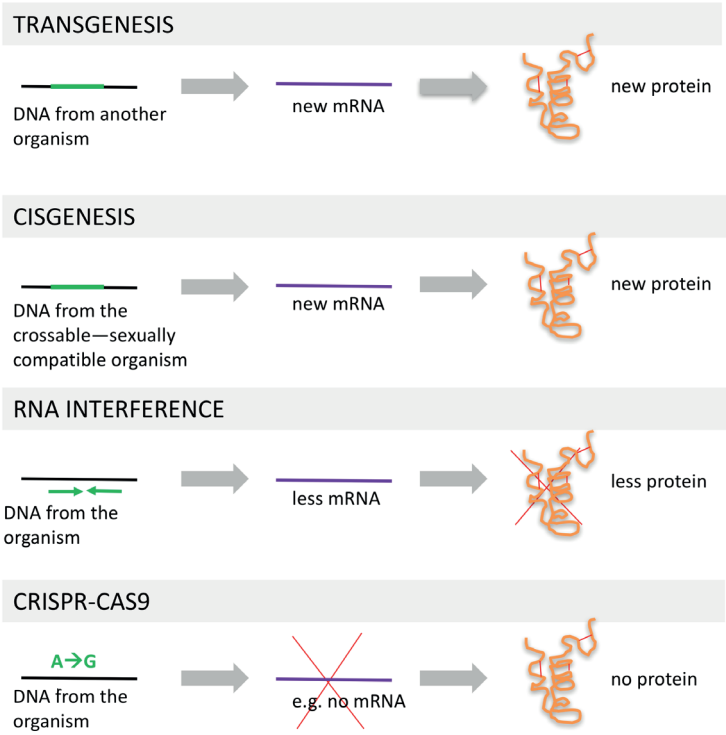

Figure 1. Techniques used to obtain GMOs

trance, whereas the second generation of genetic modifications focuses on output traits (nutritional features or improved processing features).

Economic and environmental benefits of Bt crops introduction

Hutchison et al., (2010) established a correlation between the suppression of the primary pest European corn borer (*Ostrinia nubilalis*) and Bt maize cultivation for 14 years in the studied region. The study estimated that the use of the GM crop was correlated with a 27 to 73% decrease in the larvae population (mean number larvae per plant), depending on the state taken into account. The authors also illustrated that cumulative benefits reached $ 3.2 billion for maize growers in Illinois, Minnesota, and Wisconsin and more than $ 2.4 billion of this total accruing to non-Bt maize growers. The annual benefits have been calculated based on the value of the yield gain for Bt maize compared to non-Bt maize minus the additional cost of Bt maize seed. This study does not mention the use of pesticide or whether their use did decrease as well or not. This question has been addressed in a study carried out by Lu et al., (2012) in China from 1990 to 2010 at 36 sites in six provinces, which showed that an increase in abundance of three types of generalist arthropod predators (ladybirds, lacewings and spiders) and a decreased abundance of aphid pests were associated with widespread adoption of Bt cotton and reduced insecticide spraying. First of all, there was not found any effect of the type of crop (Bt cotton or non-Bt cotton) on the predators and aphid pest's populations without chemical control. However, the use of insecticides for cotton bollworm (*Helicoverpa armigera*) was correlated with a lower and higher abundance in predators and aphids, respectively. The introduction of Bt cotton was correlated with a diminution of both all-pests and cotton bollworm-specific insecticides: from 15 and 10 sprays per season in 1997 (introduction of Bt cotton) to 11 and 2 sprays per season in 2010, respectively. The decrease in the number of sprays per season was associated with a slight increase in the predator population (from 9 to 14 individual/100 plants) over the same period. Finally, these observations were linked to a decrease in the aphid population from the introduction of Bt cotton to 2010 (from 1.100 to 400 aphids/100 plants). Thus, the authors suggested that the predators might provide additional biocontrol services spilling over from Bt cotton fields onto neighboring crops (maize, peanut and soybean).

Remaining challenges associated with the introduction of Bt crops

Unintended effects have been recorded in the literature and have to be taken into consideration. A study reported that the use of Bt maize might have led to western corn rootworm field-resistance to this crop (Gassmann et al., 2011). The authors observed severe rootworm feeding injury in several Bt maize fields. Bioassays also demonstrated that these populations of western corn rootworm displayed significantly higher survival on Cry3Bb1 maize compared to western corn rootworm from fields not associated with such feeding injury. Large deployment of such a strongly resistant phenotype would lead to the application of a high selection pressure on the pest, leading the phenotype to overcome after its deployment. Resistance management options, such as the high-dose refuge strategy or the pyramiding of toxins with different modes of action, can

delay the evolution of resistance, when implemented appropriately. Another risk associated with the wide use of such insecticidal producing plants is the positive selection of the non-targeted pests. For instance, a study carried out on Bt cotton in China showed that the regional increase of the adoption of this crop is associated with increased population sizes and acquired pest status of mirid bugs (Lu et al., 2010). These results show that the suppression of the primary pest might lead to the creation of a new niche for the non-targeted pests, which are then able to spread. This raises concerns about the impact of releasing GMOs into the environment and illustrates that this impact has to be assessed and tightly monitored prior and during their deployment.

Another major concern regarding genetically engineered crops is whether their consumption could be harmful or not. Indeed, in Bt crops an exogenous protein is produced and thus some concerns exist that those crops might have an allergenicity effect when consumed. However, no toxicity of any GM crop has been reported so far (Betz, 2000; Fermin et al., 2011). Taken together, these studies have shown that even though growing Bt crops can provide environmental benefits, their deployment has to be monitored and strategies to delay expected unintended effects need to be implemented. The following section aims to provide an overview of the solutions that have been proposed to address these issue.

Integrated plant protection

Integrated plant protection is defined as «all economically, ecologically and toxicologically defensible methods […] applied to keep damaging organisms below economic damage levels whilst conscious exploitation of natural control factors is emphasized» (IOBC/WPRS 1977). In the context of a sustainable agriculture, preventive (indirect) measures must be implemented first and crop health monitored before considering taking responsive (direct) actions.

