Circular Food Systems around the world: exploring concepts, ideas and opportunities

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Public Wageningen Livestock Research Report

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Preface

The Circular Food Systems (CFS) Network is a network under the Global Research Alliance on Agricultural Greenhouse Gases and was launched in 2021. The Dutch Ministry of Agriculture, Nature and Food Quality provided funding to support the CFS Network, as focus of the Ministry was to increase circularity in the Dutch agricultural system. Through the network, international collaboration and research could increase knowledge on CFS and its members could bring together and disseminate insights and lessons learned from different CFS around the world.

For the launch of the network, different case studies and abstracts were send that illustrated vast examples of CFS and how these systems change throughout different regions of the world. Eleven of these abstracts were selected to write a short communication and present a video during the launch of the network. These short communications form the basis for this white paper, wherein we explore the different concepts of CFS, how CFS change from region to region and which opportunities are present to further develop CFS to contribute to sustainability in the agri-food system.

We would like to thank all authors of the abstracts and short communications for their contributions to this white paper and the network as a whole.

On behalf of the CFS Network team,

Flavia Casu, co-chair

1. Circular Food Systems: supporting food security and combatting climate change

1.1 Background

1.1.1 More food, less emissions

Sustainable global food and nutrition security is one of the main challenges of today. Food and nutrition security exists when all people at all times have physical, social and economic access to food, which is safe and consumed in sufficient quantity and quality to meet their dietary needs and food preferences (Committee on Food Security, 2012)[i]. The United Nations' has stated in its Agenda 2030 for Sustainable Development to end poverty and hunger everywhere between 2015 and 2030 (UN, 2015). At the same time, the Agenda 2030 calls for the widest possible international cooperation aimed at accelerating the reduction of global greenhouse gas emissions and addressing adaptation to the adverse impacts of climate change, and to conserve the planet's natural resources (UN, 2015).

Currently, however, global food systems are threatening both human health and environmental sustainability (EAT-Lancet, 2019). While global food production provides sufficient calories on average, the unequal division of food and nutrients around the globe still causes more than 820 million people to have insufficient food. Even more suffer from malnutrition because of low-quality diets (EAT-Lancet, 2019). In 2020, the FAO concluded that the decades-long decline in hunger in the world has ended. Since 2014, the number of people affected by hunger even started to increase. Latest estimates suggest that 9.7% of the world population (slightly less than 750 million people) was exposed to severe levels of food insecurity in 2019 (FAO et al, 2020). The COVID-19 pandemic is expected to worsen the world's level of food insecurity.

Food systems are a well-known contributor of greenhouse gas (GHG) emissions. Food systems contribute to 19%–29% of global anthropogenic GHG emissions, releasing 9,800–16,900 megatons of carbon dioxide equivalent (Mt CO_2 eq.) in 2008. Agricultural production, including indirect emissions associated with land-cover change, contributes to 80%–86% of total food system emissions, with significant regional variation (Vermeulen et al., 2012). In addition, food production is related with issues of biodiversity loss, land-use change, social inequality and local pollution. Springmann et al. (2018) state that if the expected demand for food will be produced with our current production approaches, its projected GHG emissions are expected to increase by 87% in 2050.

We may not be able to produce enough food nor reduce the GHG emissions from agriculture, if we do not change our way of producing and consuming food. The FAO stated in 2015 that agriculture, forestry, fisheries, and aquaculture can be transformational forces in the global response to climate change. A paradigm shift towards agriculture and food systems that are more resilient, more productive, and more sustainable is required (FAO, 2015). The EAT-Lancet Commission (2019) concluded that food systems potentially provide healthy diets in a sustainable way, but that an urgent and radical transformation of the global food system is needed.

1.1.2 Circular food system as approach to increase food security and mitigate GHG?

The search for global food security and climate change mitigation has resulted in tremendous efforts of researchers, policy-makers, business and development workers to develop innovative approaches such as the Circular Food Systems (CFS) approach. CFS may contribute to increase food security and GHG emissions reduction by increasing the resource security (use of waste streams reduces need for inputs such as land, water, fossil energy, nitrogen and phosphorus). Additionally, CFS can reduce net greenhouse gas emissions from CO_2, N_2O and CH_4 during the different stages of the food system: via direct mitigation interventions such as reduction of methane emissions through increasing nutrient cycling and indirect mitigation interventions such as through additional carbon sequestration in soils and biomass.

Are circular food systems the holy grail to tackle the challenge? What is a circular food system? How do CFS differ per region? How to measure or monitor the impact of CFS? And can it contribute to food and nutrition security while reducing emissions of greenhouse gasses?

This report aims to provide an overview of, as well as sharing, the different ideas that exist on circularity in food systems worldwide. The report constitutes eleven short communications by scholars from all over the world, that have been submitted to the kick-off workshop of the Circular Food Systems network in 2021 (see box). Together they provide an overview of current state-of-the-art research and practice of circularity and identify the knowledge questions to further advance our knowledge and understanding on CFS. Core questions that this compilation report addresses are:

1. What do Circular Food Systems (CFS) mean in different parts in the world?
2. What are the opportunities? What are foreseen benefits for GHG mitigation and other benefits or trade-offs?
3. What are the next steps to advance CFS and how do they benefit future sustainable food systems?

The Circular Food Systems Network

The Global Research Alliance on Agricultural Greenhouse Gases (GRA) brings countries together to find ways to grow more food without growing greenhouse gas emissions. The Circular Food Systems (CFS) network is part of the GRA's Integrative Research Group.

The CFS network is a growing group of international researchers and policy-makers working on exploring opportunities for GHG emissions mitigation by introducing circularity in food systems. The objective of the CFS network is formulated as: to contribute to food security with mitigation of GHG emissions by circularity across the entire agri-food system. We do that by:

- Bringing together, developing, and disseminating knowledge about circular food systems;
- Mobilising agricultural scientists to explore circularity within different agricultural systems focusing on GHG emissions
- Providing policy makers with methodologies and system designs for a climate-smart, circular food system

In June 2021, the network organised its (online) kick-off meeting. Eleven short communications have been prepared for the kick-off meeting, to present a variety of views on circularity in different regions. The short communications are presented in this report.

For more information on the work and activities of the CFS network, please visit the webpage.

Report outline

This introduction chapter will first dive into the theoretical concept of circularity and circular food systems. The second chapter presents the eleven short communications, all addressing circularity aspects of food systems in a specific region. Chapter 3 concludes with a reflection on the short communications and aspects of circular food systems in different regions.

1.2 Introducing the concept of Circular Food Systems

1.2.1 Circularity: resource and nutrient use efficiency

Circular food systems are food systems in which waste streams are minimised and inevitable waste is utilised in processes of production of food, energy, or non-food products. Losses of raw materials in the production of biomass are kept to a minimum by pursuing a closed loop in which all produced biomass is utilised to a maximum extent. Such circular food systems apply practices and technologies that minimise the input of finite resources (e.g. phosphate rock, fossil fuel and land), encourage the use of regenerative ones (e.g. wind and solar energy), prevent leakage of natural resources from the food system (e.g. nitrogen (N), phosphorus (P)), and stimulate recycling of inevitable resource losses in a way that adds the highest value to the food system (De Boer and Van Ittersum, 2018; Van Zanten *et al*., 2019). The benefits resulting from circular food systems are expected to go beyond mitigation of GHG-emissions and food security, so moreover may also include increased biodiversity, and development of opportunities for ecosystem services.

CFS specifically focus on the whole food system, rather than using an on-farm or value chain approach. It is a whole-system approach that looks at the individual parts of the food system as elements of an integrated entity. Such a food system approach is more than the sum of its parts, as interaction between the different parts of the food system results in additional resource efficiency. Box 1 further introduces the food system approach.

An example of how circularity in food systems can be achieved was described by adhering to the following four principles (De Boer and Van Ittersum, 2018; Van Zanten et al., 2019):

1. Use arable land and water bodies primarily to produce food for direct human consumption.
2. Avoid or minimise food losses and wastes.
3. Recycle by-products (such as crop residues, co-products from processing, manure, excreta) and inevitable food losses and waste streams in the food system.
4. Use animals for unlocking biomass unsuitable for human consumption into value food, manure and other ecosystem services.

These principles are indicative for strategic developments towards circularity and need operationalisation in local contexts. For instance, with respect to the 3rd principle, biomass in residues and waste streams may be used to improve soil quality or to feed livestock. Organic matter in such plant and animal residues, but also in waste produced further downstream in the food cycle may also be converted to valuable products such as bioplastics, protein, volatile fatty acids or other platform chemicals, or as organic soil amendments or as an energy source. Nutrients (both macro- and micro-nutrients) in the waste streams may be recovered and re-used in food production.

De Boer and Van Ittersum (2018) suggest an order of prioritisation for the use of biomass streams in circular food systems (i.e. plant production first, followed by soil quality improvement, animal feeding, and finally for use as fertiliser and energy source; see Figure 1).

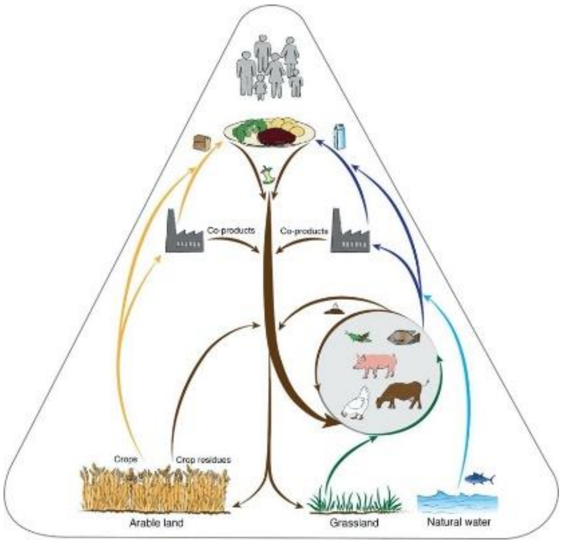


Figure 1 *The concept of circularity with priority given to production of crops for direct human consumption. Biomass unsuited for direct human consumption prioritised as animal feed, with secondary use for soil improvement and fertilisation (Source: Van Zanten et al. 2019).*

1.2.2 Contextualisation of the concept

The proposed order of prioritisation by De Boer and Van Ittersum (2018), however, depends on local contexts. The prioritisation of higher-level objectives in a region plays a role, for example mitigating greenhouse gas emissions vs increasing food and nutrition security. Also, the scale at which circularity is best operationalised is context specific and depends on objectives.

For many Western countries, optimal circularity and sustainability of the total food system can only be achieved by reducing population size of farmed-animals (Oosting et al., 2021). Though, this differs in developing countries. Looking at the healthy dietary guidelines presented by the EAT-Lancet Commission (2019), an increase of animal protein consumption will contribute to more nutritious diets in these countries. Besides providing useful protein and micro-nutrients, animals play a key role in circular food systems: waste stream biomass can be used as feed, and farmed animals provide manure and pond sediment which can be used as fertiliser to maintain or improve soil quality. The use of waste streams for feed may reduce the need for feed production with associated GHG, land and water use, and N and P pollution (Van Zanten et al., 2019). Hence, this requires different higher-level objectives per region.

While concepts such as circularity, circular economy, and bioeconomy are receiving more attention in the global North in the past decades (FKBP, 2020), the concept as such is not new. In many low- and middle-income countries (LMICs), circular approaches to economic and agricultural activity are still more common today, though they are often born out of economic necessity (Preston et al., 2017). Preston (2017) found that the evidence base for the existing practices, norms, and behaviours in LMIC's remains weak and higher-value opportunities for 'reducing, reusing and recycling' are relatively unknown. Though, the concept could potentially contribute to solving various economic, environmental, and social challenges in LMICs and existing processes can be learned from to address the challenges in local food systems in a systemic way.

1.2.3 Knowledge gap

The nexus of circularity, food security and greenhouse gas emission reduction is a complex playing field and it requires a broad representation of stakeholders to address. Depending on local conditions and local policies, the concept of circular food systems may be defined differently, and practices and outcomes may vary.

De Boer and Van Ittersum (2018) discuss the variety in concepts and practices that exist, as well as possible synergies and trade-offs within the various concepts. Finally, they also discuss about strategies on how to implement circular food systems. This implies need for a science-based development of the concept of circularity in a wide variety of food systems across the world, fitting to local environmental and social conditions. But also the need for practical extension of these concepts, for example in living labs as good practice hubs.

Hence, the exchange of global knowledge is key, and collaboration between institutions globally, with a focus on sustainable food security, is essential to have impact on a larger scale. This report is an attempt to contribute to knowledge sharing of circular food systems concepts, and to contextualise practices and solutions.

1.3 CFS in practice: a first exploration of the concept across the world

To explore the concept and formulate a common ground as to what CFS are, a first step was made by sending a survey on CFS and agricultural greenhouse gases to members of the Global Research Alliance in April 2019. GRA members are national governments, sometimes represented by researcher institutes.

Thirteen countries[1] responded to the survey. Although the number of thirteen is limited, and it can be expected that the high number of non-respondents may imply that circularity is not on their agenda, the responses do provide an interesting first overview of the diversity of circularity thinking, policies and practices around the world.

All thirteen stated that the concept of circularity in food production is recognised by their government, and circularity is mainly focused on: (1) producing food with a minimum of resources, (2) recycle and reuse waste streams (i.e. create zero waste systems) and (3) reducing GHG emissions. To a lesser degree, increasing biodiversity through circularity is included as well, but mainly by countries that have a strong focus on CFS already and where governments are actively promoting such systems for future food production.

All countries stated that research on CFS is increasing. Focus of this research is mainly on recycling and processing of waste streams (e.g. manure, by products) into use as organic fertilisers, feed for animals or energy. However, research on circularity is not yet a substantial part of agricultural research in most countries and is limited to recycling and processing of waste streams. This first exploration thus emphasised the need for further research on the broader concept of CFS.

[1] Argentina, Colombia, Denmark, France, Indonesia, Ireland, Netherlands, New Zealand, Spain, Norway, UK, USA, Viet Nam.

Box 1: Food System Approach

Food systems comprise all activities, processes, infrastructure, institutions that relate to feeding the human population: growing, harvesting, storing, processing, packaging, transporting, marketing, consumption and disposal of food and food-related waste streams and the outputs of these activities, including socio-economic and environmental outcomes. (High Level Panel of Experts on Food Security and Nutrition (HLPE, 20212 [High Level Task Force on Global Food and Nutrition Security (HLTF) (un.org)](un.org))).

A Food System Approach takes the intended outcomes as starting point and comprises all the processes associated with food production and food utilisation. The key benefits of using a food system approach is that it aims to take the full complexity into account and that it pays explicit attention to the interaction among various elements of the system. In other words: a food system approach considers trade-offs and synergies, interaction among technological and behavioural change, multi-stakeholder interests and interactions, issues of scale and scope, and alternative options (Van Berkum and Dengerink, 2018). It helps to find leverage points within the system that can trigger changes or transformation of the whole system. When looking at circularity, a food systems approach is especially helpful as it takes into account the complexity and therewith the opportunities of the whole food system to improve circularity. The interactions between these elements of a food system are depicted in Figure 1.

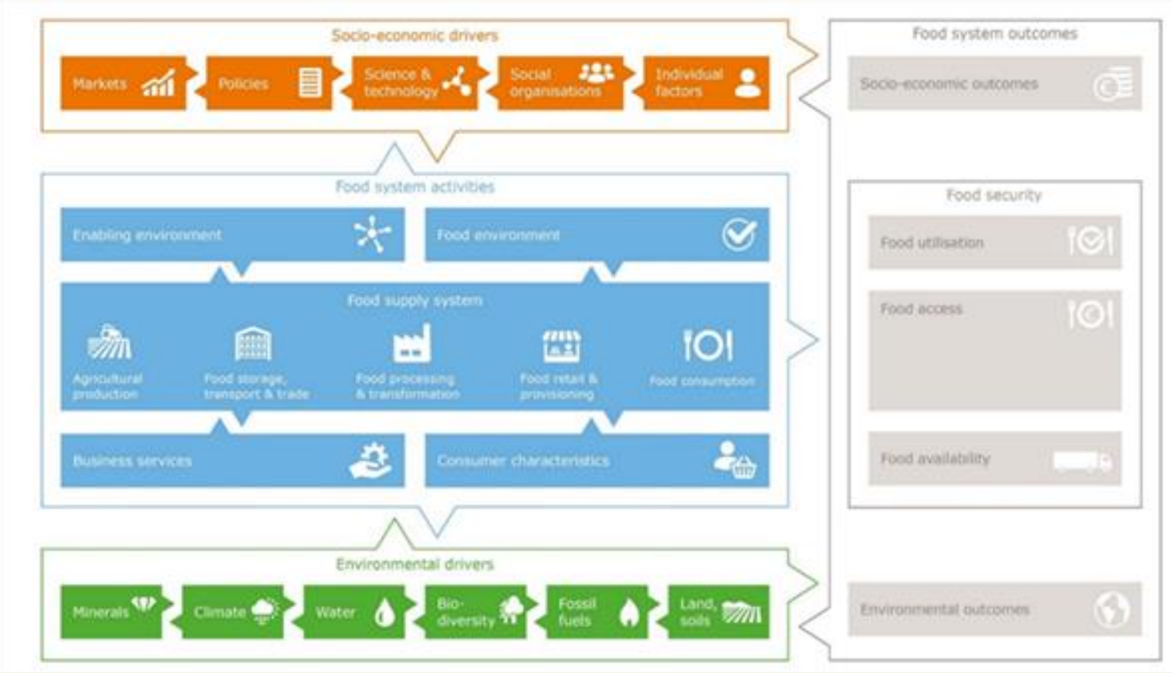


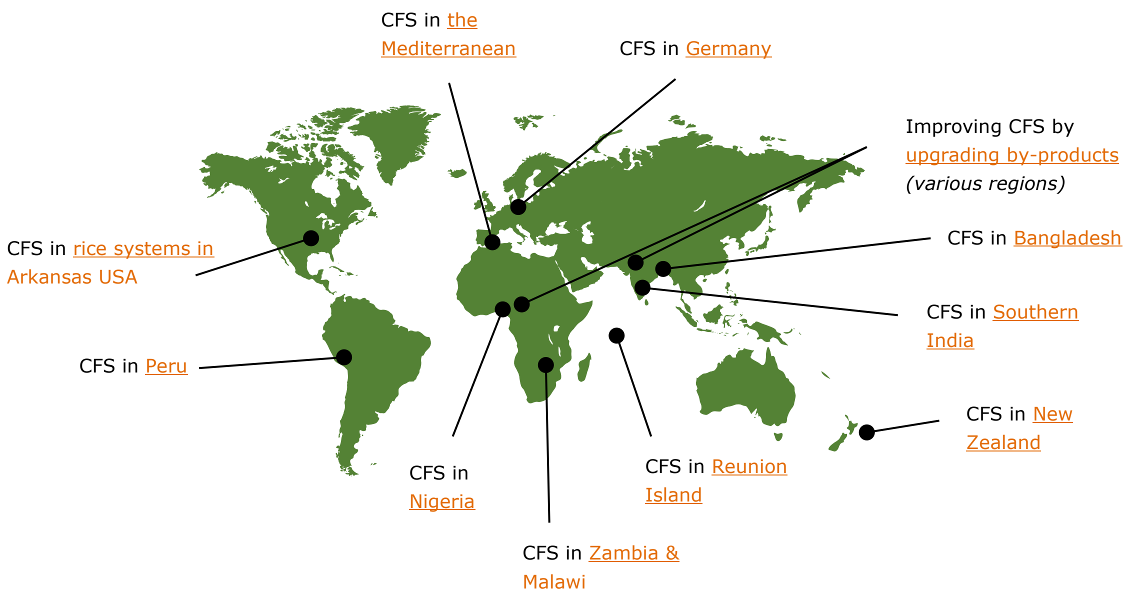
Figure 1. Drivers, activities and outcomes of food systems (Van Berkum et al. 2018).

2. Circular Food Systems around the world

In the quest for sustainable development of our societies, the concepts of bio economy, circular economy, biobased production, circular agriculture are getting more and more attention throughout the world. The concept of circular food systems is rather new, and does not yet have a vast definition. Also, the complexity and context-specific developments across the globe ask for a broad application of the concept. A common ground on how CFS could contribute to food security and combatting climate change, will be a helpful basis to further develop understanding of the approach.

This chapter presents a diversity of examples of circular food systems around the world. It is constituted by X short communications that were developed for the CFS network kick-off meeting in June 2021. The short communications present a wide variety of challenges, practices and solutions, fitting to local environmental and social conditions. All short communications are accompanied by online presentations. The link to these online presentations can be found in the world map below.

What a circular food system is, or could be, in different regions is shown in this short movie: https://youtu.be/nO0-NTX3lhU



The short communications are all prepared as individual papers. They are brought together in this report to provide an overview of the diversity and opportunities of CFS. The following short communications can be found in the next section:

1. Zambia & Malawi: Using a living lab approach to promote nutrient cycling from crop-livestock integration in rural Malawi and Zambia
2. New Zealand: Circularity in pastoral agricultural systems in New Zealand
3. Mediterranean: Achieving carbon neutral and resilient Mediterranean agro-food systems through the circular management of organic resources
4. Peru: Challenges, opportunities, and research needs to improve circularity in the Peruvian food system
5. Rice systems USA: Rice husk soil amendments as a GHG-mitigating piece of the circular rice production system
6. Bangladesh: Winter cultivation of legume beans instead of rice to reduce field methane emissions and use legume by-product for low methane emitting livestock and fish production in Bangladesh

7. Germany: Regional opportunities to mitigate GHG emissions in the capital region Berlin-Brandenburg, Germany
8. India: Circular Food Systems: The Economic and Environmental Benefits of Integrated Farming System under Small-Scale Farm-Holdings of Tamil Nadu, Southern India
9. New Zealand: Circularity in pastoral agricultural systems in New Zealand
10. Nigeria: Use of Cassava Waste in Circular Food Systems in Nigeria
11. Southern Asia: Advances in converting cereal straws and stovers into concentrates: implications for the circular economy

2.1 Using a living lab approach to promote nutrient cycling from crop-livestock integration in rural Malawi and Zambia

By Asaah Ndambi, McLoyd Banda, Margaret Chiipathenga, Chrisborn Mubamba, Monica Sanga, Kabemba Mwambilwa and Simon Mudenda

Description of the food system in the region, current developments and trends.

The production elements in the food system in Malawi and Zambia are characterised by smallholder mixed farming systems with an average land holding size of 1.2 ha per household in Malawi (FAO, 2017) and 1.4 ha in Zambia (Zulu et al., 2007) and low yields. Poorer households are less diversified and usually cultivate less than one hectare annually. The ability to cultivate is based on the capacity to access farm inputs hence poorer farmers cultivate a hectare or less annually while richer farmers may reach 5 ha, annually. Major crops grown are maize as a staple food, legumes such as groundnuts, and soybean for both consumption and income while tobacco is solely a cash crop. The main livestock species kept by the smallholder farmers in a mixed farming system are indigenous cattle, a small proportion of exotic dairy cattle, local goats, pigs and chickens for social values, income and manure. A household owns one or more livestock species in relatively small numbers. Manure is used as fertiliser in crop production, however, because of poor manure management there is low-quality manure that is utilised in the farming system (Ndambi et al., 2019). Productivity in most agricultural commodities is far below potential yields (obtainable if soils are well fertilized and irrigated), for example, maize yield average at 2 t/ha against a potential 5t/ha, and the average milk yield of 10 liters/cow/day against the potential of 25 liters/cow/day (NAP, 2016; FAO, 2017).

At harvest, a reliable grain storage system for grain in the sub-sector is the use of sacks while some use traditional silos. Huge losses at the post-harvest stage are also experienced, estimated at an average of 5 to 12% annually (Amber et al., 2017). Produce from livestock sub-sectors such as milk are also prone to losses. Post-harvest losses in milk and dairy products of up to 40% have also been experienced in sub-Sahara Africa including Malawi and Zambia due to poor handling at the farm level, distribution network, unregulated marketing channels including poor access to export markets (Kasirye, 2003).

Some important socio-economic drivers of the food system with influence on circularity in the proposed initiative include government policies, science and technology, social organisations, markets, and transportation. For instance, National Agriculture Policy for Malawi emphasises the promotion of manure utilisation among farmers and the advancement of science and technology in agriculture (NAP, 2016), which is similar to Zambia's agriculture policy (NAP, 2012-2030). The most common means of transportation is by roads, mostly earth roads to reach markets using ox-carts, bicycles, and vehicles. Social organisations such as farmer cooperatives that bring producers together in both countries are opportunities to promote implementing innovations in circularity. The lead farmer concept, which is promoted in farming communities as an extension tool in both countries makes an impact in the dissemination of agriculture technologies developed by national agricultural research systems (NARS) and international research organisations. The concept is also used for the refinement of technologies through on-farm studies.

Important environmental drivers that impact food systems include climate change, water, land and soils and biodiversity, among others. Climate change has significantly reduced the performance of the agriculture sector as the smallholder farming system is heavily dependent on rainfall. Because of the reliance on rainfall, the region only has a single cropping season in a 12-month period, running from December to March with annual average rainfall varying from 725 mm to 2,500 mm in Malawi and 500 to 1,400 mm in Zambia. Due to inadequate investment, irrigation accounts for less than 10% of agricultural GDP in Malawi and Zambia, despite potential resources and technologies for irrigation (SMEC, 2015, Mendes et al., 2015). One notable loss of biodiversity is through deforestation. Cutting down of trees due to the demand for fuelwood accelerates soil erosion and loss of soil fertility, as well as reduced carbon sequestration. The underlying factor is low access to electricity and poverty (World Bank, 2017; 2019). Through research initiatives, various renewable energy innovations such as biogas, and briquettes have been explored as potential for promotion in rural communities in Zambia and Malawi.

Literature on soils has shown that soil nutrient content has suffered a lot of mismanagement with >40% observable signs of soil degradation. The degradation has been a result of a number of factors among which are inadequate soil fertility management, limited extension services, poor adoption of soil conservation technologies, and weak implementation of environmental and resource management policies, among others, (Mbata and Westman, 2018). As such the soils have failed to sustain adequate agricultural productivity. The assessment on critical soil nutrient limits done both in Malawi and Zambia has shown that the majority of the soils do not meet key nutrient levels such as pH, K, Ca, P, N, Zn and OC (Solomon et al., 2018; Chirwa et al., 2016; Chapoto et al., 2016). In addition, an average annual loss rate of the main plant nutrient due to topsoil loss of 108g/ha of total N, 350g/ha of available P and 16.16g/ha of exchangeable K has been reported in Malawi (Omuto et al. 2018). Hence, soil nutrient improvement is highly dependent on fertilisation using inorganic fertilisers in both Malawi and Zambia.

Problem statement

The agriculture sector contributes about 39% to the country’s GDP, employs 85% of its workforce, and contributes 90% to its foreign exchange earnings, and acts as a source of savings and investible funds in Malawi. Zambia’s agriculture sector makes a significant contribution of 22% to GDP and is a source of employment for a large sector of the population. Agriculture employs 67% of the labour force in the formal sector, and is the main source of employment for rural women who account for 60% of the rural population. An estimated 60% of Zambia’s population depend directly on agriculture for their livelihood (NAP, 2016). Smallholder farmers are major players in the sector in both countries, who practice mixed farming systems. The mixed farming system in Malawi and Zambia is characterised by low productivity in crops and livestock, for instance, maize yields currently are less than 2 t/ha against a potential of 5 t/ha. Agricultural production is highly dependent on rainfall, which is erratic and with little attention to potential water harvesting innovations. The farming system relies on inorganic inputs, which are detrimental to soil and aerial environments. This is despite the potential of recycling huge volumes of farm by-products between enterprises in the prevailing mixed farming system. Despite agriculture being the backbone of Malawian and Zambian economies, the rural poor smallholders that dominate farm activities, live on less than a dollar per day (FAO, 2019). Consequently, these smallholders incur high production costs on inputs, are further prone to post-harvest losses and the majority live in chronic hunger. Practices like recycling of farm wastes (crop residues) into livestock production and livestock wastes (dung) into crop production have not been explored sufficiently due to poor management by the farming communities, despite their potential to optimise nutrient cycling and to reduce the dependence on expensive synthetic fertilisers. Efforts in promoting manure composting techniques is however challenged by (i) labour demand to produce required demand among the farmers and (ii) poor storage methods of fresh manure. There is also a lack of testing and promotion efforts on water harvesting and post-harvest losses opportunities to elevate production and storage components of the food system.

Opportunities to increase circularity in the food system

There are opportunities to increase circularity in mixed farming systems in developing countries through utilisation of existing underutilised resources and approaches. The living lab approach, which is user-centered, iterative, open-innovation ecosystem, is considered vital in learning, developing and promoting new innovations among players in development (Higgins and Klein, 2011). The project adopts the living lab by using lead farmers. The lead farmer concept was adopted by both Malawi and Zambia governments over 10 years ago in agriculture research and development in which an individual farmer is elected by the village to voluntarily assist in the delivery of good agricultural practices/technologies that are enterprise specific and is trained in those technologies. The lead farmers also become the focal point for technology refinement through on-farm experimentations. The previous project, Crop-Livestock Integrated Project (CLIP), on which the current proposal is built on, also used the lead farmer concept. CLIP efforts were to contribute to food security while reducing greenhouse gas emissions, through recycling actions of farm by-products in an integrated approach in smallholder farming systems in Mchinji and Mzimba Districts in Malawi and Chipata District in Zambia using lead farmers from 2014 to 2018. The major elements in the recycling actions were: (i) soil management through use of compost and manure, (ii) increase crop yield while reducing cost of production by substituting inorganic fertilisers with compost, (iii) processing and utilisation of crop residues as feed for cattle in lean months, (iv) use of pig or cattle waste (dung) for preparing compost and for generating household energy through biogas production. Introduction of biogas energy into smallholder mixed farming system considers huge volumes of livestock wastes as estimated in Table 1 below and (v) utilisation of bio-slurry as manure in crop production.

Table 2.1.1: Livestock populations and quantification of manure production in Malawi and Zambia.

Livestock species	Livestock population (APES, 2019 and LAC, 2017)	Estimated annual manure (dung) production, tones	References on manure (dung) quantification per species
Cattle - Malawi	1,834,845	3.7 million	Font-Palm, 2019; NRCS, 1995
Cattle - Zambia	3,654,668	7.3 million	
Pigs - Malawi	7,924,432	3.0 million	Chastain et al., 2003; NRCS, 1995
Pigs - Zambia	996,390	0.4 million	

Under the CLIP, elements become more connected in the cycle illustrated in Figure 1 below, which motivates producers and benefits the environment. Main CLIP outputs were: (i) increased manure production and utilisation through use of household biogas innovation among biogas beneficiaries, (ii) increased crop yields through use of bio-slurry based compost at reduced production cost, (iii) reduced feed deficit for cattle in dry months by 40% through fodder (crop residue) conservation techniques. However, due to its short duration and limited funds, some shortcomings were met. These include: (i) limited geographical coverage of the project and a limited number of farmers involved, (ii) selection of suitable crops per location and nutrition (ii) lack of scientific quantification on changes in GHG emissions as well as in nutrient use efficiency, (iii) the project lacked incorporation of fodder treatment techniques to improve utilisation of crop residues at farmer level, (iv) water harvesting innovations and (v) post-harvest losses. Furthermore, the installation of household biogas digesters was too costly for average small-scale farmers. Since then, more affordable low-cost designs, water harvesting innovations, and post-harvest losses have been developed and could be introduced to farmers.

