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Ecological intensification of agriculture — sustainable by nature

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Strategies towards agricultural intensification differ on the definitions of sustainability and the variables included in its evaluation. Different notions of the qualifiers of intensification (ecological, sustainable, durable, etc.) need to be unpacked. This paper examines conceptual differences between sustainable and ecological intensification as used in research, development, policy and the industry, particularly with respect to the balance between agriculture and nature. The study compares different discourses on models of intensification that differ in the role nature plays in the actual design of the systems. While sustainable intensification is generally loosely defined, so that almost any model or technology can be labeled under it, ecological intensification proposes landscape approaches that make smart use of the natural functionalities that ecosystems offer. The aim is to design multifunctional agroecosystems that are both sustained by nature and sustainable in their nature.

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Introduction

The search for paradigms to underpin new agricultural intensification models able to feed the world now and in the future, while maintaining and enhancing ecosystem functions, has led to the emergence of different qualifiers to the term intensification. Two of them in particular have gained momentum in the scientific and development literature, namely sustainable intensification [1•] and ecological intensification [2••]. These were by no means the first publications to employ these terms, but perhaps the first ones that attempted to translate them into research agendas for agricultural science. More recently, Bommarco *et al.* [3] explored synergies between ecological intensification and the provision of bundles of ecosystem services and stated, as several others did (e.g. [4–11]), that making use of the regulating functions of nature requires landscape-level agroecosystem design. A few other authors adopted the term *agro*-ecological intensification (e.g. [12]), with no discernible difference with respect to the other two. These definitions tend to differ from agroecology, which describes not only a scientific discipline but also a social movement [13••].

Sustainable intensification, as a concept, as a guiding principle, has been widely adopted by international research and policy organisations such as the Consultative Group on International Agricultural Research (CGIAR), the Food and Agriculture Organisation of the United Nations (FAO), the World Economic Forum (Davos, 2012), the Montpellier Panel (2013) or the Sustainable Development Solutions Network (SDSN, 2013), and by national policies such as the 'Feed the Future' program of the US Government. The term is now also widely employed in the agribusiness world or by large international donor organisations. Another term that is closely associated with these ideas is eco-efficiency, or producing more value with less impact, which was first coined around the time of the Earth Summit of Rio in 1992 by the World Business Council for Sustainable Development (WBCSD). More recently, Keating *et al.* [14] re-introduced the concept when analysing input elasticity (water and nitrogen) in agriculture in a paper presented at the 2009 Science Forum of the CGIAR. Eco-efficiency became also part of our current jargon in agriculture.

Are there fundamental differences among all these terms? Is ecological intensification always sustainable? Can intensification be sustainable without being 'ecological' or 'eco-efficient'? These are rhetorical questions; the right answer will always be context specific, and trying to find sufficiently balanced responses would take several journal pages. It is not the objective here to compare technologies[1]

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[1] By 'technology' I mean "*the application of scientific knowledge for practical purposes*" (The Oxford Dictionary), and this broad definition may include very diverse forms of knowledge-into-practice depending on the model of intensification considered; examples of agricultural technologies range from crop rotation to irrigation techniques, genetically modified germplasm, composting, mechanisation, agrochemicals, biological control, greenhouses, GPS-controlled transit or nanotechnology sensors for early detection of plant diseases for use in organic agriculture.

or means of agricultural intensification with respect to any particular indicator, or to provide recipes to solve the world food problem.[2] Yet one thing is known for certain: the current model of agricultural intensification is not sustainable (socially and thermodynamically), it is neither ecological nor eco-efficient, it is ineffective at feeding the world, it is harmful for the environment and contributes to biodiversity loss [15–21,22•,23,24]. These are incontestable signals from reality. They point to an urgent need for alternative forms of agricultural intensification.

I will review the uses and definitions of the terms sustainable[3] and ecological intensification in recent scientific, press and policy papers, and their implications for the balance between agriculture and nature in our scientific practice. Because the concept of ecological intensification is somewhat newer and has been shown to have functional links with ecosystem services in recent scientific literature, I will more specifically review current alternative models for ecological intensification and propose a conceptual framework for portraying the transition towards more sustainable food systems.

