# Ecological Intensification: Local Innovation to Address Global Challenges

**Chapter** · February 2016

DOI: 10.1007/978-3-319-26777-7_1

P.A. Tittonell
Instituto Nacional de Tecnología Agropecuaria
**171** PUBLICATIONS **11,730** CITATIONS

Laurens Klerkx
Wageningen University & Research
**252** PUBLICATIONS **9,896** CITATIONS

Frédéric Baudron
International Maize and Wheat Improvement Center
**97** PUBLICATIONS **2,751** CITATIONS

Georges Félix
University of Puerto Rico at Utuado
**15** PUBLICATIONS **292** CITATIONS

# Chapter 1
# Ecological Intensification: Local Innovation to Address Global Challenges

**Pablo Tittonell, Laurens Klerkx, Frederic Baudron, Georges F. Félix, Andrea Ruggia, Dirk van Apeldoorn, Santiago Dogliotti, Paul Mapfumo, and Walter A.H. Rossing**

**Abstract** The debate on future global food security is centered on increasing yields. This focus on availability of food is overshadowing access and utilization of food, and the stability of these over time. In addition, pleas for increasing yields across the board overlook the diversity of current positions and contexts in which local agriculture functions. And finally, the actual model of production is based on mainstream agricultural models in industrialized societies, in which ecological diversity and benefits from nature have been ignored or replaced by external inputs. The dependence upon external inputs should exacerbate the negative impacts on the environment and on social equity. Strategies to address future global food security thus require local innovation to increase agricultural production in a sustainable, affordable way in the poorest regions of the world, and to reduce the environmental

---

P. Tittonell (✉)
Farming Systems Ecology Group, Plant Sciences, Wageningen University,
430, 6700 AK Wageningen, The Netherlands

Natural Resources and Environment, Instituto Nacional de Tecnología Agropecuaria (INTA),
Bariloche, Argentina
e-mail: Pablo.tittonell@wur.nl

G.F. Félix • D. van Apeldoorn • W.A.H. Rossing
Farming Systems Ecology Group, Plant Sciences, Wageningen University,
430, 6700 AK Wageningen, The Netherlands

L. Klerkx
Knowledge, Technology and Innovation Group, Wageningen University,
Wageningen, The Netherlands

F. Baudron
International Centre for Maize and Wheat Improvement (CIMMYT), Addis Ababa, Ethiopia

A. Ruggia
Instituto Nacional de Investigación Agropecuaria (INIA), Las Brujas, Uruguay

S. Dogliotti
Facultad de Agronomía, Universidad de la República, Montevideo, Uruguay

P. Mapfumo
Soil Fertility Consortium of Southern Africa (SOFECSA), University of Zimbabwe,
Harare, Zimbabwe

E. Lichtfouse (ed.), *Sustainable Agriculture Reviews*, Sustainable
Agriculture Reviews 19, DOI 10.1007/978-3-319-26777-7_1

impact of agriculture and its dependence on non-renewable resources. Ecological intensification, the smart use of biodiversity-mediated ecosystem functions to support agricultural production, is portrayed as the most promising avenue to achieve these goals.

Here we first review examples of ecological intensification from around the world. Functional diversity at plant, field and regional scales is shown to hold promise for reducing pesticide need in potato production in the Netherlands, increasing beef production on the pampas and campos in south-east South-America without additional inputs, and staple crop production in various regions in Africa. Strategies range from drawing on high-tech breeding programs to mobilizing and enriching local knowledge and customs of maintaining perennials in annual production systems. Such strategies have in common that larger spatial scales of management, such as landscapes, provide important entry points in addition to the field level.

We then argue that the necessary innovation system to support transitions towards ecological intensification and to anchor positive changes should be built from a hybridization of approaches that favour simultaneously bottom-up processes, e.g. developing niches in which experiments with ecological intensification develop, and top-down processes: changing socio-technical regimes which represent conventional production systems through targeted policies. We show that there are prospects for drawing on local experiences and innovation platforms that foster co-learning and support co-evolution of ecological intensification options in specific contexts, when connected with broader change in the realm of policy systems and value chains. This would require dedicated system innovation programmes that connect local and global levels to sustainably anchor change towards ecological intensification.

**Keywords** Food security • Agroecology • Soil rehabilitation • Livestock • Innovation systems • Transitions

## 1.1 Introduction

The discourse that dominates the debate on current and future global food security places emphasis on the need to intensify agricultural production in order to meet the demands of a growing world population (e.g. Huang et al 2002; Godfray et al. 2010). It is often assumed that agricultural production will have to increase by 70 % to be able to feed nine billion people by the year 2050, as a result of both population growth and expected changes in human diets associated with rising average incomes in developing countries (Tilman et al. 2011). Since the increase in food production that may be expected from agricultural land expansion is calculated to be in the order of 15 % (Lambin and Meyfroidt 2011), it is further assumed that agricultural production can only be increased through raising average crop and animal yields. This is a rather simplistic view on how to address the challenge of global food security. It is based on a large number of assumptions and only partially true. It justifies further intensification of industrial agriculture in the global "North", with all the environmental problems that this entails (e.g., Geiger et al. 2010) in the name of helping the poorest of the poor. And it is shared among the principal international actors of the agricultural sector, i.e., research organisations and consultative panels, the agro-chemical and breeding industries, most national governments, and numerous members of the academia (cf. Tittonell 2014).

Meeting food security anywhere in the world requires addressing its four pillars: availability, access, utilization and the stability of all these over time (Pinstrup-Andersen 2009). At global scale, current food production (around 2700 Kcal person$^{-1}$ day$^{-1}$) is enough to meet the demands of human kind (between 1800 and 2200 Kcal person$^{-1}$ day$^{-1}$), as estimated by the World Health Organisation (2013). Yet 805 million people go hungry for more than 6 months every year (WFP 2012). It is also true that as humans we are climbing up in trophic levels due to increased consumption of animal protein (Bonhommeau et al. 2013). Recently, however, more detailed nutritional studies examining global diets and human requirements of various food items revealed that while the current production of vegetables, nuts, fruits, milk and edible seeds are insufficient to meet world demands, the production of whole grains and fish are about 50 % higher than human requirements, while the production of red meat is 568 % higher than required for a healthy diet (Murray 2014 – Institute for Health Metrics and Evaluation, www.healthdata.org). This suggests that the assumption that food production must increase is only true for certain food items (e.g., vegetables by 11 %, seeds and nuts by 58 %, fruits by 34 %, etc.). It is also clear that the problem of food security is not primarily one of availability, but primarily one of access to food.

But it is not just a problem of food distribution. To address food insecurity in rural areas of sub-Saharan Africa, for instance, it is not enough to produce large amounts of food in the American Midwest or in the Pampas of Argentina. The agricultural production from these regions is subject to multiple demands, from the food, livestock or chemical industries, or from the energy sector, all of which are often more attractive and logistically easier to meet than the needs of poor rural dwellers in developing countries. Addressing global food security requires local solutions. In other words, food must be produced where it is most needed. Paradoxically, most poor people around the world live in rural areas and own small pieces of land; most of the hungry of the world are farmers who can potentially produce their own food. Their ability to do so is hampered by different factors, including access to agricultural inputs, knowledge and technologies, socio-political instability, lack of governance or weak institutions, climate change, demographic pressure and natural resource degradation (UNCTAD 2013, 2014; WFP 2013).

The current model of agricultural intensification that fails at feeding the world today cannot be expected it to feed the world in 2050. This model, deployed in the developed world during the post-war period, had enormous consequences for the environment, and has been largely dependent on non-renewable resources and on subsidies from other sectors of national economies. Most poor countries in the developing world, where agriculture may generate up to 70 % of the national income, are not in a position to subsidise their agriculture at the levels observed in industrialised countries – where agriculture represents only 3 % of their economy

(Koning 2013). On the other hand, the model of intensification issued from the 'green revolution' in the 1960s and 1970s did not have the positive impacts that were expected in the poorest regions of the world, in spite of the subsidies and international aid that were deployed to that effect. Current per capita food production and average agricultural yields in most of these regions remain at the same levels as 50 years ago (FAO 2014). It did, however, have negative environmental and social impacts around the world (Freebairn 1995; Matson et al. 1997; Maredia and Pingali 2001; IAASTD 2009; UNCTAD 2014). New forms of agricultural intensification are needed, both to increase agricultural production in the poorer and currently less productive areas of the world, where people go hungry, and to reduce the environmental impacts and the dependence on non-renewable resources of industrialised agriculture.

We hypothesise that food production can increase where needed and at the same time be sustainable by making intensive and smart use of the natural functionalities that ecosystems offer. Approaches to agricultural intensification that rely largely on ecosystem functions have been grouped under the generic term of ecological intensification (Dore et al. 2011). Yet, ecological intensification, which takes different forms around the world, is not a universally applicable set of guidelines on how to farm sustainably (Tittonell 2014). It requires local innovation, local adaptation, and the creation of favourable socio-technical regimes that allow for such local diversity. In other words, it can only provide local solutions to global problems. The objective of this chapter is to examine examples of ecological intensification around the world, from small-scale family agriculture to high input western farming systems, and to reflect on the diversity of intensification pathways. Many of these examples, however, emerged within specific geographical, social and economic niches, and the question is how to scale them out and anchor them in mainstream systems. Hence, what kind of innovation environment would be necessary to foster ecological intensification? At the end of this paper we reflect upon the attributes and possible structure of an innovation system that can support the transition towards ecologically intensive ways of farming.

## 1.2 Intensify, Extensify, Detoxify

Current food production in the most productive areas of the developed world represents only a fraction of global food production, as illustrated for cereals in Fig. 1.1. For example, the total cereal production of all countries in which the average cereal yield is greater than 6 t $ha^{-1}$ $year^{-1}$ (most of western Europe and North America) represents barely 12.5 % of the world cereal production. Half of the total cereal production in the world comes from countries where the average yields are lower than 3 t $ha^{-1}$ $year^{-1}$, whereas the poorest countries in the world produce average yields of around 1.3 t $ha^{-1}$ $year^{-1}$. This analysis suggest that further increasing yields in developed countries to be able to feed the world is not justified, as even doubling

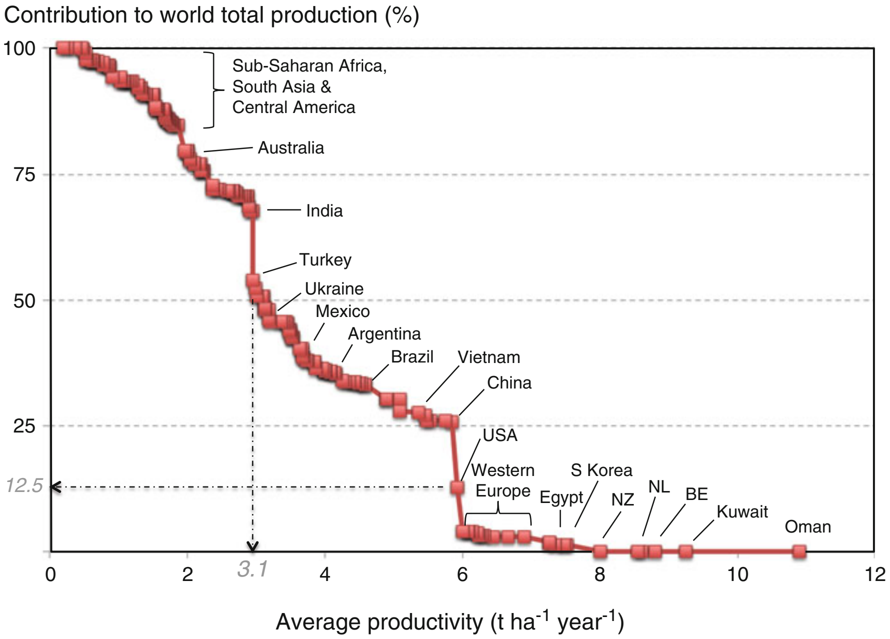

**Fig. 1.1** Average cereal productivity per country and their cumulative contribution to total world production. *Dash-dotted lines* indicate (*vertical*) that 50 % of the total world production is realized in countries where average yields are lower than 3.1 t ha$^{-1}$, and (*horizontal*) that all the cereal production in the countries where average yields are higher than 6 t ha$^{-1}$ (from USA to Oman) together represent 12.5 % of the world total

production in these countries will still contribute a relatively small fraction of the world demand. Besides, barely 20–30 % of the energy contained in the agricultural produce from these systems is delivered to the food chain, while the rest is lost in the process of transformation of grain into meat, bioenergy or other industrial products (Cassidy et al. 2013). Since yield gains in response to input intensification follow the law of diminishing returns, increasing average yields by e.g. 1 t ha$^{-1}$ in countries and regions where yields are already high requires larger investments (and potentially greater environmental damage) than in regions where yields fluctuate around 1.3 t ha$^{-1}$. Industrial agriculture consumes most of the energy, water and nutrient inputs available at global level, pushing their international price to levels that make them prohibitive for smallholder farmers in the global South.

