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How the sustainable intensification of agriculture can contribute to the Sustainable Development Goals

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The need for specific socio-ecological solutions at all spatial levels

R. Delzeit, I. Lewandowski, A. Arslan, G. Cadisch, J. W. Erisman, F. Ewert, A. M. Klein, C. von Haaren, H. Lotze-Campen, W. Mauser, T. Plieninger, A. Ratjen, V. Tekken, V. Wolters, N. Brüggemann

In face of the challenges of a growing world population and changing climate, sustainable development of the entire food chain is a monumental task requiring an effort similar to a "Second Green Revolution". The Green Revolution starting in the 1950s focused on increasing agricultural production through the development of new varieties, the replacement of manpower by machinery and higher agricultural inputs *(1)*. With agricultural production now exploiting almost 40% of the Earth's land surface *(2)*, it has become a major source of environmental problems, such as loss of biodiversity, nutrient loss to the environment, greenhouse gas (GHG) emissions, soil erosion, and reduced water infiltration. However, the increase in global population and rapid change in human diets are putting further pressure on agricultural production, which already has a limited expansion capacity. Although there is some room for improvement through the adoption of healthier, sustainable diets and reduction of food waste, future agricultural production is challenged to find solutions towards Sustainable Intensificaton (SI). This can be defined as the intensification of agricultural productivity with concomitant conservation, or even restoration, of natural and near-natural ecosystems under future climatic conditions, based on a sustainable business model. Assessing the role of SI in sustainable development first requires an understanding of the main underlying dynamics and drivers that both impact on and are affected by SI at various temporal and spatial scales.

In 2015, the United Nations (UN) adopted the 2030 Agenda for Sustainable Development, which includes 17 Sustainable Development Goals (SDGs) to guide policy towards sustainability in the next 15 years. Amongst others, these goals cover the aspects climate change, socio-economic transformation, and eradication of poverty and hunger. Sustainable land use is a core factor in achieving many of the SDGs.

Four preconditions for SI have already been defined *(3)*: a) the food security challenge should, at least partly, be met by an overall increase in production and income in rural areas of the least developed countries *(3)*, b) the largest share of this increase should come from existing agricultural land, c) biodiversity and ecosystem services (ES) should be maintained or even improved, and d) a broad range of tools and production methods should be considered. Changing diets towards more healthy food requiring less resources, reducing food waste and improving food processing efficiency, quality and distribution are important additional factors *(4)*. However, the successful implementation of agricultural management and technologies that increase productivity but are at the same time environmentally benign depends on site-specific natural conditions and requires participatory approaches involving farmers. Thus, the pursuit of SI necessitates a major research program embracing the social sciences as much as the natural sciences *(5)*. For this purpose, the following questions need to be addressed: (a) How can the inclusion of both social and ecological aspects foster implementation of SI? (b) Where should SI be preferentially implemented? (c) What are the social, economic and ecological opportunities and constraints of SI? (d) How can the success of SI implementation be measured?

The socio-ecological perspective of SI

The SDGs recognize the social aspects of land use and agricultural production as important for the conservation and protection of ecosystems and biodiversity, and for the adequacy of human livelihoods and socio-economic development. The current focus on food quantity in response to the growing global food demand is progressively giving way to a quality-, diversity-, and accessibility-oriented perspective *(6)*. The interlinkages of socio-cultural aspects, land management, agroecology and biodiversity are emphasized in landscape approaches, such as the concept of multifunctional landscapes *(7)*. Landscape approaches realign food production with other societal purposes, e.g., rural development, maintenance of biodiversity, and preservation of ES in areas where productive land uses compete with environmental goals. Focusing on landscape approaches for SI offers considerable opportunities to reduce the environmental impact of land use without compromising food security and human well-being *(3, 9)*. However, landscape approaches, which aim to improve human well-being in a broad sense rather than merely minimizing environmental impacts *(6)*, require a “real transdisciplinary engagement” *(7)* and the involvement of multiple scientific disciplines. This also applies to the implementation of tools and production methods to be employed in SI approaches, such as the use of biological nitrogen fixation, integrated nutrient management and precision farming (8). The introduction of improved production methods first depends on the empowerment of farmers and their ability and willingness to use these methods *(9)*.

To tackle SI research and implementation challenges, the currently prevailing socio-economic and natural science perspective needs to be broadened to include the social sciences and humanities in answering the following questions: (i) Which technical, management and social innovations are required to help meet increasing food demand without further environmental costs or degradation?

(ii) Which opportunities does SI offer to reconcile demands for food quantity with food quality? (iii) What are the sustainability trade-offs and socio-ecological resilience implications of SI approaches in different landscapes and social settings? (iv) What are the incentives, benefits and barriers in the adoption of SI by farmers and support of SI by policy-makers? (v) What are the educational requirements for SI implementation, particularly in developing countries, and how can practitioners be involved in developing "ownership" for the concept of SI? (vi) How can SI be integrated into broader efforts to increase food security? (vii) How can consumers be encouraged to change to healthier diets and consumption of sustainably produced food?