Preventive (indirect) crop protection

Preventive crop protection comprises three dimensions: (1) the optimal use of available natural resources, (2) the implementation of farming practices without negative impact on the agroecosystem, and (3) the release and protection of natural antagonists. Several actions can be taken to achieve preventive crop protection, among which the choice of appropriate resistant/tolerant cultivars, the use of an optimum crop rotation, where applicable and the use of a balanced fertilization (Boller et al., 2004).

Responsive (direct) crop protection

The need for a direct control measure (typically, when the levels of disease/pest/weed reach an established threshold) is determined through risk assessment and monitoring. In a sustainable production scheme, biological, biotechnical and physical methods will be used rather than chemical ones whenever they provide adequate control. As safeguarding the environment is a key element for a durable resistance strategy, chemicals/products used as control methods must be assessed for a number of characteristics, including their toxicity to living organisms, their selectivity and persistence, their pollution potential for the environment and their potential to develop resistance in the target organisms.

Management of resistance in genetically modified plants: the case of Bt crops in the US and Canada

Bt crops have been intensively used to combat insect pests of maize and cotton, especially in the US. Development of insect resistance remains a major threat to the sustainable use of Bt crops in agriculture, as shown in the former section. As early as 1988, four strategies were defined for the resistance management of Bt genes: (1) mixtures of toxic and non-toxic cultivars (refuge approach), (2) stacking of two or more toxins in each transgenic insecticidal cultivar (TIC) plant within a mixture, (3) low doses of toxins that act in concert with natural enemies to decrease pest populations and (4) tissue-, time-, or signal-dependent expression of toxins (Gould, 1998).

The refuge approach aims at increasing the durability of TICs by reducing the difference in fitness between susceptible and resistant insects and reducing the degree to which a resistant insect can pass on its phenotypic trait to its offspring (Gould, 1998). This strategy was later reviewed and further developed into the high-dose/refuge approach, which relies on the use of crops expressing high levels of insecticidal proteins (e.g., Bt plants that can kill >95% of the heterozygotes for Bt resistance), and the planting of a non-Bt variety of the same crop nearby (refuge zone). The US Environmental Protection Agency incorporated the refuge strategy into its insecticide resistance management plan.

Huang et al., (2011) extensively document how the high-dose/refuge strategy has allowed to efficiently manage major pest species of maize and cotton (*O. nubilalis* and *D. grandiosella* for maize, and *H. virescens* and *P. gossypiella* for cotton). The authors argue that the correct implementation of the fundamental requirements of this approach in the US and Canada is the reason why no increase in field resistance has been observed in the target pest species after 15 years of intensive cultivation of Bt maize and cotton.

Policy regulating GM crops in major countries

GM technology has resulted in significant developments whilst also at the same time raising many questions regarding its potential impact on health and the environment. The Cartagena Protocol on Biosafety was drafted in 2000 in response to the public discussion regarding GMOs and came into force in 2003. The protocol covers the release and international movement of GMOs and has precautionary undertones. By 2013, 166 countries became signatories to it. In 1990, the EU formulated Directive 90/219/EEC (for contained use of GMOs) and Directive 90/220/EEC (for deliberate release of GMOs) that were adop-

ted to protect human and animal health and the environment (Hartung & Schiemann, 2014).

Directive 2001/18/EC replaced the older Directive 90/220/EEC and redefined what a GMO is. Annex IA of Directive 2011/18/EC provides a non-exhaustive list of known techniques that lead to a GMO. The precautionary approach anchoring the 1990s legislation was still a central point that was adopted as a guide in the latter directive. Compared to the EU, regulation of GMOs in the US is conductive to their development (Hartung & Schiemann, 2014). GMOs are economically important in the US. Mutation of plant genes in conventional breeding excluded from GM legislation in the legislation of both the US and EU.

The United States do not have any federal legislation that is specific to GMOs. Countries such as Canada, Lebanon and Egypt follow the same principle of substantial equivalence as the US. Substantial equivalence is a starting point for the safety assessment for GM foods that is widely used by national and international agencies including the Canadian Food Inspection Agency, Japan's Ministry of Health and Welfare, the US Food and Drug Administration, the United Nation's Food and Agriculture Organization, the World Health Organization and the OECD (Millstone et al., 1999). Russia, Norway and Israel allow the import of GM food but do not allow its cultivation. Japan and South Korea have provisions for cultivation, but no GM products are yet produced. Most countries that do not allow GMO cultivation do permit research.

GMOs are regulated pursuant to health, safety, and environmental legislation governing conventional products. GMOs are not restricted categorically from the US food supply. The introduction of GM plants requires prior approval from animal and plant health inspection service, by means of a notification, permitting, or a determination of nonregulated status procedure. The US Food and Drug Administration regards most GMO foods as presumptively falling within the category of «generally regarded as safe,» thus not needing premarket approval. The Environmental Protection Agency (EPA) regulates pesticides and microorganisms developed through genetic engineering under the Federal Insecticide, Fungicide and Rodenticide Act. The EPA also regulates GMOs under the Toxic Substances Control Act (TSCA) regarding chemical substances that pose significant health and environmental risks. The US regulations focus on the nature of the products, as opposed to process in which they were produced (Devos et al., 2012).

To approve a new genetically modified plant in EU, applicants must follow procedures that were established more than 12 years ago when only a limited amount of data concerning the impact of GMOs on health and the environment was available (Craig et al., 2008). The approval procedure following EU legislation takes time (usually 4–6 years) and is costly (7–15 million euros). In the US the approval procedure takes 4 years and costs 17 million dollars. Overall costs from product discovery, optimization and registration are 136 million in the US (McDougall, 2011). For this reason, the plant science industry ranks in the top four global sectors for the most amount of money invested in developing new products. This can only be maintained if innovators and product developers are rewarded for their developments through effective intellectual property protection, which will then encourage investment of the necessary resources required for long-term research and development. Patents on GMOs and procedures are valid for up to 20 years.

The legal dilemma regarding new genome editing techniques

The growing number of crop genetic improvement technologies accompanied by elaborate transient transfer and expression techniques, provides a set of superior tools to quickly and precisely alter the genomic sequences of plants. It can be accepted that plants developed using genome editing techniques cannot be differentiated from conventionally bred plants and thus they could be expected not to possess higher risks to health and the environment (Wang et al., 2016). Therefore, countries need to develop more flexible and product-based GMO legislation focused on the potential hazards of the resulting end product and not the process leading to it (EASAC, 2013).