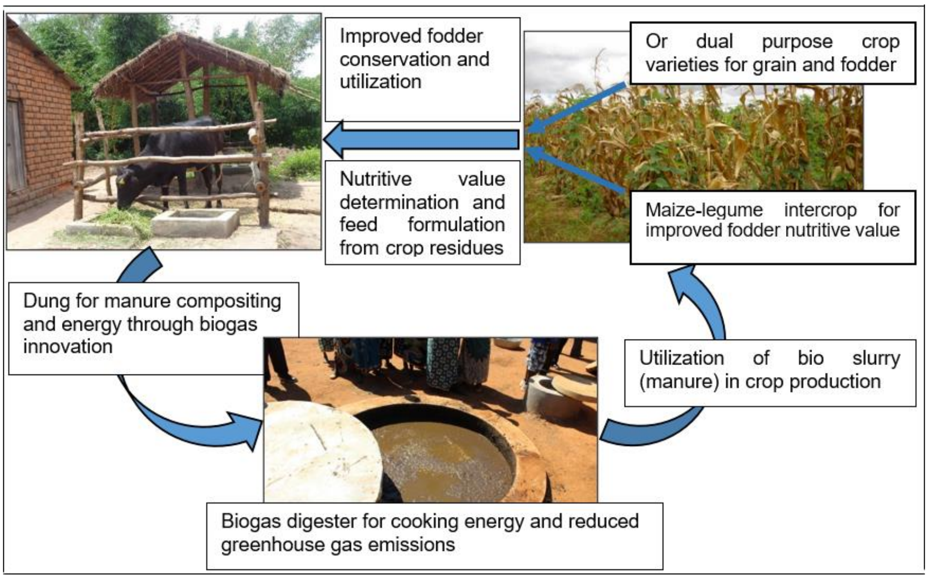


Figure 2.1.1: Illustrative model of interdependence of interventions in crop-livestock integration

To continue with CLIP efforts the proposed project strives to implement the following objectives: (i) create living labs centered on lead farms that were established during the CLIP project, as knowledge generation tools and dissemination centers in circularity, (ii) identify appropriate fodder treatment techniques for small scale farmers for efficient utilisation of crop residues as fodder in the farming system, (iii) identify and test low cost bio-digesters and also train farmers and extension workers on their management (iv) identify and promote post-harvest and water harvesting technologies for circularity in the food system (v) create awareness and demand on the socio-economic-environmental benefits in the circularity to policymakers and stakeholders (vi) apply scientific methods to quantify GHG emissions and nutrient use efficiency associated with the project interventions.

Effects of the opportunity to improve circularity on mitigating greenhouse gas emissions.

Deteriorating soil fertility is one major contributing factor to low yields among smallholder producers, which has attracted widespread use of synthetic fertilisers. Application of these synthetic N fertilisers is recognised as the most important factor contributing to direct N_2O emissions from agricultural soils (Rahman et al., 2019). Comparatively, Rahman et al., (2019) reported that in soil amendments with organic fertilisers, soil nitrous oxide (N_2O) emissions are recorded to be 66%–86% lower than those from inorganic fertilisers. Hence, in circularity there is assurance of lower soil N_2O emissions from organic fertilisers. Therefore, in addition to economic benefits of low manure costs and improved soil water retention the circularity will mitigate greenhouse gas emissions.

When looking at the potential and current practices on circularity of farming in the two countries, there is a notable but unquantified flow of biomass, nutrients and energy. In the fixed farming system, it is observed that biomass and nutrient flows are related to livestock production, which implies that they play a key role in circularity in food systems. However, due to poor livestock feed production, utilisation techniques and manure management, greenhouse gas emissions are presumably high from the livestock sub-sector (FAO, 2017; Grossi, et al., 2019). Therefore, improved fodder production and utilisation have the potential to reduce methane release from ruminants. Furthermore, improved manure management at the smallholder level, and recycling animal manure through biogas innovation for household energy needs will reduce greenhouse gas emissions from livestock manure. The promotion of biogas innovation at the household level for cooking will contribute to a reduced rate of cutting down of trees, supporting carbon sequestration. Also, training on water harvesting and water use during the dry season will increase farm output hence reducing emissions per unit of output.

Other socio-economic-environmental benefits of circular food systems beyond GHG emission mitigation.

Other socio-economic-environmental benefits of the proposed circular food systems project include (i) saving forests. The integration of household biogas innovation into circularity food systems among smallholder producers will in turn benefit the environment as it becomes an alternative energy source to forest products. Hence saving trees that are a predominant source of cooking energy amongst low-income households in Africa. (ii) Household savings. High dependence on expensive inorganic fertilisers becomes costly in production for farmers. Enhancing recycling of farm by-products such as bio-slurry from biogas would substantially replace a considerable proportion of the inorganic fertilisers and reduce production costs resulting in household savings, (iii) Soil restoration through the use of manure in food systems is also an additional environmental benefit that improves soil structures and microbial activities (iv) and through crop rotation, there is assured enrichment of soils by fixing nitrogen in the soil particularly when in rotation with leguminous crops which in turn reduces the use of inorganic fertilisers.

Knowledge development to further improve circularity in the food system and GHG mitigation:

The proposed project will implement research components to generate knowledge for further improvement of circularity in the food system by providing responses to the following research questions:

1 Can innovations through living labs contribute to improved circularity and reduced GHG emissions in predominant food systems in Malawi and Zambia?

2 What are the most appropriate treatment techniques that promote efficient utilisation of crop residues as fodder in smallholder farming systems?
3 What low-cost but durable alternative bio-digesters could be used by smallholder farmers?
4 To what extent can improved circularity contribute to reducing greenhouse gas emissions?
5 What methods are suited for GHG emissions assessment in such crop-livestock integrated systems?
6 What are the best capacity-building approaches for farmers in implementing innovations (e.g. fodder preservation and use, manure management, water harvesting, post-harvest handling) that promote circularity?
7 What are the best capacity-building approaches for local implementing partners on developing programs that encourage circularity, data collection, and assessment of greenhouse gas emissions from farming systems?
8 What is the role of policymakers and key value chain players in creating an enabling environment for promoting circularity in the food system?

2.2 Multiple on-going industrial symbiosis initiatives for a transition to a circular agri-food system on a tropical insular territory

By Vivien Kleinpeter, Jonathan Vayssières, Pascal Degenne, Jean-Philippe Choisis, Tom Wassenaar, Danny Lo Seen, Mathieu Vigne

Introduction

Réunion is a French insular territory situated in the Indian Ocean. Like several tropical islands, Réunion has a high and growing human population (342 inhabitant /km2, +0.5% per year) that fuels two conflicting dynamics: an increasing need in food and a decreasing availability in agricultural land due to urban sprawl. Pushed by resource and land limitations, Réunion chose to both import human food and set up high-input agricultural production systems that rely on imports of mineral fertilisers and raw materials for animal feed. The food system relies mostly on the imports of about 430 000 tons fresh matter (tFM) of human food, including 70 000 tFM of drinks (French customs, 2019). The local agricultural area (41 940 ha) is mostly export-oriented: 54% is sugarcane, intended for the export of sugar, 29% is grassland (grazing and production of hay and wrapped hay), intended for the local livestock production systems and 13% is fruit and vegetable, mainly intended for the local market (Table 1). The local agricultural production itself relies heavily on imports: about 30 000 tFM of mineral fertiliser and 200 000 tFM of cereals and soybean meal to produce animal concentrate feeds (French customs, 2019). No mineral fertiliser production or extraction are performed in the territory, the use of local agricultural inputs only consists of the use of biomass. The local production covers the demand and consumption at 40 % for meat and 70% for fruits and vegetables (Table 2.2.1). Réunion being a European ultra-peripheral region, and a large part of the imports coming from continental Europe, long transportation distances are required (9 000 km by air, 14 000 km by sea).

This globalised agri-food system (AFS) has numerous negative externalities such as nutrient surpluses, resources depletion and greenhouse gas (GHG) emissions. A transition to a circular AFS can potentially increase the island autonomy, partially mitigate these negative externalities and foster local economy. Biomass-based circular economy (CE) is particularly relevant for tropical volcanic islands, like Réunion, endowed with rich soils and higher crop yields.

Research question and methodology

We studied the opportunities associated with local biomasses used as agricultural inputs to increase circularity within the Réunion AFS and make the agricultural sector less dependent on imports. We also include in our study the local biomasses (by-products and wastes) potentially usable as agricultural inputs, although currently used by other sectors or eliminated (landfill or discharge to the sea). We put a focus on technical and logistical levers, e.g. those involving the technical and economical stakeholders holding the biomasses, as well as on material flows between local stakeholders at inter-firm level, i.e. on industrial symbiosis (Chertow, 2000) within the industrial metabolism (Ayres, 1989a, 1989b; Wassenaar, 2015).

The methodology used coupled a material flow analysis (MFA) (Kleinpeter et al., 2019) with a multi-stakeholder participatory approach (Vigne et al., 2021). The participatory approach consisted of an inventory of on-going industrial symbiosis initiatives, and for some of the latter a support for solving technical and logistical issues was provided using spatially-explicit modelling. The supported initiatives were chosen depending on the quantity of biomasses at stake, the potential benefits for farmers and the pertinence of the use of territory-level modelling.

Results of the MFA

Results of the MFA show that 585 000 tons dry matter (tDM) of biomass used or usable as agricultural inputs are produced in Réunion (figure 1). Except for grassland productions, all biomass is by-products and waste. The agro-industry sector is predominant, representing 58% of the production, followed by the agricultural (29%), urban (12,5%) and forestry (0,5%) sectors. Of these 585 000 tDM produced, only 325 000 tDM are used in agriculture (83 %) or urban sectors (4%), or eliminated (13%) (figure 2.2.2). The rest, which corresponds to 44% of the local biomass production used or usable as agricultural inputs, is lost (i.e. 260 000 tDM). These losses correspond mostly to important atmospheric nitrogen and carbon emissions due to intermediary processes like biomass combustion, anaerobic digestion or composting. 88% of the emissions consist in the combustion of bagasse to produce electricity, from which the ashes are then used as fertiliser on agricultural soils. Intermediary processes include economic activities such as the business of recycling waste material into soil input and/or animal bedding.

The biomass is used by the agricultural sector as animal feed, animal bedding, fertiliser, amendment, soilless substrate, mulch and substrate to levelled land. Inter-firm biomass flows include the transfers between farms.

In Réunion the transfer of biomasses within the agricultural sector is usually not restricted to on-farm level. While production systems are highly specialised, large flows are observed between farms such as for instance cane straws for feeding and bedding herds or off-farm manure spreading.

This MFA leads us to identify three main levers to increase circularity at territorial level: i) A large part of eliminated materials could be used in agriculture, e.g. urban biowaste as fertiliser, food industry waste as animal feed; ii) Atmospheric emissions could be reduced to increase nutrient conservation and carbon sequestration; iii) The efficiency of agricultural processes at both plot and herd levels could be increased by better matching available inputs (fertilisers and feeds) with plant and animal needs.

Results of the participatory approach

Results of the participatory approach show that the main stakeholders of the AFS in Réunion (farmers, cooperatives, industrials, energy producers, public and private waste management organisations and policy makers) are already involved in the transition to a CE. About twenty on-going industrial symbiosis initiatives were identified. All are expected to lead to a reduction in imports and an increase in the recycling of biomasses within Réunion. Four are in the design phase and were studied to co-build scenarios with the technical and economical stakeholders involved in order to choose the most realistic ones. Among the four, two were designed at the scale of the island and two on sub-territories. Three originated from difficulties in resource or waste management. The fourth originated from a changing legislation declaring mandatory the recycling of biowastes that are today deposited in landfills. They are thus mostly pushed by the need for solutions to technical and economic problems. The environmental benefits, such as climate change mitigation, are however also drivers in this transition, as funding institutions do take them into account when orienting funds to projects. In Réunion, reducing GHG emissions is especially relevant for the stakeholders, being themselves in a tropical area and thus particularly vulnerable to climate change (Mendelsohn et al., 2012).

Description of four industrial symbiosis initiatives

The first initiative, led by the Réunion Pastoralism Association, is to implement collective fodder storage units (Lorré et al., 2020). Fodder is produced in Réunion within a large diversity of pedo-climatic zones and there is a spatial heterogeneity between production and consumption zones. The current problem is a fodder deficit during the dry season. More (imported) concentrates are then used and/or sometimes hay is imported during the driest years. However, grass is still available on grassland during the wet season but some are not cut due to the lack of anticipation and storage capacity. According to experts, a part of the cane straw left today in the field could also well be extracted from the field without affecting yield. Spatially-explicit modelling showed that the surplus fodder could be collected and stored during the wet season, to make up for the fodder deficit during the dry season. The resulting import reduction of feed concentrates would be an economic benefit for the livestock farmers.

The second initiative, led by the Regional Chamber of Agriculture, is to spatially rearrange manure spreading plans (Jarry, 2019). Since about 2000, most livestock farmers (depending on the herd size) have had to set up a spatial manure spreading plan for each of their herds. Nitrogen and phosphorus thresholds per area spread are for example determined according to crop needs in order to avoid nutrient leaching. Spreading plans were set up over time by looking for plots that were not already in any spreading plan. New spreadable plots are needed when: i) new herds are being set up, ii) famers are willing to increase their herd headcount and iii) plots of spreading plans are being taken by urbanisation. The current problem is the difficulty for those farmers to find agricultural areas to spread manure close enough to reduce travel costs. Nearby plots are indeed often already in a spreading plan. However: i) some spreading plans were first defined with a supply of nutrients under the threshold, ii) some plots are not spread with manure anymore, or less than defined originally (e.g. the herd headcount has been reduced) and iii) some nearby plots are today spread by remote livestock farmers when they themselves have spreadable plots close to their stabling. Spatially-explicit modelling showed that spreadable areas at short enough distances could be used by livestock farmers. It also shows that the spreading today is unbalanced as farmers sometimes avoid the remote plots and over-fertilise the nearby ones. The economic benefits for the farmers are the reduced transportation costs and the savings due to less imported mineral fertiliser.

The third initiative, led by ILEVA, a public structure in charge of the treatment of urban waste, consist in establishing co-composting platforms that mix urban green wastes with manure to produce an organic fertiliser (Darras, 2019). Today, the structure treats urban green waste on several platforms by making shredded green waste. This is then sold as amendment, mostly to farmers but also to private individuals for their garden and the municipality for its urban green space. The current problem is that the product is not attractive. To clear the stocks when the storage capacities are full, the platforms often need to give them away for free. They also sometimes ask farmers to spread on any lands even when agronomic needs are already satisfied. After cyclones especially, the storage capacities are quickly reached. With low or null prices, the product can also be used for land levelling instead of as amendment to feed the soil and the plants. Co-composting the shredded urban green wastes with manure brings added value and matches the needs of vegetable farms for organic fertiliser. It also matches the need of livestock farmers as no spreading plan is required when the manure used is composted and marketed. It also frees up spreadable plots for other farmers as non-composted manure is not allowed on vegetable plots during the vegetative phase (for sanitary reasons). Spatially-explicit modelling showed that the decision-making rules of the public structure, the livestock farmers and the vegetable farmers are compatible with the production of co-compost. Economic benefits for the livestock farmers are a cost and time saving due to less distance travelled when the co-composting platform are closer than their spreadable plots. Composting of manure also means less quantity transported. Economic benefits for vegetable farmers are the availability of local organic fertiliser instead of expensive imported ones.

The fourth initiative, led by the Regional Council of Réunion (in charge of the elaboration of the Regional Waste Prevention and Management Plan), is to set up a door-to-door separate collection of organic wastes from households, collective restaurants, retailers and food industries, and to transform the wastes into fertiliser to be used in agricultural fields (Hatik et al., 2020). Today most of them are collected mixed with other non-organic wastes and deposited in landfills. This does not include the organic wastes already collected separately such as urban green waste and paper. The most ambitious process considered for obtaining a product adapted for use as fertiliser is anaerobic digestion (also producing biogas). In particular, it anticipates the necessity to organise the collection and reuse of such organic waste which will become legally mandatory by 2025. Spatially-explicit modelling was used to show possible scenarios that involve composting, shredding and anaerobic digestion plants. Benefits for farmers are the increased availability of locally produced organic fertiliser.

Does recycling biomass mean increasing circularity?

With these four initiatives, an increase in circularity is expected in terms of material flow. The initiatives plan to use more locally available un-used material and an increase in the material recycle rate (recycle material/ total wastes) can be expected. However, other results could be found when looking at the nutrient flows due to new processes in the system that could globally lead to more nutrient losses. For example, an uncertainty is to be considered for the third initiative where the composting process is a source of nitrogen emissions to the atmosphere (Ba et al., 2020). Also, these four independently designed initiatives might in reality interfere and the expected recycling could in reality take place only partially. For example, the manure-green waste compost may compete in the same market segment as the digested food waste based fertiliser.

Does increasing circularity reduce GHG emissions?

In order to evaluate the real potential benefits on climate change mitigation, a territorial carbon balance, including C storage and both direct and indirect emissions, e.g. using a "territorial life cycle analysis (LCA)" approach (Loiseau et al., 2018), is needed. For instance, all four on-going initiatives could decrease or increase GES emissions, depending of the emission segment.

On one hand, the reduction in imports of feed (initiative 1), fertiliser and amendment (initiatives 2, 3 and 4) means a reduction in indirect GHG emission due to their transport and fabrication. The reduction in local distance travelled (initiatives 2 and potentially 3) means less direct CO_2 emissions due to transport. The reduction in the spreading of fertilisers (initiative 2) means less direct N_2O and NH_3 emissions (and then secondary N20 emission). The production of energy (initiative 4) means less indirect GHG emissions due to the production and imports of fossil fuel (Table 1) and less direct emissions due to combustion. The use of compost instead of minerals (initiatives 3 and 4) also means less post-application GHG emission (Walling and Vaneeckhaute, 2020). The use of biowastes (initiative 4) means less GHG emission on landfill sites (Bogner et al., 2008). The use of more organic amendment (initiatives 3 and 4) means more carbon storage (Edouard Rambaut et al., 2021).

However, on the other hand, the potential increase of local distance travelled (initiatives 1 and 4) means more direct CO_2 emissions due to transport. The increase of the forage-to-concentrate ratio in the diet (initiative 1) could increase the CH_4 emission from enteric fermentation (Aguerre et al., 2011). The composting process (initiative 3) means more GHG emission during the pre-application (Ba et al., 2020).

Conclusion and perspectives

In conclusion, the agricultural sector in Réunion already participates in the AFS circularity from a material point of view(i.e. the recycling of wastes and the reduction of imports). The trend of the carbon balance is more uncertain as the desired modifications of the system could, depending on the emission segment, either increase or decrease GHG emissions.

The research is now continuing on three fronts: i) A nutrient flow analysis and an ecological network analysis of the whole island economy will be performed to assess the efficiency and the integration of the different sectors, including agriculture; ii) An integrated spatially explicit simulation model of the island AFS is under-development, using the Ocelet modelling platform (www.ocelet.fr). The four initiatives in the design phase will be simulated. A multi-criteria analysis of the potential benefits will be performed, including both circularity indicators and the carbon balance of the modelled system. We found it necessary to use a spatially-explicit model. It allows to calculate distance travelled by materials using the road network in order to: a) implement in the decision making the distance between the suppliers and the receivers; b) quantify the local GHG emissions due to local transport; iii) The coexistence of the four initiatives over time will be simulated to consider potential interactions (positive or negative) between them. Indeed, the four initiatives were designed separately but some are willing to change the same material destination and/or are willing to create new products with the same use. The expected effects (technico-economic benefits, circularity and carbon balance) could thus be different for each initiative if other initiatives are put in place at the same time. Also, the sum of the expected effects of the individual initiatives considered separately could be different from the overall effect of simultaneously putting in place the initiatives due to possible interferences. So an integrated, multi-criteria, territory level, and simulation based assessment of the multiple on-going initiatives is needed.

Table 2.2.1. Main characteristics of Réunion island

variable		unit	value
population[1]		inhabitants	860 000
area		km[2]	2 500
population density		inhabitant /km[2]	342
land cover[2]	forest and natural area agricultural area artificialized area	%	71 19 10
agricultural area[2]		ha	41 940
agricultural area per crop[2]	sugar cane grassland fruits and vegetables other (fallow, non-food, cereal, oleaginous)	ha (% among total)	22 700 (54) 12 237 (29) 5 402 (13) 1 601 (4)
agricultural area per inhabitant[2]		m[2]	557
number of farms[2]		unit	6 800
number of farms with livestock[3]		unit	3 750
average area per farmer[2]		ha	6,2
livestock population[2]	bovine porcine caprine ovine poultry	heads	29 289 68 977 11 921 3 454 3 647 000
local food production[2]	vegetables fruits meat (carcass equivalent) milk	tons row matter (% intended for the local market)	52 800 (100) 35 100 (90) 32 475 (100) 18 437 (100)
food self-sufficiency[2]	meat fruits and vegetables cereals	% of local demand and consumption	40 70 0
electricity production[4]	imported coal / used oils imported fuel oil / diesel fuel hydraulic photovoltaic / wind power/ biogas local bagasse local bioethanol	GWh (% of the total)	1 090 (36) 1 007 (33) 418 (14) 287 (9) 240 (8) 7 (0)

Sources: INSEE 2020, DAAF La Réunion 2020, DAAF La Réunion 2010, Horizon Réunion 2019.

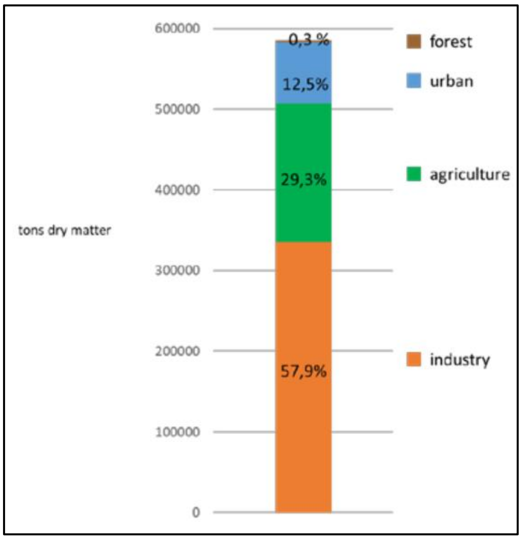


Figure 2.2.1: tons dry matter of local biomass used or usable as agricultural inputs produced in Réunion.

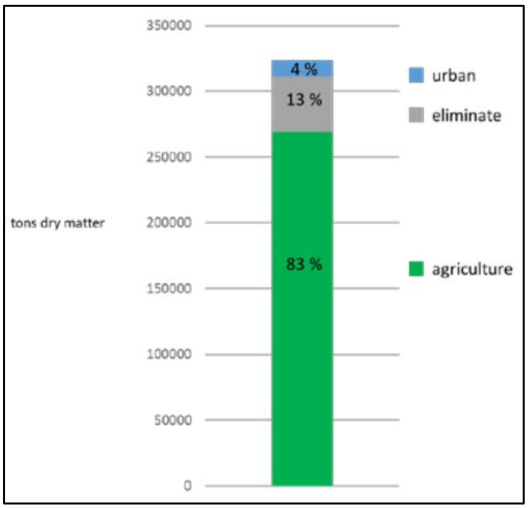


Figure 2.2.2: tons dry matter of local biomass used or usable as agricultural inputs in Réunion according to the destination: agriculture (soils, feed, animal bedding), urban (soils, feed) or eliminated (landfill or discharge to the sea)

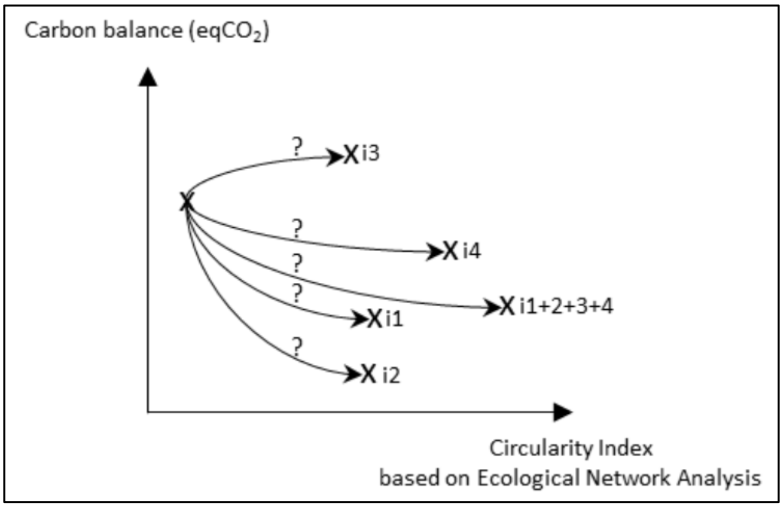


Figure 2.2.3: Hypothesis on consequences of the four industrial symbiosis initiatives individually (i1 to i4) and combined (i1+2+3+4) on circularity and the Carbone balance of the modelised system among the AFS agri-food system.

2.3 Achieving carbon neutral and resilient Mediterranean agro-food systems through the circular management of organic resources

By Ngonidzashe Chirinda, Mohamed Louay Metougui, Amine Ezzariai, Mohamed Hafidi, Naoufal Mahdar, Youssef Berriaj, Alberto Sanz Cobeña, Shamie Zingore, Hichem Ben Salem, Hazelle Tomlin, Richard Eckard

Description of the Mediterranean food system

A food system includes all the elements and activities linked to production, processing, distribution, preparation, and food consumption (HLPE, 2014). The traditional Mediterranean food systems in Southern Europe and North Africa are based on local agricultural products and emphasise the connections between biodiversity, local food production, culture and sustainability. Nevertheless, despite the traditional Mediterranean food systems having deep socio-cultural roots, increased globalisation and dramatic changes in regional food production systems and supply chains increasingly disrupt it with dire consequences on local production and more impoverished rural communities (González de Molina *et al.*, 2020). On the other hand, recurrent droughts, resource depletion, increased health consciousness and rising inequalities necessitate a return to less intensive (in terms of resource use) and locally-based production systems. Moreover, the traditional Mediterranean diet is presently gaining increased attention due to its health benefits and the Mediterranean culture and traditions (Saulle and La Torre, 2010; Springmann *et al.*, 2018). From an environmental perspective, Saez-Almendros *et al.* (2013) estimated that a return to a traditional Mediterranean diet would result in a >70% decrease in the agro-food system-based greenhouse gas (GHG). Despite local variations, the traditional Mediterranean diet is frugal and plant-based, with daily consumption of vegetables, fruits, legumes, nuts, whole grains, and unsaturated fats' food such as olive oil; a low (weekly) consumption of eggs and dairy products (mainly cheese); moderate but variable consumption of fish (depending on the local distance from the sea), and a low level of meat consumption (Trichopoulou *et al.*, 2014). Most of the Mediterranean fruits and vegetables were traditionally consumed fresh and, in some cases, preserved by natural preservation means. However, since the last quarter of the 20th century, fruits and vegetables have been subjected to highly mechanised processing to produce juices, sauces, and other products.

Problem statement

In the previous decades, the agricultural industry has become the main driver for urbanisation, economic development, and fast growth. In the Mediterranean region, the human population went from 281 million in 1970 to 472 million in 2010. It is currently estimated that from the ~500 million persons living in the region, more than 60% are living in the burgeoning cities. Currently, urban population growth is based on a linear food system supplying the necessary calories, albeit with enormous costs to human health and the environment. Population growth and higher incomes increase the flow of food from rural to urban areas. However, poor synchrony between food supply and demand and agro-processing creates massive amounts of organic waste in unconsumed or spoiled food or unused agro-processing by-products. For example, in Spain, France and Italy, more than 7.6 million, 9 million and 8.8 million tonnes of food are wasted each year (Charalampopoulou *et al.*, 2014; Capone *et al.*, 2016). In North African countries, an estimated 32% of the food is wasted, mostly in urban centers, with significant amounts of food wasted during social events and festivities (FAO, 2014). In the Mediterranean region, food waste is disposed of on dumpsites or landfill, where they present several challenges, including high landfill maintenance costs and greenhouse gas emissions of 4.4 Gt CO_2-eq per annum (Capone *et al.*, 2020) and health risks. However, since only a small fraction of the produced waste is currently valorised, there are considerable opportunities to valorise waste and increase circularity leading to sustainable use of nutrients, energy and matter. The Mediterranean area is also vulnerable to climate change due to recurrent and extended drought periods, water resource depletion, emerging plant and animal diseases and biodiversity loss.

Opportunities to increase circularity in the Mediterranean food system

The Mediterranean Circular Food Systems (Med-CiFoS) network will focus on increasing the visibility of organic waste production, the related management options and promoting environmental biorefinery and circular management of the agro-food component of Municipal Solid Waste (MSW). The network's goal is to explore opportunities for decreasing the amount of organic material deposited at dumpsites and landfills and increase the share of recycled by investing in the valorisation of organic waste. Reducing losses of carbon and nutrients in MSW and increasing their cycling in food systems is one of the critical imperative investments for building a sustainable food system at multiple levels and creating positive economic, social and environmental benefits. A possible way forward is to accelerate and scale circular economy strategies. The first step towards achieving this goal will be to map organic waste sources, drivers and attitudes responsible for organic waste generation in at least eight cities in Mediterranean countries. A combination of desktop studies, surveys and stakeholder workshops will be used. The resultant in-depth understanding of local production-consumption-waste management patterns will facilitate the exploration of benefits of circular management on local food security and determine carbon (C), nitrogen (N) and phosphorus (P) flows from agricultural lands to cities and potential flows from the selected cities to local farms. Focusing on local systems will enable us to identify the potential of various types of organic waste to produce bioenergy, livestock feeds and biofertilisers and also unlock opportunities for sustainable growth. A detailed assessment of components (crop, livestock, household) and overall system-level C, N and P balances at various spatial scales will be conducted to assess the critical intervention points that offer the highest prospects for reducing losses and enhancing the cycling of C and nutrients. Furthermore, the potential for recycling MSW to reduce the leakage of nutrients in the local food systems will be addressed using four key steps (i) estimating the quantity of

MSW of potential agronomic value; (ii) determining the nutrient value for replacing external nutrient sources; (iii) assessment of potential undesirable quality traits for crop nutrition and animal feed, including biochemical (e.g. secondary compounds, fungi, mycotoxins) and heavy metal contaminants and (iv) developing guidelines for integrated agricultural management practices that prioritise the use of local recycled waste products and optimised supplementary use of external resources. Organic waste treatment options will depend on the local context, the type of available organic waste and the local demand for different waste treatment by-products in the different regions.

Effects of improved circularity on mitigating greenhouse gas emissions.

Disposal of organic waste in landfills is an essential source of GHG emissions in the Mediterranean region. For example, a study conducted in Italy suggested that 14.3 million tonnes of CO_2 equivalent were related to food waste in 2012 (WWF-Italy 2013). The IPCC (2019) gives the regional defaults of municipal solid waste that originates from food as 36% and 50% in the Southern Europe and North Africa region, correspondingly. The fraction of municipal solid waste disposed of in open dumpsites is 79% in North Africa (IPCC, 2019). According to the IPCC (2019), almost none of the MSW generated in Southern Europe is disposed of in open dumpsites. On the other hand, 17% and 76% of MSW generated in North Africa and Southern Europe are correspondingly disposed of in landfills (IPCC, 2019). However, since those data are based on limited studies, they are associated with high uncertainties. These uncertainties influence the estimations of current emissions and an accurate assessment of the mitigation potentials of circular management of organic waste. Nonetheless, based on current understanding of GHG science, avoiding disposal of organic waste on open dumps and landfills results in the avoidance of GHG emissions, and the circular management of organic resources reduces fertiliser requirements and, consequently, GHG emissions associated with fertiliser production, which vary based on the production technology, feedstock and energy sources. For example, emission factors for urea production (1.3 to 5.5 kg CO_2-eq./ kg of N) are lower than those for ammonium nitrate production (3.5 to 10.3 kg CO_2-eq./kg of N) due to higher N_2O emissions from nitric acid production during the production of ammonium nitrate (Brentrup *et al.*, 2004; Walling and Vaneeckhaute, 2020).

Though studies are limited, a French report (ADEME, 2012) showed that GHG emissions from the composting of MSW vary widely (0-106 kg CO_2-eq./tonne of waste) based on the feedstock and the various parameters influencing microbial processes. In a recent study on food waste emissions, Jeong *et al*. (2019) reported CH_4 and N_2O emission factors of 0.17–0.19 g-CH_4 kg-waste^{-1} and 0.10–0.13 g-N_2O kg-waste^{-1} for the composting process. In the same study (Jeong *et al*., 2019), for anaerobic digestion, emission factors for CH_4 and N_2O were reported to be 1.03 g-CH_4 kg-waste^{-1} and 0.53 g-N_2O kg-waste^{-1}, respectively. The by-products of controlled aerobic or anaerobic treatments are also valuable soil amendments that increase C storage and provide nutrients to supplement crop growth. Other waste treatment processes that support circular food systems, such as feeding waste to insects and feeding insects to livestock, are expected to have lower GHG emissions than conventional livestock production systems (Oonincx *et al*., 2010).

Increasing circularity would reduce waste transportation to landfills typically done using heavy vehicles, representing a source of GHG emissions. Also, within landfill sites, additional GHG emissions result from waste movement and the use of bulldozers and compactors to manage waste heaps. At dumpsites, the open burning of organic waste results in different greenhouse gas emissions, including CO_2, N_2O and CH_4. The appropriate use of food wastes in livestock feeding could also contribute to the decrease of GHG emissions. The emission reductions could be achieved through balanced diets containing food wastes, mixing with tannin or saponin-containing feed sources or additives. Therefore, unambiguously, innovative recycling of organic waste resources will support low-carbon development.