On the other hand, since agriculture represents an important economic activity in many developing countries, and the major form of livelihood for the rural poor, increasing agricultural productivity in the currently less productive countries and regions of the world is imperative. About 50 % of the food consumed worldwide is produced by low-input, smallholder family agriculture. These systems occupy approximately 20 % of the area available for agriculture in the world, and often not the most productive land within a country (FAO 2012). Some of such systems rely on local genetic resources, institutions and traditional practices that in some cases may be millennia old. These systems are often termed ‘organic by default’ because they use very few or no external inputs. But for all the genuine attractiveness of traditional practices and natural resource management systems, it is obvious that they are unable to feed a currently increasing urban population in developing countries (Tittonell and Giller 2013). They were developed in a different historical context, in which most of the human population in the world still lived in rural areas. Their intensification is urgently needed. But, what form of intensification?

Over the last years, environmental concerns have increasingly influenced the terminology used to describe and communicate the need to increase agricultural productivity worldwide (e.g., ‘sustainable intensification’, ‘eco-efficiency’, ‘more with less’, etc.) but they did not influence the technological paradigm around intensification much beyond a recognised need for precision agriculture to improve physical and economic efficiencies (e.g., Cassman 1999). Such a view still assumes that the technologies of industrialised agriculture are effective at increasing yields anywhere in the world. Current efforts in this direction are placing emphasis in reducing yield gaps between actual and potential yields around the world (e.g. van Ittersum et al. 2013). Yet, closing yield gaps does not necessarily imply moving towards higher resource use efficiency (van Noordwijk and Brussaard 2014). In particular, the role that biodiversity can play in increasing efficiencies has been often overlooked (e.g., Kremen and Miles 2012), and there is increasing evidence on the benefits from diverse soil communities, beneficial arthropods or from agroecosystem diversification contributing to increased food production and reduced reliance on non-renewable resources (e.g., Bommarco et al. 2013; Fonte et al. 2012; Lin 2011).

We know that current levels of investment in terms of assets, labour and external inputs and current levels of attainable productivity differ widely worldwide (Fig. 1.2). Contextual demographic and socio-political pressures in the South condemn smallholder systems to very resilient poverty traps (Tittonell 2013), while economic pressures push farmers to unsustainable over-investment and indebtedness in the North (Van der Ploeg 2009). Serious investments in research are needed on ecological intensification in the South and on ‘extensification’ based on ecological principles in the North to allow moving from regime 1 (red line) to regime 2 (blue dotted line) in Fig. 1.2, and serious policies, institutions and territorial development are needed to shift to regime 3 (green dotted line). The set of actions in research, development and policy necessary to address the global food problem, which is not only one of food insufficiency but also of obesity, malnutrition, overconsumption, and waste, can be summarised as follows: intensify in the South, extensify in the North, and detoxify everywhere. In the following section, we describe examples of ecological intensification strategies from contrasting agricultural systems around the world, but all of them based on putting biodiversity to work for agriculture.

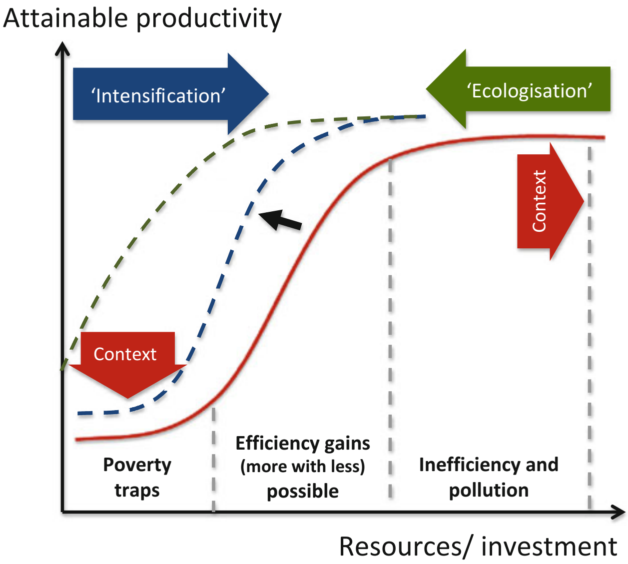

**Fig. 1.2** Attainable productivity, contexts and pathways. The *red* curve (*solid line*) describes the current situation where institutional and political contexts create situations of poverty traps or of inefficiency and pollution. The zone of the curve where efficiencies are greater often corresponds to agricultural systems in emerging and developing economies (cf. Fig. 1.1). The ecological intensification *arrows* describe desirable directions of change: 'ecologisation' involving efforts to maintain productivity while reducing fossil fuel inputs, and 'intensification' to increase productivity per unit area in an affordable and sustainable manner (From: Tittonell 2013)

## 1.3 More with Less, the Same with Less, More with More or More with the Same?

In this section we will show successful practical examples of ecological intensification that lead to producing more value(s) with less resource investments, reducing the damage to nature and society. Non-exhaustively, we focus on strategies to reduce agrochemical inputs in high output agricultural systems, on the key roles that livestock may play in preserving nature and facilitating synergies, on the integration of annual and perennial species, and on the rehabilitation of degraded soils, particularly in Africa.

### *1.3.1 Designing Plant Disease-Suppressive Landscapes*

Potato late blight caused by *Phytophthora infestans* has been estimated to result in a cost of M€ 4800 globally due to application of fungicides and residual yield loss (Haverkort et al. 2008). In the Netherlands, conventional potato production resulted in some 10 kg active fungicidal ingredient per ha being used in 2008 (CBS 2014) on

165,000 ha (Haverkort et al. 2008), making it the most pesticide-consuming crop in the country. Cultural means of control such as early cropping, strip cropping and reduced N application have been found to somewhat reduce disease pressure in organic production systems (Finckh et al. 2008). Eradication of sources of pathogen inoculum is an important means of control. In the Netherlands, the removal of potato volunteers and heaps of culled potatoes is compulsory by law to protect (seed) potato production. Breeding for resistance provides only temporary relief due to the aptitude of the pathogen to quickly overcome plant resistance by genetic mutation (Haverkort et al. 2008; Haas et al. 2009). It is thus evident that no silver bullet approach to disease control exists, and that smart combinations of multiple means are called for.

Skelsey et al. (2009) evaluated the combination of mixing cultivars with different resistance genes at field and regional scales with a set of disease management options. They explored virtual landscapes in which a susceptible and a partially resistant cultivar were grown in different spatial patterns. Disease appeared at a random location in the landscape and the resulting spores spread depending on atmospheric conditions (Skelsey et al. 2008). Spore viability was assumed to decrease with time and solar (UV) radiation levels. The epidemiological model, the spore viability model and the atmospheric dispersal model were all evaluated with field data. All scenarios were considered over 10 years of Dutch weather conditions, assuming 25 % of the area to be planted to potato. Random aggregation of resistant and susceptible potato fields was compared with block, strip or clustered arrangements of fields, considering also the shape and orientation of fields relative to the predominant wind direction. At the field scale, genetic monocultures were compared with different ratios of randomly mixed susceptible and resistant plants.

Results showed that donor landscapes as far away as 16 km could infect receptor landscapes, confirming the observation that the pathogen can travel large distances. Weather over the 10 simulation years caused considerable variation in final disease levels, indicating that stochastic effects play an important role in this ecosystem. Reducing the fraction of potato in the landscape, reducing the fraction of susceptible potato cultivars and orienting narrow and long fields perpendicular to the dominant wind direction all reduced percentage infected potato area at the end of the season. However, the strongest reduction in final disease level was consistently found when susceptible and partially resistant cultivars were mixed within each field. These results were confirmed by previous experiments at field level (; Bouws and Finckh 2008; Andrivon et al. 2003) and used to design new experiments to explore optimum spatial arrangements and cultivar mixtures (Fig. 1.3a, b).

In a complex strip cropping experiment in 2014 potatoes were grown in pure and mixed plots of potato cultivars. Due to the early onset of potato late blight (*Phytophthora infestans*), the yields were severely reduced by the disease. Pure plots of the partially resistant cultivar Raja had significantly lower yields than mixed plots of partially resistant cultivars of Raja and Connect mixed with resistant varieties of Carolus and Sarpo mira. The progress of the disease in the mixed plots was much lower than in the pure Raja plots (Fig. 1.4a). Analysis per cultivar showed that the contribution per cultivar was not uniform (Fig. 1.4b). The cultivar Connect was

**Fig. 1.3** (**a**) A homogeneous, healthy potato crop at flowering in sandy soils near Wageningen, The Netherlands; (**b**) Detail of a potato cultivar mixture after a strong *Phytophthora* infestation, showing differences in susceptibility between cultivars – infested plants had been already removed from the field; (**c** and **d**): Cattle and sheep grazing together in bio-diverse, native grasslands of eastern Uruguay; (**e** and **f**): images of the same wheat crop growing in the open (*left*) or under the canopy of *Faidherbia albida* trees (*right*) in Ethiopia – both photos were taken the same day and at the same time (Photo credits: **a**–**c**: P. Tittonell; **d**: W. Rossing; **e** and **f**: F. Baudron)

responsible for 73 % of the total tuber yield of 31 t ha$^{-1}$, while the remainder was equally distributed over the other three cultivars. The yield of Raja in pure and mixed plots were the same but the mixed plots yielded larger potatoes, and roots were more evenly distributed over the soil layers.

From these (preliminary) results it is clear that (i) cultivar growth characteristics in mixed stands are crucial for reaping the full benefits of mixed cultivar cropping and (ii) the diversification of the genetic composition of potatoes at field scale thus appears as a promising option to reduce disease spread. It has also been argued that deployment of several genotypes in one field would expose all genotypes to inoculum pressure and might exacerbate selection of virulent spores. This debate is as yet unresolved and may well call for a re-assessment of the trade-off between efficiency and stability (e.g. Bousset and Chèvre 2013).

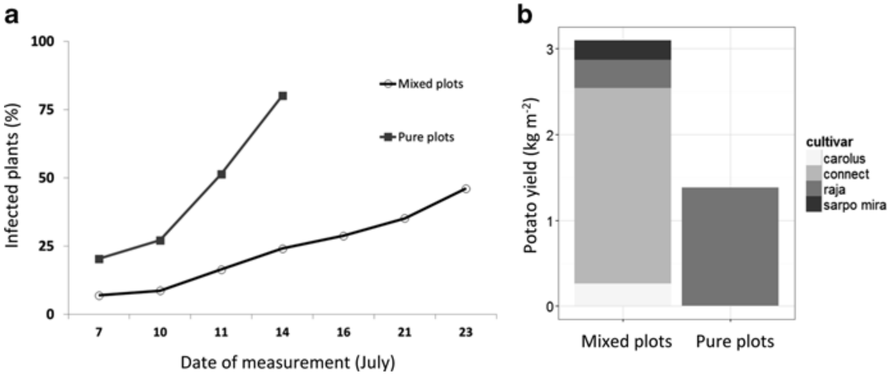

**Fig. 1.4** (**a**) Disease progress in pure and mixed plots expressed as the number of plants infected over time; (**b**) Yield of the mixed and pure plots and the contribution to the total yield per cultivar. Preliminary data from an on-going experiment on the organic farm De Droevendaal, Wageningen, The Netherlands

### *1.3.2 Beef Production on Natural Grasslands*

Extending over parts of Argentina, southern Brazil and Uruguay, the Pampas and Campos comprise 500,000 km$^2$ of natural grasslands that are mainly used for grazing cattle and sheep (Fig. 1.3c, d). The region is a hotspot for biodiversity of native C3 and C4 grasses and leguminous species. Some 450 grass species and 150 leguminous species are used as forages. In addition to biodiversity and livelihoods for 500,000 farmers, most of them family farmers, the Pampas and Campos provide a range of supporting, regulating and cultural ecosystem services of local and global importance (Sala and Paruelo 1997). Low productivity levels,, many cases around 60–80 kg meat equivalent ha$^{-1}$ year$^{-1}$ (Nabinger et al. 2000) make family farms on the more productive soils economically vulnerable to conversion to large-scale arable cropping of soybean and forestry monocultures. Ecologically, conversion to cropping will reduce biodiversity and make the region more vulnerable to droughts and soil erosion events, the frequency of which is predicted to increase due to climate change (Marengo et al. 2012). It will also cause rapid loss of carbon from soil stocks (DuPont et al. 2010), resulting in reduced water holding capacity (Alliaume et al. 2013) and plant growth limitation. Such threat is not hypothetical. Nabinger et al. (2009) report annual rates of decrease of natural grassland area in the region of about 1 % (440,000 ha year$^{-1}$) over the past four decades.