Conclusion

In light of the debate on the future regulation of New Plant Breeding Techniques and the accumulated evidence on the biosafety of genetically modified plants that have been commercialized and risk-assessed worldwide, it may be suggested that plants modified by crop genetic improvement technologies, including genetic modification or other future techniques, should be evaluated according to the new trait and the resulting end product rather than the technique used to create the new plant variety. The current system of GMOs approval significantly increases the cost of GMOs release leading to only a handful of companies being able to invest in developing and releasing GMOs thus creating a market dominated by a few major players.

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Climate-smart agriculture: case study on drought in livestock grazing systems in Patagonia, Argentina

Mariela Soto[1], Miguel Santos[2], Tony Reyhanloo[1] and Dimitrios Drakopoulos[3]

* shared first authors contributed equally in this report

[1] Department of Evolutionary Biology and Environmental Studies, University of Zurich, Switzerland

[2] John Innes Centre, Norwich Research Park, UK

[3] Institute for Sustainability Sciences, Research Group Ecology of Noxious and Beneficial Organisms, Agroscope, Switzerland

Introduction

It is widely believed that sustainable agricultural production is often the most effective and equitable strategy for reducing poverty and increasing food security (FAO, 2010). Great potential to meet these challenges is seen in the climate-smart agriculture (CSA) approach from the FAO, which aims to «guide actions to transform and reorient agricultural systems to effectively and sustainably support development and food security under a changing climate» (FAO, 2013a). As agriculture is the most important source of income for 75% of the world's poor that live in rural areas threatened by climate change, strengthening the CSA approach could generate a triple-win situation that has the potential to avoid the high environmental and socio-economic costs that climate change would bring along (FAO, 2013b):

- The CSA approach builds resilience to climate change through formulating and implementing effective adaptation strategies, by mainly adopting agro-ecological principles, landscape-approaches and diversification of production systems and incomes, which all strengthen social and ecological resilience to our changing climate in the long-term. As a consequence, food security will be sustainably increased for a significant percentage of the world population, along with increasing agricultural productivity, provision of jobs and income as well as social welfare of farmers (FAO, 2010; FAO, 2013a; FAO, 2013b).
- CSA can also lower net greenhouse gas emissions in agricultural production systems, predominantly through carbon sequestration processes and ecosystem-based mitigation (Vignola et al., 2015).

To make CSA a successful practice, awareness and knowledge about the effects of climate change on agricultural production systems must take multiple social, economic and environmental dimensions into account. CSA must be efficiently incorporated in policies addressing climate change strategies, as well as planning actions from local to global level. Results have to be shown on the ground to the farmers, policymakers, international organisations and donors, who provide the financial support.

Case study: drought in livestock grazing systems in Patagonia, Argentina

Patagonia is a region located in the south of Argentina, and 90% of this area is composed by drylands from the arid and semi-arid sub-type (Ravelo et al., 2011). Drylands are characterized by water scarcity, which constrains primary productivity and nutrient cycling, nevertheless they can embrace a high biodiversity and support a great number of ecosystem services. Many of these services have significant economic value for agriculture and livestock worldwide (MEA, 2005), and are the basis of livelihood of people in Patagonia (Ravelo et al., 2011). Grasslands are the most predominant vegetation types in Patagonian drylands, and have a high importance for livestock production, which vary from subsistence livestock systems with low technologies methods to large areas with commercial proposes, particularly, this region is relevant for sheep farming, wool production and meat export (Golluscio et al., 1998).

Patagonia has a high level of land degradation, and approximately 84% of its surface is affected of desertification (del Valle et al., 1998). The main reasons for land degradation are climate variations, droughts, overgrazing, deforestation, mining, overexploitation of natural resources and other non-sustainable land uses, which consequences are an increasing rate of biodiversity loss and soil erosion (Ravelo et al., 2011). Drylands are affected by droughts that have become more frequent and unpredictable due to climate change (MEA, 2005). Drought periods have implications on the resilience of livestock farming by decreasing the production of wool, meat and milk, and consequently on social vulnerability, through increasing food insecurity and reducing incomes. A simplified model adapted from Gitz & Meybeck (2012) describes the impact of drought in livestock grazing systems in Patagonia (Figure 1).

Experiments have been conducted to evaluate potential solutions for livestock grazing systems in Patagonia. Results have not been satisfactory enough to make positive and permanent changes, considering the environmental and socioeconomic conditions of Argentinean drylands (Golluscio, 1998; Oliva et al., 2012, 2016).

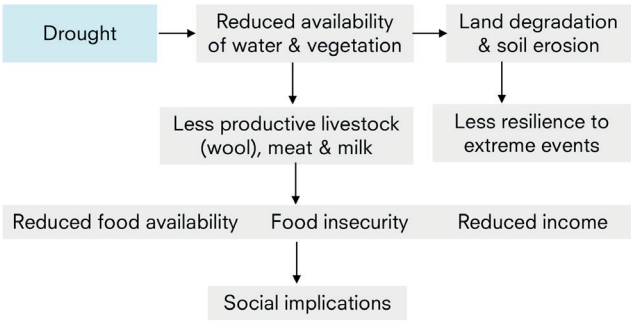

Figure 1. Impact of drought in livestock grazing systems in Patagonia. Adapted from Gitz and Meybeck, 2012

Suggestions

This case study presents potential solutions and innovations within the framework of CSA. After understanding the problem, the next step is to try to determine potential solutions. The best way to find these answers is to analyze how other systems with similar climatic conditions and sometimes even the same socio-economic situation overcame or minimized the problem in their own environment. These best practises were selected from numerous cases around the world that suffer from a similar situation and could be implemented in Argentina. We analysed them for their feasibility for implementation as long-term approaches with a possible positive effect on the entire food system, and for effectively preventing the negative effects of climate change and global warming in Patagonia.

In order to tackle the problem of overgrazing in Namibia, a climate-smart sheep feedlot was developed. The feedlot consists of a smaller area, around 600 m^2 in size, with a smaller number of sheep than in extensive farming. This way fodder production of just under 6 tons per square meter annually was achieved, while using 96% less water than conventional farming. Sheep production also spent 40% less energy in grazing, redirecting the energy on gaining more weight (Namibia Economist, 2016). The use of this type of strategy could be better used by the herding community in Patagonia, taking the advantage of the sheep and guanacos available in the region.

