Rethinking food production

Opportunities and barriers for circular agriculture

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The Food & Business Research (F&BR) programme

The Food & Business Research (F&BR) programme aims at addressing persistent food security challenges in low and middle income countries. A total of 75 projects have been funded under two instruments:

- The Global Challenges Programme (GCP), which promotes research-based advanced understanding of emerging key issues in global and regional food security and their impact on local food security and the role of private sector development.
- The Applied Research Fund (ARF), which promotes research-supported innovations that contribute to food security and private sector development in the partner countries of Dutch development cooperation.

The research themes relate to the Food & Business Knowledge Agenda of the Netherlands Ministry of Foreign Affairs. All projects are run by a consortium of academic, private sector and NGO partners to promote research uptake by relevant local, national and international stakeholders.

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1 Introduction

Global agriculture is facing a major challenge: feeding a growing world population while keeping its footprint within "planetary boundaries" (Rockström et al, 2009). The current global agri-food system is built in such a way that all actors involved – including farmers, processors, seed companies, producers of fertilizers and other agricultural inputs, traders and retailers, and consumers – are first and foremost concerned with maximizing profits or minimizing costs. This conventional model of food production, characterised by a 'take-produce-consume-discard' pattern, has dramatically increased crop production thanks to improvements in agricultural technological processes, high inputs and the expansion of agricultural land (van Berkum et al., 2019).

However, the downsides of increasingly efficient production have slowly but surely become apparent. Negative impacts of intensified forms of agriculture on nature, the environment, climate change and biodiversity, as well as on human health can no longer be ignored. The reliance on monocropping, excessive food waste, diminishing soil fertility, and the inefficient use of (natural) resources are taking their toll. It is foreseen that business-as-usual will not be able to sustainably feed the growing world population and meet global food demand, without causing detrimental or even irreversible effects on the world's natural resources (FAO, 2018). Measures to improve the sustainability of the agri-food system are urgently needed to reduce climate impacts and vulnerability to climate change, to conserve and restore biodiversity, and to improve soil quality.

This sense of urgency has pushed for a rethinking of the current model of agricultural food production. To meet the nutritional requirements of a growing population in a sustainable manner, new approaches are being introduced and researched. For this purpose a food systems approach can be advantageous. This approach distinguishes all processes that are associated with food production, food utilisation and overall diets – from growing, harvesting, packing, processing, transporting, marketing, consuming and disposing of food. At the same time, the systems approach emphasizes that these processes are influenced by social, political, cultural, technological, economic and natural externalities.

Circular agriculture is one such alternative approach that has received increasing attention in the global North (see Box 1). Both circular agriculture and the food systems approach link in a very tangible way to a number of global challenges: climate change and water scarcity; urbanization and shifting diets; smallholder productivity; hunger and malnutrition; deforestation and decreasing biodiversity (van Bodegem et al, 2019). In June 2019, the Dutch government shared a knowledge and innovation agenda for its agricultural policy, in which circular agriculture was introduced as the new – sustainable - way forward. The government's aim for 2030 is a circular agricultural system with cycles closed at the most local level possible, with the Netherlands taking a front-runner's role in promoting this approach to the agriculture of the future.

Box 1: Circular Agriculture

Circular Agriculture is an ecological concept based on the principle of optimising the use of all biomass. Circular agriculture aims at closing the loop of materials and substances and reducing both resource use and discharges into the environment (Berkum, 2019).

There is no 'blueprint' for adopting a circular agriculture approach. It is a collective search by farmers, citizens, businesses, researchers and policymakers for the optimum combination of ecological principles with modern technology, with new partnerships, new economic models, and credible social services. It is all about seeking answers to how optimizing of different flows in the food system (as depicted in Figure 1) can offer minimal stress on the environment, nature and climate, while optimizing yields and sparing resources. For a broader conceptual discussion of circular agriculture, please refer to Circular Agriculture in Low and Middle Income Countries published by the Food & Business Knowledge Platform.

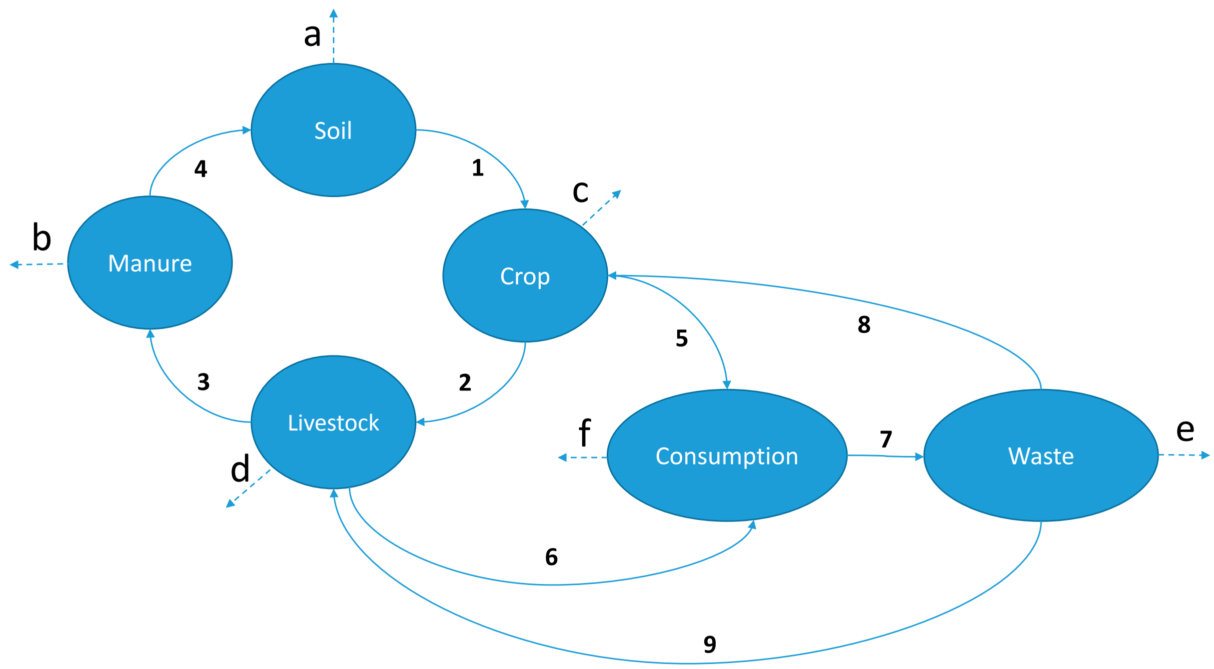

Figure 1: **Flows of circular agriculture**

The practice of circular agriculture, however, has a long history – even if it was not named as such. In the global North, urbanisation, industrialisation and globalisation have caused previously circular agricultural systems to become more linear (World Economic Forum, 2018). In many low and middle income countries (LMICs), circular approaches to economic and agricultural activity are still more common today. However, the evidence base for the existing practices, norms and behaviours remains weak. Preston et al. (2017) find that 'circular' approaches in LIMCs are often born out of economic necessity, and that higher-value opportunities for 'reducing, recycling and reusing' are relatively unknown. Nevertheless, the circular approaches adopted in LMICs have the potential to address some of the pressing issues of current models of intensive agriculture, such as negative environmental impacts and perpetual waste streams. Much can be learned from the existing processes and new approaches that are being introduced to address systemic challenges and inefficienciens of the current food system.