We postulate that a way out is to increase grass and livestock productivity on family farms to provide an economically viable alternative to a sell-out to soybean and pulpwood producers (Rossing et al. 2014). Overgrazing is considered as the main cause of low productivity, particularly on family farms where large numbers of cattle culturally display wealth. Based on an analysis of long-term experiments in southern Brazil, Carvalho et al. (2011) described how a strategy of what they call 'moderate grazing' lifted productivity levels from 60 kg $ha^{-1}$ $year^{-1}$ to 170 $ha^{-1}$ $year^{-1}$. This strategy involved allowing cattle to harvest vegetation with a forage allowance equivalent to 8–12 % of their live weight, leaving sufficient biomass for the sward to quickly re-grow and avoid loss of solar radiation interception as is the case when overgrazing. The diversity of C3 and C4 species enabled stabilization of production rates with C3 species being more productive under cooler conditions of winter and C4 species under warmer and drier conditions of summer. This required avoiding grazing during seeding times of both species types. A subsequent productivity increase to an average of 230 kg $ha^{-1}$ $year^{-1}$ was obtained from managing the dominance of grass tussocks, which appear as a result of differential grazing pressure on species of high and low palatability for livestock. Thus, increases from 60 to 230 kg $ha^{-1}$ $year^{-1}$ seem possible by changing management, without adding external inputs.[1]

These ideas were implemented in a co-innovation project with family farmers and local research and extension services in Uruguay, started in 2011 (Aguerre et al. 2015). Frequent interaction between researchers, extension teams and pilot farmers resulted in a comprehensive diagnosis of main productivity constraints and in sufficient trust on the part of the farmers to start to implement changes. Preliminary results after implementation show that by reducing the stocking rate (average −8 %) and the sheep/beef ratio (average −34 %, min. −17 %, max. −64 %), the standing biomass and consequently the forage allowance increased by 79 % and 88 %, respectively (Ruggia et al. 2015). These changes, together with adjustments in animal management, resulted in an increase in calving percentage from 62 % to 77 %, meat equivalent production per ha (including wool) from 100 to 124 kg $ha^{-1}$ $year^{-1}$ (representing 16–64 % on-farm increases), without increase in inputs or investments in infrastructure. As a result, net incomes increased on average from 58 to 97 US$ $ha^{-1}$. No less important is the fact that higher grass biomass resulted also in less soil losses by erosion, greater systems' adaptability to erratic rainfall, net carbon sequestration and more favourable habitats for biodiversity. But the preliminary results of this project also indicate that improving grazing management requires redesign of strategies across fields and over time at farm level to purposefully incorporate diversity across multiple spatial and temporal scales.

---

[1] Carvalho et al. (2011) also describe possible next intensification steps which all involve using external inputs, such as liming to increase pH, and N, P and K fertilizers and to replace native species by exotic, high production species in sown pastures. While this will substantially increase meat production levels, it will imply sacrificing the ecosystem services associated with the natural grasslands and making livestock production more vulnerable to climate change.

### 1.3.3 *Creating Synergies through the Integration of Annual and Perennial Species*

Simply by their presence, trees alter the local environment and affect other species, positively and/or negatively (Bruno et al. 2002). For example, retaining scattered trees in fields is very common in Ethiopia, and these trees affect the crop growing under or nearby the canopy in numerous ways. In the Central Rift Valley of Ethiopia, an area characterized by low and erratic rainfalls (comprised between 500 and 800 mm) and high evapo-transpiration rates, wheat is commonly grown on the heavier soils, where *Faidherbia albida* is the most common tree scattered in the landscape. Although *F. albida* is well known in literature for its reverse phenology, it generally sheds its leaves in winter and produces new shoots in summer (as other trees do) in the Central Rift Valley, probably because of heavy pruning at the beginning of summer (*F. albida* branches are extensively used for fencing). Nevertheless, *F. albida* was shown to have a facilitative effect on wheat, as the crop growing under its canopy is generally more productive (Hadgu et al. 2009). Recently, Shiferaw et al. (2014) analysed *F. albida*-wheat interactions in farmer fields (Fig. 1.3e, f), looking at the effect of the trees on microclimate, soil moisture, crop diseases, and the resulting effect on wheat development and productivity.

At anthesis, a critical stage of wheat development, air temperature under the canopy of *F. albida* was found to be significantly lower than outside the canopy during the day (Fig. 1.5a). Around midday, the temperature under the canopy was up to 5 °C lower than outside the canopy. The protection of the crop from excessive radiation at critical times by a tree canopy has been documented previously for other crops and trees (e.g. Ong et al. 2000). Soil moisture was also found to be higher under the canopy as compared to outside the canopy of *F. albida*, particularly during the early crop development (first 30 days) and grain filling stage (100–110 days after planting) (Fig. 1.5b). This may be the result of a reduction in soil evaporation (Ong et al. 2000) and/or a redistribution of soil water from the deep horizons to dry surface horizons – a phenomenon known as hydraulic lift (Burgess et al. 1998). Using the Normalized Difference Vegetation Index (NDVI) as a proxy, the crop growing under *F. albida* was found to be more vigorous than the sole crop throughout the season. The incidence and severity of *Fusarium* wilt (at anthesis) and head smut (at maturity) were also lower for wheat growing under *F. albida* canopy compared to wheat growing in the open.

These benefits were found to result in wheat producing 23 % more grain and 24 % more straw under the canopy of *F. albida* compared to sole wheat.

A different way of integrating annual and perennial plant species in agricultural landscapes is through biomass transfers. These may include transfer of tree leaf litter, of leaf biomass from trees and shrubs, or of woody biomass from these perennials. In a context in which crop residues are not available in sufficient amounts to sustain soil organic matter, or when most of this biomass is used to feed livestock, mulching with locally available woody biomass may represent a viable alternative to maintain or improve soil fertility. Experience from semi-arid zones of West

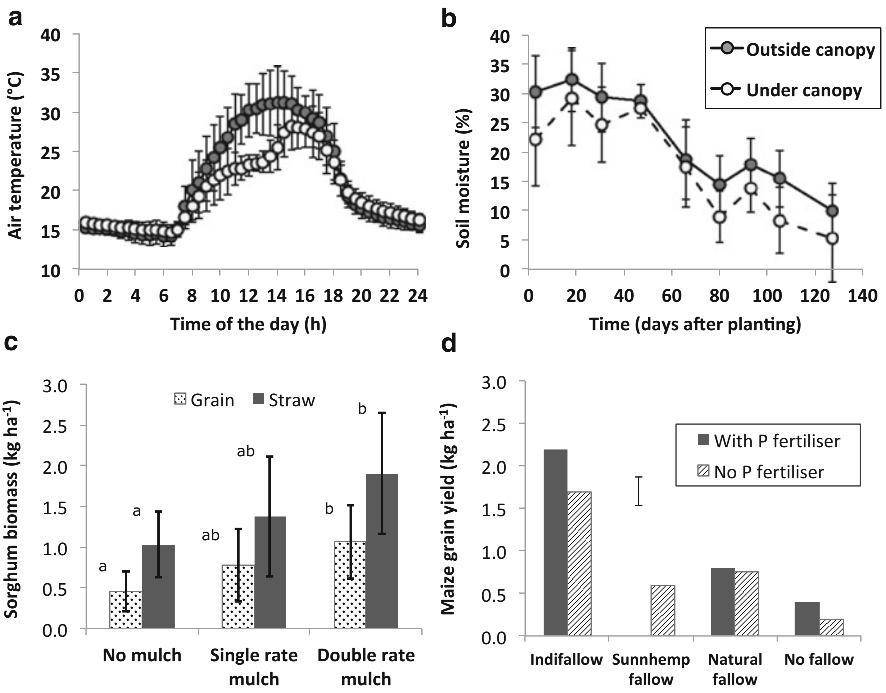

**Fig. 1.5** (**a**) Air temperature during anthesis of wheat and (**b**) topsoil (up to a depth of 10 cm) moisture content throughout the season, under and outside the canopy of *F. albida* in Ethiopia; (**c**) Sorghum grain and straw yield on non-productive farmers' fields with application of ramial wood biomass in Burkina Faso: *Piliostigma reticulatum* biomass applied as mulch at rates of 1 t ha$^{-1}$ (single) and 2 t ha$^{-1}$ (double), versus control without mulch (Ouédraogo 2014). (**d**) Maize grain yields grown after 1-year indifallows (indigenous legume species), sunnhemp improved fallows, natural fallows and continuous maize with and without mineral fertilisers in degraded sandy soils of Zimbabwe. *SSP* simple super phosphate (From: Nezomba et al. 2010)

Africa, from Senegal to Niger, shows that farmers have developed innovative temporal and spatial management of native evergreen woody shrubs that grow spontaneously on farmer fields during the dry season (i.e. *Piliostigma reticulatum*) to provide in-situ organic mulching material (Yélémou et al. 2013a). Use of shrub fallows in farmers' fields has been documented since the 1970s but only recently have shrub-crop associations been proposed as an ecological intensification mechanism for agro-pastoral systems in semi-arid West Africa (Lahmar et al. 2012; Tittonell et al. 2012). The presence of these woody shrubs in the landscape reduces erosion and intercepts wind-driven organic particles, surface soil sediments and nutrients (Dossa et al. 2013). Shrubs are pruned prior to the onset of the rainy season and fresh matter is applied on soils as mulch to maintain/enhance soil organic matter, water retention, and infiltration before the main crop is sown – sorghum or millet, usually inter-cropped with cowpea (Kizito et al. 2012; Yélémou et al. 2013b). When crops are harvested at the end of the rainy season, shrubs re-gain biomass and restore root reserves that carry them through the dry season. Farming families use woody branches with a diameter >2 cm as firewood. Hence, most of the woody organic matter applied on the fields consists of leaves and small-diameter branches, which decompose at a rate suitable for farmers to stop burning this biomass (Diack et al. 2000).

Shrub-crop associations were monitored in 2013 on farmer fields in Yilou, Burkina Faso (13°01′ N, 01°32′ W), and based on observed local management practices a series of on-farm trials of 300–900 $m^2$ plots were established in areas with homogeneous distribution of vegetation (average 500 shrubs $ha^{-1}$) and that farmers signalled as non-productive. Each plot was divided in three equivalent sections where standing woody shrub biomass was cleared and fresh matter was applied as three mulch treatments (Fig. 1.5c). In the first treatment (T1), the aboveground biomass of standing *Piliostigma* was applied as mulch at a rate of 1 t $ha^{-1}$ mulch; the second treatment (T2) received 2 t $ha^{-1}$ mulch, with biomass from standing Piliostigma in these and in the control (T0) plots. Sorghum-cowpea intercrops were established on plots using reduced tillage techniques. Sorghum grain and straw yields measured at harvest showed significant responses to the application of 2 t $ha^{-1}$ shrub biomass, although yields remained low for all treatments. When no woody mulch was applied, average sorghum grain yields were 460 kg $ha^{-1}$, versus 1063 kg $ha^{-1}$ when 2 t $ha^{-1}$ of fresh woody mulch was applied (Ouédraogo 2014). Although effects of these biomass amendments to soil are currently being assessed in the mid- to long term, both on farmer fields (e.g. Félix et al. 2015) and on experimental station (e.g. Barthès et al. 2014), these preliminary results show promise, as boosting crop biomass production (including roots) is the first step towards higher soil fertility regimes in cropping systems. This experience could be an incentive for collective shrub densification options to support crop productivity through woody biomass applications, especially in contexts of continued cultivation without fallows.

### 1.3.4 Restoration of Exhausted, Degraded Soils

After the Ethiopian drought and famine of the 1980s, various land rehabilitation techniques were implemented in the country (Hurni 1988). These included ‘grazing exclosures’ i.e. the exclusion of livestock from highly degraded common rangelands in order to rehabilitate them (Mengistu et al. 2005). Communities still had access to fuel and fodder from grazing exclosures through controlled cut-and-carry. The positive impact of exclosures on soil conservation, soil fertility build up, watershed hydrology and biodiversity is well documented (Asefa et al. 2003; Mengistu et al. 2005; Descheemaeker et al. 2006; Mekuria and Veldkamp 2012; Corral-Nuñez et al. 2014), and has been also applied to farmland, with the aim of conserving soil and water and improving crop productivity (Nedessa et al. 2005). Households involved in this collective action maintain their livestock in a year-round stall-feeding. Baudron et al. (2015) evaluated the impact of 8 years of farmland exclosure in the Central Rift Valley of Ethiopia. 'Exclosed farms' (EF) and neighbouring 'open grazing farms' (OF) had significantly different feed and fuel use strategies. Compared to OF livestock, EF livestock depended less on cereal residues and more on biomass from on-farm trees and grass from the communal rangeland. Similarly, EF depended less on cereal residues and cattle dung for fuel and more on tree biomass (both from the farm and from the communal land). Because of these different patterns of feed and fuel use, more biomass – in the form of crop residue, manure and compost – was available as soil amendment. This translated into significantly more fertile soils (soil organic matter content in the topsoil of 2.7 ± 0.9 % vs. 1.5 ± 1.1 %) and significantly higher tef yields in EF as compared to OF (2200 ± 715 vs. 1303 ± 483 kg $ha^{-1}$). However, farmland exclosures may only be feasible in particular geographic locations. They will be difficult to implement in densely populated regions with a large proportion of the land allocated to crops, where the basic infrastructure such as physical barriers preventing outside livestock to access the area is not present, or where local institutions prevent any form of 'privatisation' of biomass resources (e.g. Andrieu et al. 2015). Other options to restore degraded soils are need in such places.

