Nature and Agriculture. The Evolving Relationship

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1. Relationship between Nature and Agriculture

Agriculture is not only based on and inextricably linked to nature, but has increasingly replaced nature in land use, and is part of a new kind of nature created by humanity. Nature is understood here in broad terms, not just in terms of landscapes, flora and fauna untouched by human action (which hardly exist anymore), but also in terms of the many natural forces that control what happens in the world. In the Anthropocene (Crutzen 2002) many aspects of nature – even when broadly defined – are deeply influenced by human actions, and agriculture plays a key role in that.

Critical issues and questions

Throughout human evolution agriculture has played an essential role for the development of societies. Agriculture is understood here as the production and processing of any food and non-food items for human consumption. By mid century, the world will reach nine billion inhabitants, thus generating new challenges for the agricultural sector. This paper gives a brief overview on the evolving two-way relationship between agriculture and nature. The following questions shall be explored:

1. How did agriculture and the people related to it evolve over time, and how did this evolution impact nature?
2. What are the drivers of technical and institutional change in agriculture and their impacts on nature?
3. What may be the future agricultural evolution in a world of nine billion people and its impact on nature?

We already consume more natural resources today than what is available for sustainable use on earth (Steffen *et al.* 2015). A combination of adjustments in consumption patterns and acceleration in innovations for

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more efficient resource use in agriculture are the theoretical responses to this challenge. Both of these strategic options are at the core of enhancing sustainability. Both options need to take account of diversity in wealth (rich and poor) and locations (different agro-ecologies). The identification of harmony between nature and agriculture is science-intensive. Moreover, the relationship between nature and agriculture is not only a matter of biophysical and market issues but also entails value judgments and preferences; it touches on intergenerational fairness and thus involves ethical issues.

This paper starts with a brief historical overview on the evolution of and revolutions in agriculture. Linkages of changing agricultural structures and institutions are discussed. Agricultural innovations are reviewed and their impact on nature and societies considered. The relationship between agriculture and sustainability is discussed and future policy implications are derived.

2. Agri-Culture and Nature in History

The historical evolution

About 20,000 years ago, the appearance of the eastern Mediterranean region was strongly dominated by treeless steppes. The population was sparsely scattered around this region consisting of small and very mobile groups of hunters-gatherers. For a significant period of time, they secured their livelihood at the margin of subsistence dominated by constant traveling and great uncertainty concerning food security. The last ice age was at its peak creating a hostile environment for successful agricultural practices (Balter 2010). This changed about 5,000 years later when increasing temperature ameliorated the preconditions for the development of agriculture. This points to the fundamental character of the relationship between nature (climate change) and agricultural evolution. The steppes diversified creating new ecosystems and habitats. An exact starting point for the inception of agriculture cannot be given. In addition, it has to be noted that better climatic conditions might only be one factor which contributed to this change. Archaeological evidence dates the first domestication of animals and plants, and the building of permanent settlements about 14,500 years ago. Human food consumption evolved from a limited diet constrained by hunting and gathering success to a more stable and presumably diverse diet.

The term "Neolithic Revolution" is often used to describe these transitions. However, revolution may not be an adequate term to describe the process of early agricultural development. Studies have shown that agriculture emerged through gradual evolution at different locations, rather than in a one-time revolution spreading from one location (Pringle 1998). Looking at different regions, there was no direct conversion of livelihoods from hunters-gathers to full-time farmers but for centuries both forms co-existed in most regions on Earth. With the help of new methods to analyze archaeological evidence, it is possible to date agricultural crop cultivation to an earlier date in many regions than previously estimated. These findings have changed the perception of how agriculture evolved throughout early history (Pringle 1998).