Definitions versus discourses

Pretty *et al.* [1•] defined sustainable intensification — with special reference to Africa — as '(. . .) producing more output from the same area of land while reducing the negative environmental impacts and at the same time increasing contributions to natural capital and the flow of environmental services'. This does not differ much from the ideas expressed by Doré *et al.* [2••] around ecological intensification, which imply producing more but producing differently, and producing new things (i.e. services, bio-energy). In essence, the difference is not really in the definitions as much as in the interpretation and/or in the way in which such definitions are used, and by whom. Grass-root organisations and environmental movements around the world are weary of the term sustainable intensification which they often see as a window-dressing, green-washing strategy to justify any form of intensification (e.g. 'A wolf in sheep's clothing' — Friends of the Earth International [25]).

In 2008, the FAO stated that world food production must be doubled to feed a population of 9 billion people by 2050, and that to do so no technology should be excluded.[4] Re-investment in agricultural development and the sustainable intensification discourse emerged in response to that. Since then, the industry was quick in coming up with statements that employed the terms 'world', 'food', 'population', 'hunger' and 'sustainability' in their commercial campaigns. The statements blogged recently by the Chief Technology Officer of Monsanto, the 2013 World Food Prize laureate Mr. Robert Fraley, are a good example of that (URL: http://monsantoblog.com/2013/10/07). Recent statements by the Bill & Melinda Gates Foundation — a shareholder of Monsanto — in their sponsored blog point in the same direction (URL: http://www.theguardian.com/global-development/poverty-matters/2010/sep/29). Through the sustainable intensification discourse, biotechnology found a new avenue to promote itself as a cure to world hunger. They managed to engrave in part of the collective consciousness the idea that the world will not be able to feed itself without genetically modifies crop cultivars, a primary commercial product line from this industry.

The fertiliser industry followed a different but comparable path. Back in June 2006, a summit of Agricultural Ministers of the African Union Member States that took place in Abuja, Nigeria, in the presence of representatives of the fertiliser industry resolved ''*...to increase the level of use of fertilizer from the current average of 8 kilograms per hectare to an average of at least 50 kilograms per hectare by 2015*'', in order to achieve the African Green Revolution (AGRA, URL: www.agra-alliance.org). The scientific backstopping that led this summit to decide on such target rates of fertiliser use was never revealed. More recently, the director of the International Fertiliser Industry Association (IFA), said in their last annual report to be ''*...pleased that the new and aptly coined term ''sustainable intensification'' has been gaining traction throughout the year 2012*'' (IFA, URL: http://www.fertilizer.org/ifa). Although they portray fertilisers as the natural link between intensification and sustainability, the connection between this discourse and the original definition by Pretty *et al.* [1•], or producing more with less, remains unclear.

What does science say? Here, the field is also polarised. Yet, the discourse that characterised the green revolution, one in which all hopes are placed in a few new technologies that aim to address single problems at a time, has not really changed much in essence (cf. example in Box 1). An important implication of this discourse is that technologies are developed elsewhere and that farmers have to 'adopt' them [26,27]. Although

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[2] This would require examining the various dimensions of food security (availability, access, utilisation and stability) and the contribution of different intensification models to each of them, as well as solutions to reduce food waste, to improve food nutritional quality and to influence changes in current diets.

[3] The concept of sustainability is not being questioned here; just the use of the term 'sustainable intensification' in the discourses of science, development, policy and the industry.

[4] Although this paved the road to a neo-productivist discourse, later on however the FAO clarified that waste reduction and improved access to food should be also addressed in parallel in order to achieve food security, as our current agricultural productivity would suffice to feed the world now and in 2050 (Graziano da Silva, J., Keynote address at the Economist Conference, 'Feeding the World in 2050', Geneva, Switzerland, 8 Feb. 2012).