Southern Africa is largely a food deficit zone due to poor inherent soil fertility of granite-derived soils that predominate in many parts of the region (Mapfumo and Giller 2001; Nyikahadzoi et al. 2012). The soils typically contain about 10 % clay and over 80 % coarse sand, and are inherently deficient in N, P and S. Yet, these soils are home to >65 % of the Zimbabwean population who derive their livelihoods from maize-based smallholder farming systems. While the main source of livelihood is integrated crop and livestock farming, yields of staple crops average 0.8 t $ha^{-1}$, and complete crop failure primarily due to lack of external nutrient inputs is common in what has been described as a 'no fertilizer no crop' scenario (Mapfumo et al. 2001). Maize monocropping and associated agronomic packages typically derived from conventional (industrial) agriculture have resulted in abandonment of large tracts of degraded lands due to degradation and loss of economic returns to the limited external nutrient inputs that farmers can afford and to their family or hired labour. This has led to increased food deficits and agricultural expansion into marginal/fragile areas traditionally reserved for either livestock grazing or wildlife. The region therefore faces two main challenges to the growing calls for intensification: (i) restoring productivity of these abandoned field soils, and (ii) developing mechanisms to increase productivity on these lands and limit encroachment into natural resource areas that provide diverse ecosystems services underpinning socio-ecological resilience at community scale.

Current cropping practices have resulted not only in multiple plant nutrient deficiencies (Masvaya et al. 2013; Manzeke et al. 2012; 2014), but also in critically poor fertilizer responses. This has strong implications on major investments made by governments, NGOs and other development partners in fertilizer supply schemes including subsidy programs. In response to this problem, researchers from University of Zimbabwe and its partners under the Soil Fertility Consortium for Southern Africa (SOFECSA) introduced the concept of indigenous legume fallows to generate much needed high quality biomass to stimulate biological activity and subsequently productivity of these abandoned soils (Mapfumo et al. 2005; Nezomba et al. 2010). Indigenous herbaceous legumes growing naturally under different agro-ecologies were identified through participatory approaches. Farmers in contrasting agroecological contexts were able to distinguish the legumes, which are often viewed simply as 'weeds' and are generally unpalatable to livestock. Criteria for field identification and seed collection were developed jointly with communities, opening opportunities for field testing the population dynamics and growth performance of the legumes when sown in mixtures in farmers' fields. This provided a new dimension of improved fallows: the Indifallow.

Successful stands were better established by mixing species of prostrate growth habit such as *Crotalaria pisicarpa*, *Indigofera demissa*, *I. praticola* and *Tephrosia radicans* and erect types such as *Crotalaria ochroleuca*, *C. laburnifolia* and *C. cylindrostachys*. Major costs for establishing these self- regenerating and nitrogen-fixing legumes were largely labour for initial seed acquisition and sowing. The studies identified the following as key criteria for selection of candidate species as Indifallows:

(i) A long-lived seed bank
(ii) Rapid establishment and growth
(iii) Adaptation to poor soils with limited availability of phosphorus
(iv) High $N_2$-fixing potential and shoot N concentrations under local conditions
(v) Abundant seeding to allow ready propagation and seed collection to reinforce populations
(vi) Easy to remove should weeding be required

The legumes that best fit these characteristics are largely annuals, biennials or short-lived perennials (Mapfumo et al. 2005). Persistence of these legumes under farming systems dominated by crop–livestock interactions in Zimbabwe suggests that they are either not palatable to livestock and therefore survive grazing or are adapted to grazing.

A unique characteristic of the indifallows has been their capacity to accumulate biomass yields exceeding 6 t $ha^{-1}$ on soils with very low levels of phosphorus, and their response to mineral P fertilization, giving biomass yields exceeding 10 t $ha^{-1}$ (Nezomba et al. 2010). The indifallows therefore accumulate high amounts of N-rich biomass on soils that otherwise fail to sustain productivity of common crops. Maize grown after the indifallow yielded significantly higher than that grown under either natural fallow or continuous, fertilized maize (Fig. 1.5d). When used in the context of integrated soil fertility management (ISFM), indifallows proved an appropriate entry point for kick-starting the productivity of soils abandoned by farmers for their loss of productivity. The indifallows increased soil biological activity and favoured growth of subsequent maize crops in rotation, particularly when aided with P fertilizer (Nezomba et al. 2015). Indifallows now hold potential as a local ecological approach upon which traditional ISFM options can build upon to restore productivity of degraded and so called non-responsive agricultural soils increasingly abandoned by farmers (e.g. Rusinamhodzi et al. 2013; Nezomba et al. 2015).

## 1.4 How to Foster Innovations, and How to Anchor Change

The various examples described in the previous section illustrate a diversity of ecological intensification pathways, from individual actions of farmers at field or farm level, to community efforts at landscape and territory scale. In the first example on ecologically intensive disease management in potato production, the actual implementation of the proposed genetic diversification by farmers will require addressing a range of challenges. From an agronomic perspective, the question is which cultivars can be combined synergistically e.g. in terms of nutrient uptake, or at least without major competition effects. But also both upstream and downstream value chain partners will need to accept changes from the usual practice of single cultivars. Upstream, seed companies will need to breed with mixtures of their own and other companies' cultivars in mind, and adjust their relations with growers to allow them to source the best mixtures. Downstream, retail will need to resolve the question of selling mixtures or separating cultivars after harvest. Adjustments in harvesting machinery will be needed to arrive at planting patterns that balance the need for diversity with the need for technical simplicity. To benefit from diversification at landscape scale, regional adjustments among farmers[2] and their seed companies need to be made. This indicates that the complexity inherent to ecologically intensive management, which is also knowledge intensive, calls for innovative approaches to support such transitions and anchor positive changes through strong links between the ecological and social sub-systems (Olsson et al. 2014; Foran et al. 2014).

### *1.4.1 Ecological Intensification Transitions through the Perspective of Niches, Regimes and Landscapes*

To understand the challenges that a transition to ecological intensification faces, insights can be mobilized from innovation studies on how established worldviews, paradigms and sunk investments in physical and market infrastructure create path dependencies and keep food production systems in both developed and developing countries 'locked-in' (Elzen et al. 2012a; Horlings and Marsden 2011; Pant 2014; Vanloqueren and Baret 2009). Several related approaches to study such complex innovation processes co-exist and are complementary (such as socio-ecological systems thinking, innovation systems approach, political ecology – Foran et al. 2014; Olsson et al. 2014). Insights from these approaches have informed the strand of so-called system innovation or transition studies which conceptualize current food systems as a 'socio-technical regime' (Fig. 1.6a), a set of dominant technologies,

---

[2] While this proposition raises eyebrows in the potato sector, regional coordination among Dutch farmers on mowing regimes of grasslands for bird protection has proven to be possible and fruitful (Schekkerman et al. 2008).

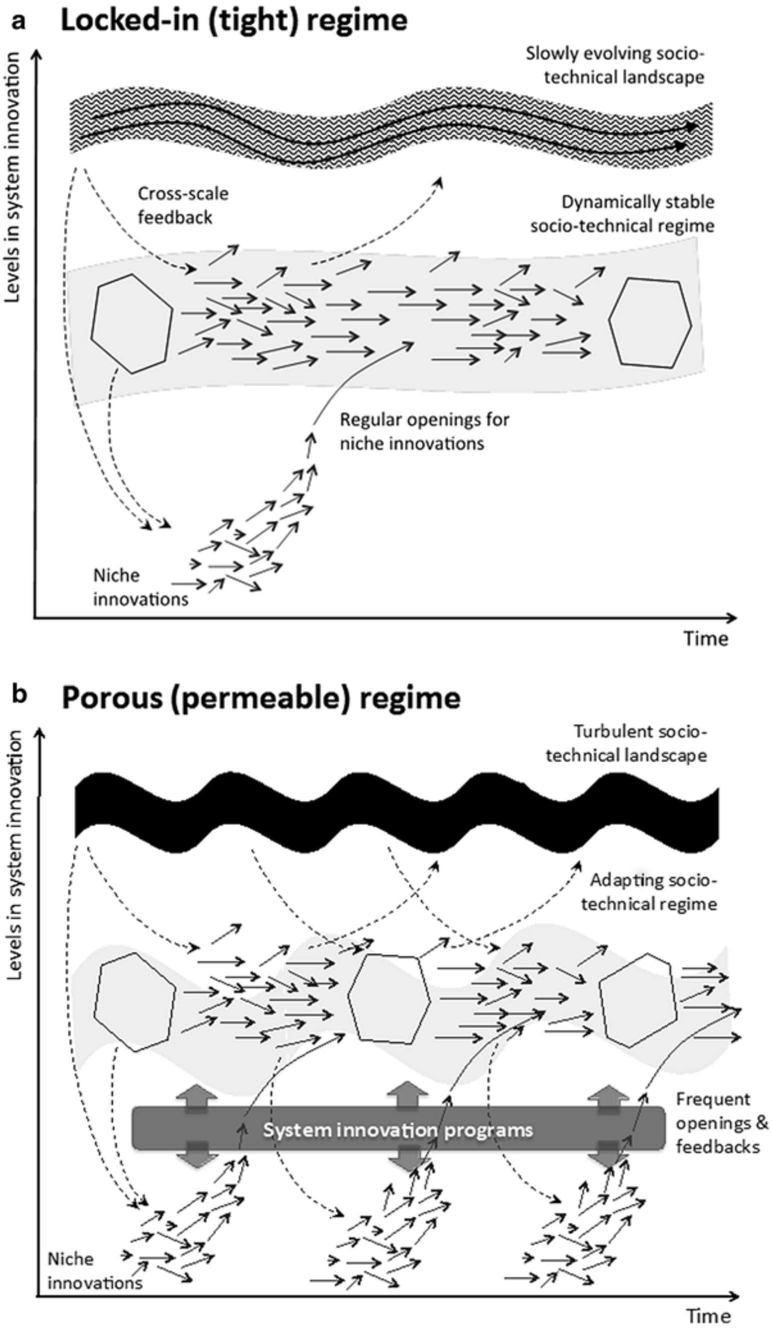

**Fig. 1.6** Graphical representation of socio-technical landscapes, regimes and niche innovations, inspired on the diagram of Geels and Schot (2007). (**a**) Stable landscapes that lock-in niche innovations; (**b**) turbulent regimes that open up opportunities under landscape pressures, indicating the place of programs to support system innovation by facilitating niche experimentation and anchoring

practices and organizational and institutional arrangements (Fünfschilling and Truffer 2013; Holtz et al. 2008; Hounkonnou et al. 2012) within production systems, value chains and agricultural innovation systems (understood here as the 'support structures' for innovation – Klerkx et al. 2012).

In this model, deviant ways of practicing agriculture take place in so-called niches, where novelties are developed competing with the existing socio-technical regime while trying to grow in importance (Roep et al. 2003; Wiskerke and van der Ploeg 2004). While originally it was thought that such niches would 'overthrow' the socio-technical regime, later studies indicate that niche activity spurs changes in the regime, i.e. the regime starts to change from within (Geels and Schot 2007). For example, organic agriculture started as a niche, but has now become more prominent and has hence influenced certain parts of the socio-technical regime in its favour (Smith 2007), and was partly absorbed by this socio-technical regime as it has become conventionalized in some cases (Darnhofer et al. 2010). Development of niches and changes in socio-technical regimes are influenced by a broader socio-technical "landscape", which represents broader developments in natural and socio-economic systems that may provide triggers for change (e.g. climate change, economic crises, environmental pollution, etc.).