This article presents and reviews new knowledge and innovations that have been introduced in LMICs and discusses the lessons learned. This thematic synthesis builds on the insights gained and innovations developed by 12 Food & Business Research projects funded by NWO-WOTRO Science for Global Development, which have all addressed aspects of circular agriculture and their application in LMICs (see Box 2 and Annex). Three key principles of circular agriculture will be discussed: (1) preserving and enhancing natural resources, (2) efficient use of resources, and (3) multi-purpose use and recovering value from waste. Insights into each of these principles will be provided from an agronomic perspective. The identified socio-economic drivers and barriers to scaling of circular approaches will be put forward, as well as some concluding critical reflections on circular agriculture.

Box 2: The projects under study

The synthesis covers a review of 12 projects that received funding as part of the Food & Business Research programme in the period 2014 to 2019. They are listed in the Annex. Of these projects, seven were funded through the Applied Research Fund (ARF) and five projects through the Global Challenges Programme (GCP). Their activities were conducted in eight different countries in Africa, Asia and South America. While none of these projects were funded through a call for proposals that explicitly addressed the topic of circular agriculture, many projects did touch upon different elements of a circular approach and provided relevant insights. Some studies, for example, addressed how manure from fisheries can be upgraded for the production of animal feed. Others explored opportunities to turn food consumption waste into organic soil fertilizer and yet others tested how natural integrated pest management strategies could reduce the use of chemical pesticides. Applying the subsidiarity principle, most projects focused on achieving circularity at the lowest possible organisational level: the farm or community of farmers. None of the project interventions focused on applying circular principles at national, regional or global scale. This can partly be attributed to the higher complexity and the resources required at higher spatial scales, such as transport costs, (inter)national trade rules and regulations, or global certification and traceability regimes; which fell outside of the scope of the projects.

2 Key principles of circular agriculture

This section presents three key principles of circular agriculture. The first principle focuses on the importance of benefiting from natural processes while limiting external (hazardous) inputs. The second principle centres on resource-efficient processes that promote an efficient cycling of nutrients, energy and water. The third principle addresses the question how to minimise food losses by turning waste streams and into valuable inputs for the food production chain. For each of these principles, we discuss knowledge insights and innovations developed, tested and achieved by the 12 projects under review. It is important to note that these three principles are not mutually exclusive but rather reinforce each other, which also means that certain interventions and insights may contribute to multiple principles.

2.1 Regenerative agriculture: preserving & enhancing natural resources

The first principle addresses the importance of capitalising on natural processes and ecosystem services while reducing non-renewable or hazardous inputs. This includes avoiding chemicals, materials and other items that are difficult to reuse or recycle, or which are toxic.

Agricultural intensification centres on optimising production with large-scale monocultures of high-yielding crop varieties. This often involves a high dependency on agrochemical inputs and intensive soil management to control weeds, pests and pathogens. While farm management varies, both within and between countries and depending on crop types – ranging from small-scale organic to large-scale industrial farm management – the mainstream agricultural model has been subject to agricultural intensification in the past decades. There is today an increasing recognition of the negative impacts of this mainstream agricultural model on the environment, on biodiversity and on ecological sustainability in the long run.

Circular agriculture takes a very different approach. It requires the development of more robust agroecosystems, which have an inherent capacity to maintain soil functions, to deal with pests, diseases and weeds, as well as with unfavourable weather conditions. A strong dependency on external inputs is thus not compatible with the circular approach. Robust agroecosystems depend on the efficient management of ecosystem services beyond mere provisioning services. This can be achieved through a variety of approaches, including the introduction of beneficial species and the adoption of less disturbing soil management practices.

The first approach involves the active introduction or augmentation of species that support ecosystem functions. For instance, the project coordinated by project lead Mariame Asfaw[1] evaluated the performance in Ethiopia of the multi-purpose tree *Acacia saligna*, which originates from Australia. The tree provides fuel, poles and feed for livestock, which is particularly important in periods of drought. These leguminous trees can contribute to maintaining soil fertility by fixing nitrogen from the air (Giller, 2001), to land restoration by reducing erosion and to providing soil cover and supporting pollinator communities (including honeybees) by providing nectar and pollen. In Kenya, the project coordinated by project lead Geoffrey Ongoya[2] showed that introducing beneficial micro-organisms in combination with other non-chemical additives to the soil had a suppressive effect on soil-borne diseases and consequently increased tomato yield. Since tomato is a major crop in Kenya that is important for income security in rural households, but can strongly suffer from pathogens, this finding can potentially have a significant impact for farmers. Still, the approach piloted in this project still depends on regular applications of crop protection inputs. It might therefore be worthwhile to explore whether the augmentation of the soil biota can also result in the permanent establishment of a community of beneficial biota that contributes to a long-

[1] 'Farmer-led agroforestry innovation in Ethiopia: improving livelihoods and food security by utilizing *Acacia saligne*' (see Annex)

[2] 'Development, Validation and Dissemination of Integrated Pest Management Packages for Tomato Leafminer (*Tuta absoluta*) and Fusarium wilt-root knot nematode complex affecting tomato production in Kenya' (see Annex)

term enhancement of the disease-suppressive potential without the need of recurrent applications. If not, the success of this technical innovation will still depend on the availability of these crop protection products on the market and the financial means of households to buy them.