Other socio-economic-environmental benefits of circular food systems

Circular food systems can lead to waste minimisation, increased economic benefits, reduced price volatility, increased revenue streams and employment growth (Ghisellini *et al*., 2016). Production models that replace the concept of "end of life" with circular food systems based on the reduction, alternative reuse, recycling, and recovery of materials contribute to improved livelihoods, economic growth, human health and the environment (Kirchherr *et al*., 2018). For example, new sources of income and jobs can be created when building the processing infrastructure, improving waste collection systems, waste processing, by-product packaging, and marketing, among other activities in the organic waste value chain. In the case of tomatoes, which are an essential component of the Mediterranean diet, those that do not meet food quality standards may be used as animal feed and feedstock for vermicomposting and other aerobic and anaerobic treatment processes (Fritsch *et al*., 2017). This implies the creation of more value and economic activity around what is currently considered waste.

At dumpsites and landfills, organic waste creates conditions conducive to the survival and growth of microbial pathogens and may also be a food source for enteric pathogen carriers such as rodents, insects, birds and large wild mammals (Mavropoulos, 2015). In addition, biodegradable waste represents a source of odors that increase the risk of illness (i.e., nausea, headaches, drowsiness, fatigue, and respiratory problems) for communities living near landfills or dumpsites (Steinheider, 1999). Therefore, reducing the amount of organic waste will mitigate the adverse health effects on communities living near dumpsites or landfill. Circular food systems also improve mutually rewarding linkages between rural and urban communities by fostering socially innovative, efficient and sustainable food systems that increase food security, create new by-products and jobs, reduce input costs, and create new and versatile markets for both high and low-quality farm produce.

Key knowledge or experimentation questions

Nitrogen (N) is both essential for food production but also the element most inefficiently recycled in agricultural systems, with >60% of the N in grazing systems and >30% N in cropping systems not recycling back into plant growth (Whitehead 1995). This N can be lost through nitrate leaching, organic matter leaching, denitrification and ammonia volatilisation, the latter two processes contributing to direct and indirect N_2O emissions, respectively. These losses have been exacerbated through cheap industrial sources of N, like urea fertiliser, which also comes with a relatively high embedded carbon footprint from manufacturing. Therefore, research aimed at improving the circularity of N in agriculture has both productivity and greenhouse gas benefits, with whole-system N balances being a handy indicator of the overall efficiency of circularity. The research to be conducted through Med-CiFoS will inform strategies to reduce reliance on highly labile inputs of N through improved recycling of organic waste streams. The research will also focus on comparing nutrient balances along more linear supply chains with local food systems and exploring these systems' options for improving circularity. Based on scientific experiments aimed at identifying suitable options and key elements to treat and/or valorise various types of organic waste to obtain biofertilisers, bioenergy and livestock feed (e.g. ensiling, pelleting, solid-state fermentation, introducing mixed animal diets). Aligning with the concept of feed-food safety, Med-CiFoS will also invest in checking the nutritive value and the availability of secondary compounds and toxins like mycotoxins in food wastes that will be distributed to animals. The potential transfer of these undesirable compounds to animal products will also be assessed, and better integration of food waste in livestock feeding will be recommended. Thus, Med-CiFoS will align with the concept of feed-food safety and show how food waste could be an alternative feed source to alleviate livestock feeding costs and reduce the water footprint of livestock-based systems and animal products. This intercontinental, multi- and inter-disciplinary and multi-sectoral network will generate information and evidence on the valorisation of organic waste and support the development of circular food systems in the Mediterranean region.

2.4 Challenges, opportunities, and research needs to improve circularity in the Peruvian food system

By Alejandro Parodi, Ian Vázquez-Rowe, Kurt Ziegler-Rodriguez, Gustavo Larrea-Gallegos, Ekatherina Vásquez

Main

Peru is the third largest and the fourth most populated country in South America. Its varied geography (i.e., coastline, highlands, and tropical rainforests) has shaped the cultural diversity of Peruvians since ancient times and has led to the use and domestication of a broad variety of crop and animal species. Food and agrobiodiversity are important elements of Peruvian identity and cuisine, allowing Lima to be currently recognised as the gastronomic capital of Latin America.
Peru has also been an important player in global food trade. During the 19th century, Peru was the major exporter of *guano*, a highly demanded agricultural fertiliser. Since the mid-20th it has been the main supplier of fish meal and, nowadays, has become the leading exporter of a wide range of fresh agricultural products such as green asparagus, blueberry and avocado. A large-scale and

export-oriented agricultural sector has flourished in recent decades, but still a great contrast exists with smallholder farmers, who occupy most of Peru´s agricultural land, safeguard the agrobiodiversity that Peruvians feel proud off, but are in most cases poor and food insecure. The aim of this short communication is to describe the current trends and challenges in the Peruvian food system and to identify opportunities and research needs to foster the transition towards more circular food systems.

1. Trends and challenges in the Peruvian food system

1.1 Fisheries

In the Pacific Ocean, both industrial and small-scale Peruvian fisheries coexist in an upwelling area which sustains one of the world's largest fisheries (FAO, 2020). Most of the fish biomass caught consists of anchoveta (*Engraulis ringens*), a low-trophic level fish species, which is fished by industrial vessels, and reduced to fishmeal and oil in different processing factories along the Peruvian coast. Most fishmeal is exported as feed (Figure 1), with China being the importer of nearly 90% of Peruvian fishmeal exports (PRODUCE, 2018). Small-scale fisheries are responsible for 10% of the reported landings, but unlike industrial fisheries, most of the catches are destined for direct human consumption in the national market (Figure 2.4.1). Even though small-scale fisheries play a key role for food security and employment in the fisheries supply chain (Christensen et al., 2014), the increasing fishing effort of small vessels is unsustainable and uneconomic for most artisanal fishermen (De la Puente et al., 2020). With the aim to increase the inclusion of fish in Peruvian diets and improve the income of small-scale fisheries, the Peruvian government has been promoting the consumption of anchoveta and other fish species for direct human consumption since 2011 via the program "*A comer pescado*" (i.e., let's eat fish!) (PRODUCE, 2019). Nonetheless, the existence of perverse legal incentives and informal networks that encourage the use of anchoveta landings for fishmeal reduction are blocking the mainstream use of this vast resource as human food (Majluf et al., 2017).

1.2 On-land agriculture

1.2.1 The Coastal region

Coastal agriculture, being close to seaports and the main urban settlements, has been characterised by being export-oriented and highly capital-intensive (Banco Mundial, 2017). The Peruvian coast is located in a warm and mainly hyper-arid region where agriculture is practiced in the valleys that cut through otherwise desert areas and in irrigated areas in which water is obtained from aquifers and recently constructed trans river basin diversion infrastructure. This region only represents 23% of Peru's agricultural land (Figure 2.4.2a & 2.4.2b), but contributes to nearly half of Peru's agricultural GDP (Banco Mundial 2017). The region produces crops for different markets, including high-value export-oriented crops (e.g., asparagus, table-grapes, mango, artichokes), industrial crops (e.g., sugar cane) and crops destined for food and feed purposes (e.g., maize, rice, sweet potato). Although highly productive, Peruvian coastal agriculture depends on an intensive use of external inputs (Bartl et al., 2012). The high application rates of (mostly imported) inorganic fertilisers have been identified as one of the main contributors to greenhouse gas (GHG) emissions of food products produced in the region (Vázques-Rowe et al., 2016; Morales et al., 2018). This high-input agriculture occurs near to Peru's most populated urban settlements. In big cities such as Lima-Callao, where one third of the Peruvian population lives, huge amounts of food loss and waste are sent to landfills or dumped (i.e., see section 1.3) and nutrients contained in human excreta are not reutilised in the food system (Vázques-Rowe et al., 2021).

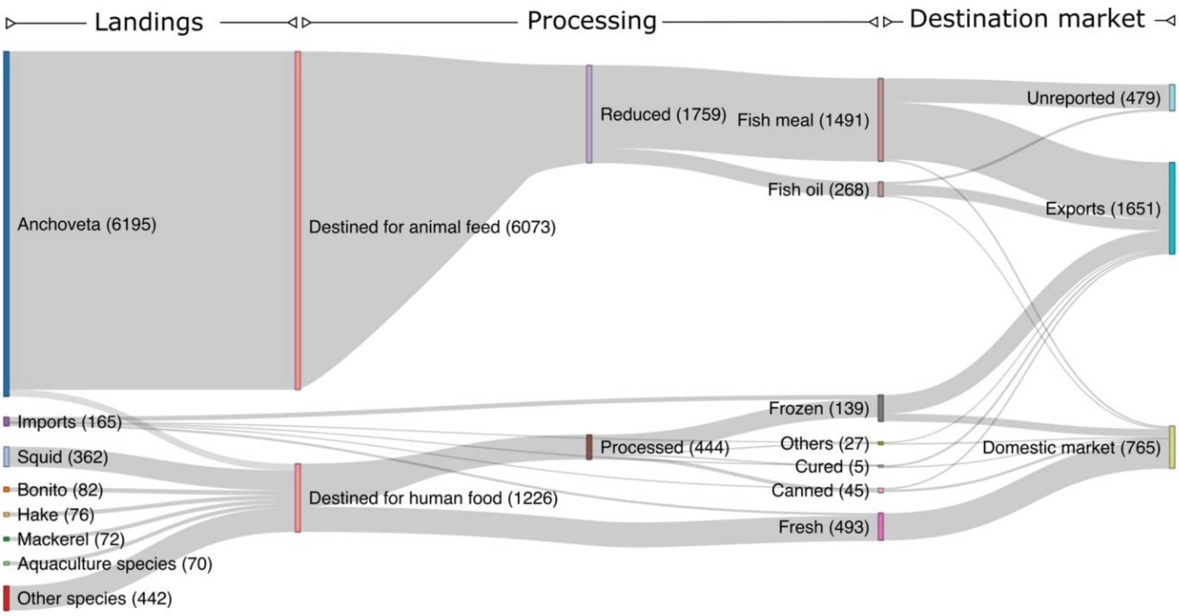
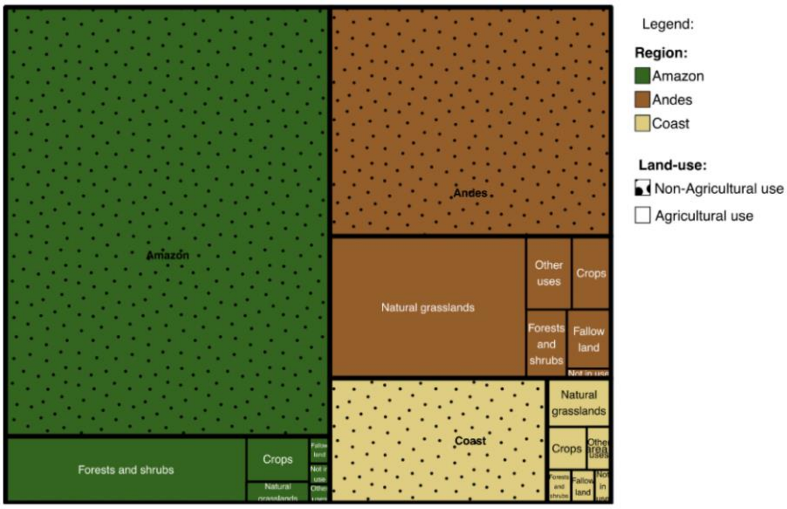


Figure 2.4.1. Biomass flows (thousands of metric tons) of the Peruvian fisheries and aquaculture sectors in 2018. Data were obtained from 2.

1.2.2 The Andean region

Andean agriculture is dominated by mixed crop-livestock smallholder farming in small agricultural units commonly smaller than 2.5 ha (MINAGRI, 2019). In 2012, nearly one third of the agricultural land in the Andes was destined for self-consumption (see Figure 2B). Nonetheless, Andean small-scale agriculture plays a key role for the provisioning of vegetables, fruits and animal products for Peruvian cities. Andean farmers use and maintain a vast crop genetic diversity (Torres-Guevera et al., 2017), produce foods with low use of external inputs (Bartl et al., 2011), and manage highland resources to obtain food and materials (Verzijl & Quispe, 2013), but many of them live below the poverty line (Eguren & Pintado, 2015). In addition, the slow onset effects of climate change pose an extra challenge, threatening their livelihoods and future food supply (Perez et al., 2010). To reduce poverty incidence in the region, the Peruvian government has been trying to involve small-scale farmers in the production of high economic-value crops for international and national markets (i.e., *Sierra y selva exportadora* program). High transaction costs, poor infrastructure for connectivity to markets, limited water reservoirs for irrigation, and high post-harvest losses are some of the main challenges to success on this aim (Banco Mundial, 2017; Díaz-Valderrama et al., 2020; Bedoya-Perales & Dal' Magro, 2021; Escobal & Cavero, 2012). The inclusion of small-scale Andean farmers in an export-oriented economy has potential to improve livelihoods, especially when participatory approaches are used to involve farmers in the supply of crops to added-value food chains (Devaux et al., 2021). However, if their inclusion is not implemented properly, it can cause significant changes in land use patterns, farming practices, and diets (Bedoya-Perales et al., 2018a; Bedoya-Perales et al., 2018b).

A)



B)

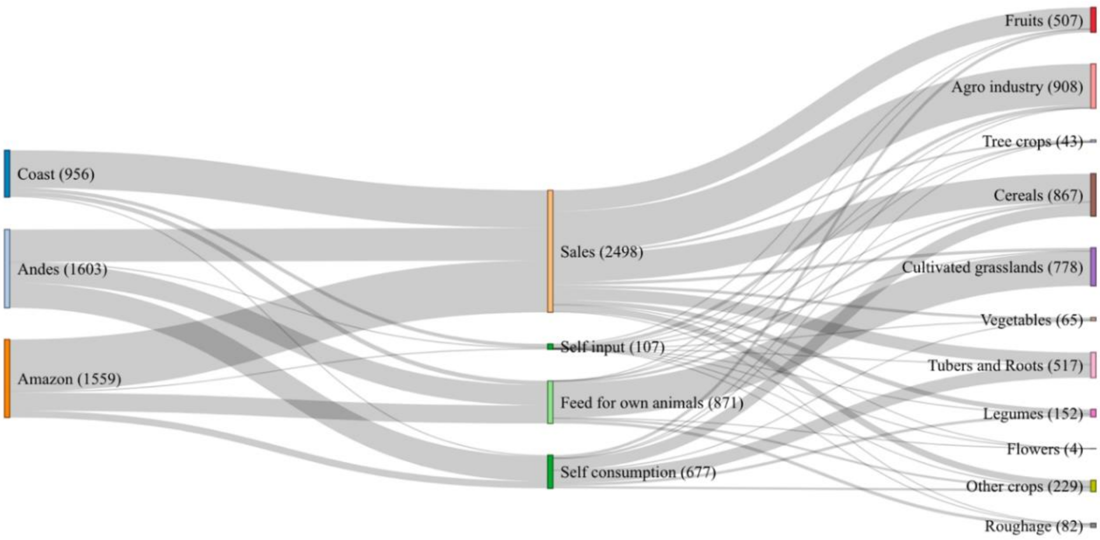


Figure 2.4.2. A). Land-use patterns in Peru by area (i.e., rectangle size), region (i.e., colour), and agricultural or non-agricultural use (i.e., background pattern). Most of the area under non-agricultural use corresponds to natural ecosystems (i.e., deserts, mountains and forests). The land use of the "crop" area of each region is shown in panel B. 2.4.2B). Use of the agricultural cropland per region, destination and type of food. All flows are based on cropland area (i.e., thousands of hectares). Data for both figures correspond to 2012 and were obtained from INEI (2012).

1.2.3 The Amazon region

The Amazon concentrates the highest biological diversity. Although population density is low, it is Peru's largest geographical region (Figure 2A). Despite its remoteness, most Amazonian cropland is used to produce food crops for the market rather than for local subsistence (Figure 2B). Local indigenous people have practiced for millennia a complex and long-term system of slash burn agriculture known to have influenced today's Amazonian tree communities (Levis et al., 2017; Roosevelt, 2013). However, they are commonly and sometimes unfairly blamed to be the main drivers for deforestation in the Peruvian Amazon (Ravikumar et al., 2016). Recent assessments have shown that in the past 20 years, the main deforestation drivers in the Peruvian Amazon were associated with medium and large-scale monocultures of cacao and palm, cattle ranching and illegal gold mining (Finer & Novoa, 2015; Finer & García, 2017). Recently, the Peruvian government promoted the implementation of agroforestry-based systems (Law N° 29763) as a way improve to improve the livelihoods of small-scale farmers, stimulate land restoration and halt deforestation to meet Peru's carbon reduction targets (Robiglio & Reyes, 2016). Coffee and cacao agroforestry systems have the potential to improve the livelihoods of Peruvian farmers (Pokorny et al., 2021) and ensure the provisioning of forest ecosystem services (Jezeer et al., 2019; De Leijster et al., 2021). However, without the adoption of good agroecological practices, land tenure measures and the consideration of farmers' interest and capabilities, deforestation due to land-use expansion is a permanent threat (Pokorny et al., 2021; Hotz & Guarín, 2014; Boeckx et al., 2020).

1.3 Solid waste management

Peru has a rudimentary waste management sector, mostly dominated by illegal open dumping. However, landfilling of all types of waste, including household organic waste and even agricultural residues, is recently overtaking open dumpsters as the main final disposition route throughout the country. Even though landfilling has the potential to alleviate some of the environmental and social impacts associated to open dumpsters (Ziegler-Rodriguez et al., 2019), most Peruvian landfills lack gas or energy recovery systems, which can lead to overall increases in GHG emissions. High levels of food waste and loss (FLW) that can reach 45% of the total food produced (Díaz-Valderrama et al., 2020; Bedoya-Perales & Dal' Magro, 2021), population growth, expected increases in organic waste share due to improvements in the average Peruvian diet (Larrea-Gallegos & Vázquez-Rowe, 2020) are all critical issues to be taken into consideration to establish a transition towards robust waste management systems. Recent Peruvian waste management evaluation studies have focused on mitigating GHGs via energy-recovery in landfilled systems. Nevertheless, even though this transition is thought to be gradual, it might be inefficient as it acts in detriment of the waste management hierarchy, where residue valorisation should be maximised (Margallo et al., 2019). Thus, it remains vital to quantify the GHG mitigation potential of existing and prospective circular practices that target the use of organic waste before it reaches the landfill. Examples of existing circular practices include the informal (but unsafe from a public health perspective) (Rosario & Miñano, 2014) and formal (Sinba 2021) use of food waste as pig feed. The recovery of food loss in the agro-export sector to develop value added products (e.g., pharmaceuticals, biomaterial) is a pending issue that will require further investment.

2. Problem statement

The Peruvian food system is highly heterogeneous and faces different challenges. Even though anchoveta is a highly abundant edible fish which could ensure a high-quality human nutrition in a country where malnutrition persists, nearly all biomass is reduced to fishmeal and exported to China to be used as livestock and fish feed in a clear case of food-feed competition. On land, the high-input and linear-oriented agricultural systems of the Coastal region have high yields, are profitable, but are carbon-intensive due to their high reliance on mineral fertilisers. This occurs in a context where there are limited incentives and intentions to adopt fertilisation practices based on the use of recovered nutrients from crop residues, urban waste streams or nutrients recovered from human excreta. In addition, due to the lack of investments to produce fourth range, value added products that can be exported through marine freight, some food products produced in the Coastal region are airfreighted abroad on a fresh basis, skyrocketing GHG emissions. In the Andean region, most smallholder farmers safeguard a high agrobiodiversity, use circular practices embedded in multifunctional crop-livestock systems, and obtain animal-based food and materials from natural grasslands, but many of them live below the poverty line. Andean farmers are being motivated to join an export-oriented economy but without proper implementation this could lead to negative outcomes for their traditional livelihoods. In the Amazon, the government has proposed the adoption of agroforestry-based systems to halt deforestation and improve farmer´s livelihoods. However, farmers operating under agroforestry systems use good agricultural practices and, in some cases, envision land-use expansion as a more likely alternative to improve their livelihoods, compared to increasing the productivity of current plantations. Lastly, the Peruvian waste management system is transitioning from the use of open dumpsters to landfill systems. While this is a positive move, most of the implemented landfills lack gas recovery systems and no further technological improvements have been considered (e.g., anaerobic digestion or incineration). This could lead to overall increases in GHG emissions, especially considering the upcoming trends in dietary changes. So far, most of the attention on mitigating GHG emissions from FLW has been on formalising the waste sector and using gas and energy recovery systems, while alternative waste valorisation strategies have had limited representation in the technical and political agendas.

3. Opportunities to improve the circularity of the Peruvian food system

Peru´s Ministry of the Environment (MINAM, using its acronym in Spanish) launched a new initiative in late 2019, named *Plataforma Perú Circular*, which aims to build agreements between

the private and the public actors, especially in food-related sectors such as fisheries and agriculture. In parallel, other national ministries related to the primary sector (e.g., production, agriculture) have recently initiated conversations with stakeholders to establish a roadmap on circularity. Additionally, the recent creation of environmental management schemes, such as the nationally determined contributions (NDCs), include a set of mitigation actions for organic waste treatment, agriculture and forestry. The abovementioned initiatives show that there is a desire from public actors to incentivise circularity in the Peruvian food system. However, it is crucial that all these initiatives come together into an integrated national circular vision that tackles key challenges that the country is facing (see section 2), including food insecurity. Such vision should not only involve governmental and private actors, but also include farmers, academia and civil society.
Recent successful examples have shown the importance that market participatory approaches can have on the livelihoods of smallholder farmers when local and added-value food chains are created. Such chains disrupt the existing model established since colonial times based on the production and export of raw products and focus on the commercialisation of added-value food products for new markets (e.g., not only export raw potatoes or cacao seeds, but also export potato chips and chocolate!). Recently, an increasing number of local start-ups are becoming new actors in the food system by aiming to process locally added-value products for local and international niche markets. This scenario creates an opportunity to foster the utilisation of by-products in the circular economy, increase the competitiveness of the Peruvian food sector, foster innovation and recognise the value of traditional circular practices performed by smallholder farmers.

4. Research actions needed

To improve and foster the circularity of the Peruvian food system, we propose the following research actions:

- Evaluate at a food system level the effect that the inclusion of anchoveta for human consumption would have on dietary GHG emissions. Such assessment should not only focus on the impacts that this measure will have at the Peruvian level but should also consider consequences in the existing supply chains (i.e., rebound and ripple effects) that currently depend on imported Peruvian anchoveta fishmeal and oil.
- Quantify the environmental mitigation potential (i.e., GHGs, nitrogen and phosphorus eutrophication, water use) of the use of crop residues and urban-waste streams recovered from nearby cities (i.e., compost, nutrients extracted from human excreta) to reduce the high dependence on mineral fertilisers in the Peruvian coastal agriculture. Considering that circularity does not guarantee reductions in environmental impacts (Schaubroeck, 2020), such assessments are key to foster a transition from linear to circular agricultural practices in the region and to keep the sector competitive by meeting future environmental demands of international markets (i.e., US, EU).
- Assess on a quantitative and qualitative basis the current use of on-farm traditional circular strategies used by Peruvian farmers and their contribution to the national food supply. A national benchmark is crucial to recognise the dimension that these practices have for national food security, to value them, and to implement participatory approaches to optimise them via the implementation of local added-value supply chains.
- Evaluate the current yield gap of crops produced under agroforestry-based systems in the Peruvian Amazon and estimate how much it could be reduced by treating and reusing postharvest waste and improving the use of fertilisers and nutrient recycling.
- Quantify the mitigation potential of existing and potential alternative waste valorisation strategies (i.e., composting, animal feed, production of insects) that target the recovery of nutrients from waste streams to be reused in the food system and compare their performance with energy-focused waste management strategies.

2.5 Rice husk soil amendments as a GHG-mitigating piece of the circular rice production system

By Benjamin R. K. Runkle, L. Seyfferth, Matthew C. Reid, Matthew A. Limmer, Beatriz Moreno-García, Colby W. Reavis, Michele L. Reba, M. Arlene A. Adviento-Borbe, Jasquelin Peña, R.M. Pinson

Introduction: Thorough description of the food system in the region, plus current developments and trends in the food system.

The Lower Mississippi River Basin in the mid-south United States grows over 60% of the US's rice output (USDA-NASS, 2021). The states in this region (Arkansas, Louisiana, Mississippi, and Missouri) rely heavily on the agricultural sector for employment, income, and identity. As an example, in 2019, agriculture was responsible for nearly 10% of Arkansas' gross domestic product; of this amount, 1.5% and 5.9% were from agricultural production and processing respectively (English et al., 2020). The sector will also likely be asked to play a role in generating "natural climate solutions" through build-up of soil organic matter and avoidance of greenhouse gas (GHG) emissions such as methane (CH_4) and nitrous oxide (N_2O). Such initiatives will be built among a backdrop of active conservation efforts – many farmers in the region are working to reduce groundwater consumption and deliver biodiversity, wetland, and water quality ecosystem services (Reba et al., 2013)**.**

Typical rice production practice in this region is highly mechanised and productive, where average county yields range around 8.3 t ha^{-1}. (USDA-NASS, 2021). Widespread practices include planting hybrid seed (~60%), drill seed planting into dry soil (84%), and delayed flood irrigation (Hardke, 2020). Innovations in irrigation management include precision leveling (even to zero grade), multiple-inlet irrigation via polypipe, furrow irrigation, and alternate wetting and drying, where each is incentivised to varying degrees through public and private conservation programs (Reba and Massey, 2020; Shew et al., 2021). Most rice is then stored, handled, processed, and milled in the state where it is grown; and approximately 50% of rice produced in the US is exported.

Despite the advances in production, there remains space for improving yield outputs (Espe et al., 2016; Yuan et al., 2021). There are also opportunities for increased implementation of sustainability practices; for example alternate wetting and drying irrigation (AWD), which can reduce field CH_4 emissions by 64% (Runkle et al., 2019) and water use by 39% (Atwill et al., 2020) is applied on less than 3% of rice fields in Arkansas (Hardke, 2020) despite being economically competitive (Nalley et al., 2015). There are also economic opportunities to reduce water use, herbicides, diesel, and labor to increase the competitiveness of rice from this region (Watkins et al., 2021). After harvest, rice production also generates significant leftover material, including the 20% of the harvested rice weight that is husk, removed in the milling process.

In this region there is developing interest from across the rice sector (including consumers, farmers, millers, and supply chain partners) to enhance the sustainability of rice production. There are interests that vary from climate change mitigation and adaptation, economic feasibility, soil health and biodiversity promotion, and grain quality improvements. Fortunately, we see several opportunities to improve in many of these areas through implementation of practices that also reduce the loss of raw biomaterials, namely rice husk amendments into rice field soils. We hypothesise that these amendments will enable a suite of beneficial, sustainable production practices.

Problem statement

There are multiple sustainability needs in rice production, including to: (1) minimise the climate impacts of rice production; (2) reduce irrigation water use; (3) limit toxic metal(loid) accumulation in rice; (4) improve nutrient use efficiency; (5) close the Si cycle in paddy environments; and (6) reduce the waste products associated with rice processing systems. We propose a focus on the reuse of rice husk as a field amendment to simultaneously resolve these and other rice production challenges and as a step forward in the circularity of the rice production system.

Opportunities to increase circularity in the food system, as was addressed in the abstract.

Rice husk comprises approximately 20% of the harvested grain by mass, and globally ~5 Tg are produced annually. Presently, rice husk is largely regarded as a nuisance or worse; its disposal can be a challenging waste stream for millers (Kumar et al., 2016). When burned as a low-value fuel, it can even create ash that is carcinogenic due to the respiratory silica particles (Okutani et al., 2018) and still requires landfill of the residue. We argue that the present use of rice husk is relatively inefficient and difficult to scale. Indeed, many uses for rice husk have been explored (Sun and Gong, 2001), including for sorbency properties in wastewater treatment (Daifullah et al., 2003; Ahmaruzzaman and Gupta, 2011) or oceanic oil spills (Kumagai et al., 2007), an energy source (Pode, 2016), animal bedding (Corrêa et al., 2009) or a source of silica for nanomaterials (Shen, 2017). However, we argue that these uses all represent extractive uses of the husk, and that its return to the field may offer compound benefits, in GHG terms and in delivering many more co-benefits for sustainable production. This view aligns with Principle 2 of circularity in agricultural production (de Boer and van Ittersum, 2018), that by-products of production should be recycled back into the food system, for soil quality and other benefits.

The return of husks to the fields on which they were grown offers an attractive approach amenable to bio-circularity. The silicon (Si) content that makes them unappealing for use as animal fodder is an essential nutrient for grasses, including rice (Savant et al., 1997b, 1997a). Application of Si-containing materials can boost yields through physiological mechanisms like improved posture and agronomic benefits such as improved fertiliser efficiency (Pati et al., 2016; Cuong et al., 2017; Mohanty et al., 2020) and resistance to abiotic and biotic stresses (Seebold et al., 2001; Tubana et al., 2016). Husk amendments specifically provide a plant-available Si that improves yield (Teasley et al., 2017) and act as a slow-release fertiliser (Linam et al., 2021). They also provide a degree of resilience against drought stress (Chen et al., 2011) and increase water use efficiency (Agarie et al., 1998; Nwugo and Huerta, 2008)**.**

The mills and other parts of the rice production system may need some modification to enable the return of husks to the farm. For example, mills would need to separate the husk waste stream from other wastes, including weed seeds separated from the harvested grain. Additionally, work is needed to incentivise transport back to the farm (for example, by trucks that would then bring stored grain to the mill) and study husk application methods and timing on the field.

The effects of the opportunity to improve circularity on mitigating greenhouse gas emissions.

Husk additions have the potential to enable practices that reduce field emissions of CH_4 and N_2O while also building up stores of soil organic matter. The increased drought resilience and fertilisation effects of husk Si may enhance the agronomic effectiveness of AWD irrigation, which can significantly reduce CH_4 emissions while reducing water use (Linquist et al., 2015; Carrijo et al., 2017; Runkle et al., 2019). While AWD is known to increase N_2O emissions (Lagomarsino et al., 2016; Kritee et al., 2018), the increased nitrogen use efficiency of husk additions may enable reduced inorganic N applications, thus reducing one source of N_2O. In terms of soil carbon storage, the slower dissolution of husk and higher lignin content provide encouraging lines of evidence that husk can effectively build carbon stocks. There may be minor GHG costs associated with husk addition, such as increased microbial respiration of husk-derived carbon in the field and the CO_2 cost of transport from the mill to the farm. However, these costs must be evaluated in the systemic context that includes the eventual CO_2 costs of husk respiration or pyrolysis of current disposal strategies.

Off the field, husk addition may enable reduced agronomic inputs (of water, which requires pumping energy, and fertiliser and other agrochemicals, which require substantial energy for synthesis and transport). Thus, the energy reductions from these sectors can be associated with the husk addition, further reducing the net CO_2 cost of rice production.

Other socio-economic-environmental benefits of circular food systems that go beyond GHG emission mitigation.

Husk additions will also enable a reduction in toxic metal(loid) accumulation in rice grain. This challenge is most closely associated with arsenic (As) and cadmium (Cd). This public health threat includes arsenic and cadmium that can accumulate in rice grain via plant extraction from the field soils (Arao et al., 2009). These processes are greatly affected by water management, as anoxic, flooded conditions enable increased grain As concentrations (Ma et al., 2008) while oxic, drained soil conditions enable an increase in grain Cd (Li et al., 2019). These elements present a public health risk (Hojsak et al., 2015; Meharg et al., 2008) and are both toxic at low concentrations; the polished rice maximum level values are 0.2 mg kg^{-1} (As) and 0.4 mg kg^{-1} (Cd) (FAO/WHO, 2013).

Fortunately, there is evidence that husk additions can help reduce both elements from accumulating in rice grain. For As, its mobilised form is chemically similar to Si, so Si additions can outcompete As into the plant – on pathways developed by rice to facilitate Si intake (Ma et al., 2008; Meharg and Meharg, 2015). Husk has been successful in reducing grain arsenic levels through higher soil pore Si:As ratios (Seyfferth et al., 2016, 2019)**.** Si additions can also reduce grain Cd levels through increased biomass that dilutes plant Cd concentrations and increased soil pH that retains Cd in the soil (Seyfferth et al., 2016, 2019). Other biochemical mechanisms also work to inhibit Cd ion uptake in the presence of Si (Liu et al., 2013; Ma et al., 2015). As noted earlier, husk also provides some resilience against drought and other stresses; therefore its addition may create greater confidence for implementing AWD management, which induces toxic soil conditions and so is also a method to decrease As mobilisation (Maguffin et al., 2020).

Beyond these benefits, soil amendments provide a key step towards producing a regional culture of regenerative agriculture (Schreefel et al., 2020). This type of agriculture can be incentivised by public or private sector groups (Lal, 2020) and may enable a price premium for products grown that way (Yang et al., 2021). This economic incentive will likely be attractive across the supply chain, from farmers to mills and brands, provided these benefits are equitably distributed among the sector's partners (LeBaron et al., 2017; Borsellino et al., 2020).