Box 1 What is, and what is not

The report published by the Thematic Group on Sustainable Agriculture and Food Systems of the Sustainable Development Solutions Network (SDSN, 2013) starts off with a series of 20 questions that this group of agricultural scientists[9] qualifies as 'tough' questions that need to be addressed. Amongst them, these two are quite illustrative:

1. ''*How can biotechnology best contribute to future food and nutritional security and serve the needs of the poor?*''
2. ''*How much can organic agriculture contribute to feeding the world? Where and at what cost?*''

The controversy does not reside in the questions, which are important, but in the way they are formulated. The first question assumes that biotechnology *can* contribute to food and nutritional security for the poor; the real question – to them – is *how best*? The second question presupposes that organic agriculture can only offer a partial solution to feeding the world (*how much?*), only in certain places (*where?*) and with associated costs that need to be quantified. In linguistics, a discourse is a body of text that communicates specific information and knowledge, which is not isolated from other discourses (inter-discourse). Within a field of intellectual inquiry, practitioners discuss 'what is' and 'what is not' discourses (Foucault M, The Order of Things. *Pantheon*, 1970). The two questions quoted above provide a good example of that. Why is it that the *Where-and-at-what-cost* part of the question only applies to organic farming? Are there no costs, restrictions or risks associated with biotechnology that need to be investigated? I do not mean to discuss this here. I just mean to illustrate to what extent the faith-in-new-technology discourse that marked the generation of scientists from the green revolution remains influential, preventing out-of-the-box thinking. The report I refer to is part of the process leading to the Sustainable Development Goals that will succeed the Millennium Development Goals in 2015. While we know that there is not such a thing as unbiased, 'value-free' science, and that we have to cope with that, there is still room to wonder whether we might not be trying to solve today's problems with the same mind-set that created them.[10]

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[9] In actuality, not all authors of this report are practicing scientists; this work is also co-signed by representatives of the FAO, the industry and the donor community.

[10] Statement attributed to Albert Einstein (1879–1955).

the sustainable intensification discourse has been embraced by most international research organisations as an aspiration, it has seldom been translated into strategies for its realisation that would exhibit discernible differences from any of their previous actions. The term remains loosely defined. For as long as different parties disagree on how they define sustainability, or on the indicators and boundary conditions for its evaluation, perceptions on 'sustainable' intensification are likely to divert considerably. There are also examples in which the term ecological intensification is used in a similarly ambiguous way, although by contrast, this concept has brought in new keywords to the agricultural research for development jargon such as 'landscape' or 'ecosystems' approaches, 'functional biodiversity', 'regulation', 'stability', 'pest-suppressive landscapes' or the notion of 'trade-offs and synergies' between rural livelihoods and ecosystem services (cf. references in the first paragraph). The role of local resources and indigenous knowledge is also recognised, so that farmers are not mere adopters of technologies; they generate locally adapted knowledge and technologies [28,29].

The difference between both qualifiers of intensification is thus not merely semantic, and it is reminiscent of the old dichotomy between input technologies versus process technologies [30]. In practice, however, ecological intensification does not exhibit a consolidated set of management techniques but rather alternative models that take different shapes around the globe and that integrate culture and nature to a variable extent.

Models of ecological intensification

There is no single generalizable model of ecological intensification. Any generalization would be contrary to the context-specific, ecosystem-based principles of ecological intensification[5] [2••]. Models of ecological intensification may include, non-exhaustively, the practice of agroecology [31–34], organic agriculture (IFOAM, URL: www.infohub.ifoam.org), diversified farming systems (e.g. [35]), nature mimicry (e.g. [36]), and some forms of conservation agriculture (e.g. [37]) and of agroforestry (e.g. evergreen agriculture) (e.g. [38]). Traditional farming systems around the world may also offer valuable knowledge to inspire ecological intensification (e.g. [39,40]). Indeed, the term *Intensification ecologique* was first used by francophone researchers to describe practices by pastoralists in the tropics [41]. Even permaculture may be seen as a source of knowledge for ecological intensification, especially for the restoration of degraded landscapes in tropical drylands, although the scientific underpinning of permaculture principles is still incipient [42]. These systems differ especially in the way they regard the impact of the surrounding natural environment on agriculture, the impact of agriculture on the surrounding natural environment and the way natural elements are embedded in agricultural systems.