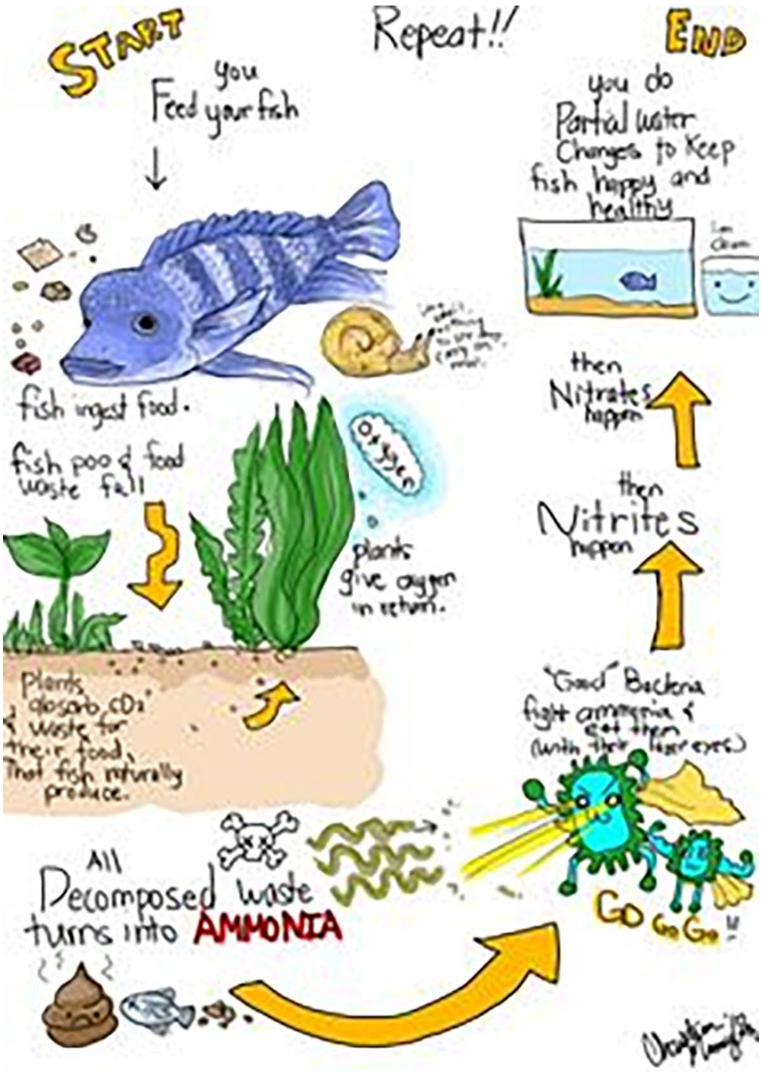

Figure 2: **Graphical representation of efficient pond aquaculture** (Verdegem et al)

A second approach to managing ecosystem services involves adopting less disturbing soil management, as this may favour the development of more diverse agroecosystems. 'Conservation agriculture' is a practice that aims to reduce soil disturbance by avoiding ploughing or other intensive soil management and leaving crop residues on the soil. This may benefit soil biota and the associated soil-mediated ecosystem services and also helps to reduce erosion. Moreover, conservation agriculture reduces the workload of farmers because ploughing is a labour-intensive activity. However, this approach requires increased input of herbicides to suppress weeds that otherwise would have been ploughed under the soil, which may be costly and/or have undesirable environmental side effects. This finding from a project coordinated by project lead Tsjeard Peter Bouta[3] dealing with farmer-led soil innovations to sustain food production in Uganda, shows that trade-offs are not uncommon and that win-win scenarios are not always easy to attain .

[3] 'Farmer-led soil innovations to sustain food production' (see Annex)

With their project in Viet Nam, the project coordinated by project lead dr. Marc Verdegem[4] showed that the use of well-balanced feed in shrimp aquaculture can stimulate microbial mediated mineralization of wastes in the pond. While the primary goal was to better close the nutrient cycle in the pond, the new pond systems also appeared to be resilient to shrimp disease outbreak. Although the mechanism of the disease suppressive effect still needs to be further interpreted, the results seem to suggest that the stimulation of the microbial and algal community slowed down the spread of diseases.

The insights gained and innovations applied by the above projects suggest that tailored ecosystem management, which stimulates natural processes, may indeed contribute to more robust agroecosystems and a reduced reliance on external inputs. In many cases, diversified systems prove to be less susceptible to pests and diseases. This important finding supports the urgent need to manage agrobiodiversity and to diversify the agroecosystem across space and time. Yet, the cases also indicate that there are trade-offs to be accounted for (i.e. Farmer-led Soil Innovations). Moreover, the outcomes are context specific (i.e. Integrated Pest Management) and must be made to fit the realities of farmers. This implies that the practices should not lead to a major increase in work load, and be affordable, accessible, and culturally acceptable. The knowledge intensity of some of the innovations, such as integrated pest management (i.e. Integrated Pest Management) can also be an obstacle for adoption by low-educated small-scale farmers because it requires knowledge about the crop pest species and diseases, as well as their natural enemies and antagonists. Acquiring these skills requires training, for instance via farmer field schools. Strengthening ecological litaracy levels of farmers may contribute to the adoption of more sustainable pest management practices (Wyckhuys et al. 2019).

Box 3: What are ecosystem services?

Ecosystem services are the direct and indirect contributions of ecosystems to human well-being, and as such, support our survival and quality of life. Four broad categories of ecosystem services are distinguished:

1. **Provisioning services:** the products obtained from ecosystems such as food, fresh water, wood, fiber, genetic resources and medicines.
2. **Regulating services:** the benefits obtained from the regulation of ecosystem processes such as climate regulation, natural hazard regulation, water purification and waste management, pollination and pest control.
3. **Supporting services: the benefits** obtained from ecosystems that support other ecosystem services, such as nutrient cycling, offering habitat for species and maintaining the viability of gene-pools.
4. **Cultural services:** non-material benefits that people obtain from ecosystems such as spiritual enrichment, intellectual development, recreation and aesthetic values.

2.2 Efficient use of resources: closing nutrient loops

The second principle addresses the importance of a ‘circular metabolism’. Agricultural production systems can become more resource-efficient by using and re-using resources and improving feedback loops. Natural ecosystems are often characterised by an efficient cycling of nutrients, energy and water. This is fostered and supported by species that occupy different niches (e.g. rooting systems in different soil layers) and by beneficial species interactions (e.g. enhanced nutrient uptake by plants via symbiosis with mycorrhizal fungi). Circular agriculture can learn from nature by developing production systems that include species that are efficient in resource capture and/or that benefit from synergies between species. There are three levels at which increasing resource use efficiency can be attained.

