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Presentation

This proceedings book results from the AgEng2021 Agricultural Engineering Conference under auspices of the European Society of Agricultural Engineers, held in an online format based on the University of Évora, Portugal, from 4 to 8 July 2021.

This book contains the full papers of a selection of abstracts that were the base for the oral presentations and posters presented at the conference.

Presentations were distributed in eleven thematic areas: Artificial Intelligence, data processing and management; Automation, robotics and sensor technology; Circular Economy; Education and Rural development; Energy and bioenergy; Integrated and sustainable Farming systems; New application technologies and mechanisation; Post-harvest technologies; Smart farming / Precision agriculture; Soil, land and water engineering; Sustainable production in Farm buildings.

We would like to thank all the participants who made this conference possible, despite the constraints in which it took place.

Also thanks to the sponsors and members of the scientific committee, for their important and fundamental contribution to this congress

A Regenerative Agricultural System at Scale: an Outline of Required Outcomes for the Netherlands

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Abstract

Regenerative agriculture is considered a more sustainable alternative to current farming practices, but it is not yet well defined. Building on scientific literature we have defined regenerative agriculture as 'an approach to farming that uses soil conservation as the entry point to regenerate and contribute to multiple provisioning, regulating and supporting ecosystem services, with the aspiration that this will enhance not only the environmental, but also the social and economic dimensions of sustainable food production'. In addition to this definition at farm level we propose the following vision for a regenerative agricultural system at landscape or higher system levels: A regenerative agricultural system enables production of food and biomass and enables ecosystems to maintain a healthy state and evolve, while contributing to biological diversity, integrity of the biosphere, human and farm animal well-being and economic prosperity of society. Based on this long-term vision we have defined a comprehensive outline of a regenerative agricultural system that includes, and takes into account, all ecosystem services, soil functions and planetary boundaries. This outline covers fourteen topics and describes the 'outcomes' that are needed to meet the objectives of a regenerative agricultural system, without being prescriptive on 'how' these outcomes should be achieved. Therefore, we use the term 'required outcomes' which precisely and quantitatively describe the target performance of the regenerative agricultural system. These 'required outcomes' are related to the inputs and use of resources, the output (i.e. food, biomass) and losses/emissions, and the preferred state of soils, water bodies, animals, biodiversity and society. The outcomes encompass environmental, social, and economic aspects, and are defined at five different system levels: 1) field (above and below ground), 2) farm, 3) local landscape (including air and water bodies), 4) the Netherlands and 5) international. All required outcomes are based on and supported by scientific literature.

Keywords: Sustainable agriculture, required outcomes, ecosystem services, soil conservation, vision on regenerative agriculture

Introduction

The Netherlands is known for its highly efficient agricultural sector, with high production levels per unit of input, low resource use and low emissions and losses to the environment per kilogram of food produced. Over the last decades impressive results have been achieved in the reduction of environmental impacts per kilogram of food produced.

Despite these results, Dutch agriculture faces serious challenges to achieve the sustainability goals of the UN, the EU and the Dutch government with respect to planetary boundaries (climate change, biodiversity, freshwater use, nutrient cycling and losses, and land system change), as well as to society (consumer and societal acceptance, risk of zoonoses). Furthermore, many farmers are facing significant challenges to earn a living income. A team of researchers from universities in Wageningen, Utrecht and Amsterdam, coordinated by the Top Institute Food and Nutrition (TiFN), explored how the Dutch agricultural system can become regenerative, with positive impact on nature and the living environment, and with healthy farmer business models.

Regenerative agriculture is considered a solution to a more sustainable way of farming, but not yet well defined. As a result, an integrated long term (year 2050) outline of what a regenerative agricultural system at scale looks like is missing. The aim of this paper is to specify the concept of a 'regenerative agricultural system' i.e. to define the goals as precisely and concretely as possible and provide an integrated science-based overview of long-term required outcomes it has to achieve, without describing and prescribing how these goals should be achieved. This paper will present a summary of these required outcomes, though not all detailed background and supporting material and references. The outline of a regenerative agricultural system can be used to evaluate and compare current agricultural practices, assess

the potential impact of existing best practices and to design future scenarios that can meet the required outcomes.