Often niches start as a response to dissatisfaction with current regime practices, and self-organize to start realizing alternatives (Elzen et al. 2012a; Fressoli et al. 2014; Roep et al. 2003; Smith and Seyfang 2013), but they can also be stimulated through dedicated support policies (Elzen et al. 2012a; Geels et al. 2008). Within the ecological intensification movements (i.e., agroecology, organic farming, permaculture, etc.), much grassroots activity or 'bottom-up' innovation by pioneers can be witnessed (Kirwan et al. 2013; Sage 2014), focused on 'anchoring' ecological intensification. As has become clear from some of the examples in the previous section, this goes beyond working on improved farming systems, but is also about creating favourable input supply systems, value chains and policy environments (Roep et al. 2003; Klerkx et al. 2010; Blesh and Wolf 2014). Such anchoring consist of 'cognitive anchoring' (changing mindsets and capabilities for ecologically intensive production), 'network anchoring' (building support networks and changing existing production and market configurations) and 'institutional anchoring' (changing rules, regulation and standards unfavourable for ecological intensification) (Elzen et al. 2012b).

A main question is how to accelerate and support such grassroots innovation activity with a view to anchoring ecological intensification niches, i.e. what are the roles of government policies and science in this transition (i.e. top-down innovation support to complement bottom-up actions by pioneers or champions) (Brussaard et al. 2010; Caron et al. 2014; Duru et al. 2014). As Westley et al. (2011) argue, a combination between bottom up activity and top down action is most effective, what Elzen et al. (2012a) call 'dual track governance' in which a co-innovation approach involving collaborative work and learning between different stakeholders is advocated (Dogliotti et al. 2014; Klerkx and Nettle 2013). However, government policies and science agendas are often part of the socio-technical regime (Sumberg et al. 2012; Thompson and Scoones 2009; Vanloqueren and Baret 2009; Foran et al.

2014) and do not accommodate paradigms on ecological intensification and support of niches. This requires that government policies acknowledge diversity in development directions for the agricultural sector (Scoones and Thompson 2009; Brooks and Loevinsohn 2011). Here lays an important role for grassroots movements in influencing the political agendas (Fressoli et al. 2014).

### *1.4.2 Linking Top-Down and Bottom-Up Approaches*

As regards concrete instruments and interventions to support and govern transition towards enhancing the anchoring of ecological intensification, focusing both on bottom-up grassroots activities, top-down action, there are several promising examples:

1. Grassroots learning and experimentation at the level of farming systems can be a fruitful way of expanding principles of ecological intensification among farmers. Co-learning approaches enhance scope and capacity of farmers to understand, adapt and apply principles, and use of Learning Centres in Southern Africa is a notable example (Mapfumo et al. 2013). Farmer-driven research (Waters-Bayer et al. 2009) and farmer field schools (Friis-Hansen and Duveskog 2011) were also found to deliver contextually embedded farming systems. A risk however is that farmer field schools can be captured to serve other people's purposes and lose their farmer-driven and experimental character (Sherwood et al. 2012). Farmer-driven experimentation can also become isolated from larger regime and landscape developments if not properly connected (Elzen et al. 2012a), so that broader anchoring can be inadequate. Also, formal scientific knowledge may be under-utilized while it can help in re-designing and prototyping farming systems and help legitimizing the claims made about the benefits of ecological intensification (Bos et al. 2009; Caron et al. 2014; Lamine 2011).
2. To overcome some of the weaknesses of a purely bottom-up approach and enable broader anchoring, so-called 'hybrid forums' are needed, where niche and regime players negotiate change (Elzen et al. 2012b). This resonates with the increasingly popular concept of innovation platforms, where multiple stakeholders coordinate amongst themselves for co-innovation and enhance co-evolution between technical, social and institutional innovations to ensure effective anchoring at different levels in agricultural systems (e.g. farming system, value chain, policy environment, science system) by means of, for example, reformulating research agendas, and changing regulations and value chain standards (Duru et al. 2014; Kilelu et al. 2013; Pant 2014). While these platforms generally promote inclusiveness of stakeholders and co-innovation (Kilelu et al. 2013; Swaans et al. 2014), they are not without caveats as they are the scene of power imbalances and political struggle (Cullen et al 2014). This may lead to regime players stalling advancements of platforms to protect vested interests, and platforms being used to push externally imposed objectives and ignore local dynamics

(Cullen et al. 2014; Kilelu et al. 2013). This points to the need for adequate facilitation and monitoring, and for working with dedicated 'innovation champions' (Kilelu et al. 2013; Klerkx et al. 2010, 2013) or what have been called 'institutional entrepreneurs' (Van Paassen et al. 2014; Westley et al. 2013; Farla et al. 2012) who can make linkages between different levels and scales in systems (Klerkx et al. 2010; Olsson et al 2014).

3. While platforms generally are useful for enhancing co-evolution and may bring about conditions for broader scaling of practices towards ecological intensification (Millar and Connell 2009), they are also cost intensive. The high cost of innovation platforms implies that permanent innovation support systems such as agricultural research, extension and advisory services must support the learning needed for transitions at the farming system level via regular contacts with farmers. This requires a joint learning process between farmers, researchers and advisors, through an intensive relationship. As many countries nowadays have (semi) privatized research and extension systems with different type of providers, it is essential that these systems are orchestrated and supported to build capacities to support learning on ecological intensification (Chantre and Cardona 2013; Klerkx and Jansen 2010).

In summary, to stimulate transitions towards ecological intensification by stimulating niche activity, and make the link with regime activities, with an awareness of changing landscape factors, simultaneous work is needed at different levels combining bottom up and top-down action (Elzen et al. 2012; Westley et al. 2011; Olsson et al 2014), both oriented towards present ecological intensification efforts and desired future systems. For example, in the case of small-scale beef production in Uruguay, the position of farms in value chains should be considered along with the necessary support of farmer organisations to implement ecologically intensive management. While most of the current family farms in Uruguay produce for a bulk market, purposefully designed ecological intensification strategies may also help in (i) accessing market niches that fetch higher prices when consumers are aware of the multiple functions of natural grassland-based production systems, or (ii) accessing more competitive private credit when greater resilience of the ecologically intensive systems can be demonstrated. Earlier approaches with integrated 'system innovation programmes' fostering innovation networks and innovation platforms have shown these can be vehicles to connect grassroots activities with top down formal support, balancing farming system level work with reconfiguration of policy systems, science and advisory systems, and value chains (Elzen et al. 2012a; Fischer et al. 2012; Veldkamp et al. 2009; Wijnands and Vogelezang 2009) (see Fig. 1.6b). Such programmes can also foster learning amongst champions or institutional entrepreneurs in different projects in ecological intensification niches to support technological innovations and create joint capacity for lobbying for institutional change.

## 1.5 Outlook

We illustrated the potential of local ecological intensification strategies with detailed evidence from a number of examples that span contrasting agricultural systems and contexts around the world. An example from a high input agricultural system such as potato production in The Netherlands illustrated that even in the most industrialised systems in the world it is still possible to intensify agriculture ecologically. An example from beef production in the Pampas native grasslands of South America showed how livestock production is not necessarily always unsustainable or detrimental for the environment. Examples of integration between crops and shrub perennials in semi-arid Burkina Faso showed how native woody biomass could support the restoration of soil productive capacity and enhance yields within one year in farmers' fields. The analysis of agricultural production systems that reproduce the ecological structure of the native savannah in the Ethiopian highlands showed that biodiversity should not only be seen as a 'service' from farming landscapes but rather as the basis for their functioning. In Zimbabwe, on some of the world's most challenging sandy soils known for their low inherent P and N levels, naturally occurring herbaceous legumes grow to kick-start soil productivity in fields abandoned by smallholder farmers due to poor soil fertility, leading to staple maize yields beyond attainable average on smallholder farms.

These examples on ecological intensification of crop and livestock systems are not isolated or anecdotal, and they are certainly not the only ones in which biodiversity supports efficiency in agriculture. We chose these examples to embrace cultural, economic, and geographical diversity, and to illustrate that strategies for ecological intensification differ in complexity, contexts and scales. Due to inherent biases in current research and development paradigms towards industrial forms of agriculture as the convention, these localized "islands of success" are often circumscribed – widening the knowledge gap that separates local meanings of food systems from 'idealistic' forms of industrial agriculture as an approach to feeding the world. The increasing emphasis on research and development approaches hinged on co-learning, participatory, and innovation platforms has yielded much needed insights on the value of 'hybridizing' bottom-up and top-down approaches, connecting local experimentation with formal innovation systems. To enhance the transition to ecological intensification, this does, however, require that agricultural innovation systems of the different countries should recognize and foster *diversity*, and enable experimentation in the niches of ecological intensification. For this purpose, dedicated 'system innovation programmes' which build on the experience of pioneers and innovation champions and strengthen these with formal support (scientific support, facilitation of innovation platforms and farmer learning networks) could be an option. Since the niches of ecological intensification are not just confined to single countries and their agricultural innovation systems, transnational learning and action is key in this process (Coenen et al. 2012; Diaz Anadon et al. 2014).

### 1.5.1 *More with Less?*

In the most productive and industrialised areas of the world the concept of 'more with less' is certainly engaging but rather utopic, as these agricultural systems operate mostly beyond their physical and economic efficiencies already (cf. Fig. 1.2). It is hard to get 'more' form these systems and this should not be a priority from a global food security perspective, as such production does not contribute to alleviate hunger in the poorest regions of the world (cf. Fig. 1.1). The greatest contribution to humanity from the most productive and industrialised areas of the world would be to maintain current productivity using less inputs of non-renewable resources and reducing their huge environmental impact; in other words, producing "the same with less". In the most unfavourable regions of the world, where agricultural productivity is poor as the result of interacting biophysical, socio-economic and political factors, the concept of "more with less" is also inappropriate. Investments are needed in production resources, infrastructure, education and knowledge to foster agricultural productivity in a sustainable manner. This requires both technological and institutional innovation (Tittonell 2014), and supportive policies to make investments possible (e.g., consolidation of land rights). In these regions, we should probably speak of "more with more" or "more with the same". Agriculture alone cannot solve poverty in the least favoured regions of the world, but it can contribute to alleviate the cruel reality of thousands of rural families.

### 1.5.2 *Livestock as Part of the Solution*

Livestock is increasingly perceived as a global environmental threat, for example because of its implication to climate change (Steinfeld et al. 2006). At local-level, livestock grazing is also recognized as a driver of land degradation (Lal 1988). Heavy grazing may lead to soil compaction, soil erosion, riverbank erosion, and shifts in vegetation such as woody plant encroachment (Evans 1998; Sharp and Whittaker 2003). Heavy grazing is often the result of the increase in livestock number in parallel with a gradual conversion of rangelands into croplands, fuelled by demographic pressure. Excluding livestock from farmlands – and confining them into zero-grazing units – is often mentioned as a precondition to the implementation of sustainable land management options such as conservation agriculture or agroforestry (Franzel et al. 2004; Erenstein et al. 2008). In opposition to that view, we argue here that grazing is a fundamental ecological function that should be maintained in agroecosystems and integrated with crop production, particularly in low-input systems such as those of South America and sub-Saharan Africa.

Herbivores tend to by-pass the slow litter decomposition pathway, by returning to the soil labile organic materials rich in nutrients – such as urine and faeces – that stimulate soil microorganisms (McNaughton et al. 1997). In addition, certain plant species appear to respond positively to grazing, increasing their productivity through compensatory growth (Agrawal 2000), and increasing the nutrient concentration of their roots and foliage through nutrient reallocation (Hiernaux and Turner 1996). The production of greater quantities of richer biomass generally has a positive effect on soil microorganisms and soil fertility. Moreover, grazing may increase root exudation by these plants, with a resulting stimulation of soil microorganisms (Hamilton and Frank 2001). By definition, forages are plant species that respond positively to grazing: it is likely that these mechanisms apply to most forage species (e.g. perennial ryegrass and clover, as demonstrated by Bardgett et al. 1998).

Integrating forages to existing cropping systems and grazing these fields during a pasture phase is thus likely to be beneficial for soil fertility. This is illustrated by the findings of Franzluebbers and Stuedemann (2009) showing that soil organic carbon and total soil nitrogen after grazing may be higher than after haying, and even higher than in a non-harvested control. Grazing fallow land between cropping sequences may also control pests and weeds (Hatfield et al. 2007a, b). Integrating pasture phases grazed by ruminants in farming systems dominated by crops may also increase profit and financial stability (Russelle et al. 2007). In addition, forages used in pastures are generally perennial plants that offer a permanent soil cover that controls erosion more efficiently, are characterized by a longer photosynthetic period resulting in a higher light use efficiency, and have a more developed and deeper root system that stores more carbon and captures more water and nutrients than annual crops (Glover et al. 2010). Pastures – as undisturbed land units with permanent vegetation cover – also play an important role in maintaining biodiversity within agricultural landscapes (Bretagnolle et al. 2011).