[4] ‘Nutritious system pond farming in Vietnam’ (see Annex)

The first and most basic level involves improvement of production by means of standard agricultural production systems; the performance of these systems (and the associated resource use efficiency) is optimised by careful management and breeding. For instance, in the project coordinated by project lead Godfrey Nyang'ori[5] in Kenya, disease control of dairy herds improved productivity and milk quality, confirming that managing animal health and welfare may increase milk output without increasing inputs. The study also highlighted that water and feed shortages can compromise the productivity of the cattle, which could be addressed by water harvesting innovations (e.g. collection of rain water from roofs, roads or slopes in reservoirs) or the use of more drought-tolerant fodder plant species. Likewise, the project on pork production in Brazil in the project coordinated by project lead dr. John Bastiaansen[6] showed that tailored breeding programmes – adapted to local circumstances such as tropical climate – can improve productivity without increasing feed input. The team reduced the economic costs and environmental impact of producing pork by introducing diets that included alternative ingredients that have a smaller ecological footprint (in contrast to common feed such as corn and soy).

The second level involves the replacement of species with a relatively low resource use efficiency by species that have a higher resource use efficiency. This involves the substitution of a certain component of the agricultural production system (e.g. replacing one crop type with another) but does not necessarily require a complete redesign of the system. Insects have recently attracted a lot of attention because they have a very favourable feed conversion rate and moreover represent a high-quality protein source for animal feed (van Huis et al., 2013). For instance, performance studies in catfish fingerlings revealed a 37% higher growth rate and a 23% higher weight gain was achieved when feeding the catfish black soldier flies compared to conventional feed (i.e. project dr. Marcel Dicke[7]). Importantly, this research in Kenya showed that, once protocols for rearing these insects have been developed and adopted, rearing is expected to be relatively easy and can be carried out from a farmer's home with minimal inputs. This is particularly important for women who are often constrained by limited access to agricultural resources and/or are expected to work from home (i.e. ILIPA). Further testing will show whether these benefits can be expected in practice.

The third level at which resource use efficiency can be achieved, involves the design of circular, multi-species production systems in which waste streams of one species (e.g. animal manure) serves as input for another species (e.g. manure as high-quality fertilizer), or vice versa by using crop residues as feed for animals. Such systems typically comprise both crops and animals, and the internal circulation of resources between the two makes these systems highly resource-use efficient, which means that the reliance on external inputs is reduced. A compelling example is the production of duckweed for animal feed using a waste stream consisting of bioslurry by the project coordinated by project lead Paul Adams[8]. The high-protein aquatic plant duckweed was introduced at farms in Indonesia that already possessed a biodigester for biogas production. The smallholder farmers collected the manure of their cows, pigs, ducks or chicken to generate biogas for cooking, heating or lightning purposes using the biodigester. Biodigesters produce bioslurry as residual product, which can be used as a fertilizer for duckweed. For this purpose, farmers created their own 'duckweed ponds' of approximately 5 by 5 meters wide and 15 cm deep and added the bioslurry and a handful of duckweed. Duckweed has a superior productivity compared to traditional feed crops and is a high-quality fodder because of high protein content. The duckweed grew quickly and could be harvested within a few weeks to feed farm animals. The duckweed-biodigester system reduced the purchase of dry commercial feed input by 10 to 20% (i.e. PROFARM).

A second example are the aquaponics systems with integrated fish and vegetable production that have been developed in Ethiopia by the project coordianted by project lead dr. Maja Slingerland[9]. Fish that are capable to thrive in restricted environments, such as carp, catfish and tilapia, are reared in a tank. The fish are fed with fish meal, yet thanks to an exchange of insights between researchers from this project and the insect for feed project

[5] 'Project Innovations for Sustainable and Profitable Intensification of Smallholder Dairy in Kenya' (ISPID)' (see Annex)

[6] 'Project Locally adapted pork production in Brazil versus the Netherlands' (see Annex)

[7] 'Project Improving livelihood by increasing livestock production in Africa: An agribusiness model to commercially produce high quality insect-based protein ingredients for chicken, fish and pig industries (ILIPA)' (see Annex)

[8] Project The application of Lemna and biodigestate to enhance profitability of sustainable integrated farming in Indonesia (PROFARM)' (see Annex)

[9] Project Aquaponics in Ethiopia: Developing a business model for sustainable implementation of small scale aquaponics systems improving food and nutrition security of urban and peri-urban households in Ethiopia' (see Annex)

in Kenya (i.e. ILIPA), it was discovered and proven that the fish can also be fed with locally produced black soldier fly larvae. The fish excrements and left-over fish feed are used by bacteria that produce nitrate. The nutrient-rich water from the fish tanks is then utilised by the vegetables that grow directly with their roots in the water and which in turn clean the water. The circularity of the system saves water compared to rainfed and irrigated agriculture and can be implemented on non-fertile lands as it is a soil-less growing technique. The aquaponics systems still depend on fertilizer inputs to compensate for the nutrient losses caused by the harvesting of fish and vegetables. Yet, because of the introduction of bacteria that can convert ammonia into nitrate, these systems also work with organic fertilizers. This system developed and piloted by the Ethiopian-Dutch research team is highly circular and may offer a pathway to empower women who develop and invest in this technology. However, the technology also requires a sufficiently large size to be efficient, with implications for the initial investment to establish the system, and inputs in terms of fish feed and fossil or alternative energy to maintain the circulation.