1. Defining objectives for a regenerative agriculture

1.1 Review of existing definitions in scientific literature

A review of scientific literature on regenerative agriculture by Schreefel et al. (2020) showed that, thus far, there is no shared common definition of regenerative agriculture, nor of its objectives. Most definitions rather describe aspirations and activities of regenerative agriculture at farm and/or local level, with a notable absence of objectives and quantified outcomes for a regenerative system at larger scales.

Focussing first on the environmental pillar of farm-level sustainability, we observed a convergence of definitions, all of which mentioned objectives and/or practices to reduce environmental externalities and specifically soil-related issues, as shown in Figure 1. Objectives above farm level and aspirations regarding socio-economic aspects were also found, but without associated operationalisation into specific activities. Overall, the articles found in the literature describe regenerative agriculture as a farming approach which can contribute to ecosystem services in which the entry point is soil health and which stimulates a system change in which primary productivity should be balanced with its ecological and human surroundings. For the outline of a regenerative agricultural system, we will elaborate on this common ground in the relevant literature to create a vision for regenerative agriculture.

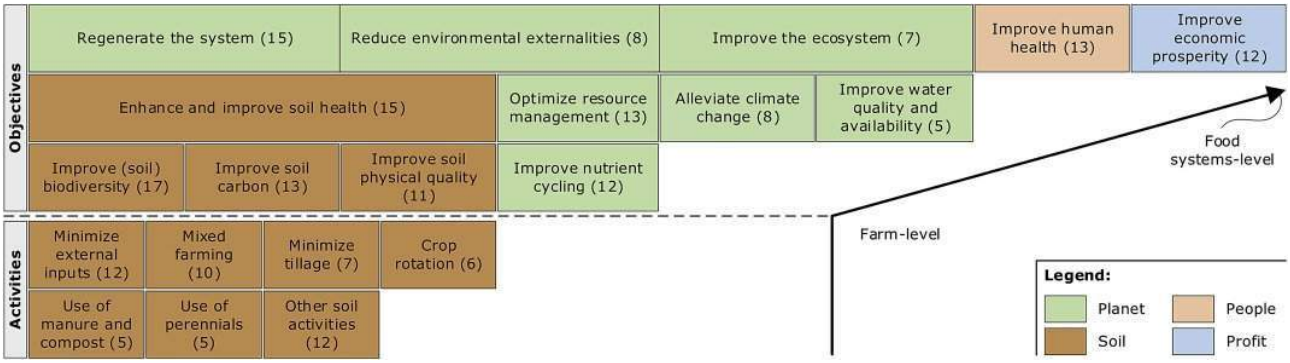

Figure 1. The core themes of regenerative agriculture as identified in Schreefel et al. (2020), categorized (indicated by colors) according the three pillars of sustainability, and soil; 'the number between brackets' represents the number of peer-reviewed articles referring to each theme.

1.2 Vision

Building on the literature review we defined the following definition of *regenerative agriculture* as formulated by Schreefel et al. (2020):

> An approach to farming that uses soil conservation as the entry point to regenerate and contribute to multiple provisioning, regulating and supporting ecosystem services, with the aspiration that this will enhance not only the environmental, but also the social and economic dimensions of sustainable food production.

In addition to this definition at farm level we propose the following vision for a *regenerative agricultural system* at landscape or higher levels:

> A regenerative agricultural system enables production of food and biomass and enables ecosystems to maintain a healthy state and evolve, while contributing to biological diversity, integrity of the biosphere, human and farm animal well-being and economic prosperity of society.

1.3 Explanation and justification of the formulation of this vision

Most existing agricultural systems are aimed at maximizing efficiency per unit of input (energy, nutrients, labour, land), thereby minimizing land use footprint and negative impacts per kilogram of produced food and biomass (de Boer and van Ittersum, 2018). Across the globe, impressive efficiency gains have been achieved towards this aim: the global crop production index has grown almost 300% since 1960 (World bank, 2020a), while arable land area increased with only 12% (World Bank, 2020b). Land use footprint per kilogram of produced food and biomass has thus been reduced by 70% or more. These efficiency gains were essential to feed the growing world population. Despite these efficiency gains food production contributes significantly to the crossing of planetary boundaries (Eat-Lancet, 2019). In order to produce the amount of food that is needed for today's world population within planetary boundaries, many sustainable agriculture efforts aim to optimize the current systems and gradually try to comply to stricter conditions on e.g. inputs and emissions/losses. Current production systems, however, do have their limitations in reaching these stricter conditions and better performance, and many trade-offs are encountered; improvements on one aspect lead to negative

side-effects and lower performance on another aspect (Kanter et al., 2018; Zwetsloot et al, 2020).