What knowledge should be developed to further improve circularity in the food system and GHG mitigation by circularity principles: key knowledge or experimentation questions.

There are a number of future research aims to consider prior to implementing husk amendments on a large scale:

First, agronomic consequences should be weighed. Relevant questions include the rates, timing, and manner of implementation, and how this amendment boosts growth and interacts with other farm decisions. Since husk contains other nutrients, how can its use reduce other fertiliser applications? It is particularly important to do field-scale research in areas without a history of Si amendment to discover how effective this approach is in soils not traditionally considered Si limited. Previous research on Si amendments has tended to focus on Si-poor organic histosols (Deren et al., 1994; Savant et al., 1997b).

Second, environmental implications should be examined. For example, how does husk fare as a source of long-term soil carbon sequestration? How does it change the emission of CO_2, CH_4, and N_2O, particularly in concert with AWD water management? How does soil chemistry change, and do those changes in redox or pH conditions alter the relationship between metal(loid)s and grain chemistry? We also note that here we have focused on husk amendments rather than straw: straw has less accessible Si than husk (Penido et al., 2016), more labile carbon that could drive CH_4 emissions (Naser et al., 2007; Contreras et al., 2012), and is less effective in attenuating metal uptake (Penido et al., 2016). However, a beneficial use for straw, whether on-field or off-field, should be better developed and researched (Goswami et al., 2020)**.**

Third, systems needs should be analyzed. What are the logistical shifts and economic incentives needed to close the loop between farmer and mill? How can regenerative practices be recognised and rewarded within the supply chain in an equitable manner? Implementing systemic changes in agriculture requires partnerships among researchers, civic-society organisations, and supply chain partners to develop science-based conservation practices with predictable outcomes (Thomson et al., 2017). We also anticipate that while this work comes from a perspective of the US Mid-south production region, much of the ideas are transferable to other parts of the world where rice is grown. Research and experimentation is encouraged to discover and articulate the benefits and drawbacks of husk amendments and their role in the shift to a circular bio-economy.

2.6 Winter cultivation of legume beans instead of rice to reduce field methane emissions and use legume by-product for low methane emitting livestock and fish production in Bangladesh

By Ashraf Biswas and Arjan Jonker

Bangladesh is a country in the Southeastern part of Asia with a subtropical climate where agricultural production follows an integrated approach. Since hundreds of years, rice is a main food staple in Bangladesh and boiled rice is eaten at lunch, dinner and even at breakfast. The rice is generally eaten with some vegetables and as protein source pulses, meat, dairy or fish.

The production of rice requires water logging of fields during winter season, and it is well documented that this practice results in field methane emissions (IPCC, 2000). By-products of rice cultivation, including rice polish and rice straw, are commonly used for ruminant livestock production, combined with unscientific feeding and manure management resulting in large enteric and manure methane emissions (NZAGRC, 2017). Fish production is another important component of agricultural production in Bangladesh which can result in methane emissions from the pond (Ma et al., 2018; Rosentreter et al., 2021) because of the lack of proper fish feeding and management procedures. The objectives of this project are to reduce methane emissions with an integrated approach of legume beans, livestock and fish production.

Rice production in winter (dry season in Bangladesh) needs huge amounts of irrigation which facilitate methane emission through the anaerobic decomposition of rice stem and leaf in the water logged field. Instead of rice production, we propose to grow legume crops like French bean and Soya bean in the winter season.

Growing soybean and French bean crops instead of rice will reduce methane emissions emitted from the field as these crops do not need irrigation. Soyabean and French bean-based production systems produce more protein relative to rice which consists mainly of carbohydrates. Bean by products such as bean stem, leaf and covering offer a good source of high protein legume hay, which could be used as a feed for livestock. Soyabean oil is the main cooking oil used in Bangladesh, which is mainly from imported sources i.e. approximately 0.75 million metric tons in the year 2020 (Indexmundi 2021). Furthermore, soybean meal is used as the main protein source for livestock, poultry and fish feed and Bangladesh imported 0.235 million metric tons in the year 2020 (Indexmundi 2021). Growing bean-based crops during the winter season, instead of rice, could fulfil the demand of soybean oil and soybean meal in Bangladesh in addition to other crop by-products that can be used to feed ruminant livestock.

Livestock farming in Bangladesh is largely based on intensive housing systems and cow manure is transferred to a dumping pit, which is associated with CH_4 and N_2O emissions (IPCC, 2000). The climatic conditions in Bangladesh are suitable for establishment of simple biogas production plants at each livestock farm household to produce biogas from waste streams like manure (Singh, 2012). The biogas can be used as energy source for electricity generation or fuel for cooking, and will reduce CH_4 emissions from manure storage and spreading. The residue of the biogas plant is a slurry, which could be used as a organic fertiliser for crop production and it could be used as a nutrient source for plankton production in the pond for aquaculture. Usually, mustard oil cake is used for the plankton production in the pond in Bangladesh. Mustard oil cake is costly and ferments in the pond, resulting in CH_4 emissions. Using the biogas slurry will be an economic and environment friendly fish culture method for Bangladesh.

Therefore, replacing winter rice production with bean crop production and integration of biogas plant at each livestock farm will reduce methane emissions from the field, from ruminant livestock eating bean by-products, from manure using bio-fermentation and from fish ponds using bio-fermenter slurry. In addition, soil fertility will increase with legumes bean production and bio-gas slurry application. Furthermore, the need to import bean products (soybean meal, soybean oil) into Bangladesh and it associated transport greenhouse gas emissions will reduce. Finally, this circular system will reduce production costs of the agricultural commodity.

To proof that this circular system of bean based production system and bio-gas fermentation is a low

cost environment-friendly technology, establishment of methane concentration estimation system by the portable gas detector is required at every level of production system i.e. field, manure storage, bio-gas plant, fish pond and enteric animal emissions, which will be a first for Bangladesh.

Increasing methane emission along with increasing population of Bangladesh is alarming for a climate change vulnerable country. There is a need to address this issue with technology that is economically viable.

2.7 Regional opportunities to mitigate GHG emissions in the capital region Berlin-Brandenburg, Germany

By Barbara Amon, Federico Dragoni, Anja Hansen, Cornelia Weltzien, Thomas Amon, Annette Prochnow

Problem statement: The region Berlin-Brandenburg

The region of Berlin-Brandenburg combines rural areas with the capital city of Germany. The proximity to a large city allows investigating the whole food production chain, from agriculture to food processing, consumption and waste recycling. The metropolis of Berlin generates demand and market trends for new types of food from regional, environmentally, climate and animal-friendly production. At the same time, it is a source region for extensive residual material flows. Agriculture and the food industry are important pillars of Brandenburg's economy (BMBF, 2018).

Brandenburg´s agricultural soils are predominantly low-yield sites, which are characterised by high sand content, low humus content and a general lack of nutrients. Such sites are particularly affected by climate extremes and are already today characterised by low precipitation. The region of Lusatia, Branden-burg also hosts a post-mining landscape that is currently developed into a model region for research into the adaptation of land use to climate change and bioeconomy oriented value creation Wirtschaftsregion (Lausitz, 2020). Brandenburg offers very good framework conditions as a real-life laboratory for the development of plant cultivation solutions for the adaptation of cultivation systems to climate change and thus makes a highly relevant contribution to regional value creation and the protection of natural resources. A broad spectrum of solution options open up. This includes, for example, the physiological and plant-ecological characterisation of native cultivars adapted to the site conditions, the associated development of novel crop rotations, the integrated cultivation of crops and trees/hedges in agroforestry systems, and the development of circular mixed crop-livestock systems.

The region Berlin-Brandenburg has the highest density of agricultural, engineering, life and economic sciences research institutions in Germany. Here, we find an optimal showcase at a high readiness level for the establishment of circular food systems (CFS) where we integrate the food and the agricultural system. The capital region with rural Brandenburg and the central metropolis of Berlin is predestined to be a model region for the transformation to a circular food system.

Vision: The future circular food system in the region Berlin-Brandenburg

The UN 2030 agenda provides a framework to address the world’s current challenges and the agricultural sector is central to the achievement of nearly all of the 17 SDGs (FAO, 2017a; FAO, 2018a). The sector is expected to play a bigger role with projections revealing that global population growth to about 10 billion will increase demand and consumption of quality food (BMEL, 2020). However, the current global share of agriculture in total production and employment is declining, growth of yields has slowed, transboundary pests and diseases spread faster, a proportion of which are resistant to antimicrobials, natural resources are being degraded, biodiversity progressively lost and emissions increased (FAO, 2017b; Peyraud & MacLeod, 2020). Concurrently, only about 25% of total biomass produced yearly is harvested, leaving large amount of crop residues and agro-industrial by-products underutilised. In addition, food losses and wastes claim about 30% of agricultural outputs (BMEL, 2020; FAO, 2017b).

There is need for transformative processes, using systems thinking approaches, to integrate crop and livestock production effectively in the circular economy (BMEL, 2020). The livestock sector can play a key role in addressing, directly or indirectly, many of the global challenges (BMEL, 2020; ATF, 2019; ATF, 2020). Livestock can provide valuable ecosystem services through their direct interaction with land, vegetation, soil and habitat (FAO, 2018a).

However, livestock production has become increasingly de-coupled from crop production (ATF, 2021; Ghimire et al., 2021). The increased availability of cheap mineral fertilisers and animal feed, the high prices and subsidies in favour of cash crops in accordance with the soil-climatic conditions, the stable product prices and incomes and the increased economic competition between production areas (EIP-AGRI, 2017; Schut et al., 2021) provided the conditions for increased farm size and regional specialisation. There is a clear need for more circularity in agricultural systems, and an improved economic viability of a crop-livestock integrated systems (Ghimire et al., 2021; EIP-AGRI, 2019; European Commission, 2020; Lemaire et al., 2014; Sanderson et al., 2013; Vinholis et al., 2021).

The EU has resolved to strengthen connections between livestock and cropping systems and outlined research and innovation priorities to achieve it (EIP-AGRI, 2017; ATF, 2019). Through the farm to fork strategy, the EU strives at a transition to fair, healthy and resilient and economic livestock production systems with positive environmental impacts supported by precision farming technologies (European Commission, 2020). The EU Green Deal pledges to act to restore natural ecosystems and promote sustainable use of resources and improving human health (EU Green Deal, 2018). The deal advocates for digital transformation to speed changes in the agricultural sector and for adequate considerations to the trade-offs between economic, environmental and social objectives. Many European countries have recently installed climate laws where – for the first time – mandatory GHG emission reduction targets are set for the agricultural sector (Ecologic, 2020). The methane strategy has called to strike a balance between technologies, markets, changes in diets and to provide sustainable business opportunities for farmers (EU Methane Strategy, 2020; UN Coalition, 2021).

Concepts such as sustainable intensification, agro-ecology, agro-forestry, climate smart agriculture, nature based farming and conservation agriculture are of importance (FAO, 2016; Rockström et al., 2017; Van der Wiel et al., 2020; Wezel et al., 2015). They will contribute towards (re)connecting livestock and crop productions to achieve synergies and higher performance based on new feed sources, fertilisers and biocontrol solutions, and soil fertility (FACCE-JPI, 2020; UN Coalition, 2021). Hence, recycling carbon and nutrients, will lead to lower waste and emissions, especially of methane (EU Green Deal, 2018; EU Methane Strategy, 2020; FAO, 2017a; FAO, 2018a; FAO, 2018b; FAO, 2019a; FAO, 2020). Action is also required to support One Health approaches, minimise the use of antimicrobials, promote multi-stakeholder dialogue, strengthen regulatory bodies, promote improvement in production practices and treat welfare of animals as priority (FAO, 2019b; European Commission, 2020; Peyraud & MacLeod, 2020).

A better system level quantification and identification of mechanisms of transition from linear to circular bioeconomy is needed. There is evidence that nutrient exchanges among farms at regional level increases nutrient recycling and crop diversity (Nowak et al., 2015). Integrated modelling approaches using multi-criteria assessments, improved life cycle assessment and policy analysis tools will need to be strengthened (EU Green Deal, 2018).

We are currently at the cusp of unimagined opportunities with regard to progress in digital technologies to create smarter and circular agricultural systems. The principles of "Precision Agriculture" (PA) will be further developed towards a "Diversity by Precision" approach. While currently working towards adapting the production system to the environmental heterogeneity, within existing agricultural structures and production goals, the new Diversity by Precision (DbP) approach differs fundamentally. It aims to support changes of agricultural structures towards a higher level of diversity by cultivating more crops sequentially (crop rotation) or in parallel (agroforestry, patch cropping, multi cropping), and by integrating livestock into mixed crop-livestock systems. The research goal is to strive for diversity as a management goal in agricultural production by applying digital tools for knowledge based, precise, dynamic and adaptable process control.

Concept: The Leibniz Innovation Farm for Sustainable Bioeconomy

Concept of the Leibniz Innovation Farm

In 2021, the Leibniz Institute for Agricultural Engineering and Bioeconomy (ATB) started to coordinate the development of the "Leibniz Innovation Farm for Sustainable Bioeconomy". This is a unique model farm for circular bioeconomy, where Leibniz institutions and universities will perform joint inter- and transdisciplinary research. This network also includes companies and associations, favouring stakeholder dialogue to secure the acceptance and implementation of the innovative methods. The aim is to make better use of natural resources in the Berlin-Brandenburg region and to jointly develop a holistic approach for a sustainable bio-based circular economy where sustainable crop and livestock agriculture, healthy food, biobased materials and residue management are optimally linked to each other. The objectives of the Leibniz Innovation Farm are resource efficient crop production, animal and environment friendly livestock farming, regional production of healthy food, cascade use of a variety of by-products, promotion of biodiversity and agro-ecosystem services, and new business models for farmers.

Innovations in sustainable farming aim to close nutrient cycles, avoid losses, reduce GHG emissions and increase C sequestration. Key objectives are firstly a balanced C cycle and a self-sufficient supply of nutrients based on a detailed analysis of nutrient streams, secondly the correct dosage and synchronisation of nutrient provision for the requirements of the crops, aiming to the best integration of crops with food and livestock production. The role of livestock production in circular sustainable Agro-Food Systems will mainly focus on the conversion of biomass that cannot be eaten directly by humans to high value proteins. With livestock production, the most urgent problems are currently the emission of nitrogen compounds and GHG, the spread of antibiotic-resistant pathogens and the link between animal welfare and environmental protection. The focus here is on livestock-agroecosystem-environment interaction.

The model farm is a forward-looking agricultural research facility in which innovative concepts are researched and put into practice through the integration and development of new technologies. The model farm encompasses the entire value chain of the bioeconomy (Fig. 2.7.1).

Figure 2.7.1: The Leibniz Innovation Farm supports a circular food system in the region Berlin-Brandenburg (drawing by Karré and ATB)

Aims of the Leibniz Innovation Farm

Regional production of healthy food and biobased materials: Circular food systems must produce healthy food in quantities and high quality that meet demand, and must also produce biobased materials for a wide range of uses as close to the users as possible. This can be achieved through a diverse range of crops and livestock, alternative sources of high-quality food and biomaterials, the conversion of diverse biogenic raw materials in decentralised biorefineries and the collection, treatment and recycling of residues. Digitalisation serves the purpose of monitoring the complex processes more precisely and controlling them ever more precisely. Knowledge-based microbiome management contributes to higher efficiency and stability of processes and resilience of production systems.

Closing nutrient cycles (N, C, P): Operational measures to reduce CO_2 emissions include C sequestration in soils through crop rotations and organic fertilisation, as well as the implementation of energy self-sufficient operation based on renewable energies. CH_4 emissions can be reduced through adapted ruminant feeding and an optimised manure management. To close N cycles, nutrient contents must be reliably recorded, fertilisers must be applied according to crop demand, the use of synthetic N fertilisers and emissions of nitrous oxide must be reduced, N in the animal diet must match the animals' needs as closely as possible, ammonia and nitrate emissions must be avoided. Digitalisation plays a key role in implementing precise fertiliser application in line with demand. To close P cycles, residues must be returned to the cycle in a consistent and risk-minimised manner. Innovative residue treatment processes play a key role in keeping biomass in the cycle in a way that minimises losses, emissions and risks. Most material transformation processes in the bioeconomy are caused or supported by microbial communities. The development and establishment of targeted microbiome management is therefore also a key factor in closing nutrient cycles.

Adapting to climate change: As a result of climate change, Brandenburg is expected to experience rising temperatures, decreasing precipitation during the growing season and a more frequent occurrence of extreme events such as heat, drought, heavy precipitation and storms (Drástig et al., 2011). Adaptation measures in crop production consist primarily of the diversification of cultivation systems, including the cultivation of heat- and drought-tolerant plant species and varieties, and the efficient use of water. In livestock production, the priority is to avoid heat stress, which is detrimental to animal welfare, health and performance. Digitalisation supports these adaptation measures by providing sensor-based, spatially and temporally high-resolution information on soil, plant, animal and environmental conditions.

Promote biodiversity: Today's agriculture is considered a major cause of biodiversity loss (German National Academy of Sciences, 2020). In order to promote biodiversity, cropping systems and livestock species must be diversified, the use of chemical pesticides must be significantly reduced, over-fertilisation must be avoided and emissions must be reduced. The range of plant species and varieties in diverse crop rotations shall be expanded. In animal husbandry, site-adapted mixtures of animal species and breeds contribute to a higher diversity not only of the livestock itself, but also of the landscape. Precision crop protection, non-chemical weed control, appropriate cropping systems and targeted microbiome management reduce the use of chemical pesticides.

Knowledge to be developed within the Leibniz Innovation Farm to further improve circularity in the food system

Three essential fields of action for innovations will be followed within the Leibniz Innovation Farm: diversification, digitalisation and microbiome management.

Diversification: In crop production, there is a need for far-reaching diversification of the range of species and varieties, the temporal and spatial rotation of crops and management. On the innovation farm, the existing crop spectrum of maize, cereals and arable grass is to be expanded and diversified. This is done in adaptation to the natural conditions, farm resources and requirements of the circular agro-food system. Additional crop species include large-grain legumes for the production of protein-rich food and small-grain legumes in under sown crops as well as fibre crops with multipurpose use for human nutrition and production of biomaterials. The crops are integrated into diversified crop rotations and new cropping systems, especially agroforestry systems and cropping systems with flowering plants. In livestock husbandry, diversification contributes to improving animal welfare and animal health, optimizing the use of regional nutrient resources and thus closing material cycles. On the innovation farm, several breeds of dairy cattle, suckler cows, ewes and goats are already kept in different utilisation directions and intensities, and barn and grazing management are practised. Diversification in crop and livestock production will also lead to a diversification in biomass use, residue management and energy management.

Digitalisation: Digitalisation and precision farming technologies are key in the implementation of circular food systems, reduction of GHG emissions and negative environmental impacts (Balafoutis et al., 2017; Tullo et al., 2019). Digitalisation in agriculture and biomass conversion offers the opportunity to manage and use diversity in a knowledge-based way. Autonomous machines, sensor technology, machine data analysis and the net-working of systems make machine information and the knowledge derived from it available at any time and any place, thus creating the conditions for implementing a highly flexible, knowledge-based control system for farm management measures. In the innovation farm, the latest methods of sensor technology, robotics, data processing and artificial intelligence for precision farming, precision horticulture and precision livestock production, digitalised residue conversion and comprehensive material flow management are used, investigated, further developed and demonstrated on a large scale and in a holistic approach for the entire farm.

Microbiome management: Microbial communities are the invisible and still largely unknown drivers of many material transformation processes on which the bioeconomy is based. Humans, soils, plants, animals, food and feed, bioconversion plants and residues harbour diverse and complex communities of microorganisms that interact with each other and their environment in a variety of ways and are transferred between the aforementioned elements of the bioeconomy. Rapidly developing technologies such as meta-barcoding, multi-omics, innovative microscopic methods and high-throughput cultivation are opening up entirely new possibilities for understanding and targeting the management of microbiomes (Krüger et al., 2020; Gutleben et al., 2018; Lewis et al., 2020; Shendure et al., 2017; French et al., 2021; Röttjers & Faust; 2018; Zheng et al., 2018), which are key to closing material cycles and promoting biodiversity and the shared health of humans, plants, animals and the environment (Berg et al., 2017; Boetius, 2019; D'Hondt et al., 2021; Hutchins et al., 2019; Trivedi et al., 2020).

2.8 Circular Food Systems: The Economic and Environmental Benefits of Integrated Farming System under Small-Scale Farm-Holdings of Tamil Nadu, Southern India

By Geethalakshmi Vellingiri, Gowtham Ramasamy, Priyanka Shanmugavel, Natarajan Sekkarapatty Kandasamy, Sakthivel Nalliappan, Subash Natarajan

Introduction

India has a population of about 1.3 billion, growing at 1.9% per annum, expected to double in 2070s. Currently, around 200 million people are reported to be food insecure. Unexpectedly, cultivable and irrigated area are shrinking at 0.5 and 1.3% each year respectively. In the 2050s, however, demand for food grains is anticipated to rise by 60%, meat by 173%, and dairy products by 158%.

Around 85% of the Indian farming community belongs to marginal and small farmer category who are resource poor. Lack of capital investments is a common phenomenon, making it unsuitable for single commodity farming that is being practiced in developed countries. It is imperative to focus attention on the whole farm approach by integrating various allied enterprises with cropping for better security, sustainability and productivity. Location-specific, low-cost farming systems were established with the goal of maximising the farm's existing resources and labour.

"Integrated Farming Systems (IFS)", is an inter-related set of enterprises with crop activity as base, integrated with livestock. In IFS, nothing is wasted, by-product of one system becomes input for other. IFS enables small and marginal farmers, who has less than one hectare of land for cultivation and a few heads of livestock, to diversify farm production, increase cash income, improve quality and quantity of food produced. This diversified farming system increases the risk bearing ability of the farmer by reducing the physical threat due to weather aberrations, biological dangers (pests and diseases), market hazards and to certain extent personal risks, that increases higher level of confidence and self-respect among the farming community. IFS also preserves vegetative cover, provides consistent supply of organic matter, improves nutrient recycling, and pest control through increased bio-control activity. Very importantly, IFS approach addresses sustainable issues of agricultural production and it helps in achieving the seven sustainable development goals (SDG-2030) of United Nations, i.e., no poverty, zero hunger, good health and well-being, responsible consumption and production, climate action, life below water and life on land.

Integration of farm enterprises depends on many factors such as edaphic and climatic features; availability of resources such as land, labour and capital; present level of utilisation of resources; returns from existing farming system; economics of proposed IFS and managerial skill of the farmer. In India, IFS is practiced under different environmental conditions such as wetland, irrigated upland and dryland ecosystems. In this paper, we describe the case studies of most common IFS practiced in Southern India in each of these ecosystems.

1. **Wetland Ecosystem: Case-study -1**

Wetland farming is practised in areas with assured water supply. Source of irrigation is mainly through surface water such as canal irrigation from the dams and other storage structure like tanks. Water intensive crops such as rice, sugarcane is grown. In Tamil Nadu, paddy is grown in about 1.93 million hectares. A recent study on the climate change and its impact in the Cauvery delta districts (known as rice bowl of Tamil Nadu) reveals a disturbing trend of shrinking paddy coverage, loss of *Kuruvai* [2]as a season (June – September), Samba crop (September - January) at the mercy of monsoon and importantly agricultural concerns turning more intense than ever before. Hence, there is a dire need to identify suitable IFS combining related agro-based activities to increase the income of the farmers. A case study on wetland ecosystem from the western agro-climate zone of Tamil Nadu is presented below.

Components: Rice crop (8000 m2) – Azolla in the rice field + Mushroom (with a production level of 2 kg / day) + Dairy (2 cows + 2 calves) + Fish-pond (800 m2 - 800 fingerlings) + Duck (100 birds) + poultry (40 birds) + Kitchen Garden around fish pond (200 m2) + Boundary trees + Vermicompost (50 m2) + Compost yard (100 m2) + Biogas.

Resource Recycling: From the crop, economic produces are harvested and used as food for human consumption, crop residue is fed to cattle. Rice straw is used as base for mushroom production, provides proteinaceous food for family. Dairy unit gives milk and meat. Manure from cattle goes to biogas plant for energy production and used for lighting and cooking purpose. The slurry from biogas plant and mushroom spent is fed to vermicompost unit for production of enriched manure for crop production. Poultry shed is placed on the fish pond. The droppings from poultry and ducks are feed to fish. Broken grains are used as feed for poultry and duck unit. Ducks also eat the larva and control the pest in paddy field. Nutritious vegetables from kitchen garden are used for family consumption. Coconut trees grown along the border of rice field, sequester carbon and provide income.

Economics: From IFS unit, farm income increased by 58% compared to crop alone. Family gets income of USD 1470 and generated employment for 1880 man-days per annum (Income (USD) / employment generated (man-days) from IFS components: Crop: USD 270/ 900 man-days; Coconut trees: USD100/ 25 man-days; Mushrooms: USD270/ 150 man-days; Dairy: USD 330/ 365 man-days; Biogas: USD160/ 100 man-days; Vermicompost: USD 90/ 120 man-days; Poultry: USD 60/ 100 man-days; Fish: USD 100/ 50 man-days; Duck: USD 60/ 50 man-days; kitchen garden: USD 30/ 20 man-days). By residue recycling, total quantity of nutrient addition was 272:98:235 kg N:P:K/ha. GHG emission reduction was 46%. Atmospheric carbon is sequestered with border trees.

2. **Irrigated Upland Ecosystem with surplus water: Case Study - 2**

Irrigated upland, known as garden-land, is characterised by growing crops with supplemental irrigation. The source of water for irrigation is mainly from underground water. A model of IFS to suit to small farmers of western zone for one hectare was analysed by Bhuvaneswari et.al (2020), and the result is presented as a case study.

Components: Out of one ha of garden-land IFS, cropping activity occupied 0.8 ha of land area (0.2 ha each of sugarcane, banana, turmeric and maize), fodder crops occupied 0.18 ha of land area (fodder sorghum and Cumbu-Napier grass) and the rest of the area (0.02 ha) is allocated for animal components (2 Dairy cows, 50 poultry birds and two units of vermicompost). The IFS model was compared with the conventional farming system (Rice, Groundnut, Maize cropping alone) in the same one ha of land.

Resource Recycling: Sugarcane, banana and turmeric are economically important commercial crops, providing cash income to the family. Maize grains are used as poultry feed and the surplus is sold

[2] Kuruvai season, also known as the 'short-term' seasons which typically occurs between June and September

for income. Maize straw is used as dry fodder and the biomass of fodder crop was used as green fodder for cattle. The crop residues are fed into vermicompost unit for production of manure using earth worms. Poultry droppings and cattle dung are used as manure for crops. Dairy and poultry units provide milk, egg and meat that paves way for regular income to the family, besides providing balanced nutrition.

Water Productivity and Economics: By integrating allied enterprises with crop activity, income and productivity was enhanced. IFS consumed lower water (14249 m3) compared to conventional farming system (22925 m3). The higher gross income of Rs.5,62,044/- was obtained with IFS model. Physical water productivity (8.26 kg m-3) and economic water productivity (39.44 Rs.m-3) was also higher under IFS compared to conventional farming system.

3. Irrigated upland Ecosystem with limited water supply: Case-study - 3

In the irrigated upland, water is the major constraint. The share of water allocated to irrigation is likely to decrease by 10 to 15 % in the coming decades (CWC 2018). Most of the small and marginal farmers have the issue of insufficient water for their cropping activity. To maximise the income and to reduce risk, farmers integrate multivarious agro-based activities in their farming.

Components for one hectare: Maize (4000 m2) + Vegetable crops (4000 m2) + Mulberry (1000 m2) + Fodder grass - CN grass (400 m2) + Dairy (2 cows+2 calves)-(40 M2)+ Poultry unit with 2000 broilers (400 m2) + Piggery unit - (5 Pigs) (40 m2) + Silkworm unit with rearing house for 40000 worms (50 m2) + Apiary (20 Beehives) + Vermicompost unit (50 m2) + Biogas unit (20 m2).

Resource Recycling: From maize crop grown in 4000 m2, economic produces are harvested and used as feed for broiler consumption and crop residue is fed to cattle. Vegetable crops (Bhendi, Brinjal, Tomato, Ribbed guard, Bitter guard) grown in 4000 m2 area, are used for home consumption to provide Nutrition, and excess vegetable is sold in the market for cash income. The vegetable waste is fed to piggery unit for pork meat production. Piggery unit waste is fed into vermicompost pit. Mulberry crop is grown in 1000 m2 area and the leaves are fed to 40000 silkworms. CN grass is fed to cattle, milk from the cattle is consumed by the farm family and excess milk is sold. Cow dung is fed into biogas plant for biogas production and is used for cooking and lighting. Vermicompost, biogas slurry and poultry litter are used as manure for all the crops. Honey bees help in better pollination and yield improvement of crops. Valuable honey is also obtained.

Economics: From IFS unit, farm income got doubled compared to crop alone. Family gets an income of USD 5260 in IFS system, besides family consumption valued to USD 1101. It was also quantified that USD 2140 worth of by-products were recycled within the system, that led to reduction cost of cultivation and increased environmental safety. External inputs usage was very minimum and generated employment for 2205 man-days. Under conventional system, the net income generated including family consumption was USD 1560 with 718 man-days per annum employment generation.

4. Rainfed Ecosystem: Case-study - 4

About 5.58 million hectares of agriculture land in the state of Tamil Nadu is under dry farming which depends mainly on rainfall as its source of water for crop production. Features of rainfed ecosystem are characterised by increased drought frequency due to changing climatic conditions, leading to rapid soil degradation and loss of soil fertility. Inadequate supply of quality inputs, dominance of traditional farming system, poor resources base and weak market linkages of farmers leads to a lot of uncertainty in the dry land production systems. Due to limited access to water and low soil fertility, farmers struggled to maintain a consistent income throughout the year with cropping alone. Hence, farmers integrate the cropping activity with animal rearing to maintain continuous flow of income for the family. As an example, common IFS followed in the western agroclimatic zone of Tamil Nadu is described below.

Components for one hectare: Agro forestry system including Fodder trees and rainfed Sorghum (4000 m2) + Agro Horticulture including fruit trees with short duration pulse crops (4000 m2) + Area for open grazing of animal (1000 m2) + Sheep / Goat (25 Nos) + backyard poultry (50 Nos) + Biofencing around the farm land + Farm pond.

Resource Recycling: Fodder trees like Supapul, Gliricidia, Neem, Surrogate, Agathi, Sithaagathi, Achan, Udiyan, Thespesia and Kalyana murungai trees are planned in organised rows. In the interspace of the trees, rainfed sorghum crop is cultivated. Protein and mineral content is high in the leaves and pods of these trees that are fed to sheep / goat. Cereal grains are also mixed to feed the animal, that helps in increasing the productivity by reducing the cost of concentrated feed. In Agro horticulture, drought hardy trees such as ber, custard apple are grown and, in the interspace, short duration pulse crops are grown. A small area is allocated for open grazing. During monsoon season, seeds of cereals, pulses and oilseeds are mixed together to increase quality and a balanced fodder for livestock. Animal protein, which is needed for humans, is available and the surplus meat is fetching regular income for the farm family. Sorghum seeds are used as feed for backyard poultry and in turn, poultry give eggs and meat for the family. It also fetches income for the family. Around the land area, bio-fencing with fodder trees like udhiyan, thespesia, kodukkapuli are grown. Such woody species could be planted in 4 to 5 m intervals and the small gap between these trees are filled with small trees like Supabul, Gliricidia planting. These trees should be pruned at 1.5 m height to generate new lateral branches, which can be used as feed for animals. From the bio fence, we can get 3 or 4 tonnes of fodder for sheep / goat annually. Sheep and goat penning results in very rich manure, that helps in improving the soil health. Water collected from the farm pond is utilised for giving protective irrigation during critical stage of the crop growth, which has improved the growth of the trees as well as crops.

Economics: In dryland condition, with conventional system of growing crops alone, realised income is only USD 300 and the family consumption is around USD 40 with employment generation of 80 man-days. With Dryland IFS, realised income is USD 2150, besides the family consumption: up to USD 230 worth of products from different components. With the IFS, from one component to another component, USD 375 worth of products are getting circulated. Employment generated for the family is 565 man-days.