Agroecology *sensu* SOCLA (Spanish acronym for the Latin American Society for Agroecology, URL: http://www.agroeco.org/socla) is in my opinion the most conspicuous example of ecological intensification for family agriculture in terms of both technological and institutional development [13••]. The movement counts thousands of followers — researchers and practitioners — and more than 20 years of existence in Latin America. Agroecology has inspired successful development policies in countries such as Brazil (*Fome Zero* Program,

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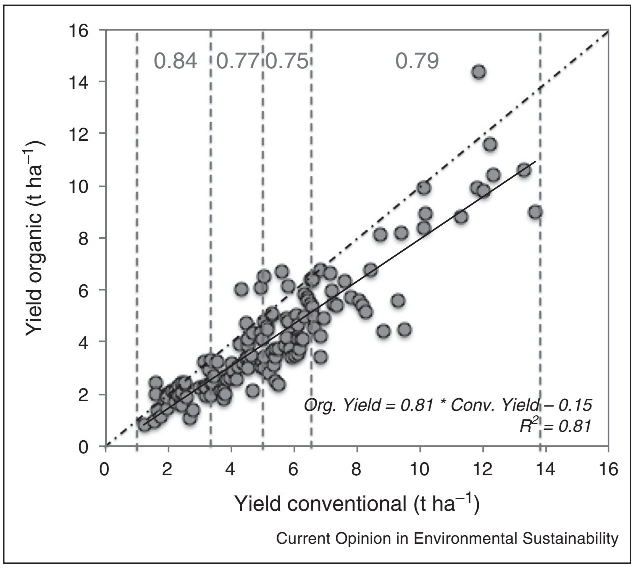
[5] It must be noticed that these ideas differ from the sense in which Cassman [43] employed the term ecological intensification earlier on, a synonym with yield potential, soil quality and precision agriculture. Tittonell and Giller [44] explored critically the validity of this particular definition in the context of Africa smallholder agriculture.

URL: http://www.fomezero.org, or the National Program on Agroecology and Organic Production, URL: http://portal.mda. gov.br/portal/institucional/planapo), where even a Governmental Ministry for Agrarian Development was created that promotes this form of agriculture through territorial development [45]. Agroecology does not work through any standard or certification system, save participatory community guaranty systems in certain cases (e.g. [41]). Other models of ecological intensification such as eco-agriculture [9] or diversified systems [35] rely on similar principles as those that form the pillars of agroecology — diversity, efficiency, recycling, regulation — and deal mostly with large scale farming systems. Unlike Agroecology, these models are not necessarily linked to social movements and do not always have unanimous positions on polemic technologies such as genetically modified crops, which are not used in agroecological farming due to their implications for food sovereignty and bio-safety [46,47]. Towards the end of the 1990s a new model emerged in Europe that was termed integrated agriculture, which applied largely to mixed farming system [48]. The model was presented as a go-between that brought in practices of organic farming such as crop rotation, pure grazing or planting of flower strips to conventional farms.

One of the largest existing models of ecological intensification worldwide in terms of surface area is organic agriculture (37.2 million ha in 2011 [49]), although not all forms of organic farming can be considered to be ecologically intensive or necessarily sustainable [50,51]. Yet, organic agriculture may be seen as a laboratory for ecological innovations, which are also applicable to large-scale commercial farming in the North. Individual organic farmers who constantly try, fail, learn and retry, are largely responsible for most of such innovations, assuming all the associated risks and costs. This farmer-driven process of knowledge and technology generation has led to crop yield levels that are worldwide barely 20% lower on average than those attained under conventional farming[6] (Figure 1), as concluded recently by two independent studies conducted in parallel [52,53]. While the attainable yield gap between organic and conventional agriculture is in the order of 20%, according to these studies, the gap in terms of investments in research for both models of agriculture is much wider. Conventional agriculture receives not only the majority of the governmental funding but also almost the totality of the investment in research by the private sector.[7]

Figure 1



Current Opinion in Environmental Sustainability

A comparison of cereal yields (wheat, maize, rice, barley, rye and oats) under conventional vs. organic management as published in the scientific literature and compiled by de Ponti *et al.* [52]. The dash-dotted line indicates a 1:1 ratio. Vertical dotted lines correspond to quartiles in the distribution of conventional yields, and the figures in grey on top of the chart are the average relative yield (organic/conventional) within each quartile. In 50% of the cases conventional yields ranged between 1.2 and 5 t ha^{-1}. Organic yields were greater than conventional in 10% of the cases.