For the reasons mentioned above, we think it is no longer enough to minimize land use footprint and negative impacts per kilogram of produced food and biomass. We therefore propose with our vision that the aim of agricultural systems needs to be broadened from 'maximizing production and efficiency' towards 'reaching the goals of food and biomass production, and at the same time contributing positively to biosphere integrity, human well-being and economic prosperity'. This vision addresses all three pillars of the People-Planet-Profit concept, and a series of Sustainable Development Goals (SDGs) and specific targets of the UN, in particular SDG2 (zero hunger), SDG3 (good health and well-being), SDG6 (clean water and sanitation), SDG8 (decent work and economic growth), SDG12 (responsible consumption and production), SDG13 (climate action), SDG14 (life below water), and SDG15 (life on land).

1.4 Objectives for a regenerative agricultural system

To deliver on the vision we propose three overarching objectives for a regenerative agricultural system:

1. Natural Capital Stocks: all natural capital stocks used in agricultural systems are regenerated to and subsequently maintained above threshold levels that are required for a resilient agro-ecosystem i.e. "a system that has the capacity to recover from disruption of functions, and the mitigation of risks caused by disturbance" (Jackson, Pascual and Hodgkin, 2007);
2. Natural Capital Flows: the biophysical conditions and processes in the agro-ecosystem allow that all ecosystem functions and ecosystem integrity in agricultural areas are enabled perpetually;
3. Impact beyond agriculture: The agro-ecosystem has neutral or positive impact on natural capital stocks in natural ecosystems outside the agricultural ecosystem, and on health and well-being in human settlements and public spaces (OECD, 2020).

2. Required outcomes of a regenerative agricultural system

2.1 Different scales in the biophysical system

To define the required outcomes that are needed to meet these overarching objectives we need to first define the relevant systems, subsystems and the elements in the system (objects and subjects), and with that the various system levels. Most work on regenerative agriculture to date is aimed at describing the aspired impact of regenerative practices at farm or field level. In this paper we will propose required outcomes at higher system levels as well. We distinguish five relevant scales in the system:

1. Field;
2. Farm;
3. Local landscape;
4. National (the Netherlands);
5. International (Europe/Global).

2.2 Frameworks used for the required outcomes of a regenerative agricultural system

The list of required outcomes for a regenerative agricultural system that we propose is developed by combining the objectives that are described by Schreefel et al. (2020) with three existing frameworks: the list of ecosystem services according to TEEB (2019), the planetary boundary targets from EAT-Lancet (2019) and the soil functions in the Landmark study (Schulte et al., 2014) (see figure 2).