Tackling the problem of degraded grazing lands, in the Qinghai province of China the objective was to restore degraded grazing lands and sequester soil carbon in an attempt to increase productivity, build resilience and improve livelihoods in herder communities. A number of measures were taken into account, for example, a delayed grazing during the summer in areas with high soil degradation risks; reseeding and cultivating of grass on severely and heavily degraded areas; improved animal husbandry by investing in winter housing and feeding supplementation; and livestock product marketing (Gerber et al., 2012). All of these strategies are potential solutions for the situation in Patagonia in an attempt to delay soil degradation and rehabilitate the soil.

Tackling the problem of drought, in Madagascar in order to increase the resilience to drought, the cultivation of different plant species was supported according to water requirements following a landscape-approach (Gathigah, 2016). A proposed example is the plantation of wheat and maize in areas with higher water availability, and cultivars more resistant to drought and salinity, like cassava and sweet potatoes in areas more vulnerable to drought, could be a promising solution on creating farming alternatives in Patagonia and developing a more resilient system to climate change.

Tackling the problems of drought conditions, in the Republic of Moldova several policies were implemented in order to create a CSA in drought conditions, including using manure as fertilizer; increasing the amount of legumes in order to increase carbon in soils; reducing the use of nitrogen fertilizer to decrease N_2O emissions; and rotating crops to reduce carbon emissions. A new law was implemented supporting the transition from conventional agriculture to organic agriculture to reduce the amount of greenhouse gas emissions resulting from the agricultural industry. A series of new policy options were also proposed, consisting in investing in irrigation infrastructure and water management systems; the use of drought-tolerant crops; and farming with perennial crops to enrich the amount of carbon in the soil (Lendenmann, 2014). Patagonia could benefit from a transition from conventional agriculture to organic and making use of their native legumes in order to increase the nitrogen in the soil. Although establishing irrigation infrastructure and other water management facilities would be difficult due to the large area and the high cost associated with it, Patagonia could still try to implement the use of tolerant and perennial crops, and associate them to a minimal water facility that would not need to much effort and maintenance.

A new study in Patagonia itself showed that *Pinus ponderosa*, an exotic conifer, is capable of increasing the quality of the soil and decrease its erosion rate. This plant species can also protect inner lands from strong winds mainly coming from the coastline, creating a safer environment for agricultural production (La Manna et al., 2016). In addition, many other techniques within sustainable land management practices have been suggested to contribute to a more diverse flora, as well as for an improved soil fertility and water availability in drylands. These techniques are: plantation of nitrogen fixating plants such as leguminous trees, mycorrhization, bioirrigation, composting, a better use of animal manure management, a better use of water reservoirs and water retention technologies like construction of infiltration ditches, multi-storey crops that consist in the cultivation of compatible plants together in the same plot so that they can improve the yield of each other and the creation of vegetative strips in slopes in order to not only retain water, but also protect the slopes against soil erosion.

In conclusion, there are several technologies and practices within the CSA framework that can be tested and implemented as potential solutions to prevent or remediate the negative effects of droughts in livestock grasslands systems, such as in Patagonia. Nevertheless, to succeed with such novelties, many considerations are essential for this process. Solutions, invest-

ments and policies should be seen in short term to obtain positive effects after the implementation, and in long term because the greatest benefits usually are visible in a larger time scale, practices, technologies, and training programs should have a continuous participation approach, taking into consideration the rights and needs of farmers, landowners and the rural community. The objective of switching from conventional to CSA systems, from local to regional scale, might seem unattainable, but we should keep on mind that this is a transition processes and any small victory now can become an immeasurable benefit in the future.

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Fusarium head blight case in the context of agroecology and sustainable intensification in Europe

Myriam Deshaies *[1], Alejandro Gimeno*[2], Eric Rahn*[3] and Edward C. Rojas Tayo*[4]

* shared first authors contributed equally in this report

[1] Auranta, NovaUCD, and UCD School of Biology and Environmental Science and UCD Earth Institute, University College Dublin, Ireland

[2] Department of Plant Protection, Research Group Ecology of Noxious and Beneficial Organisms, Agroscope, Zurich, Switzerland

[3] Department of Environmental Systems Science, ETH Zurich, Switzerland

[4] Department of Plant and Environmental Sciences, University of Copenhagen, Denmark

Introduction

There is consensus that the required global increase in food demand should be reached through sustainable intensification (SI) rather than conventional intensification (CI) (Tilman et al., 2002). Nevertheless, various definitions of SI exist and there is considerable debate regarding the means to reach this goal (Tittonell, 2014; Cook et al., 2015). A common ground is that any increase in production should not come at the cost to the environment (Garnett et al., 2013). Here we follow the definition of SI given by Pretty and Bharucha (2014) as: «a process or system where agricultural yields are increased without adverse environmental impact and without the conversion of additional non-agricultural land». European agriculture involves mainly highly intensive systems and little room for yield improvement. It is associated with environmental impacts and a decrease of agricultural land area (Buckwell et al., 2014). It is suggested that the role of European SI is to exemplify how high intensive agriculture can be combined with much higher standards of environmental performance (Buckwell et al., 2014).

Agricultural ecosystems are modified natural ecosystems, where inputs, processes and outputs are altered by agriculture to benefit human interests. Ecosystems are functional entities characterized by energy flows, nutrient cycling and population regulation (Wezel et al., 2014). Agroecology studies agricultural systems from a holistic perspective. It provides a global vision of agricultural systems rather than just a set of farming techniques, its purpose is to provide new diagnostic methodologies that allow improving agricultural systems (Altieri, 1989). Agroecology should define the ecological principles necessary to develop sustainable production systems (Gliessman, 2011). The implementation of agroecology aims to exploit or restore the natural interactions that sustain ecosystems but are disturbed during farming interventions. Its implementation in European agriculture is recommended as one approach to increase sustainability in the already highly-productive systems (FAO, 2015).

One of the main natural processes affected by agricultural practices is the balance between pathogenic and beneficial organisms. Besides the millions of losses caused by pathogens in global agriculture (between 20–40% of world production) (Savary et al., 2012), the consequent control measures (mostly based on pesticides) also generate undesired effects such as overruns, contamination, toxicity-related problems and pathogen resistance issues (MEA, 2005).