Biodiversity, regulation and ecosystem services

Research on ecological intensification requires a shift in disciplinary principles. Most of the progress made in agronomy over the last half century was supported by studying the ecology of mono-specific populations (crops) or autoecology, which refers to the study of individual species in relation to their environment. This has been largely the approach followed by the strongly positivist school of Theoretical Production Ecology funded by C.T. de Wit in The Netherlands since the end of the 1960s, which has influenced to a large extent the way in which we have analysed agricultural systems worldwide [54]. These principles are less applicable in the realm of

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[6] Such comparisons are only partial. In the first place, because they consider yield instead of productivity over time. Secondly, because the boundary conditions from where resources are drawn differ. In the case of nitrogen, for example, organic farming often draws resources from animal production (adjacent or not) or from symbiotic fixation, whereas conventional farming draws (non-renewable) resources largely from the Persian Gulf, the Niger delta or the Gulf of Mexico in the form of fossil energy to fuel the production of synthetic fertiliser. The rates of nitrogen used also differ widely between both systems.

[7] For example, The Netherlands has been pioneering in terms of investment in organic agriculture research over the last decade. The Dutch government committed to invest €20 million over the period 2012-2016 in organic farming research, provided that the private sector matches this investment (http://topsectoren.nl/). A company like Monsanto invested in research (in conventional agriculture) as much as US$ 980 million or 10% of their sales only in 2012, and part of it was used to finance research done by public universities (http://www.monsanto.com/investors).

Table 1

Key criteria to illustrate differences in the approach taken in 'classical' agronomy and in agroecology, the disciplines that underpin respectively the sustainable and ecological intensification discourses, with particular reference to quantitative systems analysis

Criterion	Classical agronomy	Agroecology
Discipline	Auto-ecology (populations)	Synecology (communities)
Dynamics	Predictable outcomes (risk probabilities), feedbacks formalised, continuity	Complex feedbacks, randomness, hysteresis (non-linearity, irreversibility, discontinuity)
Diversity	A burden (e.g. weeds, heterogeneity, asynchrony) Theory of control (best practices)	An attribute (e.g. synergies, natural antagonisms, risk spreading) Theory of regulation (let nature do its job)
Up-scaling	Aggregation (nested systems from field to world). Production at scale S (Ps) is calculated as: $\mathrm{Ps} = Y\mathrm{e} \times A\mathrm{e} + \ldots + Y\mathrm{n} \times A\mathrm{n}$ Ye,n: yield in production environments e, n Ae,n: area of production environments e, n	Emerging properties and interactions (the whole is more than the sum of its parts). Production at scale S (Ps) could be calculated, for example, as: $\mathrm{Pe} = (Y_1\mathrm{e} + Y_2\mathrm{e} + Y_i\mathrm{e} + Y_1\mathrm{e} \times Y_2\mathrm{e} \times Y_i\mathrm{e}) \times A\mathrm{e}\ldots$ $\mathrm{Pn} = (Y_1\mathrm{n} + Y_2\mathrm{n} + Y_i\mathrm{n} + Y_1\mathrm{n} \times Y_2\mathrm{n} \times Y_i\mathrm{n}) \times A\mathrm{n}$ $\mathrm{Ps} = \mathrm{Pe} + \ldots + \mathrm{Pn} + \mathrm{Pe} \times \ldots \times \mathrm{Pn}$ $Y_{1,2,i}$e,n: yield of activities 1, 2, *i* in production environments e, n Ae,n: area of production environments e, n
Diagnosis (examples)	Land use efficiency (yield) Yield gap/yield potential or water-limited potential Nutrient flows and balances Efficiency as a ratio (output per unit input) Calories per unit area per unit time	Land equivalent ratios Farm or landscape productivity gap/possibility frontier Nutrient networks, cycling and ascendency[a] Efficiency as an emerging property (matrix) Nutritional diversity over time

[a] *Sensu* Ulanowicz RE, 2001. Information theory in ecology. Comp Chem 25: 393–399.