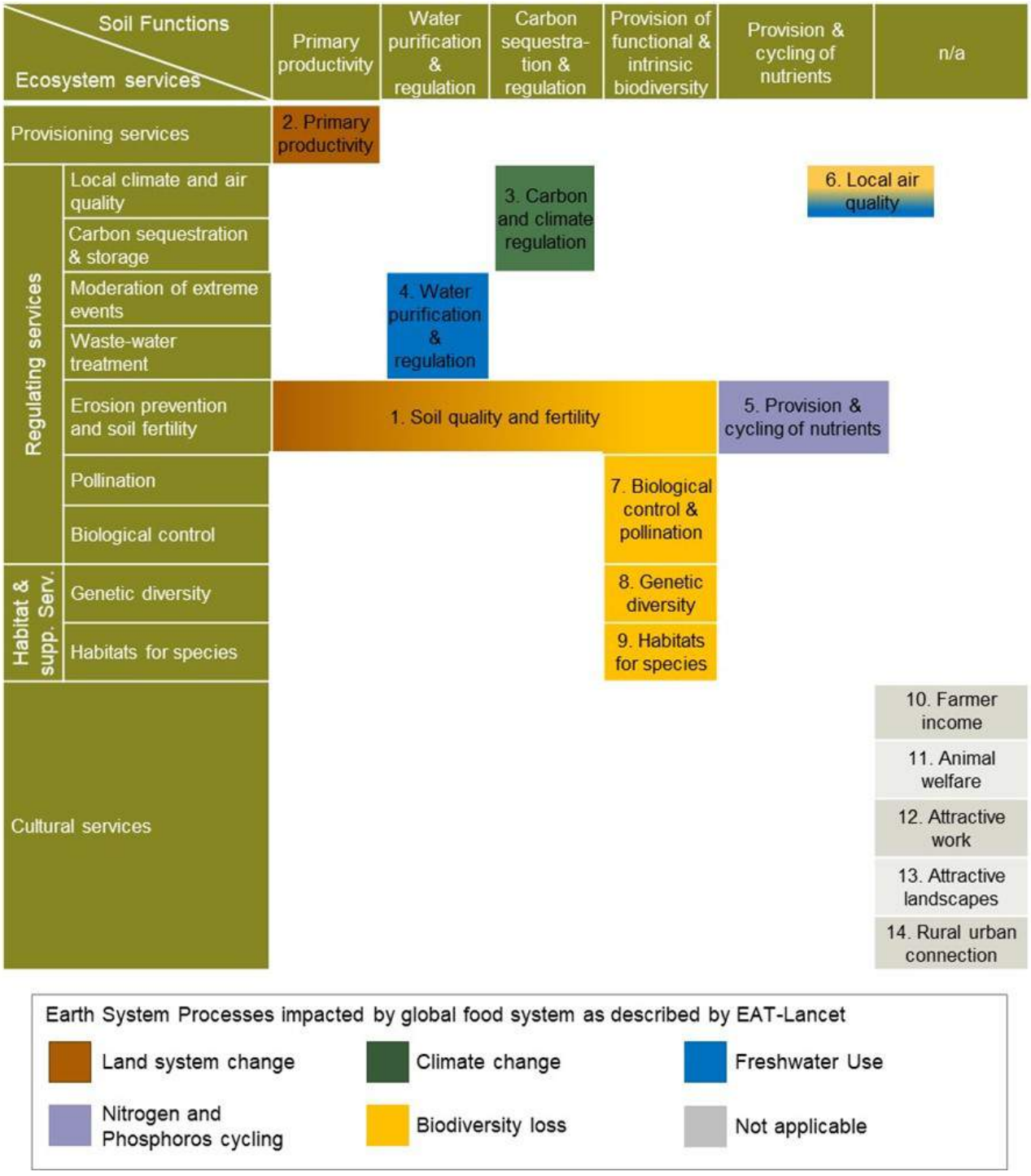

Figure 2. The fourteen identified topics for the outline of a regenerative agricultural system plotted against the five soil functions of the Landmark Study (horizontal axis), the ecosystem services according to TEEB (vertical axis) and linked to the planetary boundary targets from EAT-Lancet (in colour, see legend).

By combining these existing frameworks we identified fourteen topics for which we need to define required outcomes and conditions:

Biophysical outcomes and conditions of a regenerative agricultural system:

1. Soil quality and fertility (biological, physical and chemical soil quality);
2. Primary production of food and biomass;
3. Carbon and climate regulation;
4. Water purification and regulation;
5. Provision and cycling of nutrients;
6. Local air quality;
7. Biological control and pollination;
8. Genetic diversity (diversity and abundance of species)
9. Habitats for species;

Required socio-economic outcomes

10. Farmer income;
11. Animal welfare & health;
12. Safe and attractive work;
13. Attractive landscapes;
14. Rural – urban connection.

The defined required outcomes for these fourteen topics link to various aspects and describe what is needed to meet the overall objectives, without being prescriptive on how these outcomes should be achieved. In addition it needs to be noted that we do not expect that individual farms can contribute to all the outcomes above farming systems levels. For a regenerative system at scale it will be necessary to create symbiotic mixes of diverse farming and natural systems. As a mosaic, these systems can generate a net outcome that meets all the requirements at the appropriate scales, for example: regional scale for nitrogen deposition and (inter-)national scale for greenhouse gas (GHG) emissions.