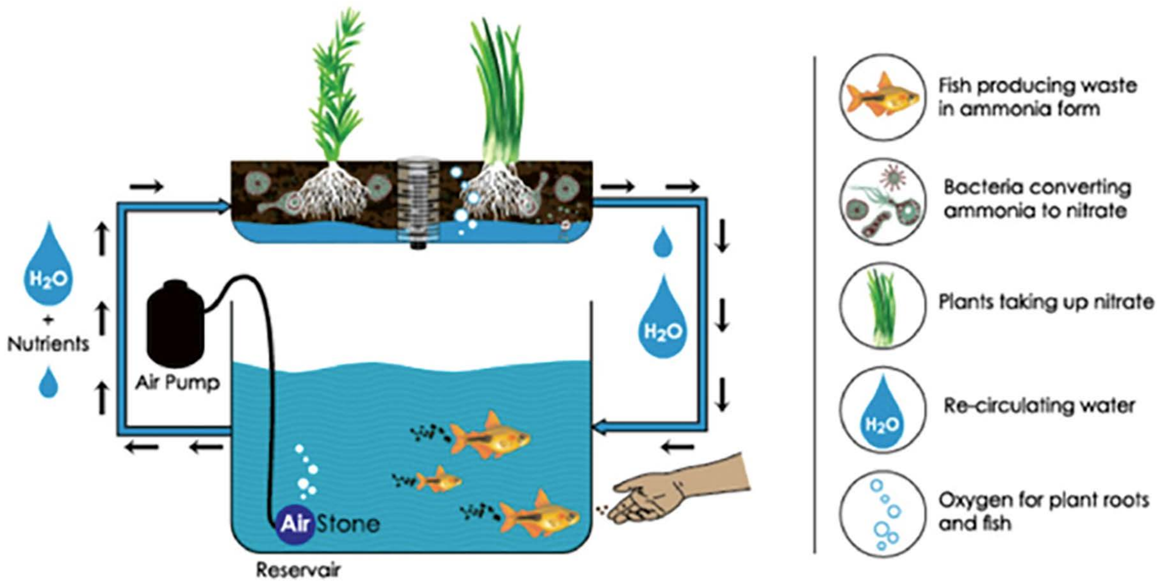

Figure 3: **Graphical representation aquaponics system**

In conclusion, integrated systems have the potential to make agricultural practices more sustainable by closing the loop of water and nutrients and thus improving the efficiency of resource use. This can have both economic and environmental benefits. Business risks associated with volatility of the prices of external inputs are reduced, and at the same time the pressure on (natural) resources is diminished (EIP 2015). There are challenges too. These integrated system innovations still require a basic level of input (e.g. for pumps in the case of aquaponics), as well as knowledge and technical support to be able to manage these systems efficiently. In the duckweed and aquaponics projects, the innovation was implemented at the household level, which makes the decision-making and management of these systems relatively easy. However, if the goal is to upscale this innovation, then many individual households will need to be supported with knowledge, know-how and possibly small funds. For this purpose, initiatives to foster upscaling may be considered, for instance by setting up or using existing cooperatives (i.e. ISPID). However, the project inisghts also indicate that such initiatives are sometimes hampered by bureaucracy and cultural aspects, such as hierachy and associated power relations of stakeholders (i.e. Urban Aquaponics).

2.3 Multi-purpose use & recovering value: from waste to value

The third principle of circular agriculture is to try and minimise food losses by using waste streams and turning these into valuable inputs for the food production chain. Mainstream food systems suffer losses at nearly all stages of the value chain: during production, harvesting, storage, processing, transport, and because food products are discarded by retail when not sold, and wasted by consumers.

Circular agriculture has similarities with circular economy, which can be defined as: "Circular economy – the economic counterpart of the ecological circularity concept – stands against the linear economic model of 'take-produce-consume-discard' and entails three economic activities, to be referred to as the 3Rs: reuse, recycle and reduce existing (used) materials and products. What was earlier considered as waste or surplus becomes a resource that is (re-)valorised" (Berkum et al 2018). In the circular agriculture perspective, the 'reuse and recycle' motto is translated to turning waste streams into valuable resources. Developing waste valorisation chains may involve several steps, including the actual separation of waste into streams that can and cannot be upgraded; setting up processing facilities that can generate upgraded products, developing a market for these products, and organising the trade logistics. This requires the involvement of multiple actors and may provide business opportunities for each of them. A Ghanaian research team pioneered the possibilities of valorising organic waste by turning it into compost in the project coordinated by project lead Richard Yeboah[10]. The organic waste was collected at local markets in the Greater Accra region (Ga West municipality), where market vendors were encouraged to dispose their organic waste for free. While separating their waste and disposing of the organic waste stream themselves caused them additional work, it also saved the market vendors money as their usual non-separated garbage is collected and charged according to its total weight. The organic waste collected at the markets was transported to a basic composting facility, and the compost was sold to farmers by unemployed young people who welcomed the opportunity to earn a small income (i.e. Youth Organic Waste). As such, the circularity approach was used as a bussiness model to support and empower young people, whose lack of livelihood opportunities is a mounting problem across many African countries, with both socio-economic and political repercussions for society as a whole.

In Bangladesh, the project coordinated by project lead Jillian Waid[11] identified that crop residues and liquid manure are underutilised waste streams. Liquid manure and urine are typically discarded and contaminate surface and ground water. However, as the project team showed convincingly, these waste streams can be converted into valuable organic fertilizers by burning non-used crop residues, such as rice straw, and mixing this with compost, liquid manure, and/or cow or human urine. The product is an affordable, non-odorous organic fertilizer that has proven effective in boosting yields in carrot and pumpkin (i.e. BUNCH2Scale).

Yet another project showed that organic waste streams from plants, animals (manure) and the food industry can also be used for rearing black soldier flies, crickets, grasshoppers, silkworms and cockroaches, which in turn are used as feed for poultry or fish (i.e. ILIPA). The insects can upgrade the waste to a higher protein content and can then be used as fishmeal for animal feed. The result of this innovative approach to producing animal feed is two-fold: it provides an answer to waste streams that are now ending up useless in landfills, and, secondly, the approach is particularly relevant for smallholders who often struggle to access affordable, sufficient and high-quality feed (averring 70% of production costs for pigs, chickens and fish farming). For instance, in Kenya, the production of fishmeal from Lake Victoria has proved to be unsustainable and fish stocks from the Lake have gone down, which means that most animal feed is currently imported from abroad, making it more expensive and leaving a bigger ecological footprint. The local production of insect-based feed therefore offers potential to provide a much-needed supplementary feed source. The study showed that Nile tilapia fed with BSF-based feed were 23% heavier than those fed with conventional feed, and the performance studies on pigs revealed similar growth rate, weight gain and blood profile when replacing traditional feed, such as fishmeal, by BSF (i.e. ILIPA) .

[10] 'Project Utilization of Organic Waste to Improve Agricultural Productivity in Ghana' (see Annex)

[11] 'Project Scaling-Up "Biochar-Urine Nutrient Cycling for Health" in rural Bangladesh (BUNCH2Scale)' (see Annex)