Conclusions

Adoption of improved farming system models can result in higher food production to equate the demand of the exploding population of our nation. In all the ecosystems, it increases the farm income through proper residue recycling between the components, besides sustainably maintaining the soil fertility. Integration of allied activities also results in making nutritious food enriched with protein, carbohydrate, fat, minerals and vitamins available to the family continuously. Integrated farming will help in environmental protection through effective recycling of waste from animal activities like piggery, poultry and pigeon rearing. Regular stable income is ensured through the products like egg, milk, mushroom, vegetables, honey and silkworm cocoons from the linked activities in integrated farming. Inclusion of biogas & agro forestry in IFS will solve the prognosticated energy crisis. Cultivation of fodder crops as intercropping and as border cropping will result in the availability of adequate nutritious fodder for animal components. IFS models are mostly self-input generating, seeking minimum requirement of external resources from the market, able to generate year-round employment, effectively reduce GHG emission and check soil and nutrients erosions.

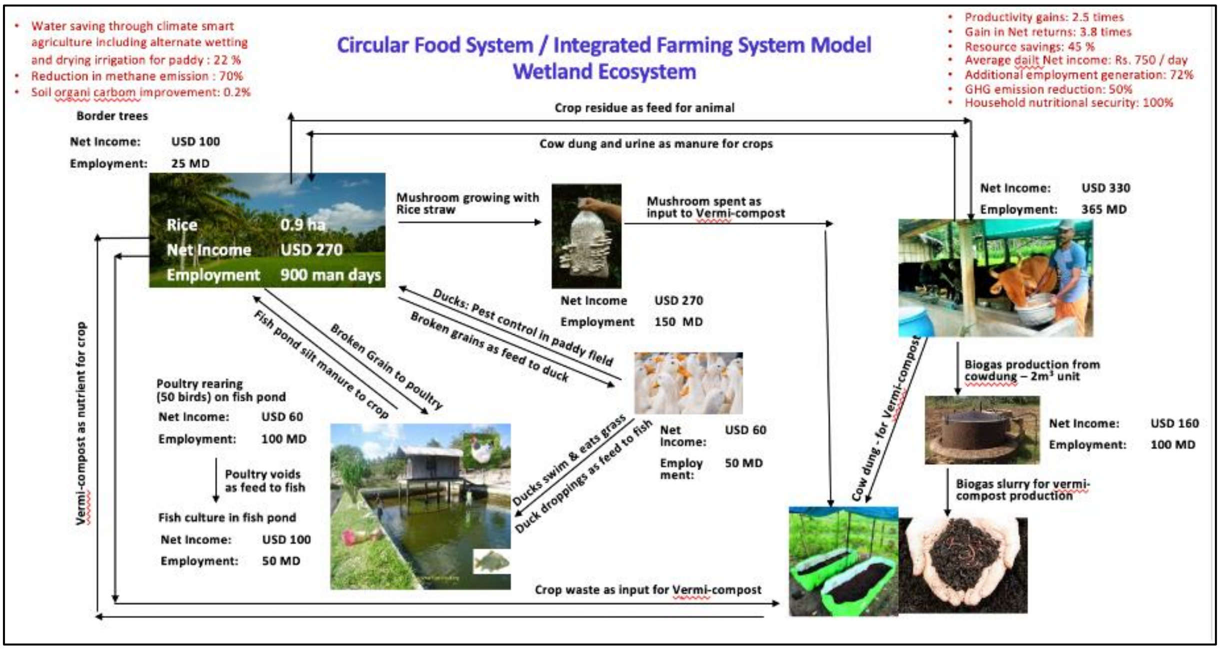


Figure 2.8.1: Resource recycling and economics of wetland Integrated Farming System

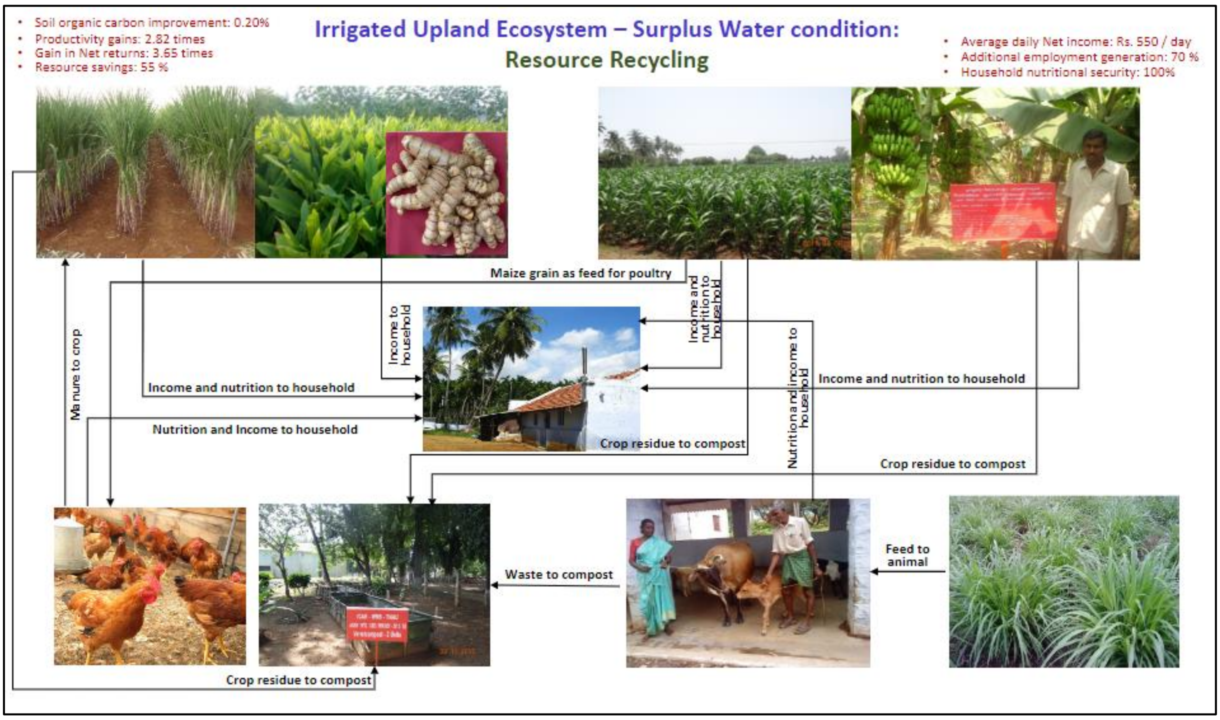


Figure 2.8.2: Resource recycling under IFS – irrigated upland ecosystem with surplus water

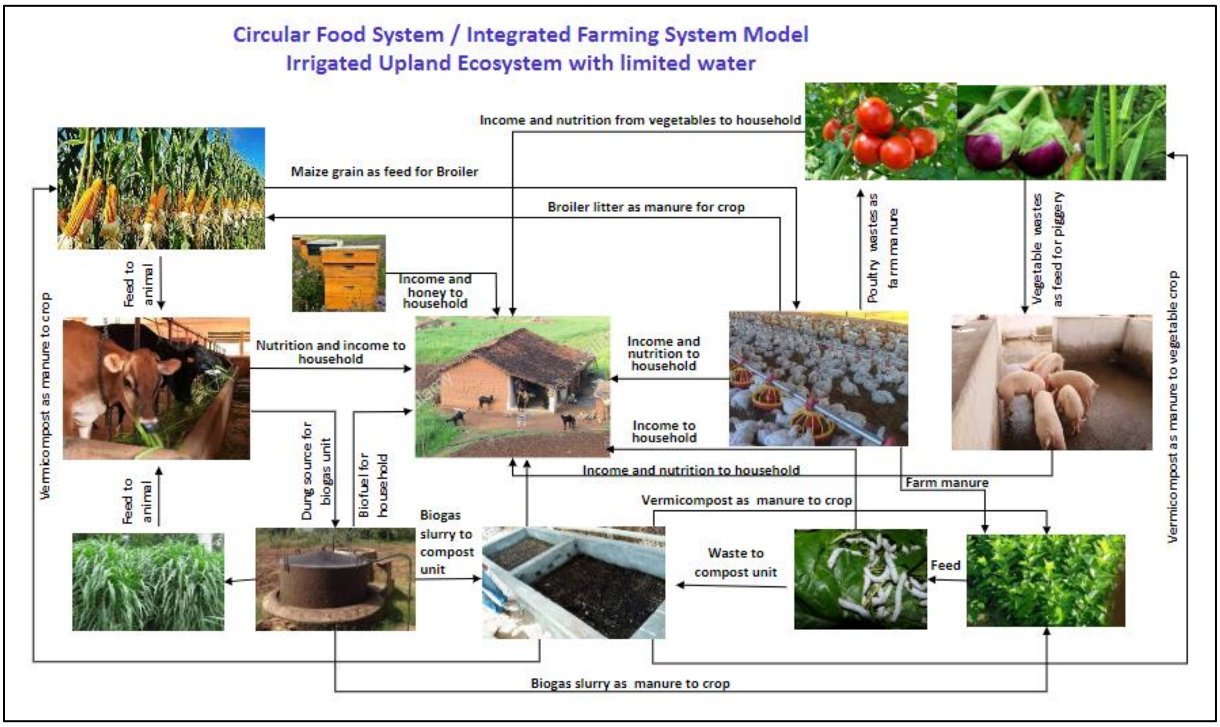


Figure 2.8.3: Resource recycling under IFS – irrigated upland ecosystem with limited water

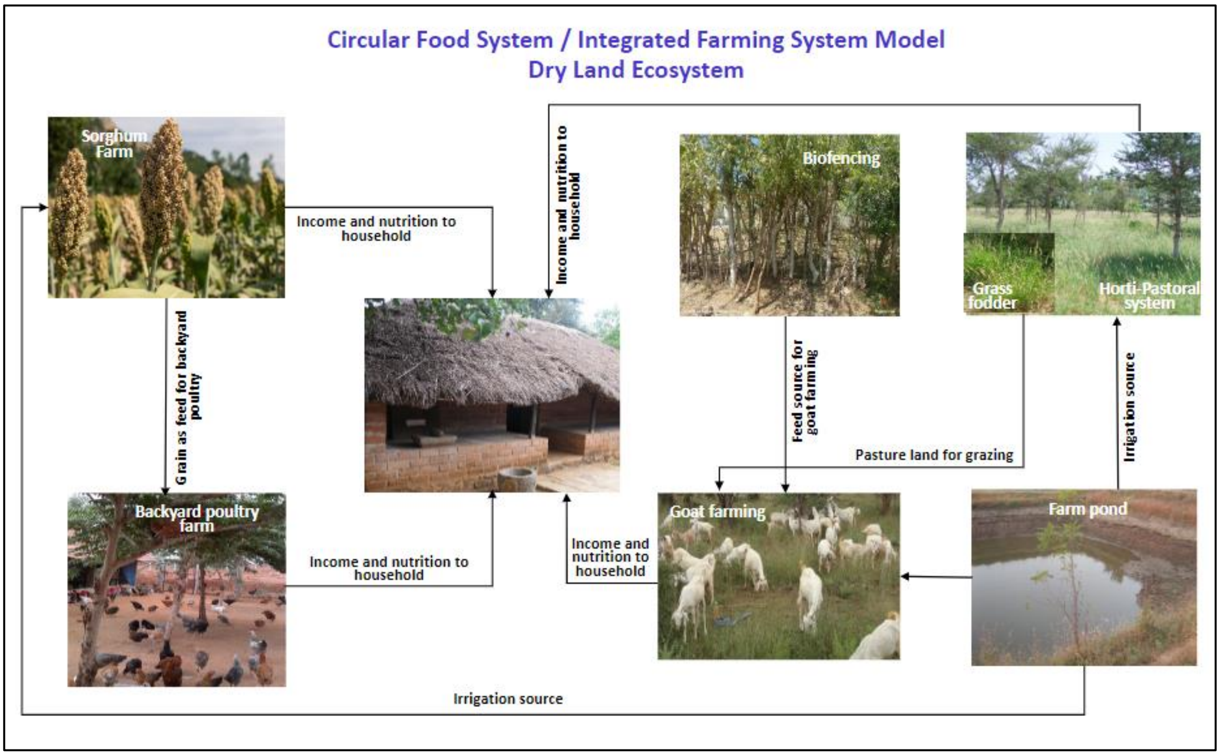


Figure 2.8.4: Resource recycling under IFS –Dryland ecosystem

Table 2.8.1: Comparison of performance of irrigated upland IFS (Sufficient water) with conventional cropping system (Adopted from Bhuvaneswari et al., 2020)

I. IFS Components in 1 ha	Area (ha)	Water usage (m^3)	Unit yield (kg)	Gross income (USD)	Water Productivity	
					Physical (Kg/m^3)	Economic (USD/m^3)
A. Crop components						
Sugarcane	0.20	2866	22250	701	7.77	0.25
Banana	0.20	3174	3325	1551	1.05	0.49
Turmeric	0.20	2047	5338	854	2.61	0.42
Maize	0.20	1076	1258	218	1.18	0.20
Fodder Crops	0.18					
a. Fodder s orghum		2039	5450	109	2.67	0.05
b. Cumbu Napier Grass		2942	2942	1085	18.44	0.37
B. Animal components						
Dairy – 2 cows	0.02	99.12	5017 lit	2341	50.61	23.62
Poultry – 50 Nos.		1.49	148	393	99.02	262.48
Vermicompost – 2 units		4.48	1805	241	403.30	53.72
IFS in 1 ha of land area	**1.0**	**14249**	117784	7494	8.26	0.53
II. Sole crop in 1 ha in conventional system						
Rice	0.33	11655	5225	1045	0.45	0.09
Groundnut	0.33	5275	1343	895	0.25	0.17
Maize	0.34	5995	5488	951	0.92	0.16
Conventional system in 1 ha of land area	**1.0**	**22925**	12055	2891	1.62	0.13

Note: Physical Water Productivity = crop yield / amount of water consumed; Economic Water Productivity = (crop yield x its price) / amount of water used (Bastiaanssen et al., 2003)

Table 2.8.2: Comparison of performance of irrigated upland IFS with limited water with conventional cropping system

I. IFS Components in 1 ha	Area (ha)	Employment generation (Mandays)	Gross Income (USD)	Cost of cultivation (USD)	Net income(USD)			Inference about usage within the IFS
					Used within IFS	Used by family	Realised income	
A. Crop components								
Maize	0.40	56	800	280	520			Feed for broilers
vegetables	0.40	658	1400	620		80	700	
Mulberry	0.10	48	420	150	270			Feed for silkworm
Fodder: CN Grass	0.04	365	250	50	200			Fodder for dairy
B.Animal components								
Dairy: 2 cows + 2 calves	0.06	365	3272	932		330	2010	
Broiler: 2000 Nos. x 3 batches in a yers		225	3350	1265	250	185	1650	Manure to crops
Silkworms: 40000 larvae		288	795	245	100		450	fed into vermicompost
Piggery unit – 5 Nos		90	770	150		220	400	
Vermicompost			700	50	650			Crop manure
Biogas		100	456	40	150	266		Slurry as manure
Honey bee		10	90	20		20	50	
IFS in 1 ha of land area	**1.0**	**2205**	**11503**	**3802**	**2140**	**1101**	**5260**	
II. Sole crop in 1 ha in conventional system								
Maize	0.6	60	1300	580			720	
Vegetables	0.4	658	1630	850		80	700	
Conventional system in 1 ha of land area	**1.0**	**718**	**2930**	**1430**		**80**	**1480**	

Table 2.8.3: Comparison of performance of Dryland IFS with conventional cropping system

I. IFS Components in 1 ha	Area (ha)	Employment generation (Mandays)	Gross Income (USD)	Cost of cultivation (USD)	Net income(USD)			Inference about usage within the IFS
					Used within IFS	Used by family	Realised income	
A. Crop components								
Agro forestry (Forage trees + Sorghum)	0.40	55	420	150	50	0	220	Leaves from forage trees to feed as animal + sorghum seeds as feed for broilers
Agro Horticulture (Fruit trees + Pulses crop)	0.40	55	550	160	30	120	240	Crop residue as feed for sheep/goat
Open grazing area	0.10	5	150	50	100	0	0	Grazing by animals
Bio-fencing around farm land		25	375	200	175	0	0	Leaves used as feed to sheep and goat
B. farm Pond	0.01	10						Collected water used for giving protective irrigation to crop component
C.Animal components								
Sheep / Goat – 25 Nos	0.09	365	2400	800	0	60	1540	-
Back yard poultry – 50 Nos		50	250	30	20	50	150	Manure to crops
IFS in 1 ha of land area	**1.0**	**565**	**4145**	**1390**	**375**	**230**	**2150**	
II. Sole crop in 1 ha in conventional system								
Sorghum	0.6	40	350	150	0	10	190	
Pulses	0.4	40	260	120	0	30	110	
Conventional system in 1 ha of land area	**1.0**	**80**	**610**	**270**	**0**	**40**	**300**	

2.9 Circularity in pastoral agricultural systems in New Zealand

By Vicki Burggraaf

The New Zealand food system

New Zealand's primary sector land use is dominated by sheep and beef farms, followed by dairying, forestry and then cropping (Table 2.9.1), with over 85% of our total food production exported. Over 100 varieties of fruit and vegetables are grown in New Zealand, with kiwifruit, apples, potatoes, avocadoes, onions, peas and cherries being the largest contributors to export earnings (Horticulture New Zealand, 2020), whilst vineyards occupy 28,360 hectares of land (New Zealand Wine 2021). In addition, approximately 256,000 tonnes of seafood was exported in 2020 (Seafood New Zealand 2021). This paper discusses circularity and greenhouse gas mitigation for sheep, beef and dairy farming systems, which are predominantly based on year-round grazing of perennial pastures.

Table 2.9.1. New Zealand farm types and land use (StatsNZ 2017).

Farm type	Farms	Total area (1000 ha)	% of total area
Sheep and beef	23,403	8,765	63.1%
Dairy	11,100	2,442	17.6%
Cropping	2,991	365	2.6%
Deer	783	261	1.9%
Pigs	150	8	<1%
Poultry	162	4	<1%
Forestry	4,194	1,784	12.8%
Other	9,510	271	1.9%

A temperate climate with regular rainfall and fertile soils allows for good pasture growth in most regions, which reduces the cost of production and lowers the water footprint (Payen et al. 2018). Nutrients are cycled back onto the pasture through grazing animals, spreading of dairy shed effluent and nitrogen fixation by legumes. This reduces the need for mineral fertilisers, which are added at an average of 14, 11 and 5 kg/ha of N, P and K, respectively, for sheep and beef farms (Beef + Lamb New Zealand 2020a), and 140, 26 and 30 kg/ha of N, P and K, respectively, for dairy farms (Ledgard et al. 2020, StatsNZ 2021, Fertiliser Association n.d.).

In 2019/20, 21 billion litres of milk were processed, with production averaging 12,220 L/ha or 4,296 L/cow (DairyNZ 2020). Intensification of dairying between 1990 and 2015 has required increased use of supplementary feed (Table 2.9.2). In the 1990's, non-pasture feed largely comprised of maize grain and maize silage, along with winter and summer crops such as barley, kale, swedes and turnips. Since then, palm kernel expeller (PKE) has become the predominant supplementary feed (36% of total supplements), followed by maize silage (31%) and fodder beet (17%). Some by-products of the food industry, such as brewers grain, fish meal and fruit and vegetable waste make up a very small proportion of total supplementary feed (DairyNZ 2016).

Since 2000, New Zealand beef cattle and sheep numbers have declined by 13% and 30% respectively (Beef + Lamb New Zealand 2017), with conversion of land use to dairying. This has been coupled with a larger proportion of these animals being farmed on steeper, lower fertility land. The average stocking rate on sheep and beef farms in 2018/19 was 6.1 stock units/ha (Beef + Lamb New Zealand 2020a), where one standard stock unit has the feed demand equivalent of one ewe. Beef cattle and sheep (and in some cases deer) are usually farmed together as they complement each other in terms of pasture requirements at different times of the year. Over 95% of the diet is grazed pasture or whole crop, with brassicas and fodder beet the dominant crops.

Table 2.9.2. Changes in feed supply and production in the dairy industry between 1990 and 2015. From DairyNZ (2016).

Year	Cows milked (millions)	Stocking rate (cows/ha)	Feed demand (t DM/cow)	Pasture eaten (t DM/ha)	Crop eaten (t DM/ha)	Harvested supplement (t DM/ha)	Imported supplement (t DM/ha)
1990-91	2.40	2.35	3.94	8.86	0.08	0.20	0.11
2014/15	5.02	2.85	4.93	11.61	0.52	0.90	1.13

Total meat production (1000's tonnes carcass weight) in the year ended 30 September 2019 was 361 for lamb, 91 for mutton, 697 for veal and 17 for venison (Beef + Lamb New Zealand 2020a). Lambing percentages and carcass weights have increased considerably since 1990, whilst beef productivity has been relatively steady (Table 2.9.3).

Table 2.9.3. Change in sheep and beef farm productivity from 1990/91 to 2018/19. From Beef + Lamb NZ (2020a).

	1990/91	2018/19
Lambing percentage	102%	133%
Lamb carcass weight (kg/head)	13.9	19.1
Wool (kg/head)	5.3	5.0
Steer carcass weight (kg/head)	297	313

Current developments and trends in New Zealand agriculture

Although pastoral farms have significantly increased food production per hectare of land over the last 30 years, this has been coupled with increased inputs of livestock, fertiliser and supplementary feed, particularly for the dairy industry, and has led to detrimental effects on the environment. Agriculture contributes 48% of New Zealand's greenhouse gas emissions (Ministry for the Environment 2021a). Reducing the impacts of agriculture on water quality and greenhouse gas emissions have become key goals for the industry.

To improve freshwater quality, restrictions have been imposed on winter grazing and cropping practices and land use intensification, and a manufactured nitrogen fertiliser cap of 190 kg N/ha/year will come into effect on 1 July 2021 (New Zealand Government 2020). In addition, the Government has formed an agreement with the primary sector to address greenhouse gas emissions (He Waka Eke Noa 2021), whereby in 2025 all farms will require a written plan to measure and manage their greenhouse gas emissions, to help reach the Government's commitment to lower greenhouse gas emissions by 30% below 2005 levels by 2030.

The New Zealand Government has proposed a National Policy Statement to protect and restore indigenous biodiversity (Ministry for the Environment 2019). Sheep and beef farms contain 25% of New Zealand's indigenous vegetation, with over 2.8 million hectares (Beef + Lamb New Zealand 2020b). Although this assists with off-setting carbon emissions on these farms, it also may impact how farmers can use their land in the future.

Agricultural supply chains are increasingly looking to produce high quality sustainable products and gain a marketing edge through provenance stories. This may include environmental footprints (including being carbon neutral), reduced plastic packaging, high standards of animal welfare or improved consumer experience in terms of product quality, nutrition and health attributes (Beef + Lamb New Zealand 2019). Some agricultural producers and supply chains have banned the use of PKE on their suppliers farms due to societal concerns about its association with deforestation and habitat destruction (PAMU 2016). A range of small supply chains have emerged, claiming sustainability attributes. For example, Wholly Cow (Wholly Cow 2021) is a small meat supply chain that markets their circularity, recycling waste from meat processing, packaging and local horse manure back onto their farm via composting and worm farms.

The effects of increased circularity in agriculture on mitigating greenhouse gas emissions, nutrient losses and other impacts

New Zealand pastoral farming achieves a low carbon footprint through the circular practices of relatively low use of external inputs, efficient use of resources, and cycling of nutrients on farm, producing more food with fewer inputs. Ledgard et al. (2020) showed an average carbon footprint of New Zealand milk of 0.75–0.81 kg of CO_2eq/kg of FPM (fat and protein corrected milk), or 0.73 to 0.77 kg of CO_2eq/kg FPCM using the IPCC (2007) global warming potential. The largest contributor to this footprint was enteric methane production.

Energy efficiency and reduced use of non-renewable energy are goals of a circular economy. New Zealand farming systems reliance on outdoor grazing systems results in very low fossil fuel and electricity consumption, with a combined contribution of <2% of dairy farm carbon footprints (Ledgard et al. 2020). Methane may also be captured from dairy effluent in anaerobic ponds as an energy source (Leahy et al. 2019).

The main contributors to CO_2 emissions from New Zealand dairy farms, in the study of Ledgard (2020) were manufacturing of nitrogen fertiliser and production of bought in feeds. However, external fertiliser inputs are minimised by the cycling of excreta back onto pasture, the use of legumes and the use of precision agriculture (Leahy et al. 2019). Circularity could be improved by using organic waste as fertiliser but there is limited use of organic fertilisers such as pig and poultry manure. Manure must be appropriately managed or processed to prevent transfer of pathogens and contaminants (Mossa et al. 2020) and to reduce methane and nitrous oxide emissions and issues with smell (Bos et al. 2017).

Ruminant livestock can have a critical role in circular economies through utilising crop residues and wastes from human food production and processing, potentially lowering the carbon footprint of livestock production. The main brought-in feed on NZ dairy farms is PKE, which is cheap but has a relatively high carbon footprint (515 g CO_2/kg DM; Ledgard et al. 2020). Horticultural waste (fruit, vegetables, grape marc) and food processing waste (brewers grain, bakery waste) are fed where and when locally available and have a low carbon footprint. There is potential to reduce the carbon footprint of milk by up to 5% through more selective use of brought-in feeds or by moving further to a pasture-only diet (Ledgard et al. 2020), with careful pasture management to maintain quality and utilisation.

Some feeds such as fodder beet, rape, maize and plantain can reduce greenhouse gas emissions per unit of feed intake (Leahy et al. 2019) but require careful animal health management or are difficult to integrate into the farm system at the level required to be effective. Nitrogen concentrations in New Zealand pastures typically exceed livestock requirements, with excess nitrogen excreted, particularly in urine, which contributes to nitrous oxide emissions (Van der Weerden et al. 2016) and contamination of waterways with nitrogen. Ensuring supplementary feed is low in nitrogen will minimise this waste of nitrogen. Aeration of effluent ponds and strategic spreading of manure and fertiliser also minimises nitrous oxide emissions (Leahy et al. 2019) and nitrogen losses.

Ensuring resources are used efficiently for food production lowers the carbon footprint of milk and meat in New Zealand. Animal feeds should have a high energy concentration to ensure high animal production per unit of feed intake. This is also achieved by ensuring that a large proportion of the animals on farm are highly productive so that animal feed inputs are going towards milk or meat production, rather than to maintenance requirements or growing replacement breeding stock. In dairy systems, this is achieved by having a low cow replacement rate (22%), maintaining animal health and fertility (Ledgard et al. 2020) to reduce animal wastage, optimising stocking rates and increasing the genetic gain of livestock. In sheep and beef systems, large gains have been made in lambing percentage and production per animal (Table 2.9.3).

Repurposing surplus calves from the dairy industry and diverting them to beef production systems is a circular use of these surplus animals. This practice is common and reduces the need for 'resource-hungry' methane-emitting beef breeding cows, whilst providing better value for surplus calves from dairy farms. Van Selm et al. (2021) showed that greenhouse gas emissions per kg beef can be reduced29% via using dairy-derived calves rather than calves from beef breeding cows, whilst Ledgard et al. (2016) showed the nitrogen footprint of beef can be reduced by 7 -13%. This also improves the dairy industries social licence to operate, reducing the slaughter of surplus calves at 4-

days-old for meat processing. This is best achieved using easy-calving beef sires on dairy farms and with collaboration across the dairy and beef industries (Burggraaf and Lineham 2016).

Integration across the food system can reduce some costs, labour and agrichemical use and increase soil carbon, but these responses are highly variable and in some cases are less profitable. An example is the integration of sheep in vineyards. This largely occurs in winter, when pastoral farms are feed limited. The understorey control by sheep reduces mowing and agrichemical use in the vineyard (Niles et al. 2018). Alternatively, sheep may be integrated for short time intervals to pluck grape leaves and open up the canopy. The value for the sheep farmer depends on the animal management skills of the viticulturalist.

Unproductive agricultural land may be used for forestry, adding to carbon sequestration, with woody vegetation offsetting 33% of carbon emissions on sheep and beef farms (Ministry for the Environment 2021b). New Zealand soils generally contain high stocks of soil carbon (>100 tonnes per ha to a depth of 30 cm) and, thus, the scope to increase soil carbon sequestration may be limited (Whitehead et al. 2018).

Additional promising research has shown a range of future options to reduce emissions (Leahy et al. 2019). This includes the use of livestock bred to emit less methane while maintaining productivity, rumen methane and nitrification inhibitors and methane vaccines.

Problem statement

There is a lack of data on the current state of the flow of wastes and inputs across the food system. This is needed to determine how best to reuse or repurpose waste to replace unsustainable inputs, or design new food systems with reduced inputs and waste. There is also a lack of appropriate assessment frameworks to understand how improved circularity across the food system impacts total greenhouse gas emissions and other sustainability goals.

Knowledge required to improve circularity while mitigating greenhouses gases

To gain the most benefit from circularity, there is a need to first map the flows of resources into, and wastes out of, various parts of the local food system, including volumes, timing and composition. There must also be collaboration and communication across the food system to gather and use this knowledge to optimise use of waste as a resource and minimise unsustainable inputs.

To get the best use of biological waste as a supplementary feed or soil nutrient, appropriate storage or processing technology may be required to maintain or enhance its quality, remove or prevent odours, toxins and contaminants and prevent methane production. Processing will assist with optimal use of waste, particularly when the supply of the waste stream occurs at a time when additional nutrients are not required on farm. Solutions must be cost-effective and easy to implement for the farmer.

Alongside this, we need to be able to quantify circularity and the impact of circular inputs, practices and systems, ensuring global food production, socio-economic outcomes and the environment are not compromised. This includes not only the impact on global greenhouse gas emissions, but also resource depletion, nutrient use efficiency and nutrient losses to water. There is a need to understand any risks to animal health, welfare and productivity and pasture and crop performance and resilience under current and future climates and farming systems.

Circularity assessment tools are available (Ellen MacArthur Foundation 2019), but these have been developed for non-biological industries. Although circularity assessment is emerging in the food industry (Rufi-Salis et al. 2021), there is a need to ensure metrics are suitable across the food system, including pastoral agriculture, and that broader impacts are captured. These tools need adaptation and testing for future, more integrated farm and food systems.

Future crop and pasture plant breeding will also require a focus on better capture and use of nutrients in the soil, adapted to reduced external inputs of mineral fertilisers that have a high environmental footprint or use scarce resources.

2.10 Use of Cassava Waste in Circular Food Systems in Nigeria

By Tunde Amole[1], Alan Duncan[1,3], Chris Jones[2], Jan van der Lee[4] and Adolfo Alvarez Aranguiz[5]

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Food system in Nigeria, West Africa and current developments and trends

Nigeria, the most populous country in Africa, has a population growth rate of 2.6 per cent annually, which is expected to further increase in the coming years. While there is a huge and growing demand for affordable food, owing to a fast-growing population, agricultural productivity is low and inefficient in many parts of the country. As the food system does not produce enough food to feed everyone, Nigeria depends on food imports to help meet the growing demand. Nigeria's food imports have increased considerably in the past 20 years, from a value of 964 million US dollars in 1995 to 4,566 million dollars in 2016 (FAO 2019), resulting in a substantial trade deficit for the agri-food sector. This scenario is owing to several socio-and economic environmental factors with underlying institutional drivers.
Against this background, rising income levels are resulting in a shift towards more protein-rich diets and this is driving demand for meat, dairy and eggs. Such demand for animal-sourced foods is projected to double by 2050 (FAO 2016). As a result of the expansion of the monogastric sector, the demand for maize and coarse grains, already in short supply, is also projected to double by 2050. The food-feed competition (especially grains used as animal feed) is becoming intense and closing feed demand gaps will require the use of non-food feed resources (human-inedible resources). The circular economy (CE) is based on four main principles: (i) controlling finite stocks of natural resources and regenerating natural systems; (ii) closing loops; (iii) designing out waste; and (iv) using animals to unlock biomass into value-food, manure, and ecosystem services. The main idea of CE is that rather than discarding products before their value is fully exploited, they could be re-used within the food system. For example, the strategy of using waste products as livestock feed has potential to improve the supply of protein as human food without exploiting additional natural resources. Use of manure as an organic fertilizer also closes nutrient loops. The Nigerian poultry industry, being the most well-organised sub-sector in the agriculture sector and contributing 25% of the total agricultural contribution to GDP, is well positioned to benefit from this. Turning crop residues and agricultural waste, especially the most abundant cassava peels, into feed ingredients is a key strategy to following the circular-economy principles.

Problem statement

Nigeria is seen as one of the nine countries where the increase in the world population will be concentrated. It is expected that the population will double from 201 million in 2019 to 401 million in 2050. This population growth is also accompanied by increased demand for animal-sourced food. In addition, the contradictions surrounding the production, movement and supply of other sources of protein, such as beef, have further awakened interest in poultry as a convenient source of animal protein. Nigeria currently has the second largest chicken population in Africa, with a standing stock of about 180 million birds. Annually, 454,000 tons of meat and more than 14 billion eggs are produced. The poultry industry engages over 20 million Nigerians in direct and indirect employment, providing families with cheap protein while sustaining family livelihoods (Ibrahim, 2020).