In the following section, these concepts will be discussed in the context of European wheat production. We will use the example of Fusarium head blight (FHB) to illustrate alternative control options with an agroecological approach.

The wheat-fusarium head blight problem

Wheat is the most cultivated crop in the world. It is particularly suited for temperate conditions (Curtis et al., 2002). According to the EU Cereal Farms Report 2013, cereal production occupies one-third of the EU agricultural area and one-quarter of crop production. Fungal diseases represent the main constraints for wheat production in Europe, causing high dependence on pesticides and fungicides use (Karabelas et al., 2009). This has raised concerns among governments and consumers. In fact, in 2009 the European Commission (EC) through the directive 129/EC/2009 compels its countries to move towards a sustainable use of pesticides and encourage use of alternative control measures. In contrast to one-dimensional combat strategies, SI must consider combined efforts stemming from new innovations from science and technology and already available knowledge.

FHB can be caused by a complex of several fungal species belonging mainly to *Fusarium* spp. (Osborne & Stein, 2007). It can cause losses in yield up to 50% in some areas like Canada or the US, but most importantly it significantly reduces the quality of the grain. The fungus produces mycotoxins (vomitoxin) such as deoxynivalenol (DON) that are harmful for humans and livestock (see EC, 2006). Currently, conventional breeding programs have not yet achieved highly resistant cultivars. Therefore, integrated management involves mostly cultural practices and the use of fungicides, which in some cases are not completely

efficient (Gilbert & Haber, 2013). Biological control is emerging as a viable alternative to replace the use of fungicides. Extensive research argues that biological control with microorganisms that naturally antagonize pathogens could reduce the environmental side effects caused by excessive pesticides formulations (Jensen et al., 2016).

Biocontrol of FHB

A lot of research is invested for developing biological control agents (BCAs) and their application in the field, due to the increasing interest in environmental friendly solutions. Microorganisms that were isolated from healthy wheat anthers exhibited a significant effect against FHB in the greenhouse and the field by reducing the disease severity by 95% and 56% compared to the untreated control, respectively (Schisler et al., 2002). This approach is also discussed by Jensen et al., (2016) who stated that isolation of BCAs from appropriate plant parts under pertinent environmental conditions increases the likelihood of identifying effective BCAs. Xue et al., (2014) were able to demonstrate that their near-commercial formulation of *Clonostachys rosea* strain ACM941, a fungus infecting plants without being pathogenic, reduced FHB and mycotoxin contamination under field conditions with the same efficacy as commercial fungicide. Also, they showed an enhanced effect on moderately resistant cultivars. Finally, Palazzini et al., (2015) studied the impact of two bacterial strains, *Bacillus subtilis* and *Brevibacillus sp*., on FHB infection. They were applied at the anthesis stage on infected wheat during field trials. The biocontrol treatment reduced FHB severity by 62–76% and 42–58% for 2010 and 2011 trials, respectively. Moreover, treated heads did not contain any DON (mycotoxin), meaning that the bacteria completely inhibited the mycotoxin production. Regarding these successful studies, the biocontrol of FHB and possibly of other cereal diseases could become a reality.

Benefits of using biocontrols

This new type of disease management would enable to reduce or replace the use of pesticides (fungicides in this case study), enabling to shift towards sustainable intensification. Additionally, it increases food safety through reducing toxic contamination. This added value benefits the farmer and the whole food supply chain by increasing the grain quality and safety regarding the toxins. Possible synergies between plants and beneficial organisms may also contribute to further yield increase, contributing to a sustainable intensification of wheat production. Also, some biocontrols can be certified organic and, therefore, be used in organic farming, facilitating the development of a sustainable agriculture. Biocontrols are based on mechanisms already present in nature that require an understanding of the ecosystem. The use of ecosystem services is an essential part of agroecology.

Challenges in the use of biocontrols

There are uncertainties and risks associated with the use of biocontrols, as the understanding of the modes of action of biocontrols is often not elucidated yet. They might modify surrounding microorganism communities by having a microbicidal activity, and be detrimental for the environment. They might, as well have an impact on plant metabolism, which could result in a change of food composition. Their modes of action remain partly unknown and might have an impact on molecular mechanisms involved in plant development. Some of these products might specifically target one disease, resulting in the necessity for farmers to multiply the treatments with different products. Multiplying those treatments to protect plants from all sorts of pathogens would require higher financial inputs.

Conclusion

Biological control agents are a promising alternative to control FHB since they fit within the concept of agroecology and could represent a way towards sustainable intensification of wheat systems by sustaining yields while reducing the use of fungicides. However, aspects such as mode of action, molecular mechanisms involved, as well as optimal application conditions remain understudied. This knowledge is necessary to develop efficient and safer control alternatives.

Likewise, understanding how BCA interact with all the pieces of the system and how they can complement common control methods and practices is a key component in their integration to productive systems. Research, reflecting the complexity that sustainable intensification faces in already highly standardized and efficient cropping systems in temperate regions, is needed in order to modify the way FHB in controlled.

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How to achieve the transition of European agriculture towards self-sufficiency in protein supply?

Milica Nenadic*[1], Johanna Rüegg*[2] and Ruyu Yao*[3]

* shared first authors contributed equally in this report

[1] ETH Zurich, Switzerland

[2] Department of Environmental Systems Science, ETH Zurich, Switzerland

[3] Department of Systematic and Evolutionary Botany, University of Zurich, Switzerland

Introduction

The European Union (EU) relies heavily on importing protein crops. This is seen as the result of previously established international trade agreements that lead to high competition in protein crop production (Häusling, 2011). According to Schreuder and Visser (2014), the production of protein-rich feed was 39 Mt, while the consumption was 67 Mt, which makes EU totally dependent on imports from South America (Boerema et al., 2016). Trading of international food commodities has many effects on social, economic and environmental aspects of sustainability of the global food systems. The aim of this case study is to present the opportunities of more balanced protein supply and demand in EU, as well as the current or potential policies that target the problem.

Consequences of decoupled production and consumption of protein crops

Steffen et al. (2015) revised and updated the nine planetary boundaries that were proposed by Rockström et al. (2009). Biosphere integrity (rate of biodiversity loss), climate change and land-system change (the amount of forest cover remaining) are the thresholds described as overstepped by humankind (Steffen et al., 2015). In part, this overstepping is directly linked to agricultural production in areas where the tropical rainforests are natural ecosystems. Some of those areas, like in Brazil and Argentina, are also the areas of major exports of protein crops (Lassaletta et al., 2014). Biogeochemical flows present the fourth overstepped planetary boundary, and the analyses show that human activities extremely enhance the flows, especially affecting the nutrient cycles of nitrogen and phosphorous.