It can be presumed that changing diets and permanent settlement had a beneficial effect for increasing longevity and population size and the emergence of villages and urban centers. The diversity of cultivated crops increased, as did animal production, and technologies (e.g. plough and irrigation) transformed agriculture. Agriculture (and forestry) changed the landscape of large parts of the Earth. Agriculture remained the foundation of economic activity until the industrialization age in the 18th century. Climate and weather continued to play important roles for land and labor productivity. Nowadays, climate change and variability again put pressure on agricultural production systems and food security, especially in regions where the population is already vulnerable to undernutrition (Wheeler & von Braun 2013). Adapting agricultural systems to these new challenges is the aim of many initiatives fostering climate-smart food systems.

Philosophy and thought in relation to agriculture and nature

Agriculture has shaped philosophy and vice versa, and the philosophical underpinnings of agriculture and its practices evolved over time. In the 1830s, Jeremy Bentham argued that the morally right action is an action that produces the maximum good for people. The value of farmland was based on the capacity to grow crops that people wanted. This view of agriculture is in the tradition of utilitarianism (Driver 2014). In utilitarianism, achieving the greater good is the goal, though this neither depends on the way the goal was achieved nor on how long it took to get there (Harrison *et al.* 2005). Libertarianism, in turn, holds high the concept of self-ownership as it represents the point of view that agents have certain moral rights. This includes the definition of land rights and the overall manifestation of private property. The legitimation of land rights and private property also has an effect on the production process since the farmers' liberty to decide on the production process may result in a higher work ethic. Egalitarianism favors equality and links land and water rights with the right to food. A main representative of this trend of thought of political philosophy is John Rawls. The ecological approach defines the Earth as an organism. Human communities are built upon a foundation of the surrounding ecosystems. Land has an intrinsic value. The main representatives of this approach are Aldo Leopold (1840s) and Henry Thoreau (1850s). In diverse forms, all of these schools of thought remain influential today.

Agriculture not only shapes landscapes and economies, but may also be responsible for shaping the mindsets of people. Talhelm *et al.* (2014) showed that there may be a two-way relationship between people's behavior and agriculture. Looking at China, they found that rice farming makes societies more interdependent whereas farming wheat has the opposite effect, making societies more independently thinking. Testing Han Chinese in six sites, they found in rice-producing regions a comparatively higher degree of holistic thought; also, group goals were given a higher priority than individual goals (Cross *et al.* 2011). In wheat-producing regions, people tended to be more analytic and individualism was given a higher priority than the overall welfare of the group.

3. Evolution of Agricultural Structures, People and Institutions

Global land use has changed significantly in the last 300 years (Table 1). Taking the amount of 134.1Mkm² as the total available land on Earth, an increase in cropland and pasture can be observed namely from 2.7 Mkm² in 1700 to 14.7Mkm² in 1990 for cropland and from 5.2Mkm² to 31 Mkm² for pasture (Goldewijk 2001). Agriculture expanded until it globally dominated many landscapes (Dickson *et al.* 2014). Today ca. 40% of terrestrial land is used for crops and pasture.

Table 1: Global Use of Land: from ages of 'undisturbed' until today (in Mkm²)

	Forest	Steppe	Shrubs	Tundra, Desert	Cropland	Pasture	Total
Undisturbed	58.6	34.3	9.8	31.4	0.0	0.0	134.1
1700	54.4	32.1	6.8	31.1	2.7	5.2	134.1
1990	41.5	17.5	2.5	26.9	19.7	31.0	134.1

Source: Klein Goldewijk & Battjes (1997).

There are about 570 million farms worldwide, the majority of which are located in China and India. About 72 percent of all farms worldwide are small-scale, operating land sizes less than one hectare (Table 2). Most small farms are where most of the world's population is concentrated. The predominant form are family-based businesses, that is, a single family manages and operates the business. However, agriculture is in most cases not the only income source (Mollett 1986). Data from 1980 to 2000 demonstrate that Asian countries whose farm size increased show higher agricultural growth rates (von Braun & Mirzabaev 2015). This result is driven by developments in a few countries, while small average farm sizes and little agricultural growth remain characteristic for the majority of Asian countries. However, these findings still contribute to the positive relationship between farm size and agricultural growth.