### *1.5.3 From Fields to Landscapes, from Individuals to Communities*

The landscape is the most relevant scale at which the various components of the agricultural system need to be integrated. This resonates with the idea already mentioned that biodiversity is not simply a "service" from agriculture. Current agro-environmental payments in the European Union, for example, are based on the principle of rewarding farmers for the maintenance of biodiversity. But biodiversity – planned or unplanned – is not acknowledged as a service provider to farming (e.g. natural predators, microclimate effect, etc.). Perhaps the greatest difference between the concepts of sustainable and ecological intensification resides here: in seeing biodiversity as a service in itself, or as the necessary ecological structure to support agricultural production. This echoes the land sharing/sparing debate (Baudron and Giller 2014). It is generally established that for biodiversity, land sparing may be more desirable than land sharing in several cases (Balmford et al. 2012), except for open-habitat species that may depend on farmland (such as

European farmland birds, Wright et al. 2012) or in cases where farmland is structurally very similar to the native vegetation and supports high biodiversity (e.g. tropical agro-forests; Clough et al. 2011). However, agricultural production systems may be more stable and less vulnerable with land sharing than with land sparing, because of stronger interactions between cultivated and uncultivated patches (denser networks in a landscape mosaic), and due to more gradual gradients between the two land uses (Loeuille et al. 2013). And, since most of the ecological functions necessary to sustain agriculture operate at the landscape rather than individual field or farm levels, ecological intensification requires collective rather than individual actions.

### *1.5.4 A Dialogue of Wisdoms*

Options for the ecological intensification of agriculture can be inspired by the type of interactions between structures and functions that can be observed in nature (e.g. Malézieux 2012), by the practical experience of local indigenous knowledge (e.g., Khumairoh et al. 2012), and by combining these with the latest scientific knowledge and technologies. Ecological intensification calls for a constant dialogue between the practical wisdom of farmers and our own scientific wisdom. Success in promoting integrated soil fertility management in Southern Africa that was described in Sect. 1.3.4 was achieved following the introduction of learning centres, which are interactive non-linear and field-based learning platforms bringing together farmer communities, researchers, extension and other development practitioners and service providers (e.g. Mapfumo et al. 2013). Their study proved that co-learning with communities could unlock innovations enabling them to harness resources within the bounds of their contexts to increase productivity and find pathways to achieving food and nutrition security. Ecological intensification not only has the potential to increase agricultural production, but also to support the development of capabilities and skills to manage biodiversity in complex systems, as the perceived extra labour provides jobs that are meaningful and empowering for local communities, and incentives to contribute, share, and evaluate observations and ideas for every participating farm member in all parts of the agroecosystem (Timmermann and Félix 2015). Thus, as the private sector will continue to invest in patentable technologies – understandably – to reinforce their position in the current socio-technical regime, the key role of the public sector should be to reinforce the diversity of approaches, prioritizing alternative rather than mainstream technologies, creating favorable ‘openings’ in established socio-technical regimes, and embracing the complexity and the associated transaction costs of system innovation programs or what could be called ‘co-innovation systems’. In other words, investing in the creation and support of new niches rather than supporting technological ‘solutions’ that are already embedded in current regimes.

## References

Agrawal AA (2000) Overcompensation of plants in response to herbivory and the by-product benefits of mutualism. Trends Plant Sci 5:309–313

Aguerre V, Albicette M, Ruggia A, Scarlato S (2015) Co-innovation of family farm systems: developing sustainable livestock production systems based on natural grasslands. In: 5th international symposium on farming systems design, Montpellier, 7–10 Sept 2015

Alliaume F, Rossing WAH, García M, Giller KE, Dogliotti S (2013) Changes in soil quality and plant available water capacity following systems re-design on commercial vegetable farms. Eur J Agron 46:10–19

Andrieu N, Vayssières J, Corbeels M, Blanchard M, Vall E, Tittonell P (2015) From synergies at farm scale to trade-offs at village scale: the use of cereal crop residues in an agro-pastoral system of the Sudanian zone of Burkina Faso. Agric Syst 134:84–96

Andrivon D, Lucas JM, Ellisseche D (2003) Development of natural late blight epidemics in pure and mixed plots of potato cultivars with different levels of partial resistance. Plant Pathol 52:586–594

Asefa DT, Oba G, Weladji RB, Colman JE (2003) An assessment of restoration of biodiversity in degraded high mountain grazing lands in northern Ethiopia. Land Degrad Dev 14:25–38

Balmford A, Green R, Phalan B (2012) What conservationists need to know about farming. Proc R Soc B Biol Sci 279:2714–2724, rspb20120515

Bardgett RD, Wardle DA, Yeates GW (1998) Linking above-ground and below-ground interactions: how plant responses to foliar herbivory influence soil organisms. Soil Biol Biochem 30:1867–1878

Barthès BG, Penche A, Hien E, Deleporte P, Clermont-Dauphin C, Cournac L, Manlay RJ (2014) Effect of ramial wood amendment on sorghum production and topsoil quality in a Sudano-Sahelian ecosystem (central Burkina Faso). Agrofor Syst 89(1):81–93

Baudron F, Giller KE (2014) Agriculture and nature: trouble and strife? Biol Conserv 170:232–245

Baudron F, Mamo A, Tirfessa D, Argaw M (2015) Impact of farmland exclosure on the productivity and sustainability of a mixed crop-livestock system in the Central Rift Valley of Ethiopia. Agric Ecosyst Environ 207:109–118. doi:10.1016/j.agee.2015.04.003

Blesh J, Wolf S (2014) Transitions to agroecological farming systems in the Mississippi River Basin: toward an integrated socioecological analysis. Agric Hum Values 31(4):621–635

Bommarco R, Kleijn D, Potts SG (2013) Ecological intensification: harnessing ecosystem services for food security. Trends Ecol Evol 28:230–238

Bonhommeau S, Dubroca L, Le Pape O, Barde J, Kaplan DM, Chassot E, Nieblas A-E (2013) Eating up the world's food web and the human trophic level. Proc Natl Acad Sci U S A 110(51):20617–20620

Bos AP, Groot Koerkamp PWG, Gosselink JMJ, Bokma S (2009) Reflexive interactive design and its application in a project on sustainable dairy husbandry systems. Outlook Agric 38:137–145

Bousset L, Chèvre A-M (2013) Stable epidemic control in crops based on evolutionary principles: adjusting the metapopulation concept to agro-ecosystems. Agric Ecosyst Environ 165:118–129

Bouws H, Finckh MR (2008) Effects of strip intercropping of potatoes with non-hosts on late blight severity and tuber yield in organic production. Plant Pathol 57:916–927

Bretagnolle V, Villers A, Denonfoux L, Cornulier T, Inchausti P, Badenhausser I (2011) Rapid recovery of a depleted population of Little Bustards Tetrax tetrax following provision of alfalfa through an agri-environment scheme. Ibis 153:4–13

Brooks S, Loevinsohn M (2011) Shaping agricultural innovation systems responsive to food insecurity and climate change. Nat Res Forum 35:185–200

Bruno JF, Stachowicz JJ, Bertness MD (2002) Inclusion of facilitation into ecological theory. Trends Ecol Evol 18:119–125

Brussaard L, Caron P, Campbell B, Lipper L, Mainka S, Rabbinge R, Babin D, Pulleman M (2010) Reconciling biodiversity conservation and food security: scientific challenges for a new agriculture. Curr Opin Environ Sustain 2:34–42

Burgess SSO, Adams MA, Turner NC, Ong CK (1998) The redistribution of soil water by tree root systems. Oecologia 115:306–311

Caron P, Biénabe E, Hainzelin E (2014) Making transition towards ecological intensification of agriculture a reality: the gaps in and the role of scientific knowledge. Curr Opin Environ Sustain 8:44–52

Carvalho PCF, Nabinger C, Lemaire G, Genro TC (2011) Challenges and opportunities for livestock production in natural pastures: the case of Brazilian Pampa Biome. In: Feldman S, Oliva GE, Sacido MB (eds) Proceedings of the IX international rangeland congress: diverse rangelands for a sustainable society, Rosario, Argentina. Fundación Argentina, Buenos Aires, pp 9–15

Cassidy ES, West PC, Gerber JS, Foley JA (2013) Redefining agricultural yields: from tonnes to people nourished per hectare. Environ Res Lett 8:034015. doi:10.1088/1748-9326/8/3/034015 (8pp)

Cassman KG (1999) Ecological intensification of cereal production systems: yield potential, soil quality, and precision agriculture. Proc Natl Acad Sci U S A 96:5952–5959

CBS (2014) Central Bureau of Statistics, http://statline.cbs.nl/StatWeb/publication/?DM=SLNL&PA=37995&D1=2-3&D2=2&D3=11,17,24&D4=a&VW=T. Accessed 22 Sept 2014

Chantre E, Cardona A (2013) Trajectories of French field crop farmers moving toward sustainable farming practices: change, learning, and links with the advisory services. Agroecol Sustain Food Syst 38:573–602

Clough Y, Barkmann J, Juhrbandt J, Kessler M, Wanger TC, Anshary A, Buchori D, Cicuzza D, Darras K, Dwi Putrak D, Erasmi S, Pitopang R, Schmidt C, Schulze CH, Seidel D, Steffan-Dewenter I, Stenchly K, Vidal S, Weist M, Christian Wielgoss A, Tscharntke T (2011) Combining high biodiversity with high yields in tropical agroforests. Proc Natl Acad Sci 108(20):8311–8316

Coenen L, Benneworth P, Truffer B (2012) Toward a spatial perspective on sustainability transitions. Res Policy 41:968–979

Corral-Nuñez G, Opazo-Salazar D, GebreSamuel G, Tittonell P, Gebretsadik A, Gebremeskel Y, Tesfay G, van Beek CL (2014) Soil organic matter in Northern Ethiopia, current level and predicted trend: a study case of two villages in Tigray. Soil Use Manag 30:487–495

Cullen B, Tucker J, Snyder K, Lema Z, Duncan A (2014) An analysis of power dynamics within innovation platforms for natural resource management. Innov Dev 4:259–275

Darnhofer I, Lindenthal T, Bartel-Kratochvil R, Zollitsch W (2010) Conventionalisation of organic farming practices: from structural criteria towards an assessment based on organic principles. A review. Agron Sustain Dev 30:67–81

Descheemaeker K, Nyssen J, Poesen J, Raes D, Haile M, Muys B, Deckers S (2006) Runoff on slopes with restoring vegetation: a case study from the Tigray highlands, Ethiopia. J Hydrol 331:219–241

Diack M, Sene M, Badiane AN, Diatta M, Dick RP (2000) Decomposition of a Native Shrub, Piliostigma reticulatum. Litter in soils of semiarid Senegal. Arid Soil Res Rehabil 14:205–218

Diaz Anadon L, Matus K, Moon S, Chan G, Harley A, Murthy S, Timmer V, Abdel Latif A, Araujo K, Booker K, Choi H, Dubrawski K, Friedlander L, Ingersoll C, Kempster E, Pereira L, Stephens J, Vinsel L, Clark W (2014) Innovation and access to technologies for sustainable development: diagnosing weaknesses and identifying interventions in the transnational arena. Sustainability Science Program working paper 2014–01. Sustainability Science Program and Belfer Center for Science and International Affairs, Kennedy School of Government, Harvard University, Cambridge, MA

Dogliotti S, García MC, Peluffo S, Dieste JP, Pedemonte AJ, Bacigalupe GF, Scarlato M, Alliaume F, Alvarez J, Chiappe M, Rossing WAH (2014) Co-innovation of family farm systems: a systems approach to sustainable agriculture. Agr Syst 126:76–86

Doré T, Makowski D, Malézieux E, Munier-Jolain N, Tchamitchian M, Tittonell P (2011) Facing up to the paradigm of ecological intensification in agronomy: revisiting methods, concepts and knowledge. Eur J Agron 34:197–210

Dossa EL, Diedhiou I, Khouma M, Sene M, Badiane AN, Ndiaye Samba SA, Assigbetse KB, Sall S, Lufafa A, Kizito F, Dick RP, Saxena J (2013) Crop productivity and nutrient dynamics in a shrub-based farming system of the Sahel. Agron J 105:1237

DuPont ST, Culman SW, Ferris H, Buckley DH, Glover JD (2010) No-tillage conversion of harvested perennial grassland to annual cropland reduces root biomass, decreases active carbon stocks, and impacts soil biota. Agric Ecosyst Environ 137:25–32

Duru M, Fares M, Therond O (2014) A conceptual framework for thinking now (and organising tomorrow) the agroecological transition at the level of the territory. Cah Agric 23:84–95