The human interference with the nitrogen cycle consists of the production of mineral fertilizer through the Haber-Bosch process, as well as the huge volume of nitrogen moved in a one-way trade of feed and foo. The biggest nitrogen flux, the one from Brazil and Argentina to Europe, can be associated with the feed trade. These fluxes of feed and food, expressed as nitrogen fluxes in the study of Lassaletta et al. (2014), are the main concerns of this case study, as they come at high environmental, social and economic costs, thus making the current food system unsustainable.

In exporting countries, such as Brazil, the intensive agricultural production of leguminous crops, mainly soybeans for feed, has led to environmental and social damages. After deforestation and loss of biodiversity Lassaletta et al. (2014) also identify pollution of air and water, decrease in soil fertility, greenhouse gas emissions, water and land grabbing as consequences in protein crop producing countries.

In the importing countries, on the other hand, large specialized areas for livestock farming, which are sustained by the massive imports of feed, can be found (Lasaletta et al., 2014). Therefore, livestock farming became disconnected from local crop or forage production (sometimes completely, like in the feedlot systems). In China, intensification of the livestock production systems based on imported soybeans have led to considering manure as a waste that is directly discharged in waterways instead of being applied to cropland (Gerber & Menzi, 2006; Houlton et al., 2013). Big nitrogen surpluses on European farms have also led to detrimental emissions and leakages to the atmosphere and water bodies.

The economic sustainability of this food system is similarly threatened as dependence on import can cause the rise in volatility of prices. To illustrate, doubling of nitrogen fertilizer prices in past 16 years has led to continuous increase in soya feed prices. The effect of EU-soybean trade has also been a loss of natural capital, e.g., loss of ecosystem services due to deforestation, which can be monetarized and is estimated to 1.7 trillion dollars between 1961 and 2008 (Boerema et al., 2016).

Equally important is the negative effect of protein crop import on social justice. Large scale industrial agriculture in the producing countries can lead to distributions of power that disadvantage small-scale farmers or indigenous communities, especially if land ownership is not clearly regulated (WWF Global, 2016). Soybean expansion and conversion of land into large farms had been important motives for migration of small farmers into cities. In Pampas region of Argentina, number of farms decreased by 18% between 2002 and 2008.

As seen, the negative effects of decoupled protein crop production and consumption are manifold and urgent solutions have to be implemented. The most obvious one is to return to the geographically closer production and consumption of protein crops (Häusling, 2011).

Opportunities from more balanced protein supply

Growing more legumes and including legume mixtures in European crop rotations could lower the level of imported feed, leading to more independence of the EU. This is especially interesting, because legumes are known to have various agronomic and environmental benefits. Leguminous crops provide better soil coverage and improve its structure, thus decreasing the risk of erosion or nutrient run-off (Häusling, 2011). Likewise, improved humus contents and carbon-to-nitrogen ratios increase soil fertility. This is directly reflected in the yield of subsequent crops. As seen in temperate climate regions, the average yield of cereals is reported to be 15% higher after a break legume crop than after a cereal (Miller et al., 2002; cited in Kirkegaard et al., 2008). Diversified crop rotations also enhance agro-biodiversity and legumes often provide nectar for pollinating insects. On the other hand, a higher agro-biodiversity makes the production system steadier against changes, for example, the environmental change or market fluctuation (FAO, 2008). Finally, mineral nitrogen fertilizer inputs can be reduced up to 100 kg N, because leguminous crops fixate nitrogen, lowering both climate impact as well as production costs and reliance on import (Häusling, 2011). The reduced input of nitrogen rich feed and fertilizer may also reduce the nitrogen surpluses on European farms, leading to greater environmental sustainability.

An example of realized re-coupling of production and consumption of plant protein can be seen in organic farming in Switzerland. There, the goal has been to close the nutrient cycles at the farm level. This entails moving away from the specialized production of either crops or animal husbandry, towards higher diversity of production at the farm level. To obtain the Bio Suisse label, a farm has to use its self-grown feed with the possibility of purchasing additional feed only under stringent rules (Bio Suisse, 2016). Further, the use of mineral nitrogen fertilizer is not allowed, motivating farmers to use their own organic fertilizers like manure.

There are trade-offs associated with the proposed solutions that have slowed down the adoption of more protein crops in crop rotations in the EU (Setälä et al., 2014). Introducing legumes in crop rotations increases the complexity of the growing system, which then requires more expertise from the farmer and more diverse infrastructure. There are trade-offs associated with a change of production of certain crops to be replaced by legumes. This change is further discouraged as in comparison to cereals, the income derived from grain legumes fluctuate more between years due to their higher susceptibility to climatic factors (Bues et al., 2013). In general, a big challenge in producing and processing more animal protein feed in Europe, is that this industry and associated know-how have been disappearing during the last decades (Häusling, 2011). Traders became focused only on import, while infrastructure and practical on-farm experience associated with production, processing and use of protein crops have been lost.

Policies to encourage transition

The European Parliament (EP) has recognized the need to end «the EU's protein deficit» (Häusling, 2011). As part of the Common Agricultural Policy (CAP) of the EU there are already policies in place to encourage transition from the current very specialized, geographically decoupled animal feed production to a more integrated food system. The CAP currently consists of two pillars (according to Bues et al., 2013):

- Pillar 1: production support through market measures and direct payments; and
- Pillar 2: rural development.