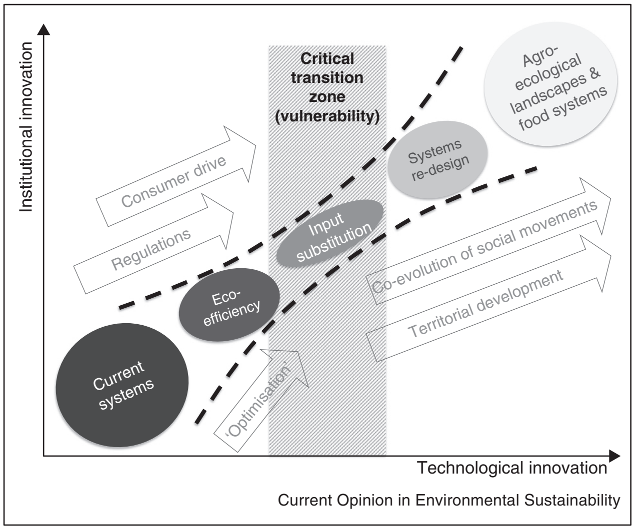
community ecology or synecology, the study of groups of organisms in relation to their environment. Ecological intensification through agroecology relies largely on spatio-temporal diversification (of species, of functional traits) and on the emergent patterns and processes that result from that [5,55]. As a consequence, 'classical' agronomy and agroecology differ not only in their core scientific discipline but also in the way they deal with principles such as diversity, dynamics and scaling, with unpredictability and risks (from control to regulation), or in the indicators used to assess systems performance (Table 1). In particular, the differences in the criteria used for diagnosis lead to endless discussions between the proponents of both approaches. Although both parties attempt to argue which model is best, the problem is that they often use different definitions of what 'best' means.

The ability of ecologically intensive systems to contribute to ecosystem service provision and to system regulation in the face of external shocks such as climate change has been recently reviewed, usually in comparison with conventional systems [11,56–61]. Rossing *et al.* [62] made a comparative analysis of the data presented in these reviews and concluded that organic and agro-ecological farming systems performed better in providing climate change relevant ecosystem services, such as carbon sequestration up to 30 cm depth, energy use efficiency, soil water holding capacity, resilience to drought and resilience to hurricanes and heavy rainfall. No differences between systems were found for global warming potential and for carbon sequestration up to 1 m due to lack of data. Crowder *et al.* [63] and Bommarco *et al.* [3] showed the ability of ecologically intensive farming to provide ecosystem services of support and regulation by managing both in-field and off-field diversity, and pointed to the existence of major knowledge gaps in this realm (notably in the area of above-belowground interactions).

Towards sustainable food systems

Irrespective of the qualifier of intensification of choice, whether sustainable or ecological, transitioning towards sustainable food systems supported by multi-functional landscapes requires both technological and institutional innovation (Figure 2). Optimisation of current practices, as advocated in the eco-efficiency literature (e.g. [64]) will only result in limited — though necessary — progress, because the inherent structures and functions in the system that render it inefficient — for example, their dependence on fossil fuels and subsidies — are not being contested. Increased demand for organic food or any other form of production perceived as sustainable by consumers, in combination with regulations (restrictive policies, tax mechanisms or certification standards) can provoke progressive shifts towards input substitution models. These systems are often found among those certified as organic. In input-substitution models the principles of industrial agriculture are not necessarily abandoned (e.g. monocultures); only the inputs that are used are of a different nature [65]. These systems are sometimes motivated by commercial opportunities, for instance, by surplus prices for organic food. In other cases, these are systems that are in transition towards more ecologically intensive models [66]. Because they are subject to a number of restrictions, they may be even

Figure 2



Current Opinion in Environmental Sustainability

Transition towards sustainable food systems that rely on ecologically intensive, multifunctional landscapes requires both technological and institutional innovation. The trajectory may not necessarily be rectilinear, as indicated in the diagram for the sake of simplicity. Optimisation of current practices without thorough reconfiguration of the agroecosystem is just the beginning (eco-efficiency). The influence of drivers such as consumer preferences or increased regulations may require further technological and institutional innovation to support input substitution models, which are most vulnerable to both external and internal factors. Further innovation may foster agroecosystem redesign to decouple agriculture from fossil fuel energy and to make it compatible with nature conservation. Ultimately, for such new systems to be sustainably integrated within food systems they must co-evolve with social mobilisation and governance mechanisms for territorial development.

less resilient, or more vulnerable to external shocks than conventional systems, for which choices are broader [67]. Supportive policies may be necessary to overcome such critical transitions.