Elzen B, Barbier M, Cerf M, Grin J (2012a) Stimulating transitions towards sustainable farming systems. In: Darnhofer I, Gibbon D, Dedieu B (eds) Farming systems research into the 21st century: the new dynamic. Springer, Dordrecht, pp 431–455

Elzen B, van Mierlo B, Leeuwis C (2012b) Anchoring of innovations: assessing Dutch efforts to harvest energy from glasshouses. Environ Innov Soc Transit 5:1–18

Erenstein O, Sayre K, Wall P, Dixon J, Hellin J (2008) Adapting no-tillage agriculture to the conditions of smallholder maize and wheat farmers in the tropics and sub-tropics. In: Goddard T, Zoebisch M, Gan Y, Ellis W, Watson A, Sombatpanit S (eds) No-till farming systems. World Association of Soil and Water Conservation (WASWC), Bangkok, pp 253–278

Evans R (1998) The erosional impacts of grazing animals. Prog Phys Geogr 22:251–268

FAO (2012) Save and grow report. FAO, Rome

FAO (2014) FAO stats repository. FAO, Rome

Farla J, Markard J, Raven R, Coenen L (2012) Sustainability transitions in the making: a closer look at actors, strategies and resources. Technol Forecast Soc Chang 79:991–998

Félix GF, Douzet JM, Ouédraogo M, Belliard P, Lahmar R, Clermont-Dauphin C, Scholberg J, Tittonell P, Cournac L (2015). Ecosystem services for West African farming systems: the role of woody shrub mulch. Accepted in the 5th international symposium for farming systems design, Montpellier, 7–10 Sept 2015

Finckh MR, Hayer F, Schulte-Geldermann E, Bruns C (2008) Diversity, plant nutrition and prognosis: an integrated concept for late blight management in organic agriculture. Gesunde Pflanzen 60:159–170

Fischer ARH, Beers PJ, Latesteijn HV, Andeweg K, Jacobsen E, Mommaas H, Van Trijp HCM, Veldkamp A (2012) Transforum system innovation towards sustainable food. A review. Agron Sustain Dev 32:595–608

Fonte SJ, Vanek SJ, Oyarzun P, Parsa S, Quintero DC, Rao IM, Lavelle P (2012) Pathways to agroecological intensification of soil fertility management by smallholder farmers in the Andean highlands. Adv Agron 116:125–184

Foran T, Butler JRA, Williams LJ, Wanjura WJ, Hall A, Carter L, Carberry PS (2014) Taking complexity in food systems seriously: an interdisciplinary analysis. World Dev 61:85–101

Franzel S, Denning GL, Lilles JPB, Mercado AR Jr (2004) Scaling up the impact of agroforestry: lessons from three sites in Africa and Asia. In New Vistas in agroforestry. Springer, Dordrecht, pp 329–344

Franzluebbers AJ, Stuedemann JA (2009) Soil-profile organic carbon and total nitrogen during 12 years of pasture management in the Southern Piedmont USA. Agric Ecosyst Environ 129:28–36

Freebairn DK (1995) Did the green revolution concentrate incomes? A quantitative study of research reports. World Dev 23:265–279

Fressoli M, Arond E, Abrol D, Smith A, Ely A, Dias R (2014) When grassroots innovation movements encounter mainstream institutions: implications for models of inclusive innovation. Innov Dev 4:277–292

Friis-Hansen E, Duveskog D (2011) The empowerment route to well-being: an analysis of farmer field schools in East Africa. World Dev 40:414–427

Fünfschilling L, Truffer B (2013) The structuration of socio-technical regimes-conceptual foundations from institutional theory. Res Policy 43:772–791

Geels FW, Schot J (2007) Typology of sociotechnical transition pathways. Res Policy 36:399–417

Geels FW, Hekkert MP, Jacobsson S (2008) The dynamics of sustainable innovation journeys. Tech Anal Strat Manag 20:521–536

Geiger F, Bengtsson J, Berendse F, Weisser WW, Emmerson M, Morales MB, Ceryngier P, Liira J, Tscharntke T, Winqvist C et al (2010) Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. Basic Appl Ecol 11:97–105

Glover JD, Reganold JP, Bell LW, Borevitz J, Brummer EC, Buckler ES, Cox CM, Cox TS, Crews TE, Culman SW, DeHaan LR, Eriksson D, Gill BS, Holland J, Hu F, Hulke BS, Ibrahim AMH, Jackson W, Jones SS, Murray SC, Paterson AH, Ploschuk E, Sacks EJ, Snapp S, Tao D, Van Tassel DL, Wade LJ, Wyse DL, Xu Y (2010) Increased food and ecosystem security via perennial grains. Science 328:1638–1639

Godfray HCJ, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, Pretty J, Robinson S, Thomas SM, Toulmin C (2010) Food security: the challenge of feeding 9 billion people. Science 327:812–818

Haas BJ, Kamou S, Zody MC, Jiang RHY, Handsaker RE et al (2009) Genome sequence and analysis of the Irish potato famine pathogen Phytophthora infestans. Nature 461:393–398

Hadgu KM, Kooistra L, Rossing WAH, Van Bruggen AHC (2009) Assessing the effect of Faidherbia albida based land use systems on barley yield at field and regional scale in the highlands of Tigray, Northern Ethiopia. Food Secur 1:337–350

Hamilton EW, Frank DA (2001) Can plant stimulate soil microbes and their own nutrient supply? Evidence from a grazing tolerant grass. Ecology 82:2397–2402

Hatfield PG, Lenssen AW, Spezzano TM, Blodgett SL, Goosey HB, Kott RW, Marlow CB (2007a) Incorporating sheep into dryland grain production systems I. Impact on over-wintering larva populations of wheat stem sawfly, Cephus cinctus Norton (Hymenoptera: Cephidae). Small Rumin Res 67:09–215

Hatfield PG, Lenssen AW, Spezzano TM, Blodgett SL, Goosey HB, Kott RW, Marlow CB (2007b) Incorporating sheep into dryland grain production systems II. Impact on changes in biomass and weed density. Small Rumin Res 67:216–221

Haverkort AJ, Boonekamp PM, Hutten R, Jacobsen E, Lotz LAP, Kessel GJT, Visser RGF, van der Vossen EAG (2008) Societal costs of late blight in potato and prospects of durable resistance through cisgenic modification. Potato Res 51:47–57

Hiernaux P, Turner MD (1996) The effect of clipping on growth and nutrient uptake of Sahelian annual rangelands. J Appl Ecol 33:387–399

Holtz G, Brugnach M, Pahl-Wostl C (2008) Specifying “regime” – a framework for defining and describing regimes in transition research. Tech Forecast Soc Chang 75:623–643

Horlings LG, Marsden TK (2011) Towards the real green revolution? Exploring the conceptual dimensions of a new ecological modernisation of agriculture that could ‘feed the world’. Glob Environ Chang 21:441–452

Hounkonnou D, Kossou D, Kuyper TW, Leeuwis C, Nederlof ES, Röling N, Sakyi-Dawson O, Traoré M, Van Huis A (2012) An innovation systems approach to institutional change: smallholder development in West Africa. Agr Syst 108:74–83

Huang J, Pray C, Rozelle S (2002) Enhancing the crops to feed the poor. Nature 418:678–684

Hurni H (1988) Degradation and conservation of the resources in the Ethiopian highlands. Mt Res Dev 8:123–130

IAASTD (2009) International assessment of agricultural knowledge, science and technology for development: synthesis report with executive summary: a synthesis of the global and subglobal IAASTD reports. In: Beverly D. McIntyre, et al. Island Press, Washington, DC

Khumairoh U, Groot JCJ, Lantinga EA (2012) Complex agro-ecosystems for food security in a changing climate. Ecol Evol 2(7):1696–1704. doi:10.1002/ece3.271

Kilelu CW, Klerkx L, Leeuwis C (2013) Unravelling the role of innovation platforms in supporting co-evolution of innovation: contributions and tensions in a smallholder dairy development programme. Agr Syst 118:65–77

Kirwan J, Ilbery B, Maye D, Carey J (2013) Grassroots social innovations and food localisation: an investigation of the local food programme in England. Glob Environ Chang 23:830–837

Kizito F, Dragila MI, Senè M, Brooks JR, Meinzer FC, Diedhiou I, Diouf M, Lufafa A, Dick RP, Selker J, Cuenca R (2012) Hydraulic redistribution by two semi-arid shrub species: implications for Sahelian agro-ecosystems. J Arid Environ 83:69–77

Klerkx L, Jansen J (2010) Building knowledge systems for sustainable agriculture: supporting private advisors to adequately address sustainable farm management in regular service contacts. Int J Agric Sustain 8:148–163

Klerkx L, Nettle R (2013) Achievements and challenges of innovation co-production support initiatives in the Australian and Dutch dairy sectors: a comparative study. Food Policy 40:74–89

Klerkx L, Aarts N, Leeuwis C (2010) Adaptive management in agricultural innovation systems: the interactions between innovation networks and their environment. Agr Syst 103:390–400

Klerkx L, Mierlo B, Leeuwis C (2012) Evolution of systems approaches to agricultural innovation: concepts, analysis and interventions. In: Darnhofer I, Gibbon D, Dedieu B (eds) Farming systems research into the 21st century: the new dynamic. Springer, Dordrecht, pp 457–483

Klerkx L, Adjei-Nsiah S, Adu-Acheampong R, Saïdou A, Zannou ET, Soumano L, Sakyi-Dawson O, Van Paassen A, Nederlof S (2013) Looking at agricultural innovation platforms through an innovation champion lens. An analysis of three cases in West Africa. Outlook Agric 42:185–192

Koning NBJ (2013) The evolution of farm policies: a long-term global perspective. In: Moser P, Varley T (eds) Integration through subordination; the politics of agricultural modernisation in industrial Europe. Brepols, Turnhout, pp 41–63 (Rural History in Europe 8). ISBN 9782503545295

Kremen C, Miles A (2012) Ecosystem services in biologically diversified versus conventional farming systems: benefits, externalities, and trade-offs. Ecol Soc 17:40

Lahmar R, Bationo BA, Dan Lamso N, Guéro Y, Tittonell P (2012) Tailoring conservation agriculture technologies to West Africa semi-arid zones: building on traditional local practices for soil restoration. Field Crop Res 132:158–167

Lal R (1988) Soil degradation and the future of agriculture in sub-Saharan Africa. J Soil Water Conserv 43:444–451

Lambin EF, Meyfroidt P (2011) Global land use change, economic globalization, and the looming land scarcity. Proc Natl Acad Sci USA 108:3465–3472

Lamine C (2011) Transition pathways towards a robust ecologization of agriculture and the need for system redesign. Cases from organic farming and IPM. J Rural Stud 27:209–219

Lin BB (2011) Resilience in agriculture through crop diversification: adaptive management for environmental change. Bioscience 61:183–193

Loeuille N, Barot S, Georgelin E, Kylafis G, Lavigne C (2013) Eco-evolutionary dynamics of agricultural networks: implications for sustainable management. Ecol Netw Agric World 49:339–435

Malézieux E (2012) Designing cropping systems from nature. Agron Sustain Dev 32:15–29

Manzeke GM, Mapfumo P, Mtambanengwe F, Chikowo R, Tendayi T, Cakmak I (2012) Soil fertility management effects on maize productivity and grain zinc content in smallholder farming systems of Zimbabwe. Plant and Soil 361:57–69

Manzeke GM, Mtambanengwe F, Nezomba H, Mapfumo P (2014) Zinc fertilization influence on maize productivity and grain nutritional quality under integrated soil fertility management in Zimbabwe. Field Crops Res 166:128–136. doi:10.1016/j.fcr.2014.05.019

Mapfumo P, Giller KE (2001) Soil fertility management strategies and practices by smallholder farmers in semi-arid areas of Zimbabwe. P.O. Box 776: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) with permission from the Food and Agriculture Organization of the United Nations (FAO), Bulawayo, p 60

Mapfumo P, Campbell BM, Mpepereki S, Mafongoya P (2001) Legumes in soil fertility management: the case of pigeonpea in smallholder farming systems of Zimbabwe. Afr Crop Sci J 9:629–644

Mapfumo P, Mtambanengwe F, Giller KE, Mpepereki S (2005) Tapping indigenous herbaceous legumes forsoil fertility management by resource-poor farmer in Zimbabwe. Agric Ecosyst Environ 109:221–233

Mapfumo P, Adjei-Nsiah S, Mtambanengwe F, Chikowo R, Giller KE (2013) Participatory action research (PAR) as an entry point for supporting climate change adaptation by smallholder farmers in Africa. Environ Dev 5:6–22

Maredia M, Pingali P (2001) Environmental impacts of productivity- enhancing crop research: a critical review. CGIAR Technical Advisory Committee, Standing Panel on Impact Assessment (SPIA). FAO, Rome, p 35