Table 2: World farm size distribution by region

Region	Land size classes					
	< 1 ha	1-10 ha	10-50 ha	50-100 ha	100-500 ha	>500 ha
Asia	78%	19%	1%	–	–	–
Sub-Saharan Africa	62%	37%	1%	–	–	–
Middle East and North Africa	60%	33%	7%	–	–	–
Latin America and Caribbean	17%	47%	23%	6%	–	–
Europe	–	77%	15%	3%	3%	–
North America and Australia	–	19%	32%	16%	24%	9%

Source: data from Lowder et al. (2014), based on FAO datasets. Note: Blank cells mean the number of farms under this land size class is less than 0.1% of the total.

The process of structural change is ongoing with different factors influencing farm size. In the future, through economic growth, urbanization, youth aspirations, technologies, and access to financial resources, farm operation sizes will mostly likely increase. In the cases of Asia and Africa, both continents are approaching a turning point from a farm size decrease to increase. Furthermore, the demand for labor-saving mechanization will rise. This will most likely have an effect on other sectors; in many developing countries the agricultural sector is the dominant employment provider. With bigger farm operation sizes and more intense use of mechanization, this structural change will impact the labor market, thus having an effect also on other economic sectors. Yet, this transition towards larger farms especially in regions where small farms are dominant will take time due to institutional rigidities.

Regarding the relationship between nature and agriculture, it is of interest that smaller farms tend to use land more sustainably. Statistically, however, there seems to be a positive association between farm size and the share of a country's cropland degradation in Asia, but not in SSA (von Braun & Mirzabaev 2015). At the micro-level a mixed picture emerges: Ali and Deininger (2015) find that soil fertility is higher in smaller plots in Rwanda; on the other hand, Kirui (2015) finds that farmers with larger plot sizes were more likely to adopt sustainable land management practices in Tanzania and Malawi. Similarly, Sow *et al.* (2015) and Aw-Hassan *et al.* (2015) find that larger farm sizes were associated with higher adoption of soil conserving practices in Senegal and Uzbekistan, respectively.

4. Agricultural Science, Innovation and Nature

In the last 10,000 years the world has seen major agricultural innovations. Agriculture has benefited from innovations, but also has been a driver of science with important spillover effects for innovation beyond agriculture. Agriculture created demand for mathematics (e.g., to re-measure fields in flooded areas, such as Egypt, etc.) and other basic sciences (nutrients, animal health, plant breeding). Increasing population pressure and market integration contributed to the evolution of land rights and institutions' governing property rights, which, again, turned out instrumental for economic development.

Drivers of innovation

During the last 300 years several major inventions for both the agricultural sector and other sectors could be observed that had a great influence on shaping societies (Fogel 1999). This accumulation of innovations took place simultaneously with the exponential population growth, posing the question of causality, that is, whether it was agricultural change that stimulated population growth or if it was the other way around and population growth induced agricultural innovations as a response to scarcities. Technical and institutional changes are partly induced through the responses of stakeholders, including farmers, entrepreneurs, scientists and public administrators. The relative scarcity of land and labor are determining factors translating into technical change inducing new and more productive inputs to save labor or land (Hayami & Ruttan 1984).

The earliest scientific communities focused on agronomy emerged in the late 1700s. Major contributors to the agricultural economics included Johan von Thuenen (1810s) and Robert Malthus with his studies on population and hunger in the 1830s. Plant nutrition was dramatically changed by Justus von Liebig's discovery of essential plant nutrients in 1840s. Animal sciences already saw innovation in the 1700s regarding selective breeding. The increase in food safety measures was much improved by Louis Pasteur, who treated milk to stop bacteria contamination in the 1860s. Increasing awareness of food safety led to an amelioration of public health. It was Gregor Mendel in the 1850s who revolutionized plant breeding through genetic considerations. His innovative statistically-based studies had great influence on breeding. Norman Borlaug's work on plant breeding in the 1970s had a huge impact on the food security situation in Latin America and Asia through an increase of wheat and rice yield by the use of high-yielding crop varieties (Gillis 2009). Since the 1990s, genetically modified organisms have become important in agricultural science.