The price of maize, which is the main energy source in poultry feed, has doubled over the last decade. Price rises are related to scarcity caused by seasonal shortages (tied to the rainy season), incidence of pest damage such as fall armyworm and political insecurity in locations where maize is grown. About 60% of all Nigerian maize is processed into animal feeds. Imports are needed to meet demand. Recently, the COVID-19 pandemic and the ban on access to ForEx for maize imports has impacted negatively on its cost; since 2020 the price has more than doubled (from $180/tonnes - $400/tonnes) creating a huge problem for the poultry industry in Nigeria.

Cassava is a staple crop of Nigeria. Production has reached a total of 59 million tonnes annually (FAOSTAT 2019). More than 90% of cassava processing requires manual peeling. As a result, Nigeria generates 15 million tonnes of peels annually, which are usually dumped near processing centres to rot or are dried to be burned, releasing methane into the air, and leaving a stinking effluent that pollutes nearby streams and underground water. This is happening alongside situations of near perennial animal feed scarcity, and expensive compound feeds. Exploring the potential of cassava peel as an energy source in livestock feed, especially at an industrial level, is limited due to drying constraints, hydrogen cyanide content and mycotoxin contamination.

Opportunities from increasing circularity in the food system

The circular economy model promotes the concept that a product that has been perceived to have reached its end-of-life in a particular system might be used as a raw material in another, or the same, system. Transforming cassava peel waste into animal feed has the potential to reduce maize imports, reduce environmental pollution, minimise post-harvest losses in cassava, create employment, generate income and partially replace maize in the animal feed industry. Overall, it could elevate farmers' gross income and increase consumption of poultry-based protein in Nigeria.

Circumventing the challenge of drying, pilots showed that reducing drying time from 2-3 days to just 6-8 hours results in a safe and stable product/feed ingredient (High Quality Cassava Peel (HQCP) mash (Okike et al., 2015) that can be used as an energy source in livestock feed rations (Adekeye et al., 2020). The innovation involves grating and mechanical dewatering by hydraulic pressing to facilitate rapid water removal, accelerating the elimination of cyanide. Rapid processing reduces the chances of mycotoxin contamination, a toxic compound produced by fungi that can have serious health consequence on the people who consume meat, milk or eggs from animals fed on mycotoxin contaminated feed. Feeding trials conducted in collaboration with many large- and small-scale poultry farms across Nigeria, showed improved feed conversion efficiency, when fine HQCP mash was used to replace 20% of the maize in broiler rations resulting in a 10 - 15% reduction in feed costs. Such replacement will also release 20% (1.5 million tonnes) of maize going into manufactured feed annually for human consumption. The feed industry priced HQCP coarse and fine mashes at $100 to $150 per tonne, respectively, roughly half the price of maize. Redistribution of activity from managing waste to creating wealth (by producing an economically valuable feed ingredient) can reduce the cost of livestock production and the import bill nationally. Furthermore, at current extraction rates, 810,000 tonnes of HQCP fine mash could be obtained from 3.6 million tonnes of fresh cassava peels and this could be included at a 20% level of inclusion in livestock diets. Going by the selling price of $100-150/t, this would open up a $80 - 120 million industry annually that could employ an estimated 20,000 people.

The effects of improving circularity on mitigating greenhouse gas emissions

The continuous increase in supply and demand for cassava in developing countries has accentuated the negative impact cassava production and processing has on the environment and biodiversity. To remain sustainable, cassava processing must be designed to increase economic, social, and ecological resilience (Oladele, 2014). Food waste and residue streams produce methane (Mashavave, 2019). Removal of peel waste through the HQCP innovation presumably reduces the amount of methane gases emitted from millions of tonnes of fermented peels. Replacement of maize with HQCP not only releases maize for human consumption but also reduces the emissions linked to maize production through the reduction in domestic demand for organic fertilizer and transportation logistics. Nitrogen (N) fertiliser can be responsible for most of the greenhouse gas (GHG) emissions associated with the production of crops through its manufacture and N_2O emissions from the soil subsequent to its application (Kindred et al., 2008). Results of trials showed that processed cassava peels (HQCP) and leaves, fed in the ratio of 70:30 on a dry matter basis, could be the sole feed for cattle, sheep and goats and would reduce feeding costs. This high concentrate diet would be expected to decrease enteric methane emission from ruminants due to changes in rumen fermentation patterns.

Other socio-economic-environmental benefits of increased circularity in the food systems that go beyond GHG emission mitigation.

For over 1 million cassava producers, turning cassava peel waste to wealth, would provide opportunity to sell cassava peels, offering a new income source that would also spur investment in cassava productivity. With 10 persons needed to produce one tonne of HQCP mash (when produced through toasting), producing 12 Mt of HQCP from Africa's estimated 38 Mt of peels would require 120 million man-days per year or the equivalent of 400,000 new (direct) jobs at full capacity— with 80% of the jobs going to women. As incorporating HQCP into livestock feed will reduce feed production costs, consumers arguably would benefit from cheaper meat, milk and eggs, contributing to diets richer in protein and essential micro-nutrients.

Converting cassava peels into feed ingredients reduces the cost of treating water from contaminated nearby streams, wells and underground aquifers with lactic acid-laden, pungent effluent from the heaps of peels. Research has been conducted on the negative effects of cassava processing effluent on selected aquatic life (Adeyemo, 2005) as well as terrestrial plants (Olorunfemi and Lolodi, 2011).

The HQCP innovation not only results in increased feed availability but also in by-products that can be put to good use. For example using cassava waste for biogas production offers a renewable and clean source of energy that could be used for cassava processing and avoids reliance on firewood, a finite and diminishing resource. It is estimated that in Nigeria, processing cassava into various food products such as garri (a staple food derived from cassava), consumes significant firewood (Fauquet, 2015), leading to severe deforestation and desertification (FAO, 2010). 2012 data from Ghana showed that garri production alone amounted to approximately 13% of total firewood use (EC, 2013). The figure is expected to be higher in Nigeria. Exploring the use of cassava waste for fuel for the production of garri could replace firewood and result in social and environmental benefits. Analyzing the additional/saved costs allows us to have a sense of the circular economic impact on the energy system.

Key knowledge and experimentation questions: what knowledge should be developed to further improve circularity in the food system and GHG mitigation by circularity principles?

Further research is required on the cassava peel value chain to support the scaling of the technology. Assessments of the geographical distribution of cassava peel production and its relationship with demand for high quality livestock feed from commercial livestock producers are needed. Furthermore, scaling efforts will require training, advocacy and awareness-raising along with policy support. There is also a need for a GHG audit to quantify the GHG emission reductions that could result from HQCP going to scale in Nigeria.

It is equally important that physical and nutritional standard certification protocols be made available to relevant regulatory agencies establishing codes of practice and safety limits for the use of cassava for animal feed. The document is expected to strengthen commerce between buyers and sellers.

2.11 Advances in converting cereal straws and stovers into concentrates: implications for the circular economy

By Padmakumar V, A. Seshukumar, Alan Duncan, Chris Jones, John Cone, Jan van der Lee, Michael Blümmel (late)

Food system in South Asia, current developments and trends

Food systems are defined as "the entire range of actors and their interlinked value adding activities involved in the production, aggregation, processing, distribution, consumption, and disposal of food products that originate from agriculture, forestry or fisheries, and food industries, and the broader economic, societal, and natural environments in which they are embedded" (Joachim et al., 2020). The traditional approach to achieve food security was to concentrate on agricultural production so that access to affordable food could be enhanced. But this production-centric approach neglects the economic, social and environmental dimensions of food security and nutrition for future generations (FAO 2020). Food system approaches use a more holistic conceptual framework aimed at sustainable solutions for the sufficient supply of healthy food.

When we look at the food system in South Asia, we will see that it is dominated by cereals. If we take the example of Nepal to analyse the food system, rice is the principal crop in terms of area and yield. Other cereals are wheat, maize, millet, and barley. Cereals and pulses are produced partly for markets. Landholdings in Nepal are fragmented and productivity is low. Climate change is impacting agricultural production and land use change is happening mainly in the foot hills (Madhav et al., 2018). Earthquakes, floods, and landslides, drive food insecurity in the country. The national household food security is only 48.2%, though it has improved in recent years, 4.6 million people (out of 30 million) are still food-insecure (USAID, 2019). Besides crops, livestock is an important commodity in the food production system. As the food requirement for the rapidly growing population is increasing and agricultural lands are already fully utilised, crop intensification is the only option. With the increased transport facilities and market access, conventional farming is now gradually transforming into intensified systems, especially in peri-and semi-urban areas. The cultivation of cereal crops is being replaced by vegetables and other cash crops in the hills. Despite ambitious plans to raise agricultural production, and increase productivity of the land with irrigation, mechanisation and modern inputs, imports are rising to meet the growing demand (Nepali Times, 2020). Nepal is now importing 80% of the grain it consumes, and spending on food imports has increased 62% in the last five years. Even crops like rice, lentils and vegetables that are farmed extensively in Nepal, are imported. As far as livestock is concerned, cattle, buffaloes and goats constitute important components of Nepal farming systems both in hills and Terai. Most of the hill farmers own local breeds of animals. Rice straw is the main source of dry fodder for the animals. But the subsistence production is now gradually transforming into commercial/semi-commercial enterprise production, particularly in the peri urban areas and with private dairy industries. Responding to the market, Nepal has shown fast growth in the livestock sector in the recent past. Nepal is now self-sufficient in meat and egg production. However, the current food systems are not delivering healthy diets (FAO, 2020). Rapid urbanisation is rapidly changing the food habits of the urban dwellers and dietary diversity is low.

The problem in circularity

A circular food system means "searching for practices and technology that minimise the input of finite resources and encourage the use of regenerative ones, prevent the leakage of natural resources from the food system, and stimulate the reuse and recycling of inevitable resource losses in a way that adds the highest possible value to the food system" (Jurgilevich et al., 2016). In South Asia, including Nepal, crop production has long been integrated with animal production, mainly dairying. The majority of the dairy products are produced by smallholder farmers who follow a mixed farming system. They use residues of crops (straws, stovers, haulms) as the basal diet of their animals and use other agricultural by-products (oil cakes, bran, rice polish) to supplement the basal diet. But the growing demand for animal source food is currently driving the production system into a more intensive mode, breaking the circularity. Farmers who have adopted improved breeds of livestock are forced to use more and more grains (maize, rice, wheat) and concentrate feeds with reduced roughage inclusion so as to meet the higher nutrient requirements of the animals. This leads to food-feed competition and reduced use of by-products from crop production, affecting circularity in plant and animal production. Those who have land and water also cultivate forages (grasses and legumes) for feeding dairy animals, particularly the improved ones. In the case of small ruminants (goats, sheep), they are mainly fed on grazing land, mostly on degraded pastures. As far as monogastrics (pigs and poultry) are concerned, they are fed with compounded feeds, especially under an industrial production system with the exception of a few cases in urban environments where food waste from restaurants is collected for swine feeding. In the context of growing demand for animal source food, the production system is slowly shifting towards intensification with improved breeds of animals and increased use of external inputs, which is likely to dilute the traditional circularity of the system by disconnecting animal production from crop production, resulting in reduced circularity of food systems. This is a challenge, which needs to be addressed.

Opportunities in increasing circularity in the food system

Processing of crop residues to break down lignocellulose biomass is a technology that can increase circularity by increasing the amount of energy that livestock can extract from otherwise poor quality feeds. Cereal straws and stovers are a key contributor to livestock feed resources in South Asia. Almost 70% of the dairy animal diet is composed of straws/stovers. The basic carbohydrates trapped in the biomass cannot be fully accessed by animals as they are embedded in a lignified matrix. This necessitates use of supplementary feeds to exploit the production potential of the animals. Therefore, any technology that can increase energy recovery from the crop residues will significantly improve its quality and would contribute to a huge positive impact on animal performance when used as feed (Blummel et al., 2014). Besides, increased digestibility of the roughage would lead to a reduction in the quantities of forages and supplementary feed required. Therefore, the land and water requirement for production of both forages and supplementary feeds (grains) will be reduced when this technology is put into commercial use. Such an innovation would contribute in multiple ways to circular food system objectives: closing nutrient cycles, recycling of nutrients, and increased efficiency of the food system, to name a few.

Different physical/chemical/biological techniques are available to break down the lignocellulose biomass (Sarnklong et al., 2010). The treatment is expected to disrupt lignin–hemicelluloses–cellulose matrices, partially hydrolyse weaker linkages of pentoses in the structure of hemicelluloses and make hexoses in cellulose more susceptible to enzymatic hydrolysis. Some of these techniques are: (1) Steam explosion, (2) Ammonia Fiber Expansion (AFEX); (3) Two Chemical Combination Treatment (2-CCT); and (4) fungal treatment. In steam-treatment, steam is intermittently injected to heat stovers to 160°C for 10 minutes. After 10 min the stovers are expelled into a receiver tank. In Ammonia Fiber Expansion (AFEX), ammonia vapor is added to the biomass under moderate pressure (100 to 400 psi) and temperature (70 to 200°C). In the 2CCT treatment, stovers are treated with two chemicals and the treated biomass is washed, squeezed and dried. In the fungal treatment, white rot fungi are used to degrade lignin (Van Kuijk et al., 2015).

The first three are used to pre-treat biomass in the industrial ethanol production process, and these "second generation biofuel methods" have been assessed by the International Livestock Research Institute in the context of livestock feed improvement. Comparison of the effect of these three treatments on fodder quality showed that increases in true in vitro organic matter digestibility (IVOMD), measured after 48 h of incubation, were greatest under the 2-CCT (38.2% units), followed by AFEX (19.3% units) and finally steam (8.9% units) treatments (Blummel et al., 2019). 2CCT increased average the apparent and true IVOMD of straws to above 80 and 90%, respectively. In the fourth treatment with fungi the degradability of the biomass in the rumen, determined with the gas production technique, showed a considerable increase to more than 100%, depending on the fungus and substrate (Tuyen et al., 2013). Uptake of these technologies remains low for economic and socio-economic reasons (Owen and Jayasuriya, 1989). Recent global interest in second-generation biofuel technologies to produce ethanol from ligno-cellulosic biomass, provides an entirely new perspective to up-grading crop residues and could be transformational. Considering the abundance of crop residue (about 4 billion tonnes produced globally) as livestock feed, the economic and ecological impact of the proposed technologies is enormous and it will become a game changer.

The effects of increasing circularity in mitigation GHGs

Livestock emit significant quantities of greenhouse gases, mainly in the form of methane resulting from enteric fermentation, which constitutes 44.1% of overall emission from livestock (FAO 2017). There are excellent reviews (Beauchmin et al 2008; Malic et al., 2015) available on different technologies for abating GHG emissions from ruminants, but most of the strategies reviewed have been explored and studied in developed and advanced production systems (Makkar, 2016). In the case of the proposed technology it is more relevant and feasible for the Low and Middle-income Country context. In this technology the roughages are converted into feeds equivalent to good quality roughages or even concentrate feeds. This will have three effects. The first and most important is that the higher digestibility of the treated crop residues reduces the need for supplementation with compound feeds or fodder crops that are grown specifically for feeding; second, the better quality crop residues can lead to a better utilisation of the animal's potential and hence increase milk production. The total methane production per cow might not be reduced, but the higher milk production per cow will lead to a strong reduction in methane production and the related carbon footprint per kg of milk. This mechanism has been clearly explained by Gerber et al (2011). Therefore, this approach will contribute strongly to improved food security without increasing absolute GHG emissions. And third, the digestion in the rumen will partially shift from acetate pathway (with methane as by-product) to propionate pathway (with no methane) when the same roughage is fed to animals after treatment. This might even lead to lower methane production related per kg of feed intake. When the technology is scaled in South Asia, the impact on methane reduction would be colossal. Furthermore, as the crop residue will become a more valuable commodity, due to its higher value, burning of biomass will be be avoided, leading to reductions in release of nitrous oxide and CO_2 to the atmosphere.

Other socio economic and environmental benefits of circular food system that go beyond GHG mitigation

As quality of the available biomass is substantially increased it will reduce the quantity of feeds required to produce the same amount of milk. Thus, more natural resources which would otherwise be used to produce forages could be spared to produce plant biomass for human consumption or for biodiversity enhancement. In the case of small ruminants, less land will be used as a grazing resource and availability of concentrate feeds from crop residues would promote semi/stallfeeding. Since application of the technology would likely occur within small and medium businesses and in a franchise environment, potential multidimensional win-win situations exist. These would benefit small holder farmers and the rural disadvantaged directly and the environment indirectly by supporting intensification, reducing water and arable land need for feed production, and reducing pollution from rice straw burning, resulting in overall reduced environmental footprint of the livestock production. There will also be more job opportunities all along the feed value chain.

New knowledge to be developed to further improve circularity in the food system and GHG mitigation by circularity principles: key knowledge or experimentation questions

The proof-of-concept trial of the 'deconstruction' intervention was carried out with small ruminants and with the residue of only one crop (rice). Therefore, a pilot study is proposed using a larger plant, upgrading one ton of straw /stover per day. The objective is to generate sufficient data for establishing economically feasible, centralised or decentralised commercial plants by experimenting with different engineering options, chemical and steam treatment combinations, residues of different crops (rice, maize, bagasse) and animal species (sheep, dairy). During the pilot phase the following studies will also be carried out with a view to developing mechanisms for minimising environmental impacts, if any:

a) Optimisation and recycling of water to save consumption, reduce wastage, as well as to move towards a zero discharge plant.
b) Utilisation of lignin that is removed from the crop residue to generate steam in the boiler.
c) Solid wastes coming from the process or plant and also RO (Reverse Osmosis) rejects to be used for making compost.

Once commercial viability of the technology is established, the aim would be large scale conversion of biomass into concentrate feed by private industries with much reduced negative environmental impacts. Another area of study required to further improve circularity in the food system is a GHG audit to quantify the GHG emission reductions that could result from deconstruction technologies going to scale. Research is needed to assess extent of methane emission savings when straw/stover is converted to 'concentrates' relative to feeding of untreated material. This will give an idea of the methane reduction potential of the proposed technology.

3. Reflection & next steps

3.1 Reflection

The aim of this report is to provide an overview of the diversity of circularity in different food systems. The former section presented eleven short communications addressing circularity in food systems from Nigeria to Peru, to Southern India, from rice system in the USA to grassland-based systems in New Zealand. What have we learnt from these stories? What does CFS mean in different parts in the world? What are opportunities? What are foreseen benefits for GHG mitigation and other benefits or trade-offs? And what are next steps to advance CFS and more importantly, the benefits CFS aims to contribute to?

Planetary boundaries

The planetary boundaries framework aims to establish levels of human perturbation (e.g., extraction, emission, perturbation) beyond which the earth system functioning may be substantially altered, destabilizing the Holocene state in which societies have developed (Steffen et al., 2015). Increases in human population, economic growth, and consumption have resulted in unsustainable uses of biophysical resources, leading to land-use change and degradation, biodiversity loss, climate change, and water pollution (Haberl et al., 2014; Krausmann et al., 2013). By minimizing waste streams and utilizing inevitable waste in processes of food production, energy, or non-products, circular food systems could contribute to avoid exceeding the earth's biophysical limit (Muscat et al., 2021).

This report presents eleven case studies that aim, through a wide range of practices, to achieve circularity in different food systems around the world. Examples of such cases are (i) increase the value of organic waste production in the Mediterranean; (ii) map the flow of waste and input across pastoral systems in New Zealand; and (iii) increase urban waste use with industrial symbiosis initiatives in Reunion. Other initiatives proposed (i) crop substitution to mitigate rice field methane emission in Bangladesh; (ii) the establishment of a living lab to promote nutrient cycling from crop-livestock integration in Zambia and Malawi; (iii) innovative farms to increase crop diversification in Germany; and (iv) the creation of inter-related enterprises in India. Initiatives' aims vary from (i) building up on traditional knowledge (as in Peru) to the development of new technologies to (ii) use rice husk as a soil amendment in the United States, (iii) transform cassava peel waste into animal feed in Nigeria, or (iv) improving cereal straws digestibility in Nepal.

Although there is no formal definition on what a circular food system is, practices and technologies should minimize the input of finite resources, enhance the use of regenerative ones, prevent leakage of natural resources, and stimulate recycling of inevitable resource losses in a way that adds the highest value to the food system (De Boer and Van Ittersum, 2018; Van Zanten et al., 2019). This compilation of case studies provides us with a descriptive state-of-the art on how circular food systems are envisioned around the world and reveal similarities and differences in terms of ideas of what circularity in the food system entails and the problems to tackle. It gives an impression on the opportunities to explore and main barriers to overcome; and discusses how the proposed practices could contribute to food security and/or greenhouse gas mitigation, among other environmental and socio-economic benefits. In addition, this overview allows us to identify knowledge gaps for future steps in terms of research, decision-making, and policy development.

Circularity dilemma's

To achieve circularity, Muscat et al. (2021) established five ecological principles to guide biomass use: (i) save and regenerate the health of (agro-)ecosystems; (ii) avoid non-essential products and the waste of essential ones; (iii) prioritize biomass streams for basic human needs; (iv) utilize and recycle by-products of (agro-)ecosystems; and (v) using renewable energy while minimizing overall energy use. These principles are indicative of strategic developments towards circularity and should be adjusted to the local contexts. In fact, in the different case studies presented in this report, the level of circularity and the priorities given to the mentioned principles differed by systems and regions and were heavily influenced by the context. However, most of the problem statements were related to avoiding essential nutrient waste and to the utilisation and recycling of by-products. Although the cases mentioned several practices to increase circularity, seven out of the eleven case studies proposed (i) reusing crop residue, (ii) increasing crop and livestock diversity, and/or (iiii) recoupling livestock-crop production. Four of the case studies, aimed to increase organic waste use by (i) increasing the value of urban waste, (ii) creating an inventory of waste flows, and/or (iii) reconnecting urban with rural communities. It is important to note, however, that benefits derived from most of these practices were also related to other principles. For instance, bioenergy production from crop residues, as was proposed by the case study in Zambia-Malawi, India, and Bangladesh, could help to reduce deforestation and thus safeguard the (agro)-ecosystems. Although the principle states that "the production of bioenergy, is only desirable or effective for biomass streams that are not safe for recycling, such as waste streams containing human and veterinary pharmaceuticals"; in countries where the energy matrices are not developed enough, prioritization of bioenergy production over restoring the soil or feeding the animals seems to be a common choice. This example opens the discussion of how flexible we should be with the definition of circularity and principles based on the complexity of individual situations and considering the context and needs without deviating from the circularity goals.

Under the current scenario of growing biomass demands, natural resources need to be used effectively. Priority should be given first to cover basic human needs; then restore the (agro-) ecosystem e.g., build up soil health; then animal feeding; and latest energy production. However, and as the case study shows, prioritization of biomass use is a difficult task due to high competition (e.g., 40% of global arable lands are used to produce feed for livestock). Thus, this may be the principle that is more influenced by the context. Different uses of crop residues proposed in the case study are an example of how priorities change based on the context. For example, one case study proposed to use stem and leaf from legume for livestock feeding. Although feed quality in livestock systems in developing countries is a constraint that led to low productivity and high greenhouse emission intensity (Herrero et al., 2016); these products (i.e., legume stem and leaf) should be prioritized for human nutrition (principle 3). In addition, principle 1 states that to sustain biomass harvesting from agroecosystems, we should invest in restoring soil carbon stocks. This is especially important in developing countries, where the use of crop residues should be prioritized to protect the soil from erosion. For instance, African soil has experienced decades of nutrient extraction without replenishment, leading to soil degradation and low crop yields (Tully et al., 2015). In addition, increasing food production in these countries should be a priority (Van Ittersum et al., 2016) and this will be not achieved by only using compost and manure (Mafongoya et al., 2006; Vanlauwe et al., 2014; Holde, 2018). Therefore, in these systems, we should evaluate (i) what is the role of circularity and (ii) which level of circularity we could aim for without affecting food production. Future research should evaluate the current dilemma that exists between intensification of food production and circularity; in food systems where production is low and the dependency on food imports jeopardizes food security.

Circular interventions: opportunities and associated challenges

The development of new technologies, as well as the redesigning of existing ones to adapt them to local contexts, are key drivers for a transition towards circular food systems. One case study proposed an innovative technology to transform cassava peel waste into animal feed. The innovation allows the grating and mechanical dewatering of cassava peel by hydraulic pressing to facilitate rapid water removal and cyanide elimination. Other potential benefits that could emerge from the use of this technology are mitigation of greenhouse gas emission, reduction of water pollution, minimization of post-harvest losses, reduction of feed-food competition and import reliance, and the generation of income and creation of new jobs. In another case study, different mechanical and chemical treatments were proposed to improve the digestibility of cereal straw by increasing the breakdown of the biomass lignocellulose and use it as livestock feed. Further research is required to explore the scalability and potential adoption levels of both technologies which in many cases is low due to socio-economic constraints. In addition, for the adoption of these or other technologies, the participation of stakeholders from different sectors is key. For instance, to reuse rice husk, as it is proposed in the US case study, the industry will play an important role since mills would need to separate husk waste streams from other wastes, such as weed seeds. This case study highlights the importance of considering the food system's complex network and the need to integrate different actors in the discussion.

Equally important to the development of new technologies is, as the Peruvian case study proposes, to leverage traditional practices from communities as well as adding new knowledge to them. Farmers in the Amazonian region operate under agroforestry systems with good agricultural practices, but they envision land-use expansion as a more likely alternative to improve their livelihoods instead of increasing productivity of current agricultural land. Another example where local knowledge is integrated, is in India, where the creation of Integrative Farming System aims to cluster inter-related enterprises to increase diversity, reduce risk, generate income, and reutilize waste stream as compost, feed, and/or energy. In both cases, environmental and socio-economic factors influence knowledge adoption and enterprise integration. Future research should incorporate participatory tools which allow the discussion and integration of different stakeholder needs and knowledge and help to disseminate and scale up practices and technology adoption.

Regardless the intervention, opportunities that come from circularity to reduce the dependency on the speed of natural cycles -either by lowering resource use or enhancing the absorptive capacity of ecosystems- should be assessed using clear definitions and baseline scenarios. These types of activities were proposed in the case studies in the Mediterranean, New Zealand, Peru, and Reunion.

An important point to bring to the attention, is that all case studies focused mainly on waste stream recycling but none of them discussed opportunities to reduce waste production. It may be the case that interventions to reduce waste production are more complex and challenging since they require social behaviour changes and policies. However, the complexity of the situation should not make us forget that food waste at production, transportation, and consumption level are important in our current food systems (FAO, 2015; Barrera & Hertel, 2021). Avoiding food waste can prevent unnecessary exploitation of natural resources; hence the importance of avoiding losses and wastes in addition to recycling. This highlights the need for approaching food systems' issues with a system thinking perspective.

3.2 Next steps

The Circular Food System Network (CFSN) of the Global Research Alliance (GRA) aims to develop an active network of researchers in the field of circular food systems, to share knowledge and enhance collaboration to increase circularity within the agri-food system. Under the GRA, the objective of the CFSN is formulated as: 'To contribute to food security with mitigation of GHG emissions by circularity across the entire agri-food system". In this context, in most of the case studies, the discussion on the effect of the interventions on food security was relatively poor.

For future research and discussions, it will be key to evaluate the interventions with a system thinking approach that focuses on the entire food system, rather than using on-farm or value chain approaches. Most of the case studies focus on one component (i.e., production level or waste management) of the food system, ignoring the connection and complexity of different components. We need combined top-down and bottom-up whole-system approaches that look at individual parts of the food system as elements of an integrated entity considering not only the sum of the food system's components but also the interaction between them. The study of synergies and trade-offs of the different practices and interventions should be performed at different levels of the food system. It is true, however, that considering all these connections could be overwhelming and including them will take time. Thus, they should be incorporated step by step. In any case, implementing the proposed interventions from the case studies already significantly improves the current situation. Upscaling, deepening and broadening these circular initiatives will lead to widespread transformations.

For circular agri-food systems to become the norm, we need action at global, regional, and local scale. Biomass is used by many different sectors which are governed by different policy domains at different stages of the supply chain. Thus, designing a biomass cascade framework requires deep transformations and synergies at different levels, i.e., policies, technologies, organizations, social behaviour, and market level (Muscat et al., 2021). One important challenge for this transformation, is to create awareness of the socio-economic and environmental benefits that arise from circularity. For this awareness to be effective and to guide transition towards a circular system, we need metrics. Thus, case studies and future research need to incorporate metrics that address the complexity of the food system. Such metrics must capture resource and energy use efficiency, such as land-use ratio, food-feed competition, and nutrient use efficiency. This will entail deciding the scale at which recycling should be pursued and nutrient cycles closed.

Besides the short communications and the survey results, this chapter also takes into account the outcomes of the kick-off workshop, in which researchers and policy-makers from a wide variety of regions took part (CFS Network, 2021).

References

Barrera, E.L. and Hertel, T., 2021. Global food waste across the income spectrum: Implications for food prices, production and resource use. Food Policy, 98, p.101874.

De Boer, I.J. and van Ittersum, M.K., 2018. Circularity in agricultural production. Wageningen University & Research.

CFS, 2012. Coming to terms with terminology: Food Security, Nutrition Security, Food Security and Nutrition, Food and Nutrition Security. Committee on world food security, 39th session, Rome, Italy, 15-20 October 2012. CFS 2012/39/4. http://www.fao.org/3/MD776E/MD776E.pdf

CFS Network, 2021. Circular Food Systems: Regional opportunities to mitigate greenhouse gas emissions. Kick-off workshop 22-23 June, 2021. Workshop report. Wageningen University & Research, Netherlands

EAT-Lancet, 2019. Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems.

FAO, 2015. FAO's work on climate change. United Nations Climate Change Conference 2015.

FAO, IFAD, UNICEF, WFP and WHO, 2020. The State of Food Security and Nutrition in the World 2020. Transforming food systems for affordable healthy diets. Rome, FAO. https://doi.org/10.4060/ca9692en

FBKP, 2019. Circular Agriculture in Low and Middle Income Countries. Discussion paper - October 16, 2019. FBKP, Netherlands

FBKP, 2020. Opportunities and barriers of circular agriculture – insights from a synthesis study of the Food & Business Research Programme. FBKP, Netherlands.

Food, S., 2015. Global Initiative on Food Loss and Waste Reduction. Food and Agriculture Organization of the United Nations. SAVE FOOD.[Online]. Available: http://www. fao. org/3/ai4068e. pdf, 25, p.2018.

Haberl, H., Erb, K.H. and Krausmann, F., 2014. Human appropriation of net primary production: patterns, trends, and planetary boundaries. Annual Review of Environment and Resources, 39, pp.363-391.

Herrero, M., Henderson, B., Havlík, P., Thornton, P.K., Conant, R.T., Smith, P., Wirsenius, S., Hristov, A.N., Gerber, P., Gill, M. and Butterbach-Bahl, K., 2016. Greenhouse gas mitigation potentials in the livestock sector. Nature Climate Change, 6(5), pp.452-461.

Holden ST. Fertilizer and sustainable intensification in Sub-Saharan Africa. Global food security. 2018; 18:20-6.

Krausmann, F., Erb, K.H., Gingrich, S., Haberl, H., Bondeau, A., Gaube, V., Lauk, C., Plutzar, C. and Searchinger, T.D., 2013. Global human appropriation of net primary production doubled in the 20th century. Proceedings of the national academy of sciences, 110(25), pp.10324-10329.

Mafongoya PL, Bationo A, Kihara J, Waswa BS. Appropriate technologies to replenish soil fertility in southern Africa. Nutrient Cycling in Agroecosystems. 2006; 76(2-3):137-51.

Muscat, A., de Olde, E.M., Ripoll-Bosch, R., Van Zanten, H.H., Metze, T.A., Termeer, C.J., van Ittersum, M.K. and de Boer, I.J., 2021. Principles, drivers and opportunities of a circular bioeconomy. Nature Food, 2(8), pp.561-566.

Preston, *et al*, 2017. A Wider Circle? The Circular Economy in Developing Countries. Briefing December 2017. Chatham House: Energy, Environment and Resources Department

Springmann M et al. 2018. Options for keeping the food system within environmental limits. Nature 562: 519-525

Steffen, W., Richardson, K., Rockström, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., De Vries, W., De Wit, C.A. and Folke, C., 2015. Planetary boundaries: Guiding human development on a changing planet. Science, 347(6223), p.1259855.

Tully, K., Sullivan, C., Weil, R. and Sanchez, P., 2015. The state of soil degradation in Sub-Saharan Africa: Baselines, trajectories, and solutions. Sustainability, 7(6), pp.6523-6552.