Increasing resilience while contributing to support ecosystem functions of local and global relevance requires in most cases a thorough re-design of the agroecosystem. This step is known as 'agroecological articulation' in the agroecology literature, and it implies both horizontal and vertical integration within sustainable food systems [68]. In other words, if the aim is to implement diverse agricultural systems, then human diets should also be diverse. Because the ecological functions that underpin services of support and regulation operate at scales wider than the agricultural field or individual farm, this transition requires landscape approaches to agroecosystem design (e.g. pest-suppressive landscapes through evolutionary design [69], ecosystem service bundles [70]). Moving from farm to landscape scale implies moving from individual to collective decision-making, which requires innovative approaches to foster co-design [71]. Agro-biodiversity is an essential component of the system and farmers' right to manage and reproduce such diversity constitutes a central pillar of food sovereignty [72]. In the few examples in the world where such transitions are taking place, such as in family agriculture in Brazil, they are backstopped by a solid network of social movements and by enabling governance mechanisms aimed to support territorial development.[8] But none of this can be effective without vertical integration with subsequent links in the food chain, which requires articulation between responsible traders and consumers as well [74].

Conclusions

The difference between sustainable and ecological intensification goes beyond pure semantics. Although the definitions given in literature do not differ much in concept, sustainable intensification is currently in use to justify any form of intensification, by both public and private parties. Ecological intensification, on the other hand, is defined as the means to make intensive and smart use of the natural functionalities of the ecosystem (support, regulation) to produce food, fibre, energy and ecological services in a sustainable way. The major difference between both concepts resides in the role nature plays in the actual design of the systems, and in the possible synergies between food security (livelihoods), global change adaptation and mitigation. Since the ecological processes that underpin support and regulation services operate beyond the boundaries of a single farm, the scales of analysis and design also differ. While sustainable intensification — and/or eco-efficient — solutions are still designed by reasoning at the scale of a single crop or agricultural field, ecological intensification needs to embrace the complexity of the landscape. As a consequence, actions to support ecological intensification may often require collective decision-making, which calls also for institutional innovation. Current models of ecological intensification include a.o. agroecology, organic, bio-diverse and restorative agriculture. They all differ in the degree they internalise diversity, cycling, ecosystem services, governance and social movements. A common denominator is their reliance on biodiversity and natural regulation. While many of the claims made for these models are yet to be proven effective, adaptable or scalable, no form of ecological intensification is able to offer quick fixes: serious investment in this type of research requires long-term commitment. For example, nutrient management is currently a bottleneck for the expansion of ecologically intensive agriculture, which depends largely on mixed farming, and research on alternatives for the future is much needed. Global assessments of productivity levels show that investments in research for ecologically

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[8] As part of a multiyear plan to eradicate hunger, the government of Brazil created in 2000 a Ministry of Agrarian Development that attends to the specific needs of the large smallholder sector in the country (unlike the traditional and co-existing Ministry of Agriculture), supporting resettling of urban dwellers in rural areas, by providing not only land and credit but also training, infrastructure, schools, banks, access to markets and capital assets [73].

intensive farming will pay off, and the same principles that are useful in decoupling agriculture from large energy subsidies in the North can also inform strategies for soil rehabilitation and efficient use of minimum inputs in the South. Through a landscape approach, ecological intensification aims to design multifunctional agroecosystems that are both sustained by nature and sustainable in their nature.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

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This paper describes projects of sustainable intensification in Africa. The paper shows that once it is recognised that agriculture really matters, it is possible to increase agricultural production, without harm to the environment. The impact of sustainable intensification can be huge on domestic food budgets, social infrastructure, business development and the well-being of both the rural and the urban populations.

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Authors propose five avenues for agronomic research to strengthen ecological intensification and to deepen knowledge of agroecosystems for action. These include the use of new insight from plant sciences (e.g. energy conversion efficiency, nitrogen use efficiency, and defence mechanisms against pests), the use of natural ecosystems as a source of inspiration for cropping systems design, the use of farmers' systems knowledge for scientific knowledge and innovation, the use of meta-analyses, and comparative system studies.

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