Supply side and demand side innovations

Future innovations regarding the supply side of agricultural production will most likely be guided by studies focusing on the micro level of each organism and production process (Table 3). Research increasingly focuses on the goal of achieving higher and more stable yields as well as on the understanding of heterosis and plant-microbial relations. In addition, we will observe advances in molecular and cellular processes, such as C4 rice. There are already a considerable number of studies dealing with livestock engineering, from biopharmaceuticals in milk and eggs to genetically-modified cattle and fish. New forms of irrigation systems will become more important such as irrigation with brackish or saline water. This could substantially increase the availability of productively usable land. Innovations in pest and disease resistance in a post-antibiotics age, such as chemical control, biological control, sterile insects breeding and breeding for resistance as well as GM foods and vaccinations may become more important. In addition, meat substitutes made from wheat, soybean or algae have become prominent on research agendas.

Table 3: Emerging innovations in agriculture

Genomics (trans- and cisgenic plants, changing the speed and opportunities in plant breeding)
Advances in cellular processes, such as C4 rice
Utilizing relations between plant and microbial systems
Software-assisted precision agriculture, new mechanization, and soil nutrient management
Pest and disease resistance through biological control
Livestock engineering (e.g., synthetic plant-based animal products; biopharmaceuticals)
Irrigation precision technologies

Demand-side innovations will focus on consumption and behavior patterns to overcome food related health problems. In the last few decades it has been possible to observe a development towards a more homogenous global diet composition. The variation of commodity composition in consumption has decreased by about 70 percent towards a higher concentration of animal fats and carbohydrates between 1961 and 2009 (Khoury *et al.* 2014).

The demand for "natural" products has increased over time. "Natural" means that products are produced with the least amount of artificial additives. Organic production processes have grown over the last few years due to the increasing demand of consumers for organic products especially in high-income countries, but the overall share in consumption remains small. Consumer preferences and the willingness of consumers to alter these will be one of the major determinants of the change in agricultural products that is actually adopted in the next decades.

5. Sustainability and Redefining Agriculture

Concerns about the relationship between nature and agriculture are centered on sustainability in its three dimensions – social, environmental, and economic. The term "sustainability" and its meaning can be traced to von Carlowitz (1713). Most parts of Europe were during this time dominated by landscapes suffering from decreasing forest cover due to the demand for wood in various sectors, including mining. Hannß-Carl von Carlowitz introduced sustainable forestry, postulating that the harvest amount should be at the maximum sustainable yield (von Hiller 2014). "*Therefore it will be the greatest art, science, diligence, and establishment on this land, to achieve such a conservation and cultivation of wood, that there will be a continuously resistant and sustainable use of it because it is an indispensable thing without which the country does not want to stay in its existence*" (von Carlowitz 1713). His work has deeply affected German landscape until today, which becomes evident in the country's awareness of the importance of the forest as an economic input factor as well as a nationally relevant good for present and future generations.

Land and soil degradation were a problem throughout history and have become a global concern since the mid of the 20th century (Nkonya *et al.* 2015). There are several measures undertaken to deal with the degradation of land; however, negative human impact on land predominates the positive measures undertaken to improve the soil status on a global scale.

The demand for biological material is large compared to the available supply provided by the Earth's ecosystems. Human appropriation of Net

Primary Production (NPP) is about 32 percent on the global scale. Africa appropriates about 12 percent whereas Europe uses 72 percent (Krausmann *et al.* 2013). The NPP is an indicator for the conversion of solar energy into chemical energy through photosynthesis representing the primary source of food (Imhoff *et al.* 2004). Consequentially, this demand for biological material by human beings leaves less material for other species and alters the composition of the atmosphere, reduces levels of biodiversity and constrains ecosystem services.