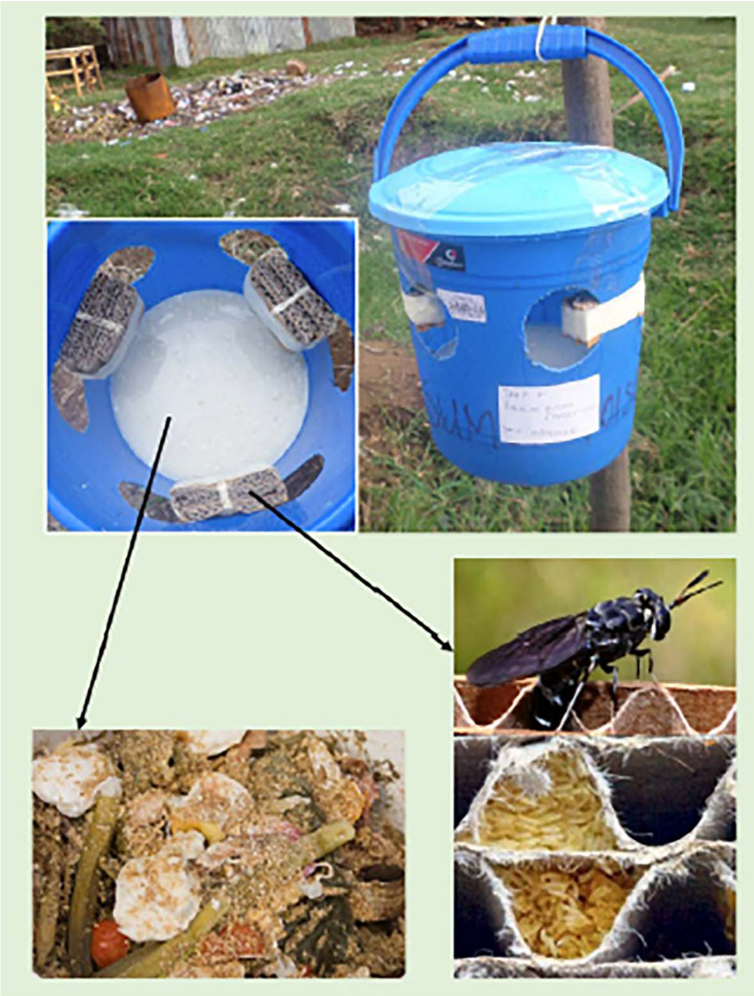

Figure 4: **Pictorial of low-cost, on-farm Black Soldier Flies rearing model (icipe/ILIPA)**

Box 4: **Economic benefits of Black Soldier Fly**

It costs US$0.20 to produce one kilogram of dry Black Soldier Flies, which is then sold at between US$0.90 and US$1/kg. Therefore, the production of 45,000 MT of insects to substitute 50% animal protein in animal feed would have a market value of around US$36,000, creating 22,500 potential new jobs, if each entrepreneur produces 2 MT of dry insect/year (i.e. ILIPA).

Finally, waste streams can also be minimised by using crops and animals that can serve multiple purposes, such that many different components of the harvested product can be used (e.g. *Acacia saligna* trees in Ethiopia provide fuel, poles and feed; Farmer-Led Agroforestry).

Concluding, waste streams are a still under-utilised and often overlooked aspect of food chains. Yet, when appropriately managed these waste streams can serve as a substrate for the production of protein-rich inputs for animals and humans, generating joint economic and environmental benefits. The above examples provide a proof of concept for upgrading waste streams. The extent to which this approach will contribute to a circular agriculture depends on the further streamlining of the technology, organisation of appropriate separation of waste streams, conducive local and national government regulations, market demand and cultural acceptance.

3 Drivers and barriers to adoption and scaling of circular innovations

From developing an innovation to its adoption by the envisaged target group is rarely a straightforward process. The projects reviewed for this synthesis, which mostly took place at farm and community level, encountered a range of barriers to adoption of new practices, but also identified some drivers.

Across the reviewed projects, the importance of “seeing is believing”, farmer groups, clusters or cooperatives, and offering targeted, customized information was established. All projects confirmed that farmers need to be given the chance to experiment with the new practices to feel confident about their usefulness. Model farmers can play an important role in encouraging and convincing their fellow farmers. Furthermore, to facilitate adoption of new practices, farmers can be clustered (grouped) according to specific characteristics (e.g. market orientation, gender) and be offered customised information about the (benefits of) the new practices, whether these are technological, financial or management innovations.

Radio can facilitate the dissemination of the practice, but these broadcasts are often rather generic and cannot be customised towards the individual user or farmer group (i.e. Farmer-led Soil Innovations). In fact, there were projects where farmers suffered from receiving contradicting messages coming from multiple sources (i.e. System Pond Farming). Most farmers in LMICs consult multiple sources of information and choose the one(s) that they consider most thrustworthy. A trusted relationship with the farmers is therefore essential for the adoption of the intervention and should be built from the start of the project onward. Many projects confirmed this. In certain projects, farmers indicated that they considered private sector advisors and middlemen less trustworthy sources of information than, for instance, government extension workers and researchers (i.e. Farmer-led Soil Innovations).

Another barrier to adoption is the fact that smallholder farmers tend to be risk averse. This is understandable because for them even a small risk of crop failure is likely to have severe consequences in terms of food security (where crop failure moreover affects income security, they will look for alternative sources of income). Risk management strategies that are common in the Global North may not be available or affordable to smallholder farmers. Often farmers prefer a ‘low but secure’ above a ‘possibly high but unsecure’ production strategy. This is for instance the reason that many smallholders fertilize their lands after the first rains, whereas theoretically, it is preferred to apply fertilizers (especially P and lime) before the first rains.

The shrimp farming project in Viet Nam showed that a distinction can be made between different farmers according to their risk perceptions (i.e. System Pond Farming). For instance, farmers with extensive (shrimp) farms with relatively low input and low outputs and with a modest market share, were more concerned about climate risks than farmers with more intensive practices and higher input-output systems. The latter farmers were more market oriented and were more concerned with market risks compared to the farmers with more extensive farms. This observation asks for different risk management and communication strategies for different (groups of) farmers.

Finally, the availability of local labour is an issue that is often overlooked, but which can be a severe barrier to uptake of innovations (e.g. projects: Farmer-led Soil Innovations and BUNCH2Scale). In the Global North, there is a perception that labour is abundantly available in most LMICs. However, several projects, including the Farmer-led Soil Innovations project, question this notion, showing that farmers often have multiple revenue generating activities and will choose for the highest labour efficiency (i.e. the highest income per unit of labour).

For many innovation projects, the new practices prove their value once a certain threshold of farmers has shown interest in adopting the innovations and appears to stick with the changes in agricultural practices this involves.

Once that has been realised, the next logical step for many projects would be to consider scaling. This review of ARF and GCP projects has presented several interventions and innovations that have the potential for scaling (see Table 1 for an overview of different approaches towards scaling of innovations). A number of projects focused on replicating their interventions, for example by encouraging adoption by other farmers through peer-learning (upscaling). In other projects, commercialisation and integration into (large scale) projects was actively promoted by creating linkages between the project and commercial actors (outscaling) (i.e. ISPID). The review showed that a larger reach was achieved by offering more support, through for example institutional arrangements, to a given pool of farmers or communities who have already started adopting a new practice (horizontal scaling). In other cases, institutional involvement could ensure that innovations are included in policies and regulations to achieve a larger impact (e.g. by supporting certification processes for the innovation) (vertical scaling).