Protein crop production has been shaped by policies in both pillars. Non-existing import taxes for soybean, coupled with its great availability on world market, lowered the cost of its import and brought a steep decline of legume cultivation in Europe. To turn this around, direct payments for certain protein crops were put in place. Article 68, one of the most widely used options for direct support for legumes under Pillar 1, states that member states may choose to provide direct payments for specific crops of up to 10% of their national ceiling under the single payment scheme. Under Pillar 2, legumes are mostly promoted under the objective for enhancing the environment and the countryside. As for all measures in Pillar 2, their design is up to the Member States at national or regional level. Unfortunately, the results of the CAP have not been satisfactory and more action is needed. Attentions should be paid on all levels along value chains (viz. production, processing, and consumer) (Lassaletta et al., 2014; FAO, 2004)

On production level, the outcomes of protein crop production should be supported. To make the protein crop production more profitable for farmers in the EU, one of the options inside CAP would be to introduce taxes on soybean import. This measure could reduce the price gap between locally produced soybeans and imported one. Secondly, direct payments for protein crops should be increased, as of monetary incentives (Bues et al., 2013). Similarly, agri-environment schemes under the Pillar 2 could be advanced. Besides, investing in education, infrastructure and research are important to address the problems of lost know-how. As pointed by Nemecek and Baumgartner (2006), the outcomes of crop rotation vary greatly depending on which crop of the rotation is replaced by the legume. Investment into research, breeding and technical progress is also needed in order to address the variation in yield due to higher climate impacts.

Outside the CAP, strengthening policies on climate protection could indirectly support the production of protein crop. Likewise, it would be desirable to tax the use of nitrogen fertilizer in agriculture (Bues et al., 2013). As food, feed and fuels outlets compete for the same limited resources such as land and

water, great potential for solving protein deficit in EU also lays in reforming the EU biofuel policy (Martin, 2014).

Equally important are policy options that address the consumer end of the food system. Consumer's diets are the major drivers of what is produced. The worldwide increasing consumption of animal products is likely to increase the mentioned problems associated with animal feed production. To make the most use of production factors, like nutrients, water and energy, consumers should be educated of the problems that are caused by current protein crop production and encouraged to use proteins of animals instead of plants (Häusling, 2011).

Conclusions

As elaborated above, the current globally decoupled production and consumption of protein crops has negative consequences for environmental, economic and social aspects of food system sustainability. As elaborated above, the environmental, economic and social sustainability in food system is hindered by the current globally production and consumption of protein crops, which is not harmonious. Moving agricultural production closer to consumption areas is, therefore, a necessary basis for moving towards more sustainable global food systems. Although, the EP has recognized the need for this transition, measures put in place have not been effective. Novel solutions are urgently required in order to close the nutrient cycle at the level of EU and reduce the negative consequences of current practice. The answer lies in policy options that will address both the production and the consumer level.

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Applying an analytical framework to assess and enhance land tenure security: case study in Cambodia

Anna Kaja Hoeyer*[1], Josep Ramoneda*[2], Quirina Merz*[3] and Lukas Welker*[4]

* shared first authors contributed equally in this report

[1] Trinity College Dublin, Botany Department, Trinity College Dublin, Ireland

[2] Department of Environmental Systems Science, ETH Zurich, Switzerland

[3] Department of Geography, University of Zurich, Switzerland

[4] Institute for Environmental Services, University of Geneva, Switzerland

Introduction

Cambodia is located in Southeast Asia and has a total area of 181.035 km^2, of which 56.5% is covered by forest. Agriculture in Cambodia takes up a third of the land, of which 22.7 % is arable land, while the rest is pasture (8.5%) and permanent crops (0.9%) (CIA, 2016). Cambodia has experienced steady economic growth for a number of years and Cambodian agriculture plays an important part in this trend. However, approximately 58% of the population is moderately poor according to the World Bank definition and 26 % of Cambodians suffer from a daily hunger according to the US aid (WBG, 2016). The agricultural land in Cambodia has huge economic importance as it is a major source of livelihoods for a large proportion of the population (CIA, 2016; HEKS/EPER, 2016). When Cambodia gained independence from France in 1953, the country suffered under the brutal regime of the communist Khmer Rouge and a 13-year long civil war triggered by the Vietnamese invasion in 1978 (CIA, 2016). First democratic elections were governed by the Paris Peace accords in 1991, followed by elections sponsored by the UN in 1993 (CIA, 2016).

In this case study land-tenure conflicts in Cambodia will be analyzed using a framework developed by HEKS/EPER (Hilfswerk der Evangelischen Kirchen Schweiz/Aid organization of the Protestant Churches of Switzerland), which is an aid organization with experience in working on ways to improve access to land by rural communities. By applying the guidelines of the mentioned framework, the report will include: 1) the assessment of the current status of land-tenure conflicts in Cambodia in the context of the prevailing economic strategies of the country concerning land ownership, 2) an attempt to identify strategies to change impacts of such conflicts.

HEKS/EPER framework

HEKS/EPER has developed a framework for the analysis and mitigation of mitigate land tenure conflicts (HEKS/EPER 2015). Its main focus is land governance, which has been defined by the Food and Agriculture Organization (FAO) as «rules, processes and structures through which decisions are made about access to land and its use, the manner in which the decisions are implemented and enforced, the way competing interests in land are managed» (Palmer et al., 2009, p.1). The framework is based around the concept of «good governance» which includes transparency, enforced laws, involvement of stakeholders in decision making and unbiased market structures (Hirsch & Scurrah, 2015). Furthermore, it provides an overview of the land tenure situation in a given territory, and highlights important problems that need attention for sustainable land use policy purposes. Land grabbing is defined as the acquisition of productive agricultural land by some countries and/or corporations, which mostly expand into developing countries (Rulli et al., 2013). The HEKS/EPER framework deals with the conflicts that arise from such practices, which are often related to inefficient or negligent national policies.

The framework has five steps, which include the assessment of: 1) the status and manifestation of land-tenure-related conflicts, 2) the causes and drivers of such conflicts, 3) the power symmetries between the involved parties, 4) possible intervention measures, 5) the faced challenges and achieved results through the analytical process (HEKS/EPER, 2015).

Four perspectives are commonly included, when applying the HEKS/EPER analytical framework to land accessibility (see figure 2 in chapter «Access to land – laying the groundwork for development»): 1) a rural livelihood perspective is concerned with land accessibility, poverty reduction and food security; 2) a human rights perspective highlights the right of communities to food, to which land access security plays a major role; 3) an economic policy perspective addresses the interests that drive local and global land acquisitions (e. g., in developing countries access to land is restricted by national and international policies) and 4) a power balance perspective, pointing out that, when dealing with governance conflicts, it is important to determine the distribution of justice and to determine which groups within society have the privilege to make decisions and laws (Sophal et al., 1998).