Sustainability of agriculture much depends on water use. Agriculture globally absorbs about 75 percent of fresh water. Water scarcity is a major global concern that will exacerbate in the future, due the pressure on water sources from population growth and climate change. For this reason, sophisticated management measures have to be undertaken to guarantee a much more efficient water usage (Lenzen *et al.* 2012).

A new reconciliation of agriculture with nature is necessary. One pathway toward that is sustainable agriculture as part of the emerging bioeconomy. Bioeconomy is defined as the knowledge-based production and use of biological resources to provide products, processes and services in all economic sectors within the frame of a sustainable economic system (von Braun, 2015). The drivers toward bioeconomy are raising factor price expectations, technological innovations and changed consumer preferences. In the long run, future agriculture will be actually re-defined and embedded in a bioeconomy which draws on biomass, industrial biotechnology, utilization of carbon, and biological processes. Biorefineries will become more important as well as integrated bioeconomy value chains and webs. Bioeconomy has intersections with various sectors including agriculture, forestry, fisheries, large parts of chemical and pharmaceutical industries, fiber and textiles, bio-based construction materials and energy sector components.

6. Conclusions

The relationship between agriculture and nature will continue to evolve. Agriculture evolved very gradually over time, though a dramatic acceleration of replacement of inherited nature happened especially in the past 200 years. This evolution is now mainly driven by a change in demand, which is related to the interaction of population growth, urbanization, and income growth, and related changes in tastes and preferences. Demand for "nature" is part of the equation.

We will most likely observe major changes in agriculture in the next decades especially in emerging economies. A more sustainable use of natural resources is not easily achievable even though agricultural innovations can be fast. At the same time, agriculture has been a potential engine of economic growth and development, and continues to play that key role in low-income countries with their sizable small-farm sectors.

Agriculture will have to deal with many upcoming challenges, including increased food needs for nine billion people, while adapting to climate change. In the history of agricultural innovation, becoming more effective while using less input was always a dominant driver. Without these science-based innovations of the last two centuries, many societies would not be able to live at the high standards reached, and even more natural resources would be used for agricultural production. Agriculture will need accelerated innovations of diverse strategies in different contexts (Table 4). Technical and institutional innovations are critical for a new and more harmonious relationship between agriculture and nature.

Table 4: Alternatives and implications of future relationship between agriculture and nature

1. Eco-agriculture: involves less yields, requires drastic adjustments in consumption
2. Sustainable intensification: expansion of innovation in agriculture; large-scale science investments needed
3. Sustainable consumption: adjustments in resource intensive consumption and reduced waste of food

To revisit the initially posed questions and provide for short answers:

1. How did agriculture and the people related to it evolve over time, and how did this evolution impact nature? This happened very gradually over centuries, with a dramatic acceleration of replacement of inherited nature in the last 200 years. The small family-operated farm became the dominant model of farming in large parts of the most populous world. Its transformation is one of the great challenges in the global sustainable development agenda.

2. What are the drivers of technical and institutional change in agriculture and their impacts on nature? Innovations facilitated population growth in history. Population and income growth drive demand for agricultural products today. Agricultural innovation is partly endogenous and can be fast. The global and national research and innovation systems for agriculture need a boost in public and private investment. The enhanced education and vocational training levels of farmers are part of that necessary investment.

3. What may be the future agricultural evolution in a world of nine billion people and its impacts on nature? Agriculture needs to be embedded in nature in new ways. This would be facilitated by a comprehensive bioeconomy, which aims for reconciliation between people and nature. Agriculture would be a central element of that. A CO_2-neutral agriculture, operating at much lower levels of water use, with protection of biodiversity, and still providing safe and secure food for all, requires much faster sustainable intensification.

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