For all different kinds of scaling, the knowledge, networks and commitment of multiple stakeholders is required, an approach that has been central to all the NWO-WOTRO projects reviewed in this article. The policy and practice outcomes that this facilitates, will be discussed in a separate series of articles[12].

Table 1: Different approaches towards scaling of innovations

	Horizontal scaling (replication)	Vertical scaling (institutional arrangements)
Upscaling (replication)	Diffusion of innovations which may be facilitated by demonstrations and trainings, (i.e. ISPID, Integrated Pest Management, Farmer-led Soil Innovations)	Influence rules and regulations (i.e. Urban Aquaponics), involve institutes (i.e. BUNCH2Scale)
Outscaling (expansion)	Technological additions (e.g. development of mass rearing technologies for BSF production, ILIPA). Involvement of more actors in the value chain who influence the farmer (i.e. Integrated Pest Management)	Development of new business models and legal frameworks (i.e. Youth Organic Waste) and/or innovation platforms (i.e. System Pond Farming). Integrate with other services, e.g. training on IPM technologies for CABI Plant Doctors (i.e. Integrated Pest Management)

Ensuring the appropriate institutional arrangements are in place (vertical scaling) is often more time consuming and therefore considered as a longer-term strategy, yet it is also important to enable replication of the innovation to take place (horizontal scaling). For instance, in cases where existing legislation hampers the replication of proven practices, supporting policies, new rules and regulations need to be formulated and implemented before these practices can be adopted by a larger public and horizontal scaling can take off. An example is the rearing of the Black Soldier Fly (BSF), which was an unknown species for the Kenyan and Ethiopian governments and hence not acceptable as a new practice for producing poultry and fish feed (i.e. ILIPA and Urban Aquaponics). The regulation in Ethiopia was adjusted at the onset of the project to ensure BSFs could be reared according to acceptable quality standards for food production (i.e. ILIPA).

Scaling of innovative circular agriculture practices may also be affected by a government's subsidy schemes and orientation towards export, which are likely to privilege linear approaches over more circular approaches (i.e. Integrated Pest Management). International trade regulations are typically value-chain based and hence limit the opportunities and incentives for the integration of value chains according to circular principles. To enable a transition towards circular agriculture, subsidy schemes and trade regulations will need to be revisited to make use of opportunities for circular agriculture at internal and external markets.

Termeer (2019) argues that for vast replication to take place (horizontal scaling), risks and quick wins are paramount. When farmers see hands-on proof of immediate benefits, they are likely to adopt the practice, but when such quick wins are absent, many farmers are inclined to return to their conventional practices. This

[12] See the overview page with all the synthesis articles inclusive three ouctome articles.

argument was confirmed by the project coordinated by project lead Arnold Bregt[13] and project Urban Aquaponics, in whose projects farmers returned to their conventional practices as soon as easy gains had been exhausted. Easy gains relate to financial revenues to make the practice financially viable, whereas long-term gains are more often related to improved management of natural resources, e.g. improved nutrient and water management. The transition towards a more circular agriculture requires a long-term vision because most benefits are only expected in the longer term (>1 year). Through 'catalyzing' incentives (e.g. initialising fees) short-term gains may be realised, which are important for the changes to take off. The project Urban Aquaponics experimented with different business designs and concluded that although some financial support is needed (for farmers to be motivated by 'early wins'), too much (financial) support may result in donor dependency and ineffectiveness.

To encourage replication (horizontal scaling), the projects used methods that are also used for first-time adoption: radio broadcasts, on-farm demonstrations, farmer field schools and training centres. For example, the Indonesian-Dutch research partnership (i.e. PROFARM) showed that after training on bioslurry management, Indonesian farmers initiated new start-ups for growing duckweed as animal feed. However, this project also showed that continuous monitoring and support (manuals, trainings) were required to keep the farmers motivated.

Scaling of an innovation is a social process in a complex reality where division of power, social stigmas and ensuring quality standards can pose significant challenges. Model farmers ('early adopters') can become the drivers of the innovation and play a crucial role in upscaling because they are respected by the community (i.e. BUNCH2Scale). The role of women was highlighted by several projects (i.e. Urban Aquaponics, ISPID and Integrated Pest Management). Women often manage the land and can have a strong say in the decision-making process within their families when it concerns food and kitchen crops for their household, but may lack the connection to the formal decision-making bodies due to language or cultural barriers. The project Integrated Pest Management moreover emphasised the role of elderly men, who were often the formal decision-makers at community level. Translation into local languages was required to involve them. Hence, different levels of decision-making procedures regarding strategic and implementation processes need to be addressed. In addition, when introducing agricultural innovation it will be important to be mindful of the – perhaps false – assumption that equality of opportunity would automatically translate into equality of returns.

Furthermore, social acceptance (taboos) can also be a barrier to both adoption and scaling, as became apparent in Ethiopia where local communities considered the *Acacia Saligna* an 'evil' tree (i.e. Farmer-Led Agroforestry) and in Bangladesh, where human urine was socially unacceptable as a source of ammonia for producing organic fertilizer (i.e. BUNCH2Scale). These barriers could be overcome by training and by rethinking the design of the intervention, by for example using an alternative source of urine (viz. animal urine), respectively.

Finally, another barrier to scaling is quality control: as value chains may need to integrate to achieve a more circular agriculture, quality control becomes more challenging. Several projects sought ways to ensure that quality was maintained by arranging certification from national government bodies (i.e. Urban Aquaponics and ILIPA) and by introducing specific protocols to ensure final products of the circular process were not contaminated when systems were integrated (e.g. when byproducts or new animal species are introduced as feed). This latter issue was particularly relevant in the case of repurposing of waste (i.e. Youth Organic Waste and ILIPA), in which for example the project ILIPA implemented a study that confirmed that no heavy metal or pesticide residues would be found in the different insect s4pecies analysed for feed purposes.

Concluding, the projects presented in this article show that the transition towards circular agriculture is complex; interferes with many actors and factors; and cannot be managed in a conventional way. 'Small wins' are crucial to drive the transition which includes the scaling of promising approaches and initiatives that have been tried and tested. By integrating the relatively small wins in multiple domains, circular agriculture gets a step closer to becoming a reality. However, change is often met with different levels of resistance and requires cautious approaches over time to achieve its desired results (Termeer, 2019).

