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Sustainable Agriculture Reviews

Volume 19

Springer

Sustainable Agriculture Reviews

Volume 19

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Volume 19

Springer

Editor
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INRA
Dijon, France

ISSN 2210-4410 ISSN 2210-4429 (electronic)
Sustainable Agriculture Reviews
ISBN 978-3-319-26776-0 ISBN 978-3-319-26777-7 (eBook)
DOI 10.1007/978-3-319-26777-7

Library of Congress Control Number: 2016931304

Springer Cham Heidelberg New York Dordrecht London

Printed on acid-free paper

Springer International Publishing AG Switzerland is part of Springer Science+Business Media (www.springer.com)

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Chapter 1
Ecological Intensification: Local Innovation to Address Global Challenges

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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

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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

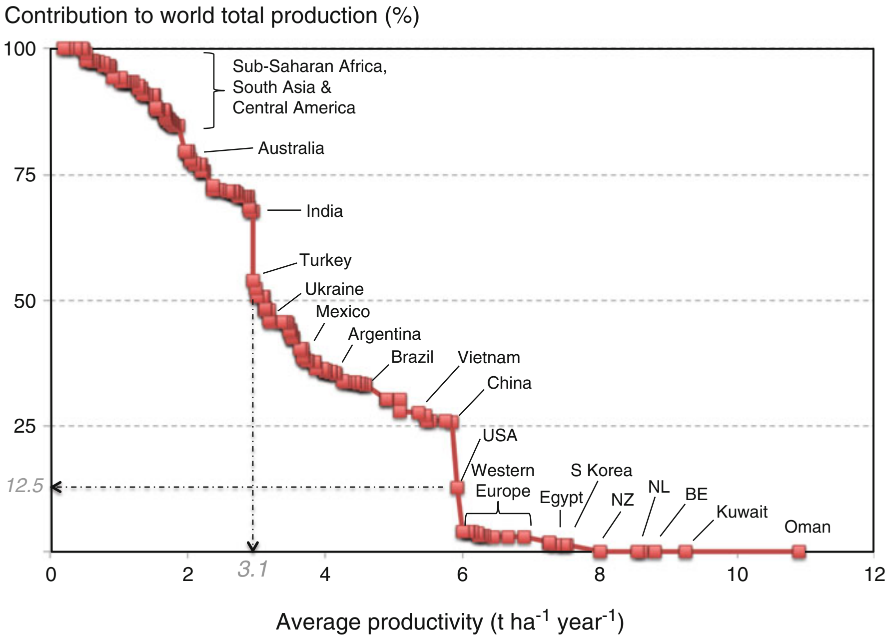

Fig. 1.1 Average cereal productivity per country and their cumulative contribution to total world production. *Dash-dotted lines* indicate (*vertical*) that 50 % of the total world production is realized in countries where average yields are lower than 3.1 t ha^{-1}, and (*horizontal*) that all the cereal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

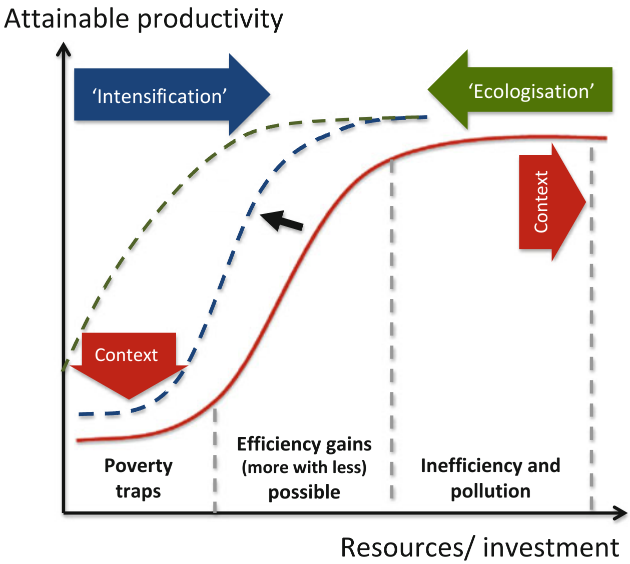

Fig. 1.2 Attainable productivity, contexts and pathways. The *red* curve (*solid line*) describes the current situation where institutional and political contexts create situations of poverty traps or of inefficiency and pollution. The zone of the curve where efficiencies are greater often corresponds 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