2.3 Required outcomes of a regenerative agricultural system

For each of these fourteen topics we distinguished and defined required outcomes at the five identified system levels. In formulating these required outcomes we combined the best available scientific insights. Most notably we built on the following sources:

- The extensive work that has been done with the development of the 'Landmark Soil Navigator'. This is a decision support system, developed by Debeljak et al. (2019). The soil navigator is based on a qualitative multi-criteria decision analysis that has been applied using the Decision EXpert (DEX) integrative modelling methodology. Five teams of scientific experts from across Europe have structured, calibrated and validated DEX models for the five soil functions: primary productivity (Sanden et al., 2019), water purification and regulation (Wall et al, 2020), carbon sequestration and climate regulation (van den Broek et al., 2019), nutrient cycling (Schröder et al., 2016) and biodiversity and habitat provision (van Leeuwen et al., 2019). More information about the Soil Navigator can be found on http://www.soilnavigator.eu/;
- The application of the Functional land management framework to map competing expectations of agricultural soils in Europe (Schulte et al., 2019);
- The work by de Boer and van Ittersum (2018) and van Zanten et al. (2019) on circular food systems; see also https://www.circularfoodsystems.org;
- The work by many scientists across Europe in the development of the EU Water framework directive (EC, 2019);
- The work by Lesschen et al. (2020) supporting the Dutch climate agreement;
- The biodiversity monitors that have been developed for dairy farming (Anonymous, 2018) and arable farming (BO-Akkerbouw, 2020).

In Table 1 we present the summary of the required outcomes. The outcomes are partly qualitatively described, but wherever possible the goals were quantified based on available scientific knowledge and insights. For a number of goals, science-based quantification was not (yet or completely) possible. Details of the scientific underpinning can be obtained from the authors and are left out here for reasons of readability and brevity. Table 1 also indicates at which system level the required outcomes need to be met. The required outcomes at field or farm level need to be met by every farm, i.e. farms cannot compensate for each other on these requirements. The required outcomes above farm level are requirements that cannot all be met by individual farms. For a regenerative agricultural system at scale there will be a need to create symbiotic mixes of a diversity of farm systems, as well as nature, that together generate a net outcome that meets all the requirements at the appropriate scales. Adequate monitoring and governance mechanisms will need to

be established to ensure the outcomes are met.

Table 1. Summary of required outcomes at different scale levels for a regenerative agricultural system (relevance for each level indicated with a black box or grey box if preferable but not strictly essential).

Ecosystem service/ soil function	Required outcome at indicated level	System Level: Field	Farm	Local landscape	National (NL)	EU/Global
1. Soil quality + fertility, 2. Primary productivity 3. Carbon & climate regulation	• A resilient soil food web with functional redundancy; high abundance and richness of soil micro-biome	■				
	• Resilient soil physical quality; a.o. dry bulk density < 1.6 g/cm^3 of dry matter	■				
	• Soil organic matter > 4%-8% (soil and farm type dependent)	■				
	• Average production per ha high enough to produce sufficient food and biomass on < 11-15 M km^2 cropland, globally				▒	■
	• Circular system; input/output ratio of human digestible protein <1			▒	■	■
	• Agriculture and nature combined are a 'net carbon sink'				▒	■
	• Intermediate steps: Deliver on commitments in climate agreement, i.e. reduce net GHG-emissions from Dutch Agri + land use with > 6MT by 2030				■	
4. Water purification & regulation 5. Provision & cycling of nutrients 6. Local air quality	• Water usage ≤ naturally available (net water replenishment)		■			
	• Water infiltration and storage capacity of soil sufficient to prevent water erosion (soil and crop type dependent)	■				
	• Water quality good/very good according to EU water framework directive			■		
	• Water surpluses are collected as buffer (in soil, groundwater, pond)			■		
	• No negative impacts on water in natural areas and for local communities			■		
	• N and P accumulation in soils limited to levels that minimize the risk of leaching and high emissions to the environment	■				
	• All N, P and micro-nutrients inputs in system come from renewable sources (air, manure, organic rest streams or recovered from sewage/environment)	■				
	• No accumulation of persistent organic pollutants (POPs) in soils, water or air	■				
	• N deposition in natural habitats < critical deposition levels for ecosystems			■		
	• NO, NH_3 and NO_2 concentrations and emissions within EU directives			■		
	• Particulate matter concentrations < WHO limits			■		
7. Biological control & pollination 8. Genetic diversity 9. Habitats for species	• >10% of *each* square km landscape (all land uses combined) is semi natural habitat		■	■		
	• Year-round diversity of habitat and resource provision for farmland species for all stages of the life cycle (providing habitat for farmland species and enabling natural pest control)			■		
	• Maintain abundance and diversity of populations for effective natural pest control	■				
	• Migration of species between all nature areas enabled			■		
	• Maintain abundance and diversity to sustain healthy populations of farm-land species and pollinators		▒	■		
	• Diversity of gene pool for locally well adapted crops and farm animals				■	
10. Farmer income	• Farmer incomes ≥ living income adequate for local circumstances		■			
11. Animal welfare	• Farm animals have a life worth living		■			
12. Attractive work	• Farms provide safe, attractive and meaningful work		■			
13. Attractive landscapes	• Agricultural ecosystems and nature combined provide attractive landscapes			■		
14. Rural/urban connection	• Good connection between rural and urban communities			■	■	