Analysis of the country case Cambodia: status of access to land

During the last 20 years there has been increasing interest of foreign investment in Cambodia, above all in the agricultural sector (Baird & Fox, 2015). Some investments are fruitful because they enhance the productivity, while others simply exploit the natural resources. Established in 2001, the Economic Land Concession (ELC) program approaches questions of land access in Cambodia (HEKS/EPER, 2016). Within this program, large areas of land have been leased for high capital projects, thus dispossessing the local farmers of the most productive land areas for the whole duration of the lease. The ELC states that one person or legal entity can lease up to 10.000 hectares of land for up to 99 years. Even though concessionaires are not allowed to forcefully remove landholders or to take private land or communal forests, local farmers face many problems when trying to acquire full ownership of land, which can only be obtained if a person has lived and worked in an immovable property before the promulgation of the Cambodian land law in 2001. Despite the fact that these concessions do not overlay areas for accessing individual land owner rights, they do collide with traditional communal land partitions, which is the origin of the tensions between the local farmers and the investors.

Causes, drivers and power

Particularly the north-east of Cambodia suffers from a conflict between farmers of an ethnic majority and those of an ethnic minority. Farmers from ethnic minority are being driven away from their land. Moreover, members of the military have been involved in abuse of authority for their private acquisition of land and logging activities (Hirsch & Scurrah, 2015).

Possible new intervention strategies

Mutual cooperation: as the government is more inclined to protect the interests and land rights of major land owners, smallholders should be supported through mutual cooperation. This could be enforced through changes in communal land titling policies, also knowledge and resource sharing would empower the farmer community and help to reduce the power imbalance between individual smallholders and other more powerful parties such as the government or investors. Workshops and community training activities can enhance the knowledge of the locals about their legal rights to land ownership.

Bringing the parties together

Better governance can be achieved by fostering interactions between the different governing bodies in charge of the ELCs. Bringing these different actors and the respective government bodies together by organizing multi-stakeholder conferences, workshops or meetings under the tutelage of relevant institutions (e.g., NGOs) could be a first step to stop double allocation of the land. Positive interactions could be fostered by including companion modeling games (Étienne, 2014), in which the stakeholders make an effort to understand the other stakeholders concerns and difficulties.

Improving national data on landlessness

Unbiased assessment of the land tenure situation in Cambodia could be pursued through the funding from external donors. Living standards surveys and agricultural census would provide a realistic picture of the most vulnerable areas to conflict, (e.g., US AID, 2014), setting the basis for conflict prevention measures.

International outreach

Scientific publications and different media coverage can be used in order to bring this issue to the international community. Outreach possibilities would be high since the international community is very sensitive to cases, where law enforcement leads to violent social conflicts. Many NGOs present in the country can promote the creation of a national network able to inform on negligence of farmer's rights by both internal and external public and private companies.

Challenges

Each possible new integration strategy faces implementation challenges. Mistrust: due to the political history of Cambodia there is a general mistrust among different members of the civil society. Mistrust affects the feasibility of the following new intervention strategies: mutual cooperation and bringing the parties together. Corruption: the endemic corruption, present at all levels of government in Cambodia (Ciorciari, 2007), affects the feasibility of the following new intervention strategies: mutual cooperation, improving national data on landlessness and bridging the gap together.

Conclusion

Access to land is a prerequisite to the enhancement of food security in the developing world, and is essential to the implementation of more sustainable agricultural practices. It is clear that the HEKS/EPER framework is a powerful tool to analyze land governance in developing countries and to propose new strategies that set the basis for environmentally, socially and economically fair agricultural systems. In addition to land tenure security and cooperation between farmers, it would seem that local NGOs needs additional incentives that attract the attention of other parties that can overcome the rigid decision making ways of Cambodia's governments. An encouraging incentive is the shift towards more sustainable practices, which could put pressure from international bodies on local governments, while enforcing the partnership among farmers. Despite being seen as a local issue, land tenure conflict in Cambodia has to do with international economic interests, which can also arise if sustainability stands out as a globally relevant aspect in agriculture. If land tenure conflicts in Cambodia are to be solved, these international players must also be convinced that all sides of sustainability are the way forward.

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About the PSC Summer Schools

The PSC Summer Schools have been carried out for PhD students of ETH Zurich, University of Zurich and University of Basel, as well as international students since 2010. Internationally renowned speakers from different disciplines and with a stake in sustainability and agriculture guaranteed a mind-changing one-week experience for the next generation of scientists.

In 2014 and in 2016 we explored new trends in sustainable agriculture and food security: *Emerging Technologies* (2014), *Concepts for an Agriculture that is Sustainable in all Three Dimensions of Sustainability* (2016). We discussed the link between agriculture and society: on what worldviews do we build our ideas of transition? How is sustainable agriculture becoming part of food system transition? What are ethical considerations that can help us to assess our different interpretations of sustainable agricultural concepts? In what political and economic environments do we navigate? What do the existing concepts, for example, sustainable intensification and agro-ecology propose? How can we assess their implementation?

The summer schools integrated lectures, workshops and case studies based on an open social inquiry approach to understand the values, beliefs, interests and conflicts in our society when discussing about sustainable agriculture. Case studies for group work were based on international and Swiss agricultural policy and farming practice.

Learning objectives

Both summer schools focused on ESD competencies (de Haan, 2006) and skills for critical thinking, e.g., foresighted thinking, interdisciplinary work or participatory skills etc.

Participants learned to:

- be guided to gain in-depth knowledge about global trends at the nexus of agriculture and society through keynote lectures, plenary discussions and workshop exercises;
- build skills in analyzing and evaluating trends and concepts of sustainable agriculture;
- learn about components of a sustainable agricultural farming system applying system thinking;
- reflect on the value systems that are behind different agricultural systems;
- learn about scenarios and design-based approaches for a transition to sustainable agriculture;
- discuss governance, policy and economic needs of a sustainable agricultural system;
- develop a stance about different options how a sustainable agriculture system should look like and write and present a position statement; and
- develop network contacts with stakeholders from science, policy and industry.

Reference

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The Zurich-Basel Plant Science Center (PSC) is a competence center linking and supporting the plant science research community of the University of Zurich, ETH Zurich and the University of Basel. The center promotes fundamental and applied research in the plant sciences. PSC seeks creative approaches to research mentoring and coursework for students and postdocs, and provides platforms for interactions with peers, policymakers, industry, stakeholders and the general public.

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