Where should SI be preferentially implemented?

The anticipated benefits of SI, i.e., increasing agricultural production while reducing environmental impacts, are assumed to be global. Mauser et al. (2015) *(10)* identified varying potentials for intensification in different regions of the world. However, both the effect on productivity and the environmental and social benefits of SI are farm- or site-, region- and landscape-specific *(11)*. The productivity increase may be high where poor soil conditions can be improved by agricultural measures, but much lower elsewhere. In addition, ES, such as provision of clean drinking water, soil carbon storage, stormwater retention, and socio-cultural services, depend on site-specific conditions and require site-specific conservation measures. Therefore, minimizing ES loss is of far greater importance in areas with high vulnerability to land-use and climate change. The locational response to SI measures calls for region- or even site-specific approaches. The safeguarding of biodiversity in particular requires a dual site-specific strategy combining the concepts of ‚land sharing‘ (to preserve widespread agro-biodiversity as well as, on selected sites, sensitive and rare species) and ‚land sparing‘ (to preserve presently valuable non-agricultural habitats or those which could become valuable in future on account of favorable site conditions).

Agricultural practices can impact ES in sensitive areas adjacent to or even far away from farms. Agroecosystems are also influenced by the properties of the landscape surrounding farms. For example, in addition to the soil and management conditions of a farm, the diversity and connectivity of the surrounding landscape affects field plant and animal biodiversity, natural pest control and other organism-mediated ES *(11)*. For this reason, both the carrying capacity of the landscape and regional productivity increase targets need to be taken into account when developing site-, landscape- and region-specific SI approaches. A broader concept of SI may need to incorporate a decrease in productivity in certain sites, landscapes or regions sensitive to specific land uses (e.g., in terms of local biodiversity) together with an increase in productivity in other areas more resilient to land-use change effects in terms of environmental quality *(12)*.

Opportunities and constraints of implementing SI

While the development of a range of agro-ecological and technological solutions for SI is important, their implementation will probably only occur within an appropriate regulatory framework. Negative externalities of agricultural production, e.g., nitrogen leaching and GHG emissions, need to be regulated by legally binding thresholds, internalized for example through taxes or other incentives. This will have two effects: it will send a price signal to consumers, encouraging them to choose more environmentally friendly food products, most likely causing a shift from livestock-based products more towards fruit and vegetables and locally produced food. Good estimates of 'true pricing' based on societal costs of production methods need to be made available. Such efforts are already underway, e.g., for nitrogen pollution, but the uncertainty range is still large and needs to be strongly reduced before societal costs can be allocated to individual products *(12)*.

Even more importantly, effective regulation will send a clear signal to primary producers and processers to invest in new technologies and management options that minimize environmental impacts. However, this requires an integrated approach *(9)* in order to prevent pollution swapping and other trade-offs, as well as enhancing synergies. For example, a tax on nitrogen fertilizer could accelerate the adoption of precision-farming techniques, hence reducing input while maintaining output levels. It may also stimulate more effective use of natural nitrogen fixation processes and N recycling *(9)*. In the context of more efficient water use in agricultural irrigation, some experience has already been gained with water pricing schemes, e.g., in Australia. More fundamentally, it is necessary to analyze the extent to which current agricultural subsidies have led to fertilizer use increasing beyond sustainability levels, especially in OECD countries *(13)*. In such cases, the taxation of agricultural GHG emissions should be considered. Reduced subsidies and effective enforcement of current regulations, e.g. on nutrient loads, may further contribute to the implementation of more sustainable agricultural production practices.

At the more aggregate market level, the role of global trade has to be considered. Internalization of environmental costs can also be used here to influence trade. More open and diversified trade relations can help to reduce local water scarcity *(14)* in water-stressed regions. On the other hand, trade and regulatory measures may also shift agricultural production into sensitive ecosystems, such as tropical forests *(15)*. Hence, deregulation of trade needs to be accompanied by regional measures to avoid negative environmental and social side effects. Prominent examples of regional policy measures supporting SI include REDD+ policies, as discussed in the UNFCCC process, and forest law enforcements *(16)*. However, given that there are multiple interlinked SDGs, it is crucial that policy measures are also linked and integrated across sectors, regions and policy domains.

How can the successful implementation of SI be measured?

Implementing SI on a global scale will require a range of approaches tailored to site-, landscape- and region-specific conditions. Therefore, the use of highly aggregated, global indicators to measure its success is predestined to fail. In order to meet SI goals without going through a tedious phase of trial and error, those ultimately responsible for their implementation at the local scale, i.e. farmers and regional extension services, will require extensive support in the form of essential information. Providing guidance for and information on SI implementation and verification will therefore necessitate a radically different approach.