Marengo JA, Liebmann B, Grimm AM, Misra V, Silva Dias PL, Cavalcanti IFA et al (2012) Recent developments on the South American monsoon system. Int J Climatol 32:1–21

Mariyono J (2014) Rice production in Indonesia: policy and performance. Asia Pac J Public Adm 36(2):123–134. doi:10.1080/23276665.2014.911489

Masvaya EN, Nyamangara J, Nyawasha RW, Zingore S, Delve RJ, Giller KE (2010) Effect of farmer management strategies on spatial variability of soil fertility and crop nutrient uptake in contrasting agro-ecological zones in Zimbabwe. Nutr Cycl Agroecosyst 88:111–120

Matson PA, Parton WJ, Power AG, Swift MJ (1997) Agricultural intensification and ecosystem properties. Science 277:504–509

McNaughton SJ, Banyikwa FF, McNaughton MM (1997) Promotion of the cycling of diet-enhancing nutrients by African grazers. Science 278:1798–1800

Mekuria W, Veldkamp E (2012) Restoration of native vegetation following exclosure establishment on communal grazing lands in Tigray, Ethiopia. Appl Veg Sci 15:71–83

Mengistu T, Teketay D, Hulten H, Yemshaw Y (2005) The role of enclosures in the recovery of woody vegetation in degraded dryland hillsides of central and northern Ethiopia. J Arid Environ 60:259–281

Millar J, Connell J (2009) Strategies for scaling out impacts from agricultural systems change: the case of forages and livestock production in Laos. Agric Hum Values 27:213–225

Nabinger C, de Moraes A, Maraschin GE (2000) Campos in Southern Brazil. In: Lemaire G, Hodgson J, de Moraes A, Nabinger C, de F Carvalho PC (eds) Grassland ecophysiology and grazing ecology. CAB International, Wallingford, pp 355–376

Nedessa B, Ali J, Nyborg I (2005) Exploring ecological and socio-economic issues for the improvement of area enclosure management: a case study from Ethiopia. DCG Report No. 38. DCG, Oslo, 55 p

Nezomba H, Tauro TP, Mtambanengwe F, Mapfumo P (2010) Indigenous legume fallows (indifallows) as an alternative soil fertility resource in smallholder maize cropping systems. Field Crop Res 115:149–157

Nezomba H, Mtambanengwe F, Tittonell P, Mapfumo P (2015) Point of no return? Rehabilitating degraded soils for increased crop productivity on smallholder farms in eastern Zimbabwe. Geoderma 239–240:143–155

Nyikahadzoi K, Siziba S, Mango N, Mapfumo P, Adekunhle A, Fatunbi O (2012) Creating food self reliance among the smallholder farmers of eastern Zimbabwe: exploring the role of integrated agricultural research for development. Food Secur 4:647–656

Olsson P, Galaz V, Boonstra WJ (2014) Sustainability transformations: a resilience perspective. Ecol Soc 19:1

Ong CK, Black CR, Wallace JS, Khan AAH, Lott JE, Jackson NA, Howard SB, Smith DM (2000) Productivity, microclimate and water use in Grevillea robusta-based agroforestry systems on hillslopes in semi-arid Kenya. Agric Ecosyst Environ 80:121–141

Ouédraogo ZM (2014)(unpublished) Effets de la couverture du sol à base de Piliostigma reticulatum (DC) Hoscht sur l’association sorgho-niébé dans le village de Yilou, Province du Bam, Burkina Faso. Master thesis, Institut du Dévéloppement Rural de Bobo-Dioulasso & African Conservation Tillage Network, Burkina Faso

Pant LP (2014) Critical systems of learning and innovation competence for addressing complexity in transformations to agricultural sustainability. Agroecol Sustain Food Syst 38:336–365

Pinstrup-Andersen P (2009) Food security: definition and measurement. Food Secur 1:5–7

Roep D, Van der Ploeg JD, Wiskerke JSC (2003) Managing technical-institutional design processes: some strategic lessons from environmental co-operatives in The Netherlands. NJAS Wageningen J Life Sci 51:195–217

Rossing WAH, Modernel P, Tittonell PA (2014) Diversity in organic and agro-ecological farming systems for mitigation of climate change impact, with examples from Latin America. In: Fuhrer J, Gregory PJ (eds) Climate change impact and adaptation in agricultural systems, CABI climate change series 5. CAB International, Wallingford, pp 69–87

Ruggia A, Scarlato S, Cardozo G, Aguerre V, Dogliotti S, Rossing W, Tittonell P (2015) Managing pasture-herd interactions in livestock family farm systems based on natural grasslands in Uruguay. In: 5th international symposium on farming systems design, Montpellier, 7–10 Sept 2015

Rusinamhodzi L, Corbeels M, Zingore S, Nyamangara J, Giller KE (2013) Pushing the envelope? Maize production intensification and the role of cattle manure in recovery of degraded soils in smallholder farming areas of Zimbabwe. Field Crop Res 147:40–53

Russelle MP, Entz MH, Franzluebbers AJ (2007) Reconsidering integrated crop-livestock systems in North America. Agron J 99:325–334

Sage C (2014) The transition movement and food sovereignty: from local resilience to global engagement in food system transformation. J Consum Cult 14:254–275

Sala OE, Paruelo JM (1997) Ecosystem services in grasslands. In: Daily GC (ed) Nature's services: societal dependence on natural ecosystems. Island Press, Washington, DC, pp 237–251

Schekkerman H, Teunissen W, Oosterveld E (2008) The effect of "mosaic management" on the demography of black-tailed godwit Limosa limosa on farmland. J Appl Ecol 45:1067–1075

Scoones I, Thompson J (eds) (2009) Farmer first revisited: innovation for agricultural research and development. Practical Action Publications, London

Sharp BR, Whittaker RJ (2003) The irreversible cattle driven transformation of a seasonally flooded Australian savanna. J Biogeogr 30:783–802

Sherwood SG, Schut M, Leeuwis C (2012) Learning in the social wild: encounters between farmer field schools and agricultural science and development in ecuador, adaptive collaborative approaches in natural resources governance: rethinking participation, learning and innovation. Routledge, London, pp 102–137

Shiferaw Sida T, Baudron F, Kim HK, Giller KE (2014) Old tricks, new insights: Faidherbia albida keeps wheat cool and productive in the Central Rift Valley of Ethiopia. In: Proceedings of the agroecology for Africa international conference, Antananarivo, 3–7 Nov 2014

Skelsey P, Holtslag AAM, van der Werf W (2008) Development and validation of a quasi-Gaussian plume model for the transport of botanical spores. Agric For Meteorol 148:1383–1494

Skelsey P, Kessel GJT, Rossing WAH, van der Werf W (2009) Scenario approach for assessing the utility of dispersal information in decision support for aerially spread plant pathogens, applied to Phytophthora infestans. Phytopathology 99:887–895

Smith A (2007) Translating sustainabilities between Green Niches and Socio-Technical Regimes. Tech Anal Strat Manag 19:427–450

Smith A, Seyfang G (2013) Constructing grassroots innovations for sustainability. Glob Environ Chang 23:827–829

Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, de Haan C (2006) Livestock's long shadow: environmental issues and options. Food and Agriculture Organization of the United Nations, Rome

Sumberg J, Thompson J, Woodhouse P (2012) Why agronomy in the developing world has become contentious. Agric Hum Values 30:71–83

Swaans K, Boogaard B, Bendapudi R, Taye H, Hendrickx S, Klerkx L (2014) Operationalizing inclusive innovation: lessons from innovation platforms in livestock value chains in India and Mozambique. Innov Dev 4:239–257

Thompson J, Scoones I (2009) Addressing the dynamics of agri-food systems: an emerging agenda for social science research. Environ Sci Pol 12:386–397

Tilman D, Balzer C, Hill J, Befort BL (2011) Global food demand and the sustainable intensification of agriculture. Proc Natl Acad Sci 108:20260–20264

Timmermann C, Félix GF (2015) Agroecology as a vehicule for contributive justice. Agric Hum Values 32(3):523–538

Tittonell P (2013) Livelihood strategies, resilience and transformability in African agroecosystems. Agric Syst 126:3–14

Tittonell P (2014) Ecological intensification – sustainable by nature. Curr Opin Envirn Sustain 8:53–61

Tittonell P, Giller KE (2013) When yield gaps are poverty traps: the paradigm of ecological intensification in African smallholder agriculture. Field Crop Res 143:76–90

Tittonell P, Scopel E, Andrieu N, Posthumus H, Mapfumo P, Corbeels M, van Halsema GE, Lahmar R, Lugandu S, Rakotoarisoa J, Mtambanengwe F, Pound B, Chikowo R, Naudin K, Triomphe B, Mkomwa S (2012) Agroecology-based aggradation-conservation agriculture (ABACO): targeting innovations to combat soil degradation and food insecurity in semi-arid Africa. F Crop Res 132:168–174

UNCTAD (2013) Least developed countries report 2013 – growth with employment for inclusive and sustainable development, 20 Nov 2013, 3365.4 KB

UNCTAD (2014) Economic development in Africa report 2014 – catalysing investment for transformative growth in Africa, 04 Jul 2014, 110 page(s), 1020.3 KB

van Ittersum MK, Cassman KG, Grassini P, Wolf J, Tittonell P, Hochman Z (2013) Yield gap analysis with local to global relevance – a review. Field Crop Res 143:4–17

van Noordwijk M, Brussaard L (2014) Minimizing the ecological footprint of food: closing yield and efficiency gaps simultaneously? Curr Opin Environ Sustain 8:62–70

van der Ploeg JD (2009) Transition: contradictory but interacting processes of change in Dutch Agriculture. In: Poppe KJ, Termeer C, Slingerland M (eds) Transitions towards sustainable agriculture and food chains in peri-urban areas. Wageningen Academic Publishers, Wageningen

Van Paassen A, Klerkx L, Adu-Acheampong R, Adjei-Nsiah S, Zannoue E (2014) Agricultural innovation platforms in West Africa: how does strategic institutional entrepreneurship unfold in different value chain contexts? Outlook Agric 43:193–200

Vanloqueren G, Baret PV (2009) How agricultural research systems shape a technological regime that develops genetic engineering but locks out agroecological innovations. Res Pol 38:971–983

Veldkamp A, Van Altvorst AC, Eweg R, Jacobsen E, Van Kleef A, Van Latesteijn H, Mager S, Mommaas H, Smeets PJAM, Spaans L, Van Trijp JCM (2009) Triggering transitions towards sustainable development of the Dutch agricultural sector: TransForum's approach. Agron Sustain Dev 29:87–96

Waters-Bayer A, Van Veldhuizen L, Wongtschowski M, Wettasinha C, Waters-Bayer A, Kaaria S, Njuki J, Wettasinha C (2009) Recognizing and enhancing processes of local innovation. In: Sanginga P (ed) Innovation Africa: enriching farmers livelihoods. Earthscan, London, pp 239–254

Westley F, Olsson P, Folke C, Homer-Dixon T, Vredenburg H, Loorbach D, Thompson J, Nilsson M, Lambin E, Sendzimir J, Banerjee B, Galaz V, Van Der Leeuw S (2011) Tipping toward sustainability: emerging pathways of transformation. Ambio 40:762–780

Westley FR, Tjornbo O, Schultz L, Olsson P, Folke C, Crona B, Bodin O (2013) A theory of transformative agency in linked social-ecological systems. Ecol Soc 18:27

WFP (2012, 2013) World Food Program 2012 and 2014 annual reports. World Food Program, Rome

WHO (2013) World health report 2013: research for universal health coverage. World Health Organisation, Geneva

Wijnands FG, Vogelezang JVM (2009) Two complementary transition pathways: supporting strategies for innovation towards sustainable development in Dutch agriculture. In: Poppe KJ, Termeer C, Slingerland M (eds) Transitions towards sustainable agriculture and food chains in peri-urban areas. Wageningen Academic Publishers, Wageningen

Wiskerke JSC, van der Ploeg JD (2004) Seeds of transition: essays on novelty production, niches and regimes in agriculture. Van Gorcum, Assen

Wright HL, Lake IR, Dolman PM (2012) Agriculture-a key element for conservation in the developing world. Conserv Lett 5(1):11–19

Yélémou B, Dayamba SD, Bambara D, Yaméogo G, Assimi S (2013a) Soil carbon and nitrogen dynamics linked to Piliostigma species in ferugino-tropical soils in the Sudano-Sahelian zone of Burkina Faso, West Africa. J For Res 24:99–108

Yélémou B, Yaméogo G, Koala J, Bationo BA, Hien V (2013b) Influence of the leaf biomass of Piliostigma reticulatum on sorghum production in North Sudanian region of Burkina Faso. J Plant Stud 3:80–90