[13] 'Assessing the learning effects of games on attitude of stakeholders towards sustainable shrimp farming (ALEGAMS)' (see Annex)

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4 Reflections

This section shares overarching insights and learnings that are cross-cutting for the different principles and projects that were reviewed. The synthesis included projects that were oriented at exploring and studying farm level interventions, where the focus of the interventions was directed mostly at more efficient use of resources and tackling the issue of yield losses and waste streams. A close study of the key findings across these projects shows insights at three levels.

First, tailored ecosystem management can contribute to agroecosystems that are less susceptible to pests and diseases without the need for or reliance on external inputs (e.g. reducing very common soil-born diseases impacting tomato yields dramatically by introducing packages of interventions). However, while Integrated Pest Mangement (IPM) has many advantages, it requires intensive training of the farmers, access to crop protection inputs (e.g. mass trapping devices, botanical extracts) and may add to the workload.

Second, the studies show that integrated agricultural production systems have the potential to make agri-practices more sustainable by closing the loop of water and nutrients and thus improving the efficiency of resource use. Circular agriculture can therefore learn from nature by developing production systems that include species that are efficient in resource capture and/or that benefit from synergies between species (e.g. duck weed and aquaponic systems). However, the interventions have shown that systems that rely on advanced technology depend critically on the availability of starting capital, training, access to spare parts and support for trouble shooting. As such, more simple systems that require little input and can be fully managed at farm level might have the highest probability for uptake.

Third, upgrading of waste streams shows potential to reduce waste. When appropriately managed, waste streams can serve as a substrate for the production of protein-rich inputs for animals and humans, generating joint economic and environmental benefits (e.g. growing insects on organic waste to improve more nutritious animal feed). Earlier studies showed, however, that the use of waste streams may, apart from the benefits, also contribute to diffusion of contaminants in the wider environment. Also, the variable quality of composted products can result in variable (crop) responses.

The Food & Business Research projects demonstrate that clear short and medium-term benefits in transitioning (small-scale) farming to adopt more circular approaches are possible through awareness raising, model farms, and targeted messaging and interventions. However, the technical knowledge transfer and time investments required to move beyond the farm level towards horizontal scaling of mass adoption of circular approaches is still high. Such scaling strategies would benefit from conducive institutional arrangements (i.e. organisation of farmers, targeted messaging, and supporting government facilities such as accommodating certification bodies). Further insights into the processes that can support achieving vertical and horizontal scaling outcomes will be discussed in a separate series of articles.

Overall, the extent to which the project approaches will contribute to a circular agro-economy at scale depends on the further streamlining of technologies; the organisation and integration of value chains; conducive local and national government regulations; and a strong market demand where consumers are willing to embrace new innovations. Only then will the possible ‘wins’ following the adoption of circular approaches at scale be made possible, including new income streams and jobs by opening up new markets (e.g. integrated waste streams with youth by Youth Organic Waste); establishing links to new sectors and businesses (e.g. insect farms for insect-based feed by ILIPA); transitioning to more resource-efficient business models (e.g. targeted pig breeding in Brasil by Locally Adapted Pork); and reducing costs through more sustainable use of resources and making more of waste resources (e.g. System Pond Farming).

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Annex

ARF projects reviewed for this synthesis article:

PROFARM

'The application of Lemna and biodigestate to enhance profitability of sustainable integrated farming in Indonesia (PROFARM)'
Paul Adams (Hivos, Netherlands)
https://www.nwo.nl/en/research-and-results/research-projects/i/34/13734.html

Farmer-Led Agroforestry

'Famer-led agroforestry innovation in Ethiopia: improving livelihoods nad food security by utilizing Acacia saligna'
Mariame Asfaw (World Vision Ethiopia)
https://www.nwo.nl/en/research-and-results/research-projects/i/35/14135.html

Farmer-led Soil Innovations

'Farmer-led soil innovations to sustain food production'
Tsjeard Peter Bouta (ZOA Uganda)
https://www.nwo.nl/en/research-and-results/research-projects/i/11/12211.html

ISPID

'Innovations for Sustainable and Profitable Intensification of Smallholder Dairy in Kenya (ISPID)'
Godfrey Nyang'ori (Mt Clara Mtakatifu Mwangaza Centre)
https://www.nwo.nl/en/research-and-results/research-projects/i/31/14131.html

Integrated Pest Management

'Development, Validation and Dissemination of Integrated Pest Management Packages for Tomato Leafminer (Tuta absoluta) and Fusarium wilt-root knot nematode complex affecting tomato production in Kenya'
Geoffrey Ongoya Wafula (Koppert Biological Systems (K) Ltd., Kenya)
https://www.nwo.nl/en/research-and-results/research-projects/i/37/13737.html

BUNCH2Scale

'Scaling-Up "Biochar-Urine Nutrient Cycling for Health" in rural Bangladesh (BUNCH2Scale) '
Jillian Waid (Helen Keller International (HKI) Bangladesh)
https://www.nwo.nl/en/research-and-results/research-projects/i/42/27642.html

Youth Organic Waste

'Utilization of Organic Waste to Improve Agricultural Productivity in Ghana'
Richard Yeboah (MDF Training & Consultancy, Accra)
https://www.nwo.nl/en/research-and-results/research-projects/i/55/12555.html

GCP projects reviewed for this synthesis article:

Locally Adapted Pork

'Locally adapted pork production in Brazil versus the Netherlands'
John Bastiaansen (WUR)
https://www.nwo.nl/en/research-and-results/research-projects/i/10/11510.html

ALEGAMS

'Assessing the learning effects of games on attitude of stakeholders towards sustainable shrimp farming (ALEGAMS)'
Arnold Bregt (WUR)
https://www.nwo.nl/en/research-and-results/research-projects/i/37/12837.html

ILIPA

'Improving livelihood by increasing livestock production in Africa: An agribusiness model to commercially produce high quality insect-based protein ingredients for chicken, fish and pig industries (ILIPA)'
Marcel Dicke (WUR)
https://www.nwo.nl/en/research-and-results/research-projects/i/36/12836.html

Urban Aquaponics

'Aquaponics in Ethiopia: Developing a business model for sustainable implementation of small scale aquaponics systems improving food and nutrition security of urban and peri-urban households in Ethiopia'
Maja Slingerland (WUR)
https://www.nwo.nl/en/research-and-results/research-projects/i/45/12845.html

System Pond Farming

'Nutritious system pond farming in Vietnam'
Marc Verdegem (WUR)
https://www.nwo.nl/en/research-and-results/research-projects/i/08/11508.html

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