This new approach should be based on: (i) globally available, spatio-temporally highly resolved and standardized measurements of basic environmental parameters (including soil quality, all agricultural activities and their environmental consequences), using both satellite and ground-based observation networks; (ii) local, regional and global socio-economic indicators (such as factor productivity, rural development, food security, cultural aspects, livelihood development, diet and consumption patterns); and (iii) a set of integral key performance indicators that both characterize the system and can be used to directly steer improvements *(9)*. A multi-disciplinary knowledge network could convert this stream of data into region-specific management options to be implemented by individual farmers and extensions services. At the same time, specific socio-ecological indicators need to be developed, which allow verification of the success of SI at the local, regional and global level and its contribution to achieving the SDGs (Fig. 1).

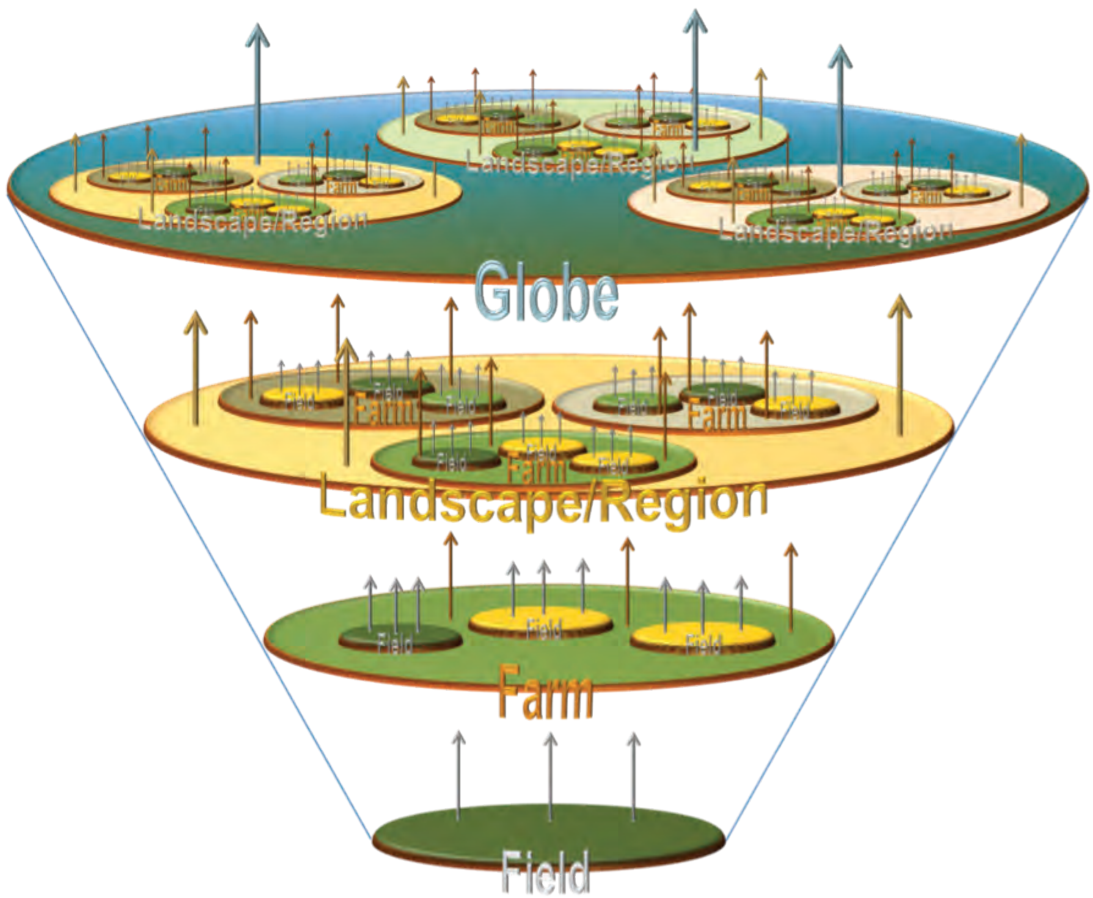

Figure 1. Schematic representation of the implementation of field- and farm as well as landscape- and region-specific sustainable intensification (SI) measures for the establishment of SI at the global scale. The overall success of SI has to be assessed with a combination of site- and region-specific as well as global indicators. Arrows indicate the sustainability indicators adapted for the specific conditions. Arrows of different colour represent scale-specific indicators.

This approach differs from classical verification in that it combines implementation support with verification at all spatial levels.

The establishment of this global, but at the same time site- and region-specific, implementation and verification system for SI poses a massive transdisciplinary research challenge. Knowledge exchange across disciplines and between science and stakeholders needs to be improved, in order to change attitudes towards the adoption of socio-ecological solutions. This calls for the development of a multi-actor community that can maintain and further improve socio-ecological solutions for farming systems. Such a community must embrace knowledge and expertise from a large number of research fields including agronomy, environmental science, landscape ecology, economics, information science, remote sensing, statistics as well as the cultural and social sciences. This new multi-disciplinary, multi-scale research approach to SI needs to be embedded in a well-structured process of continuous stakeholder engagement at all relevant levels of decision-making.

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