UN, 2015. United Nations Resolution adopted by the General Assembly on 25 September 2015. A/RES/70/1 Transforming our world: the 2030 Agenda for Sustainable Development. www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E

Van Berkum, S, Dengerink, J. and Ruben, R, 2018. Sustainable solutions for a sufficient supply of healthy food. Wageningen Economic Research, The Netherlands.

Van Ittersum MK, Van Bussel LG, Wolf J, Grassini P, Van Wart J, Guilpart N, et al. Can sub-Saharan Africa feed itself?. Proceedings of the National Academy of Sciences. 2016; 113:14964-9.

Van Zanten, H.H., Van Ittersum, M.K. and De Boer, I.J., 2019. The role of farm animals in a circular food system. Global Food Security, 21, pp.18-22.

Vanlauwe B, Wendt J, Giller KE, Corbeels M, Gerard B, Nolte C. A fourth principle is required to define conservation agriculture in sub-Saharan Africa: the appropriate use of fertilizer to enhance crop productivity. Field Crops Research. 2014; 155:10-3.

Vermeulen, S.J., Campbell, B.M., Ingram, J.S.I. 2012. Climate Change and Food Systems. Annual Review of Environment and Resources 2012 37:1, 195-222

Reference per short communication

2.1 Using a living lab approach to promote nutrient cycling from crop-livestock integration in rural Malawi and Zambia

Agriculture Production Estimates (APES), 2019. Ministry of Agriculture, Capital Hill, Lilongwe.

Ambler, K., De Brauw, A., and Godlonton, S., 2017. Measuring postharvest losses at the farm level in Malawi. IFPRI Discussion Paper 1632. International Food Policy Research Institute (IFPRI): Washington, D.C.

Chapoto, A., Chabala, L.M., and Lungu, O.N., 2016. A Long History of Low Productivity in Zambia: Is it Time to Do Away with Blanket Recommendations? Zambia Social Science Journal: Vol. 6: No. 2 , Article 6.

Chastain J. P., James J. Camberato, John E. Albrecht, and Jesse Adams, 2003. Swine Manure Production and Nutrient Content, CHAPTER 3. (CAMM Poultry Chapter 3a, last edit - January, 2003 jpc)

Chirwa Meki, Jerome Peter Mrema, Peter Wilson Mtakwa, Abel K. Kaaya and Obed I. Lungu, 2016. Evaluation of Soil Fertility Status and Land Suitability for Smallholder Farmers' Groundnut and Maize Production in Chisamba District, Zambia. International Journal of Plant & Soil Science 10(4): 1-18.

Erdogdu, A. E., Polat, R and Ozbay, G., 2019. Pyrolysis of goat manure to produce bio-oil. Engineering Science and Technology, an International Journal 22 (2019) 452–457

FAO, 2017. National Investment Profile. Water for Agriculture and Energy: Malawi.

FAO, 2017. Global Livestock Environmental Assessment Model (GLEAM). Rome (Italy): Food and Agriculture Organization of the United Nations (FAO).

Font-Palm C., 2019. Methods for the Treatment of Cattle Manure - A Review. Journal of Carbon Research. Vol. C 2019, 5, 27.

Giampiero Grossi, Pietro Goglio, Andrea Vitali and Adrian G. Williams, 2019. Livestock and climate change: impact of livestock on climate and mitigation strategies. Animal Frontiers.

Groote Hugo, Zachary Gitonga, Earnest Kasuta, Dorene Asare-Marfo and Ekin Birol, 2015. Maize Consumption Patterns and Consumer Preferences in Zambia. HarvestPlus, Research for Action. No. 5.

Higgins, A. & Klein, S., 2011. Introduction to the Living Lab Approach. DOI: 10.1007/978-3-642-15669-4_2

Kasirye F.N.M. 2003. Milk and Dairy Products, Post-harvest Losses and Food Safety in Sub-Saharan Africa and the Near East: A Review of The Small Scale Dairy Sector, Uganda.

Livestock and Aquaculture Census (LAC), 2017. Central Statistical Office, Lusaka, Zambia

Mbata J and M. Westman, 2018. Sustainable management of the environment and natural resources: Implications for food security, livelihoods and economic development in Malawi. UNDP-UN Environment Poverty- Environment Initiative. Lilongwe, Malawi. 23pp.

Mendes D. M, Lisa Paglietti, David Jackson and Felix Chizhuka, 2015. Zambia: Irrigation market brief. FAO Investment Centre. Country Highlights, Zambia.

Mphwanthe G, A. A. Kalimbira, Aand N.C. Geresomo, 2016. Consumption and wastage of home-fortified maize flour products in northern Malawi, South African Journal of Clinical Nutrition, 29:1, 23-26.

National Agriculture Policy (NAP). 2016. Ministry of Agriculture, Irrigation and Water Development, Capital Hill, Lilongwe, Malawi

Natural Resources Conservation Service (NRCS), 1995. Animal Manure Management, https://www.nrcs.usda.gov/wps/portal/nrcs/detail/null/?cid=nrcs143_014211

Ndambi Oghaiki Asaah, Pelster David Everett, Owino Jesse Omondi, de Buisonjé Fridtjof, Vellinga Theun, 2019. Manure Management Practices and Policies in Sub-Saharan Africa: Implications on Manure Quality as a Fertilizer.Frontiers in Sustainable Food Systems, Volume 3.

Omuto C. T, Vargas R. R, 2018. Soil nutrient loss assessment in Malawi. Technical report. FAO, UNEP and UNDP. Lilongwe, Malawi. 64pp

Rahman N, Bruun, B. T., Giller K. E, Magid, J., van de Ven, G. W. J. and Neergaard, A., 2019. Soil greenhouse gas emissions from inorganic fertilizers and recycled oil palm waste products from Indonesian oil palm plantations. GCB-Bioenergy – Bioproducts for sustainable bioeconomy.

SMEC. 2015. National Irrigation Master Plan and Investment Framework for the Republic of Malawi. Ministry of Agriculture, Irrigation and Water Development, Department of Irrigation.

Solomon Asfaw, Carlo Orecchia, Giacomo Pallante and Alessandro Palma, 2018. Soil and nutrients loss in Malawi: An economic assessment. Economic and policy analysis of Climate change, the Food and Agriculture Organization of the United Nations, the UNDP-UNEP Poverty-Environment Initiative and the Ministry of Agriculture, Irrigation and Water Development, Malawi.

The National Agriculture Policy (NAP 2012-2030), 2011. Final Draft. Ministry of Agriculture and Co-Operatives, Republic of Zambia

The World Bank, 2017. International Development Association Project Appraisal Document. Report No: PAD2303. Energy and Extractives Global Practice Africa Region. Republic of Zambia

The World Bank, 2019. International Development Association Project Appraisal Document. Report No: PAD3023. Energy and Extractives Global Practice Africa Region. Republic of Malawi

Zulu B., Jayne T. S and Beaver M., 2007. Smallholder Household Maize Production and Marketing Behavior in Zambia: Implications for Policy. Policy Synthesis Food Security Research Project-Zambia Ministry of Agriculture & Cooperatives, Agricultural Consultative Forum, Michigan State University and MATEP Lusaka, Zambia, Number 20.

2.2 Multiple on-going industrial symbiosis initiatives for a transition to a circular agri-food system on a tropical insular territory

Aguerre, M.J., Wattiaux, M.A., Powell, J.M., Broderick, G.A., Arndt, C., 2011. Effect of forage-to - concentrate ratio in dairy cow diets on emission of methane, carbon dioxide, and ammonia, lactation performance, and manure excretion. Journal of Dairy Science 94, 3081–3093.

Ayres, R.U., 1989a. Industrial metabolism, in: Industrial Metabolism, the Environment, and Application of Materials-Balance Principles for Selected Chemicals. pp. 23–49.

Ayres, R.U., 1989b. Industrial metabolism and global change. International Social Science Journal 121, 363–373.

Ba, S., Qu, Q., Zhang, K., Groot, J.C.J., 2020. Meta-analysis of greenhouse gas and ammonia emissions from dairy manure composting. Biosystems Engineering 193, 126–137.

Bogner, J., Pipatti, R., Hashimoto, S., Diaz, C., Mareckova, K., Diaz, L., Kjeldsen, P., Monni, S., Faaij, A., Gao, Q., Zhang, T., Ahmed, M.A., Sutamihardja, R.T.M., Gregory, R., 2008. Mitigation of global greenhouse gas emissions from waste: conclusions and strategies from the Intergovernmental Panel on

Climate Change (IPCC) Fourth Assessment Report. Working Group III (Mitigation). Waste Manag Res 26, 11–32.

Chertow, M.R., 2000. Industrial Symbiosis: Literature and Taxonomy. Annu. Rev. Energy. Environ. 25, 313–337. https://doi.org/10.1146/annurev.energy.25.1.313

Darras, A., 2019. Exploration de scenarios de valorisation en agriculture des déchets verts urbains dans le sud de l'île de la Réunion.

Edouard Rambaut, L.-A., Vayssieres, J., Versini, A., Salgado, P., Lecompte, P., Tillard, E., 2021. 5-Year Fertilization Increase Soil Organic Carbon Stock Even In Systems Reputed Saturated Such As Permanent Grassland On Andosols. in prep.

French customs, 2019. French custums database 2019.

Hatik, C., Medmoun, M., Courdier, R., Soulie, J.-C., 2020. PoVaBiA: A multi-agent decision-making support tool for organic waste management. In : Advances in practical applications of agents, multi-agent systems, and trustworthiness. The PAAMS Collection. Demazeau Yves (ed.), Holvoet Tom (ed.), Corchado Juan M. (ed.), Costantini Stefania (ed.). Cham : Springer, 421-425. (Lecture Notes in Computer Science, 12092) ISBN 978-3- 030-49777-4 International Conference on Practical Applications of Agents and Multi-Agent Systems (PAAMS 2020). 18, L'Aquila, Italie, 7 Octobre 2020/9 Octobre 2020. Springer.

Jarry, R., 2019. Modélisation des flux d'effluents d'élevage sur le territoire de Saint-Joseph, en lien avec la dynamique du bâti. Rapport de stage M2.

Kleinpeter, V., Vayssières, J., Alison, C., van de Kerchove, V., Degenne, P., Vigne, M., 2019. Inventaire et quantification des flux de biomasses locales valorisées ou valorisables en agriculture à La Réunion. Rapport technique du projet GABiR, 68 p.

Loiseau, E., Aissani, L., Le Féon, S., Laurent, F., Cerceau, J., Sala, S., Roux, P., 2018. Territorial Life Cycle Assessment (LCA): What exactly is it about? A proposal towards using a common terminology and a research agenda. Journal of Cleaner Production 176, 474–485.

Lorré, F., Magnier, J., Degenne, P., Miralles, M., Vigne, M., Vayssières, J., 2020. Appui de la modélisation spatialement explicite pour la mise en place d'une filière de fourrage structurée à l'échelle de l'île de La Réunion - 3R - Rencontres autour des Recherches sur les Ruminants.

Vigne, M., Pascale, A., Chloé, A., Christophe, C., Jean-Philippe, C., Rémi, C., Pascal, D., Agathe, D., Stéphane, D., Amélie, F., Christelle, H., Joël, H., Vivien, K., Vladislav, K., Amandine, L., Anne-Laure, P., Philippe, R., Jean-Christophe, S., Laurent, T., Tillard, E., Jonathan, V., 2021. Favoriser les démarches d'économie circulaire à l'échelle territoriale : démarche méthodologique et enseignements du projet GABiR à La Réunion. in prep. Agronomie Environnement et Sociétés.

Walling, E., Vaneeckhaute, C., 2020. Greenhouse gas emissions from inorganic and organic fertilizer production and use: A review of emission factors and their variability. Journal of Environmental Management 276.

Wassenaar, T., 2015. Reconsidering Industrial Metabolism: From Analogy to Denoting Actuality: Reconsidering Metabolism. Journal of Industrial Ecology 19, 715–727.

2.3 Achieving carbon neutral and resilient Mediterranean agro-food systems through the circular management of organic resources

ADEME. 2012. Programme de recherche de l'ADEME sur les émissions atmosphériques du compostage. Connaissances acquises et synthèse bibliographique. In: l'Énergie, A. d.l.E.e.d.l.M.d. France.

Brentrup, F., Kusters, J., Lammel, J., Barraclough, P., Kuhlmann, H. 2004. Environmental impact assessment of agricultural production systems using the life cycle assessment (LCA) methodology - II. The application to N fertilizer use in winter wheat production systems. Eur. J. Agron. 20, 265–279.

Capone, R., Bennett, A., Debs, P., Bucatariu, C.A., El Bilali, H., Smolak, J., Lee, W.T.K., Bottalico, F., Diei-Ouadi, Y., Toppe, J. 2016. Food losses and waste: Global overview from a Mediterranean perspective. In: Mediterra 2016. Zero Waste in the Mediterranean. Natural Resources, Food and Knowledge/ International Centre for Advanced Mediterranean Agronomic Studies (CIHEAM) and Food and Agriculture Organization of the United Nations (FAO) – Paris: Presses de Sciences Po, 2016.

Capone, R., Berjan, S., El Bilali, H., Debs, P., Allahyari, M.S. 2020. Environmental implications of global food loss and waste with a glimpse on the Mediterranean region. International Food Research Journal 27, 988-1000.

Charalampopoulou, N., Stuart, T., Wilkey, I. 2014. Solving the Global Food Waste Scandal: Opportunities in the Mediterranean. CIHEAM Watch Letter, 30, September, pp. 25-29.

FAO. 2014. Reducing Food Losses and Waste in the Near East & North Africa Region, 32nd session FAO Regional Conference for the Near East (RCNE), Rome, FAO, February

Fritsch, C., Staebler, A,, Happel, A,, Cubero Márquez, M.A. 2017. Processing, Valorization and Application of Bio-Waste Derived Compounds from Potato, Tomato, Olive and Cereals: A Review. Sustainability. 9:1492.

Ghisellini, P.; Cialani, C.; Ulgiati, S. 2016. A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. J. Clean. Prod. 114, 11–32.

González de Molina, M., Petersen, P.F., Garrido Peña, F., Caporal, F.R. 2020. Political agroecology. Advancing the transition to sustainable food systems. New York: CRC Press, Taylor & Francis Group

HLPE. 2014. Food Losses and Waste in the Context of Sustainable Food Systems, Rome, High Level Panel of Experts on Food Security and Nutrition (HLPE) of the Committee on World Food Security.

Jeong, S., Moon, S., Park, J., Kim, J.Y. 2019. Field measurement of greenhouse gas emissions from biological treatment facilities of food waste in Republic of Korea. Waste Manag. Res. 37, 452–460.

Kirchherr, J., Piscicelli, L., Bour, R., Kostense-Smit, E., Muller, J., Huibrechtse-Truijens, A., Hekkert, M. 2018. Barriers to the Circular Economy: Evidence from the European Union (EU). Ecol. Econ. 150, 264–272.

IPCC 2019, Waste generation, composition and management data, Volume 5, Chapter 2. 2019. Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Calvo Buendia, E., Tanabe, K., Kranjc, A., Baasansuren, J., Fukuda, M., Ngarize S., Osako, A., Pyrozhenko, Y., Shermanau, P. and Federici, S. (eds). Published: IPCC, Switzerland.

Mavropoulos A. 2015. Wasted Health – The Tragic Case of Dumpsites. International Solid Waste Association. Available at: https://www.iswa.org (accessed 30 May 2021)

Oonincx DGAB, van Itterbeeck J, Heetkamp MJW, van den Brand H, van Loon JJA. 2010. An Exploration on Greenhouse Gas and Ammonia Production by Insect Species Suitable for Animal or Human Consumption.

Sáez-Almendros, S., Obrador, B., Bach-Faig, A. 2013. Environmental footprints of Mediterranean versus Western dietary patterns: beyond the health benefits of the Mediterranean diet. Environ Health 12, 118.

Saulle, R., La Torre, G. 2010. The Mediterranean Diet, recognized by UNESCO as a cultural heritage of humanity. Italian Journal of Public Health. 7, 414-415.

Springmann, M., Clark, M., Mason-D'Croz, D. 2018. Options for keeping the food system within environmental limits. Nature 562, 519–525.

Steinheider, B. 1999. Environmental odours and somatic complaints. Zentralblatt für Hygiene und Umweltmedizin. International Journal of Hygiene and Environmental Medicine 202: 101–19.

Trichopoulou, A., Martínez-González, M.A., Tong, T.Y. 2014. Definitions and potential health benefits of the Mediterranean diet: views from experts around the world. BMC Med 12, 112.

Walling, E., Vaneeckhaute, C. 2020. Greenhouse gas emissions from inorganic and organic fertilizer production and use: a review of emission factors and their variability. J. Environ. Manage. 276.

Whitehead, D.C. 1995. Grassland nitrogen. Wallingford, UK: CAB International.

WWF-Italy. 2013. Quanta natura sprechiamo? Le pressioni ambientali degli sprechi alimentari in Italia, Rome, WWF-Italy.

2.4 Challenges, opportunities, and research needs to improve circularity in the Peruvian food system

Banco Mundial. 2017. Tomando impulso en la agricultura peruana: oportunidades para aumentar la productividad y mejorar la competitividad delsector.

Bartl, K., Verones, F. & Hellweg, S. 2012. Life cycle assessment based evaluation of regional impacts from agricultural production at the Peruvian coast. Environ. Sci. Technol 46: 9872–9880.

Bartl, K., Gómez, C. A. & Nemecek, T. 2011. Life cycle assessment of milk produced in two smallholder dairy systems in the highlands and the coast of Peru. J. Clean. Prod. 19: 1494–1505.

Bedoya-Perales, N. S., Pumi, G., Mujica, A., Talamini, E. & Padula, A. D. 2018a. Quinoa expansion in Peru and its implications for land use management. Sustain. 10: 532.

Bedoya-Perales, N. S., Pumi, G., Talamini, E. & Padula, A. D. 2018b. The quinoa boom in Peru: Will land competition threaten sustainability in one of the cradles of agriculture? Land use policy 79: 475–480.

Bedoya-Perales, N. S. & Dal' Magro, G. P. 2021. Quantification of food losses and waste in Peru: A mass flow analysis along the food supply chain. Sustain. 13: 1–15.

Boeckx, P., Bauters, M. & Dewettinck, K. 2020. Poverty and climate change challenges for sustainable intensification of cocoa systems. Current Opinion in Environmental Sustainability 47: 106–111.

Christensen, V., De la Puente, S., Sueiro, J. C., Steenbeek, J. & Majluf, P. 2014. Valuing seafood: The Peruvian fisheries sector. Mar. Policy 44: 302–311.

De la Puente, S., López de la Lama, R., Benavente, S., Sueiro, J. C. & Pauly, D. 2020. Growing Into Poverty: Reconstructing Peruvian Small-Scale Fishing Effort Between 1950 and 2018. Front. Mar. Sci. 7: 681.

De Leijster, V. et al. 2021. Ecosystem services trajectories in coffee agroforestry in Colombia over 40 years. Ecosyst. Serv. 48.

Devaux, A., Hareau, G., Ordinola, M., Andrade-Piedra, J. & Thiele, G. 2021. Native Potatoes: From Forgotten Crop to Culinary Boom and Market Innovation. Reseach Agric. Appl. Econ. 35.

Díaz-Valderrama, J. R. et al. 2020. Postharvest practices, challenges and opportunities for grain producers in Arequipa, Peru. PLoS One15.

Eguren, F. & Pintado, M. 2015. Contribución de la agricultura familiar al sector agropecuario en el Perú.

Escobal, J. A. & Cavero, D. 2012. Transaction Costs, Institutional Arrangements and Inequality Outcomes: Potato Marketing by Small Producers in Rural Peru. World Dev. 40: 329–341.

FAO. 2020. The State of World Fisheries and Aquaculture 2020. The State of World Fisheries and Aquaculture 2020.

Finer, M. & Novoa, S. 2015. Patterns and Drivers of Deforestation in the Peruvian Amazon | MAAP Synthesis #1. https://maaproject.org/2015/maap-synthesis1/#_edn8

Finer, M., Mamani, N. & García, R. 2018. Deforestation Hotspots in the Peruvian Amazon, 2017 MAAP: 78. https://maaproject.org/2018/hotspots-peru2017/

Hotz, H. & Guarín, A. 2014. Assessing Smallholder Farmers and Forest Dynamics in the Peruvian Amazon.

INEI. IV Censo Nacional Agropecuario 2012 -Base de Datos REDATAM. IV Censo Nacional Agropecuario 2012. http://censos.inei.gob.pe/Cenagro/redatam/#

Jezeer, R. E., Santos, M. J., Verweij, P. A., Boot, R. G. A. & Clough, Y. 2019. Benefits for multiple ecosystem services in Peruvian coffee agroforestry systems without reducing yield. Ecosyst. Serv. 40.

Larrea-Gallegos, G. & Vázquez-Rowe, I. 2020. Optimization of the environmental performance of food diets in Peru combining linear programming and life cycle methods. Sci. Total Environ. 699.

Levis, C. et al. 201. Persistent effects of pre-Columbian plant domestication on Amazonian forest composition. Science 355: 925–931.

Majluf, P., De la Puente, S. & Christensen, V. 2017. The little fish that can feed the world. Fish Fish. 18: 772–777.

Margallo, M. et al. 2019. Enhancing waste management strategies in Latin America under a holistic environmental assessment perspective: A review forpolicy support. Science of the Total Environmentvol. 689: 1255–1275.

Morales A., R. A., Zorogastúa C., P., De Mendiburu, F. & Quiroz, R. 2018. Producción mecanizada de maíz, camote y yuca en la Costa Desértica Peruana: Estimación de la huella de carbono y propuestas de mitigación. Ecol. Apl. 17: 13.

MINAGRI. 2019. Plan Nacional de Cultivos 2019-2020.

Perez, C. et al. 2010. Climate Change in the High Andes:implications and adaptation strategies for small-scale farmers . Int. J. Environ. Cult. Econ. Soc. Sustain. 6: 71–78.

Pokorny, B., Robiglio, V., Reyes, M., Vargas, R. & Patiño Carrera, C. F. 2021. The potential of agroforestry concessions to stabilize Amazonian forest frontiers: a case study on the economic and environmental robustness of informally settled small-scale cocoa farmers in Peru. Land use policy 102: 105242.

PRODUCE. 2018. Anuario Estadístico, Pesquero y Acuícola 2018.

PRODUCE. 2019. DOCUMENTOS DE GESTIÓN –A Comer Pescado. https://www.acomerpescado.gob.pe/documentos-de-gestion/

Ravikumar, A. et al. 2016. Is small-scale agriculture really the maindriver of deforestation in the Peruvian Amazon? Moving beyond the prevailing narrative. Conserv. Lett. 102: 170–177.

Robiglio, V. & Reyes, M. 2016. Restoration through formalization? Assessing the potential of Peru's Agroforestry Concessions scheme to contribute to restoration in agricultural frontiers in the Amazon region. World Dev. Perspect. 3: 42–46.

Roosevelt, A. C. 2013. The Amazon and the Anthropocene: 13,000 years of human influence in a tropical rainforest. Anthropocene 4: 69–87.

Rosario, A. & Miñano, H. 2014. Implementación parcial de buenas prácticas pecuarias en la producción de cerdos e implementación de un sistema piloto de biodigestión en el Parque Porcino de Ventanilla. Universidad Nacional Agraria La Molina (Universidad Nacional Agraria La Molina.

Schaubroeck, T. 2020. Circular economy practices maynot always lead to lower criticality or more sustainability; analysis and guidance is needed per case. Resources, Conservation and Recycling 162 104977.

Sinba. 2021. Por un mundo sinbasura. Empresa socioambiental. https://sinba.pe

Torres-Guevera, J., Parra, F. & Casas, A. 2017. Panorama de los recursos genéticos en Perú. in Domesticación en el continente americano 2: 102–132.

Vazquez-Rowe, I., Kahhat, R., Quispe, I. & Bentín, M. 2016. Environmental profile of green asparagus production in a hyper-arid zone in coastal Peru. J. Clean. Prod. 112: 2505–2517.

Vázquez-Rowe, I., Ziegler-Rodriguez, K., Margallo, M., Kahhat, R. & Aldaco, R. 2021. Climate action and food security: Strategies to reduce GHG emissions from food loss and waste in emerging economies. Resour. Conserv. Recycl. 170: 105562.

Verzijl, A. & Quispe, S. G. 2013. The system nobody sees: Irrigated wetland management and alpaca herding in the Peruvian Andes. Mt. Res. Dev. 33: 280–293.

Ziegler-Rodriguez, K., Margallo, M., Aldaco, R., Vázquez-Rowe, I. & Kahhat, R. 2019. Transitioning from open dumpsters to landfilling in Peru: Environmental benefits and challenges from a life-cycle perspective. J. Clean. Prod. 229: 989–1003.

2.5 Rice husk soil amendments as a GHG-mitigating piece of the circular rice production system

Agarie, S., Uchida, H., Agata, W., Kubota, F., Kaufman, P.B., 1998. Effects of Silicon on Transpiration and Leaf Conductance in Rice Plants (Oryza sativa L.). Plant Production Science 1, 89–95.

Ahmaruzzaman, M., Gupta, V.K., 2011. Rice Husk and Its Ash as Low-Cost Adsorbents in Water and Wastewater Treatment. Ind. Eng. Chem. Res. 50, 13589–13613.

Arao, T., Kawasaki, A., Baba, K., Mori, S., Matsumoto, S., 2009. Effects of water management on cadmium and arsenic accumulation and dimethylarsinic acid concentrations in Japanese rice. Environ. Sci. Technol. 43, 9361–9367.

Atwill, R.L., Krutz, L.J., Bond, J.A., Golden, B.R., Spencer, G.D., Bryant, C.J., Mills, B.E., Gore, J., 2020. Alternate wetting and drying reduces aquifer withdrawal in Mississippi rice production systems. Agronomy Journal 112, 5115–5124.

Borsellino, V., Schimmenti, E., El Bilali, H., 2020. Agri-Food Markets towards Sustainable Patterns. Sustainability 12, 2193.

Carrijo, D.R., Lundy, M.E., Linquist, B.A., 2017. Rice yields and water use under alternate wetting and drying irrigation: A meta-analysis. Field Crops Research 203, 173–180.

Chen, W., Yao, X., Cai, K., Chen, J., 2011. Silicon Alleviates Drought Stress of Rice Plants by Improving Plant Water Status, Photosynthesis and Mineral Nutrient Absorption. Biol Trace Elem Res 142, 67–76.

Contreras, L.M., Schelle, H., Sebrango, C.R., Pereda, I., 2012. Methane potential and biodegradability of rice straw, rice husk and rice residues from the drying process. Water Sci Technol 65, 1142–1149.

Corrêa, É.K., Bianchi, I., Perondi, A., de los Santos, J.R.G., Corrêa, M.N., Castilhos, D.D., Gil-Turnes, C., Lucia, T., 2009. Chemical and microbiological characteristics of rice husk bedding having distinct depths and used for growing–finishing swine. Bioresource Technology 100, 5318–5322.

Cuong, T.X., Ullah, H., Datta, A., Hanh, T.C., 2017. Effects of Silicon-Based Fertilizer on Growth, Yield and Nutrient Uptake of Rice in Tropical Zone of Vietnam. Rice Science 24, 283–290.

Daifullah, A.A.M., Girgis, B.S., Gad, H.M.H., 2003. Utilization of agro-residues (rice husk) in small waste water treatment plans. Materials Letters 57, 1723–1731.

De Boer, I.J., van Ittersum, M.K., 2018. Circularity in agricultural production. Wageningen University & Research.

Deren, C.W., Datnoff, L.E., Snyder, G.H., Martin, F.G., 1994. Silicon concentration, disease response, and yield components of rice genotypes grown on flooded organic histosols. Crop Sci. 34, 733–737.

English, L., Popp, J., Miller, W., 2020. Economic Contribution of Agriculture and Food to Arkansas' Gross Domestic Product 1997-2019.

Espe, M.B., Yang, H., Cassman, K.G., Guilpart, N., Sharifi, H., Linquist, B.A., 2016. Estimating yield potential in temperate high-yielding, direct-seeded US rice production systems. Field Crops Research

FAO/WHO, 2013. Codex General Standard for Contaminants and Toxins in Food and Feed. CODEX STAN 193, 1995. Food and Agriculture Organization: Rome, Italy.

Goswami, S.B., Mondal, R., Mandi, S.K., 2020. Crop residue management options in rice–rice system: a review. Archives of Agronomy and Soil Science 66, 1218–1234.

Hardke, J.T., 2020. Trends in Arkansas Rice Production, 2019, in: Norman, R.J., Moldenhauer, K.A.K. (Eds.), B.R. Wells Arkansas Rice Research Studies 2019, Research Series. Arkansas Agricultural Experiment Station, University of Arkansas System Division of Agriculture, Fayetteville, pp. 11–22.

Hojsak, I., Braegger, C., Bronsky, J., Campoy, C., Colomb, V., Decsi, T., Domellöf, M., Fewtrell, M., Mis, N.F., Mihatsch, W., Molgaard, C., van Goudoever, J., 2015. Arsenic in Rice: A Cause for Concern. Journal of Pediatric Gastroenterology and Nutrition 60, 142–145.

Kritee, K., Nair, D., Zavala-Araiza, D., Proville, J., Rudek, J., Adhya, T.K., Loecke, T., Esteves, T., Balireddygari, S., Dava, O., Ram, K., R, A.S., Madasamy, M., Dokka, R.V., Anandaraj, D., Athiyaman, D., Reddy, M., Ahuja, R., Hamburg, S.P., 2018. High nitrous oxide fluxes from rice indicate the need to manage water for both long- and short-term climate impacts. PNAS 115, 9720–9725.

Kumagai, S., Noguchi, Y., Kurimoto, Y., Takeda, K., 2007. Oil adsorbent produced by the carbonization of rice husks. Waste Management 27, 554–561.

Kumar, A., Priyadarshinee, R., Roy, A., Dasgupta, D., Mandal, T., 2016. Current techniques in rice mill effluent treatment: Emerging opportunities for waste reuse and waste-to-energy conversion. Chemosphere 164.

Lagomarsino, A., Agnelli, A.E., Linquist, B., Adviento-Borbe, M.A., Agnelli, A., Gavina, G., Ravaglia, S., Ferrara, R.M., 2016. Alternate Wetting and Drying of Rice Reduced CH4 Emissions but Triggered N2O Peaks in a Clayey Soil of Central Italy. Pedosphere 26, 533–548.

Lal, R., 2020. Regenerative agriculture for food and climate. Journal of Soil and Water Conservation 75, 123A-124A.

LeBaron, G., Lister, J., Dauvergne, P., 2017. Governing Global Supply Chain Sustainability through the Ethical Audit Regime. Globalizations 14, 958–975.

Li, C., Carrijo, D.R., Nakayama, Y., Linquist, B.A., Green, P.G., Parikh, S.J., 2019. Impact of Alternate Wetting and Drying Irrigation on Arsenic Uptake and Speciation in Flooded Rice Systems. Agriculture, Ecosystems & Environment 272, 188–198.

Linam, F., McCoach, K., Limmer, M.A., Seyfferth, A.L., 2021. Contrasting effects of rice husk pyrolysis temperature on silicon dissolution and retention of cadmium (Cd) and 9 dimethylarsinic acid (DMA). Science of The Total Environment 765, 144428.

Linquist, B.A., Anders, M., Adviento-Borbe, M.A., Chaney, R. l, Nalley, L. l, da Rosa, E.F.F., van Kessel, C., 2015. Reducing greenhouse gas emissions, water use and grain arsenic levels in rice systems. Global Change Biology 21, 407–417.

Liu, J., Ma, J., He, C., Li, X., Zhang, W., Xu, F., Lin, Y., Wang, L., 2013. Inhibition of cadmium ion uptake in rice (Oryza sativa) cells by a wall-bound form of silicon. New Phytologist 200, 691–699.

Ma, J., Cai, H., He, C., Zhang, W., Wang, L., 2015. A hemicellulose-bound form of silicon inhibits cadmium ion uptake in rice (Oryza sativa) cells. New Phytologist 206, 1063–1074.

Ma, J.F., Yamaji, N., Mitani, N., Xu, X.-Y., Su, Y.-H., McGrath, S.P., Zhao, F.-J., 2008. Transporters of arsenite in rice and their role in arsenic accumulation in rice grain. Proceedings of the National Academy of Sciences 105, 9931–9935. https://doi.org/10.1073/pnas.0802361105

Maguffin, S.C., Abu-Ali, L., Tappero, R.V., Pena, J., Rohila, J.S., McClung, A.M., Reid, M.C., 2020. Influence of manganese abundances on iron and arsenic solubility in rice paddy soils. Geochimica et Cosmochimica Acta 276, 50–69.