15. Discussion and conclusions

To ensure sufficient food production within planetary boundaries we think that agricultural systems should aim for 'reaching the goals of food and biomass production, and at the same time contributing positively to biosphere integrity, human and farm animal well-being and economic prosperity'. In this paper we have specified the required outcomes of such agricultural systems that need to be met. It will be challenging to reach this list of required outcomes in practice, which cannot be met with incremental efficiency gains nor with prescribing a few standardized agricultural practices. On the contrary: there will be a need for a diversity of agricultural practices that, combined, can deliver on all the required outcomes. In addition, structural adaptations in e.g. legislation, value chains and water management will be needed (e.g. Bos & Grin, 2008; Morel et al., 2020; Romera et al., 2020). The next step in our research will be to design systems at scale (landscape level and national level) that meet all the required outcomes. In such a design we will use design-principles as described in Figure 3. In parallel, we invite readers to provide input on this outline and collaborate with us to further build and improve it.

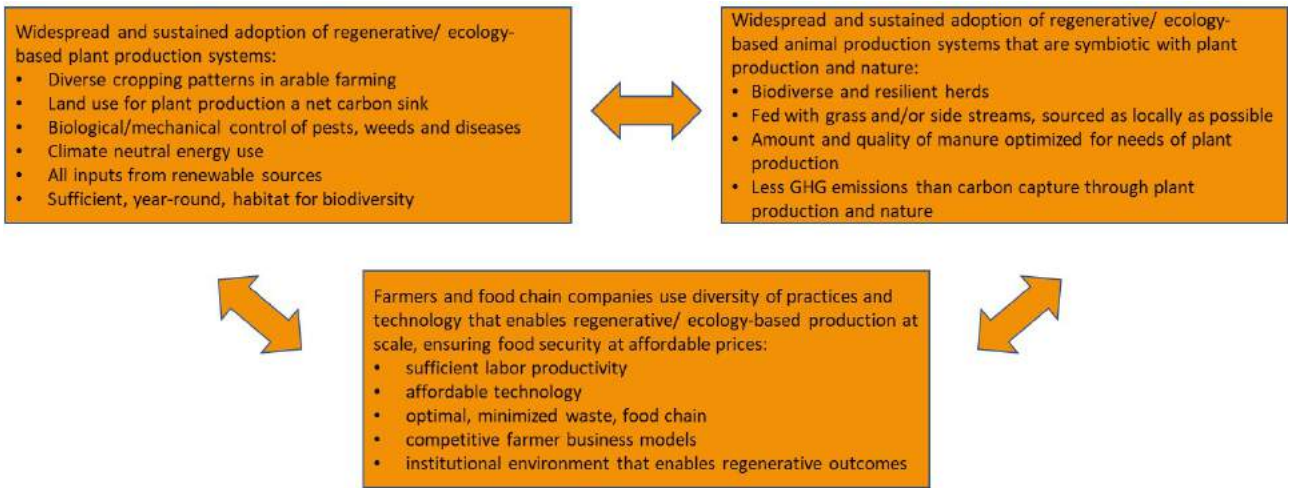

Figure 3. Design principles for a regenerative agricultural system at scale.

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