Meharg, A.A., Sun, G., Williams, P.N., Adomako, E., Deacon, C., Zhu, Y.-G., Feldmann, J., Raab, A., 2008. Inorganic arsenic levels in baby rice are of concern. Environmental Pollution 152, 746–749.

Meharg, C., Meharg, A.A., 2015. Silicon, the silver bullet for mitigating biotic and abiotic stress, and improving grain quality, in rice? Environmental and Experimental Botany 120, 8–17.

Mohanty, S., Nayak, A.K., Swain, C.K., Dhal, B., Kumar, A., Tripathi, R., Shahid, M., Lal, B., Gautam, P., Dash, G.K., Swain, P., 2020. Silicon enhances yield and nitrogen use efficiency of tropical low land rice. Agronomy Journal 112, 758–771.

Nalley, L., Linquist, B.A., Kovacs, K., Anders, M., 2015. The Economic Viability of Alternative Wetting and Drying Irrigation in Arkansas Rice Production. Agronomy Journal 107, 579.

Naser, H.M., Nagata, O., Tamura, S., Hatano, R., 2007. Methane emissions from five paddy fields with different amounts of rice straw application in central Hokkaido, Japan. Soil Science and Plant Nutrition 53, 95–101.

Nwugo, C.C., Huerta, A.J., 2008. Effects of silicon nutrition on cadmium uptake, growth and photosynthesis of rice plants exposed to low-level cadmium. Plant Soil 311, 73–86.

Okutani, T., Ichikawa, E., Nagai, H., Hashimoto, T., Makihata, T., 2018. Crystalline silica in compressed rice hull coke ash. J. Met. Mater. Miner. 28.

Pati, S., Pal, B., Badole, S., Hazra, G.C., Mandal, B., 2016. Effect of Silicon Fertilization on Growth, Yield, and Nutrient Uptake of Rice. Communications in Soil Science and Plant Analysis 47, 284–290.

Penido, E.S., Bennett, A.J., Hanson, T.E., Seyfferth, A.L., 2016. Biogeochemical impacts of silicon-rich rice residue incorporation into flooded soils: Implications for rice nutrition and cycling of arsenic. Plant Soil 399, 75–87.

Pode, R., 2016. Potential applications of rice husk ash waste from rice husk biomass power plant. Renewable and Sustainable Energy Reviews 53, 1468–1485.

Reba, M.L., Daniels, M., Chen, Y., Sharpley, A., Bouldin, J., Teague, T.G., Daniel, P., Henry, C.G., 2013. A statewide network for monitoring agricultural water quality and water quantity in Arkansas. Journal of Soil and Water Conservation 68, 45A-49A. https://doi.org/10.2489/jswc.68.2.45A

Reba, M.L., Massey, J.H., 2020. Surface Irrigation in the Lower Mississippi River Basin: Trends and Innovations. Transactions of the ASABE 63, 1305–1314.

Runkle, B.R.K., Suvočarev, K., Reba, M.L., Reavis, C.W., Smith, S.F., Chiu, Y.-L., Fong, B., 2019. Methane Emission Reductions from the Alternate Wetting and Drying of Rice Fields Detected Using the Eddy Covariance Method. Environ. Sci. Technol. 53, 671–681.

Savant, N.K., Datnoff, L.E., Snyder, G.H., 1997a. Depletion of plant-available silicon in soils: A possible cause of declining rice yields. Communications in Soil Science and Plant Analysis 28, 1245–1252.

Savant, N.K., Snyder, G.H., Datnoff, L.E., 1997b. Silicon management and sustainable rice production, in: Advances in Agronomy, Vol 58, Advances in Agronomy. pp. 151–199.

Schreefel, L., Schulte, R.P.O., de Boer, I.J.M., Schrijver, A.P., van Zanten, H.H.E., 2020. Regenerative agriculture – the soil is the base. Global Food Security 26, 100404.

Seebold, K.W., Kucharek, T.A., Datnoff, L.E., Correa-Victoria, F.J., Marchetti, M.A., 2001. The influence of silicon on components of resistance to blast in susceptible, partially resistant, and resistant cultivars of rice. Phytopathology 91, 63–69.

Seyfferth, A.L., Amaral, D., Limmer, M.A., Guilherme, L.R.G., 2019. Combined impacts of Si-rich rice residues and flooding extent on grain As and Cd in rice. Environment International 128, 301–309.

Seyfferth, A.L., Morris, A.H., Gill, R., Kearns, K.A., Mann, J.N., Paukett, M., Leskanic, C., 2016. Soil Incorporation of Silica-Rich Rice Husk Decreases Inorganic Arsenic in Rice Grain. J. Agric. Food Chem. 64, 3760–3766.

Shen, Y., 2017. Rice husk silica derived nanomaterials for sustainable applications. Renewable and Sustainable Energy Reviews 80, 453–466.

Shew, A.M., Nalley, L.L., Durand-Morat, A., Meredith, K., Parajuli, R., Thoma, G., Henry, C.G., 2021. Holistically valuing public investments in agricultural water conservation. Agricultural Water Management 252, 106900.

Sun, L., Gong, K., 2001. Silicon-Based Materials from Rice Husks and Their Applications. Ind. Eng. Chem. Res. 40, 5861–5877.

Teasley, W.A., Limmer, M.A., Seyfferth, A.L., 2017. How rice (Oryza sativa L.) responds to elevated As under different Si-rich soil amendments. Environ. Sci. Technol. https://doi.org/10.1021/acs.est.7b01740

Thomson, A.M., Ramsey, S., Barnes, E., Basso, B., Eve, M., Gennet, S., Grassini, P., Kliethermes, B., Matlock, M., McClellen, E., Spevak, E., Snyder, C.S., Tomer, M.D., van Kessel, C., West, T., Wick, G., 2017. Science in the Supply Chain: Collaboration Opportunities for Advancing Sustainable Agriculture in the United States. Agricultural & Environmental Letters 2.

Tubana, B.S., Babu, T., Datnoff, L.E., 2016. A Review of Silicon in Soils and Plants and Its Role in US Agriculture: History and Future Perspectives. Soil Science 181, 393–411.

USDA-NASS, 2021. Quickstats - https://quickstats.nass.usda.gov/results.

Watkins, K.B., Henry, C.G., Hardke, J.T., Mane, R.U., Mazzanti, R., Baker, R., 2021. Non-radial 11 technical efficiency measurement of irrigation water relative to other inputs used in Arkansas rice production. Agricultural Water Management 244, 106441.

Yang, X., Chen, Qian, Xu, Z., Zheng, Q., Zhao, R., Yang, H., Ruan, C., Han, F., Chen, Qiuhua, 2021. Consumers' preferences for health-related and low-carbon attributes of rice: A choice experiment. Journal of Cleaner Production 295, 126443.

Yuan, Y., B, L., Wilson, L., Cassman, K., A, S., V, P., B, M., Saito, K., Agustiani, N., Aristya, V., Krisnadi, L., Zanon, A., Heinemann, A., Carracelas, G., Subash, N., Brahmanand, P., Li, T., Peng, S., Grassini, P., 2021. A roadmap towards sustainable intensification for a larger global rice bowl.

2.6 Winter cultivation of legume beans instead of rice to reduce field methane emissions and use legume by-product for low methane emitting livestock and fish production in Bangladesh

Indexmundi. 2021. http://www.indexmundi.com>Home> Agriculture>Soybean oil. Bangladesh Soybean oil imports by year. Search on 9 June 2021.

Indexmundi. 2021. http://www.indexmundi.com>Home> Agriculture>Soybean meal. Bangladesh Soybean meal imports by year. Search on 9 June 2021.

IPCC. 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. IPCC National Greenhouse Gas Inventories Programme. 3 https://www.ipcc-nggip.iges.or.jp/public/gp/english/: 4.1-4.94.

Ma Y, Sun L, Liu C, Yang X, Zhou W, Yang B, Schwenke G, Liu L. 2018. A comparison of methane and nitrous oxide emissions from inland mixed-fish and crab aquaculture ponds. *Sci Total Environ* 637-638: 517-523.

NZAGRC F. 2017. Options for low emission development in the Bangladesh dairy sector – reducing enteric methane for food security and livelihoods. Vol. http://www.fao.org/3/i6822e/i6822e.pdf

Rosentreter JA, Borges AV, Deemer BR, Holgerson MA, Liu S, Song C, Melack J, Raymond PA, Duarte CM, Allen GH, Olefeldt D, Poulter B, Battin TI, Eyre BD. 2021. Half of global methane emissions come from highly variable aquatic ecosystem sources. *Nature Geoscience* 14: 225-230.

Singh I. 2012. Use of Biogas for cooking purpose a in a technical Institute: A view point. Preceedings of the National Conference on Trends and Advances in Mechanical Engineering, YMCA University of Science and Technology, Faridabad, Haryna.

2.7 Regional opportunities to mitigate GHG emissions in the capital region Berlin-Brandenburg, Germany

Animal Task Force (ATF). 2019a. Vision Paper towards European Research and Innovation for a sustainable and competitive livestock production sector in Europe. A framework for suggested priorities for R&I within Horizon Europe. p36.

Animal Task Force (ATF). 2019b. Research and Innovation towards a more sustainable and circular European agriculture Exploring syn-ergies between the livestock and crop sectors. Joint position paper p28.

Animal Task Force (ATF). 2020. Research and Innovation towards a more sustainable and circular European agriculture Exploring syn-ergies between the livestock and crop sectors. Policy brief p4.

Animal Task Force (ATF). 2021. A strategic research and innovation agenda for a sustainable livestock sector in Europe Suggested priorities for research for Horizon Europe to enhance innovation and sustainability in the livestock production sector of Europe's food supply chains. Third White Paper of the Animal Task Force. P 56.

Balafoutis, A. et al. 2017. Precision agriculture technologies positively contributing to GHG emissions mitigation, farm productivity and economics. Sustainability 9: 1339.

Berg G, Köberl M, Rybakova D, Müller H, Grosch R, Smalla K. 2017. Plant microbial diversity is suggested as the key to future biocontrol and health trends. FEMS Microbiology Ecology 93.

BMEL. 2020. Afrika Concept Assuring Food Security – Promoting Growth.

Boetius A. 2019. Global change microbiology — big questions about small life for our future. Nature Reviews Microbiology 17: 331-332.

Bonaudo, T., Bendahan, A. B., Sabatier, R., Ryschawy, J., Bellon, S., Leger, F., & Tichit, M. 2014. Agroecological principles for the redesign of integrated crop–livestock systems. european Journal of Agronomy 57: 43-51.

Bundesministerium für Bildung und Forschung (BMBF). 2018. Forschung und Innovation für die Menschen - Die Hightech-Strategie 2025. https://www.hightech-strategie.de/files/HTS2025.pdf

D'Hondt K, Kostic T, McDowell R, Eudes F, Singh BK, Sarkar S, Markakis M, Schelkle B, Maguin E, Sessitsch A. 2021. Microbiome innovations for a sustainable future. Nature Microbiology 6: 138–142.

De Boer, I. J., & van Ittersum, M. K. 2018. Circularity in agricultural production. Wageningen University & Research. P 74.

Drastig K, Prochnow A, Baumecker M, Berg W, Brunsch B. 2011. Water for agriculture in Brandenburg (Germany). Die Erde 142: 119 140.

Ecologic (2020). Climate Laws in Europe. https://www.ecologic.eu/sites/files/publication/2020/climatelawsineurope_summary_0.pdf

EIP-AGRI. 2017. Focus Group Mixed farming systems: livestock/cash crops. Final report. The European Innovation Partnership 'Agricultural Productivity and Sustainability'. Brussels. p34

EIP-AGRI. 2019. Opportunities for farm diversification in the circular bioeconomy: Final report. The European Innovation Partnership 'Agricultural Productivity and Sustainability'. Brussels. p20

EU Green Deal. 2018. Communication from the commission to the European parliament, the European council, the council, the Euro-pean economic and social committee and the committee of the regions. p24

EU Methane strategy. 2020. Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions on an EU strategy to reduce methane emissions. p28.

European Commission. 2020a. Farm to fork strategy: for a fair, healthy and environmentally-friendly food system. DG SANTE/Unit 'Food information and composition, food waste"'. p23

European Commission. 2020b. Food 2030 pathways for action: Research and innovation policy as a driver for sustainable, healthy and inclusive food systems p128.

FACCE-JPI. 2020. Strategic Research Agenda. Joint Programming Initiative on Agriculture, Food Security and Climate Change. p40

FAO. 2016. Agroecology for food security and nutrition: Proceedings of the FAO International Symposium 29-31 August in China.

FAO. 2017a. The future of food and agriculture–Trends and challenges. Annual Report. p180 http://www.fao.org/3/a-i6583e.pdf

FAO. 2017b. Livestock solutions for climate change. Rome p8. http://www.fao.org/3/a-i8098e.pdf

FAO. 2018a. Transforming the livestock sector through the Sustainable Development Goals. Food and Agriculture Organization of the United Nations.

FAO. 2018b. The future of food and agriculture – Alternative pathways to 2050 Summary version Rome p64.

FAO. 2019a. Five practical actions towards low-carbon livestock. p40 Rome.

FAO. 2019b. Averting risks to the food chain – A compendium of proven emergency prevention methods and tools. Second edition. Rome. p104 Licence: CC BY-NC-SA 3.0 IGO.

FAO. 2020. Committee on Agriculture; Livestock, natural resource use, climate change and environment.

French E, Kaplan I, Iyer-Pascuzzi A, Nakatsu CH, Enders L. 2021. Emerging strategies for precision microbiome management in diverse agroecosystems. Nature Plants. 7: 256–267.

German National Academy of Sciences Leopoldina, acatech – National Academy of Science and Engineering, the Union of German Academies of Sciences and Humanities. 2020. Biodiversity and management of agricultural landscapes – Wide-ranging action is now crucial. Halle (Saale)

Gutleben J, De Mares MC, van Elsas JD, Smidt H, Overmann J, Sipkema D. 2018. The multi-omics promise in context: from sequence to microbial isolate. Crit. Rev. Microbiol. 44: 212-229.

Ghimire, S., Wang, J., & Fleck, J. R. 2021. Integrated Crop-Livestock Systems for Nitrogen Management: A Multi-Scale Spatial Analy-sis. Animals 11: 100.

Hutchins DA, Jansson JK, Remais JV, Virginia I, Rich R, Singh BK, Trivedi P. 2019. Climate change microbiology — problems and per-spectives. Nature Reviews Microbiology 17: 391-396.

Krüger A, Schäfers C, Busch P, Antranikian G. 2020. Digitalization in microbiology – Paving the path to sustainable circular bioecon-omy. New Biotechnology 59: 88–96.

Lemaire, G., Franzluebbers, A., de Faccio Carvalho, P. C., & Dedieu, B. 2014. Integrated crop–livestock systems: Strategies to achieve synergy between agricultural production and environmental quality. Agriculture, Ecosystems & Environment 190: 4-8.

Lewis WH, Tahon G, Geesink P, Sousa DZ, Ettema TJG. 2020. Innovations to culturing the uncultured microbial majority. Nature Re-views Microbiology.

Nowak, B. et al. 2015. Nutrient recycling in organic farming is related to diversity in farm types at the local level; Agriculture, Ecosys-tems & Environment, Volume 204, 1 June 2015, Pages 17-26.

Peyraud, J. L., & MacLeod, M. 2020. Future of EU livestock: how to contribute to a sustainable agricultural sector?. European Com-mission.

Rockström, J., Williams, J., Daily, G., Noble, A., Matthews, N., Gordon, L., & Smith, J. 2017. Sustainable intensification of agricul-ture for human prosperity and global sustainability. Ambio 46: 4-17.

Röttjers L, Faust K. 2018. From hairballs to hypotheses – biological insights from microbial networks. FEMS Microbiological Reviews 42: 761-780.

Sanderson, M. A., Archer, D., Hendrickson, J., Kronberg, S., Liebig, M., Nichols, K., ... & Aguilar, J. 2013. Diversification and ecosys-tem services for conservation agriculture: Outcomes from pastures and integrated crop–livestock systems. Renewable agriculture and food systems 28: 129-144.

Schut, A. G., Cooledge, E. C., Moraine, M., Van De Ven, G. W., Jones, D. L., & Chadwick, D. R. 2021. Reintegration of crop-livestock systems in Europe: an overview. Frontiers of Agricultural Science and Engineering 8: 111-129.

Shendure J, Balasubramanian S, Church GM, Gilbert W, Rogers J, Schloss JA, Waterston RH. 2017. DNA sequencing at 40: Past, pre-sent and future. Nature 550: 345–353.

Trivedi P, Leach JE, Tringe SG, Sa T, Singh BK. 2020. Plant–microbiome interactions: from community assembly to plant health. Nature Reviews Microbiology 18: 607–621.

Tullo, E., Finzi, A., & Guarino, M. 2019. Environmental impact of livestock farming and Precision Livestock Farming as a mitigation strategy. Science of the total environment, 650, 2751-2760.

United Nations Environment Programme and Climate and Clean Air Coalition. 2021. Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions p174. Nairobi: United Nations Environment Programme.

Van der Wiel, B. Z., Weijma, J., van Middelaar, C. E., Kleinke, M., Buisman, C. J. N., & Wichern, F. 2020. Restoring nutrient circulari-ty: A review of nutrient stock and flow analyses of local agro-food-waste systems. Resources, Conservation and Recycling 160: 104901.

Vinholis, M. D. M. B., Souza Filho, H. M. D., Shimata, I., Oliveira, P. P. A., & Pedroso, A. D. F. 2021. Economic viability of a crop-live-stock integration system. Ciência Rural: 51

Wezel, A., Soboksa, G., McClelland, S., Delespesse, F., & Boissau, A. 2015. The blurred boundaries of ecological, sustainable, and agroecological intensification: a review. Agronomy for sustainable development, 35(4), 1283-1295 DOI 10.1007/s13593-015-0333-y

Wirtschaftsregion Lausitz GmbH. 2020. Entwicklungsstrategie Lausitz 2050; http://www.zw-lausitz.de/fileadmin/user_upload/ent-wicklungsstrategie-lausitz-2050.pdf

Zheng B, Zhu Y, Sardans J, Peñuelas J, Su J. 2018. QMEC: a tool for high-throughput quantitative assessment of microbial functional potential in C, N, P, and S biogeochemical cycling. Science China Life Sciences 61: 1451–1462.

2.8 Circular Food Systems: The Economic and Environmental Benefits of Integrated Farming System under Small-Scale Farm-Holdings of Tamil Nadu, Southern India

Bhuvaneswari, J., G. Thiyagarajan, M. Manikandan, S. K. Natarajan and Thenmozhi, S. 2020. Multiple Water Use in Gardenland Integrated Farming System for Enhancing Productivity. Int.J.Curr.Microbiol.App.Sci. 9(11): 2151-2156.

Bastiaanssen WGM, Van Dam JC, Droogers P. 2003. Introduction. In: van Dam JC, Malik RS (eds) Water productivity of irrigated crops in Sirsa district, India. International Water Management Institute, Sri Lanka, pp 11–20

CWC. 2018. Water and Related Statistics, Central Water Commission, Ministry of Water Resources, Government of India.

2.9 Circularity in pastoral agricultural systems in New Zealand

Beef + Lamb New Zealand. 2017. Guide to New Zealand Cattle Farming. Accessed from https://beeflambnz.com/knowledge-hub/PDF/guide-new-zealand-cattle-farming

Beef + Lamb New Zealand. 2019. Taste Pure Nature. New Zealand beef and lamb. Accessed on 19/05/2021 from https://beeflambnz.com/sites/default/files/taste%20pure%20nature.pdf

Beef + Lamb New Zealand. 2020a. Compendium of New Zealand Farm Facts 2020. 44th edition. Publication No. P20001. ISSN 2230-5777.

Beef + Lamb New Zealand. 2020b. National Policy Statement for Indigenous Biodiversity. Roadshow 2020.

Bos JFFP, Ten Berge HFM, Verhagen J, Van Ittersum MK. 2017. Trade-offs in soil fertility management on arable farms. *Agricultural Systems 157*: 292-302.

Burggraaf VT, Lineham DB. 2016. Effect of easy calving beef sires on the birth weight and growth of dairy beef cattle. Proceedings of the Hill Country Symposium. Grassland Research and Practice Series No. 16. pp 329-332.

DairyNZ. 2016. Feed use in the New Zealand dairy industry. MPI Technical Paper 2017/53. Prepared for the Ministry for Primary Industries.

DairyNZ. 2020. New Zealand Dairy Statistics 2019-20. Accessed from https://www.dairynz.co.nz/media/5794073/nz-dairy-statistics-2019-20-dnz.pdf.

Ellen MacArthur Foundation 2019. Circularity Indicators. An approach to measuring circularity. Methodology.

Fertiliser Association. n.d. Fertiliser use in New Zealand. Accessed from https://www.fertiliser.org.nz/Site/about/fertiliser_use_in_nz.aspx

He Waka Eke Noa. 2021. He Waka Eke Noa Primary Sector Climate Action Partnership.

Horticulture New Zealand 2020. Rising to the challenge. Annual report 2019/20. 56 pp.

IPCC 2007. Changes in atmospheric constituents and in radiative forcing. In Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller. ed. Cambridge University Press, Cambridge, United Kingdom.

Ledgard SF, Rendel J, Falconer S, White T, Barton S and Barton M. 2016. Nitrogen footprint of beef produced in a nitrogen-constrained lake and marketed for a price premium based on low environmental impact. Proceedings of the International Nitrogen Initiative Conference. Melbourne, Australia. 4 p.

Leahy SC, Kearney L, Reisinger A, Clark A. 2019. Mitigating greenhouse gas emissions from New Zealand pasture-based livestock farm systems. *Journal of New Zealand Grasslands 81*: 101-110.

Ledgard SF, Falconer SJ, Abercrombie R, Philip G, Hill J. 2020. Temporal, spatial, and management variability in the carbon footprint of New Zealand milk. *Journal of Dairy Science 103*:1031-1046.

Ministry for the Environment. 2019. Draft National Policy Statement for Indigenous Biodiversity. Accessed from https://environment.govt.nz/publications/draft-national-policy-statement-for-indigenous-biodiversity/

Ministry for the Environment. 2021a. New Zealand's Greenhouse Gas Inventory 1990-2019 Snapshot. Accessed from https://environment.govt.nz/publications/new-zealands-greenhouse-gas-inventory-1990-2019/.

Ministry for the Environment. 2021b. Net emissions and removals from vegetation and soils on sheep and beef farmland. ISBN: 978-1-99-003345-2. Publication number: ME 1554. Wellington.

Mossa AW, Bailey EH, Usman A, Young SD, Crout NMJ. 2020. The impact of long-term biosolids application (>100 years) on soil metal dynamics. *Science of the Total Environment 720*: 137441.

New Zealand Government. 2020. National Policy Statement for Freshwater Management 2020. 70 pp. Accessed from https://environment.govt.nz/assets/Publications/Files/national-policy-statement-for-freshwater-management-2020.pdf

New Zealand Wine. 2021. Vineyard reports. Accessed on 19/05/2021 from https://environment.govt.nz/assets/Publications/Files/national-policy-statement-for-freshwater-management-2020.pdf https://www.nzwine.com/en/media/statistics/vineyard-reports/

Niles MT, Garrett RD, Walsh D. 2018. Ecological and economic benefits of integrating sheep into viticulture production. *Agronomy for Sustainable Development 38*: 1-10.

PAMU. 2016. Landcorp farms to stop using PKE. Accessed from https://pamunewzealand.com/news/2016/landcorp-farms-to-stop-using-pke

Payen S, Falconer S, Ledgard SF. 2018. Water scarcity footprint of dairy milk production in New Zealand – A comparison of methods and spatio-temporal resolution. *Science of The Total Environment 639*: 504-515.

Rufí-Salís, M., A. Petit-Boix, G. Villalba, X. Gabarrell, and S. Leipold. 2021. Combining LCA and circularity assessments in complex production systems: the case of urban agriculture. *Resources, Conservation and Recycling 166*:105359.

Seafood New Zealand. 2021. New Zealand Seafood Exports. Report 7. Seafood exports by product type. Calendar year to March 2021 (provisional). 90 pp.

StatsNZ. 2017. Agricultural Production Census. Accessed from https://www.stats.govt.nz/information-releases/agricultural-production-statistics-june-2017-provisional.

StatsNZ. 2021. Fertilisers – nitrogen and phosphorus. Accessed from https://www.stats.govt.nz/indicators/fertilisers-nitrogen-and-phosphorus;

Van der Weerden T J, Cox N, Luo J, Di HJ, Podolyan A, Phillips RL, Saggar S, de Klein CAM, Ettema P, Rys G. 2016. Refining the New Zealand nitrous oxide emission factor for urea fertiliser and farm dairy effluent. *Agriculture, Ecosystems and the Environment 222*: 133–137.

van Selm B, de Boer IJM, Ledgard SF, van Middelaar CE. 2021. Reducing greenhouse gas emissions of New Zealand beef through better integration of dairy and beef production. *Agricultural Systems 186*: 102936.

Whitehead D, Schipper LA, Pronger J, Moinet GYK, Mudge PL, Calvelo Pereira R, Kirschbaum MUF, McNally SR, Beare MH, Camps-Arbestain M. 2018. Management practices to reduce losses or increase soil carbon stocks in temperate grazed grasslands: New Zealand as a case study. Agriculture, Ecosystems & Environment265: 432-443.

Wholly Cow. 2021. Wholly Cow. Locally Grown, Ethical Butchery. Accessed from https://www.whollycow.co.nz/page/about/

2.10 Use of Cassava Waste in Circular Food Systems in Nigeria

Adeyemo, O.K. 2005. Haematological and histopathological effects of cassava mill effluent in *Clarias gariepinus*. African Journal of Biomedical Research 8: 179-183.

Adekeye, A., Amole, T., Oladimeji, S., Raji, A., Odekunle, T., Olasusi, O., Bamidele, O. and Adebayo, A. 2021. African Journal of Agricultural Research Growth performance, carcass characteristics and cost benefit of feeding broilers with diets containing high quality cassava peel (HQCP). African Journal of Agricultural Research 17: 448-455.

Energy Commission. 2013. National Energy Statistics—2000–2013, Energy Commission of Ghana, 2013.

FAO. 2010. The millennium development Goals and climate change: taking stock and looking ahead.

Fauquet, M.C. 2014. Estimating cassava wastes in Nigeria: A consultancy report submitted to the International Livestock Research Institute (ILRI) Nairobi, Kenya

Ibrahim, E. 2020. Crisis and survival of Nigeria's poultry industry: A critical moment.

Kindred, D., Mortimer, N., Sylvester-Bradley, R., Brown, G., Woods, J. 2008. Understanding and managing uncertainties to improve biofuel GHG emissions calculations. Project Report No. 435 Part 2 London: HGCA.

Mashavave R. 2019. Transition to a circular food system. OPINION: THE FUTURE FOOD SYSTEM.

OECD. 2012. Greenhouse Gas Emissions and the Potential for Mitigation from Materials Management within OECD Countries, Paris.

Olorunfemi, D. I. and Lolodi, O. 2011. Effect of cassava processing effluents on antioxidant enzyme activities in *Allium cepa* L. Biokemistri 23: 49 – 61.

Okike, I., Samireddipalle, A., Kaptoge, L., Fauquet, C., Atehnkeng, J., Bandyopadhyay, R., Kulakow, P., Duncan, A., Alabi, T. and Blümmel, M. 2015. Technical innovations for small-scale producers and households to process wet cassava peels into high quality animal feed ingredients and aflasafe™ substrate. Food Chain Vol. 5 No. 1–2, pp71-90.

Oladele, K. 2014. Cassava processing and the environmental effect. World Sustainability Forum 2014. 1-7

Warnars, L. and Oppenoorth H. 2014. Bioslurry: A Supreme Fertilizer.

2.11 Advances in converting cereal straws and stovers into concentrates: implications for the circular economy

Beauchemin, K. A. *et al.* 2008. Nutritional management for enteric methane abatement: a review. *Australian Journal of Experimental Agriculture*. CSIRO 48: 21–27.

Blümmel, M., Steele, B. and Dale, E. B. 2014. Opportunities from second-generation biofuel technologies for upgrading lignocellulosic biomass for livestock feed. CAB Reviews 2014 9, No. 041

Blümmel, M., Sharma, G.V.M., Ravindranath, K., Padmakumar, V. and Jones, C. 2019. Spin-off technologies from 2nd generation biofuel: potential to transform fodder quality of crop residues. Ethiopian Society of Animal Production, Conference Proceedings.

Capper, J.L. 2011. Replacing rose-tinted spectacles with a high-powered microscope: The historical versus modern carbon footprint of animal agriculture', *Animal frontiers*. Oxford University Press 1: 26–32.

FAO. 2017. Livestock solutions for climate change. I8098EN/1/11.17

FAO. 2020. Building sustainable and resilient food systems in Asia and the Pacific. Regional conference for the Asia and Pacific. 35th session, 1-4 September 2020.

Joachim von Braun, Kaosar Afsana, Louise Fresco, Mohamed Hassan, Maximo Torero. 2020. Food systems – definition, concept and application for food system summit. UN Food System Summit 2021 Scientific group.

Madhav Karki, Sarba Raj Kahdka, Pawan Paudel & Archana Dhakal. 2018. Analysisng the food system of Nepal. 27 September 2018, Kathmandu, nepal

USAID. 2019. https://www.usaid.gov/nepal/food-assistance

Makkar, H.P.S. 2016. Smart livestock feeding strategies for harvesting triple gain–the desired outcomes in planet, people and profit dimensions: a developing country perspective. *Animal Production Science*. CSIRO, 56(3), pp. 519–534.

Malik, P. K. *et al.* 2015. Feed based approaches in enteric methane amelioration. *Livestock production and climate change. CABI Publishers, Oxfordshire, UK*, pp. 336–359.

Nepal Times. 2020. https://www.nepalitimes.com/latest/nepal-agro-imports-at-all-time-high/

Owen E, Jayasuriya MCN. Use of crop residues as animal feeds in developing countries. Research and Development in Agriculture 1989 6:129–38.

Preeti Mor, Bryan Bals, Amrish Kumar Tyagi, Farzaneh Teymouri, Nitin Tyagi, Sachin Kumar, Venkataraman Bringi, and Michael VandeHaar. 2018. Effect of ammonia fiber expansion on the available energy content of wheat straw fed to lactating cattle and buffalo in India. Journal of dairy science. 101:1-14

Sarnklong, C., Cone, J.W., Pellikaan, W., and Hendriks, W.H. 2010. Utilization of rice straw and different treatments to improve its value for ruminants: A review. Asian-Australasian J. Anim. Sci. 23; 680-692.

Singh, G. P. and Mohini, M. 1999. Effect of different levels of rumensin in diet on rumen fermentation, nutrient digestibility and methane production in cattle. Asian-Australian Journal of Animal Science; Vol 12, No 8: 1215-1221.

Tuyen, D.V., Phuong, H.N., Cone, J.W., Baars, J.J.P., Sonnenberg, A.S.M. and Hendriks, W.H. 2013. Effect of fungal treatments of fibrous agricultural by-product on chemical composition and in vitro rumen fermentation and methane production. Bioresource Technology 129: 256-263.

Urgilevich, A., Birge, T., Kentala-Lehtonen, J., Korhonen-Kurki, K., Pietikäinen, J., Saikku, L. and Schösler, H., 2016. Transition towards circular economy in the food system. Sustainability 8(1): 69.

Van Kuijk, S, Sonnenberg, A.S.M., Baars, J.J.P., Hendriks, W.H., Cone, J.W. 2015. Fungal treated lignocellulosic biomass as ruminant feed ingredient: A review. Biotechnology Advances 33: 191-202.

Annex

Video links

1. Video link Bangladesh: https://youtu.be/RQTdEJ0FyGQ
2. Video link Germany: https://youtu.be/ARZ33jGyK6I
3. Video link Malawi-Zambia: https://youtu.be/v8LFh0-bD04
4. Video link Mediterranean: https://youtu.be/mQLUeVwNLjc
5. Video link New Zealand: https://youtu.be/8fuYKi8eoCw
6. Video link Nigeria: https://youtu.be/nz_M9CsqW0s
7. Video link Peru: https://youtu.be/L0VpqDL39Pc
8. Video link Reunion Island: https://youtu.be/8asSvsjJ4tI
9. Video link Southern-India: https://youtu.be/b1cbcUTfJxI
10. Video link USA Arkansas: https://youtu.be/XLuk7ZcYLn8
11. Upgrading of by-products: https://www.youtube.com/watch?v=T7DPd4p9sfM

More info: CFS network website