RURAL 21

The International Journal for Rural Development

4 | 2023
VOLUME 57

ISSN 1866-8011
D 20506 F

Stemming food loss and waste

BIODIVERSITY
Why agricultural labour matters

INVASIVE SPECIES
Keeping woody weeds at bay

CONSERVATION AGRICULTURE
Potato production with zero soil movement

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Dear Reader,

"FAO estimates that each year, one-third of all food produced for human consumption is lost or wasted – around 1.3 billion tons. This costs around 750 billion dollars annually. If we reduce food loss and waste to zero it would give us additional food to feed 2 billion people." With these words, José Graziano da Silva, formerly Director-General of the UN Food and Agriculture Organization (FAO), addressed the participants at the Global Green Forum in Copenhagen, Denmark. That was in October 2013. With small deviations, the figures published by the international organisations on the topic today correspond to those of ten years ago, at least as far as the estimated global volumes are concerned (i.e. around 30–40 per cent, and revenue loss is now put at one trillion US dollars). According to the latest progress report for the Sustainable Development Goals, about 8 per cent of all food produced in the world is lost on the farm, 14 per cent between the farm gate and the retail sector, and 17 per cent at the retail, food service provider and household levels. How come these values are still so high? Hasn't that much really changed in terms of food loss and waste in the past decade? Or don't we simply have any reliable methods to adequately measure the phenomenon? The answer is that both applies.

First of all, let's clarify what we're talking about, for there is no commonly agreed definition of the terms. The World Food Programme (WFP) refers to food loss when "food gets damaged through the supply chain", for instance when fruit starts to rot or milk turns sour. According to the WFP, the term food waste, in turn, applies when "edible or surplus food is thrown away by retailers or consumers". The FAO states that "food loss occurs along the food supply chain from harvest up to, but not including, the retail level", while "food waste occurs at the retail and consumption levels". And while there have been global efforts of late to come to common definitions, in order to allow comparisons, the methods and approaches adopted for measurement still vary considerably.

A recent study by the UK's University of Greenwich arrives at the conclusion that food loss and waste measurements are usually aggregated from relatively small samples to national levels. This can result in volumes being considerably under- or overrated. Moreover, while we have a good knowledge of the problem in developed countries, above all of waste, since household surveys are the order of the day here, little is known about that phenomenon in low- and middle-income countries. The same applies to losses occurred beyond the farm level, and quality losses in the value chain. The question arising here is how a problem can be tackled if it cannot be properly measured.

While keeping these shortcomings in mind, we have asked our authors to present, wherever possible, practical and, above all, scalable solutions from the fields they work in with which food losses and waste can be prevented or reduced. Unlike in 2013, there is awareness today that tackling food loss and waste is an inherent and decisive element in our endeavour to transform our food systems towards sustainability and resilience. You will therefore also find different approaches of circular economy in this edition.

Some critics claim that the magnitude of food loss and waste is readily exaggerated – in order to cause reduction interventions to appear all the more effective and be able to boast success. There is criticism, as well, that all too stringent regulations e.g. in the retail sector result in less surplus food being available for distribution among those in need, for example via food banks. And the question certainly also arises whether the goal of "zero loss and waste", as postulated by Graziano da Silva in 2013, is a realistic one. But given the enormous squandering of resources, pressure on the climate and the environment, and economic losses which food losses and waste entail as well as the sobering developments which we are experiencing regarding "zero hunger", one has to accept that even the most minute reduction counts. And that nations should really be capable of feeding their people without needing donations is quite another matter.

Wishing you inspiring reading, on behalf of the editorial team,

Patricia Snmms Silvia Richter

Imprint

Rural 21 –
The International Journal for Rural Development

Published by:
DLG-Verlag GmbH
Frankfurt, Germany

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Editorial office, distribution, advertising:
DLG-Verlag GmbH
Eschborner Landstraße 122
60489 Frankfurt, Germany

Printed by:
Bonifatius GmbH
33100 Paderborn, Germany

Rural 21 is published four times a year.
The subscription rate is EUR 33.– (Germany), EUR 37.– (EU countries), EUR 51.– (non-EU countries) and EUR 8.30 per issue, plus postage.

CONTENTS

Global Crop Diversity Summit 2023 – why seed banks matter

Transforming our food systems towards resilience and sustainability is right at the top of the international agenda. Congresses and high-level meetings addressing this issue regularly discuss adjustments that have to be made to achieve this. The decisive role that seed banks play in this context is often forgotten. The Global Crop Diversity Summit held in Berlin, Germany, in mid-November, was meant to change this. The Summit was organised by the Global Crop Diversity Trust (Crop Trust), an international not-for-profit organisation based in Bonn, Germany.

„Seed banks – the last line of defense for global food and nutrition security" was the motto of the Summit.

"Food insecurity is coming back, at a time where the world is on fire, with global temperatures rising faster even than anticipated or predicted. We simply can't afford to lose the crop diversity we have on Earth," Stefan Schmitz, Executive Director of the Crop Trust, had warned at a press conference in the run-up to the event. The industrialisation of agriculture has resulted in only a fraction of the existing crop variety being used today, and genetic diversity continues to shrink in fields. Furthermore, plant breeding concentrated on yield increase for many years. But against the background of climate change, it is becoming more and more important that plants can withstand stress, such as heat, drought or salinity. These are precisely the features which many of the ancient varieties and wild relatives of our food crops bear. This was why it was so important, Schmitz argued, to conserve these plants in seed banks (or gene banks) and be able to provide farmers with them when needed. But these unique guardians of genetic diversity are under threat – for a wide range of reasons.

Conflict and climate change

One of these reasons is political instability or conflict. "I've been involved with the Ukraine seed bank teams since those first two days in February last year," Lise Lykke Steffensen, Director of the Nordic Genetic Resource Centre (NordGen), reported. "They were actually sitting in bunkers, and I texted the director and said, 'How are you doing?' He answered: 'Just please send some help, send something, do something.'" The Ukrainian seed bank was the 10th largest collection in the world, making it extremely important not only for Ukraine, but also for global food security, Steffensen stressed. The seed bank contains over 106,000 different seeds, lots of them endemic species. NordGen and, later on, Crop Trust have been financially supporting the colleagues in Ukraine so that they can at least carry on with their work on a rudimentary basis. Over 50,000 seeds had been duplicated, and a copy of this was now stored in safe places, Steffensen said.

The creation of safety duplicates was also a high priority in the Pacific region, reported Karen Mapusa, Director of the Land Resources Division of the Pacific Community. However, the reasons here are very different. Genebanks in the Pacific region are regularly threatened by climate change impacts such as typhoons. Mapusa remarked that this was all the more dramatic since, as a result of lifestyle changes, an ever growing section of the population were suffering from the triple burden of malnutrition – undernutrition, micronutrient deficiencies and overweight. At the same time, traditional knowledge of food and medicinal plants (and hence also healthy diets) was going lost more and more – a problem that gene banks could address.

Neil Watkins, Deputy Director, Program Advocacy and Communications at the Bill and Melinda Gates Foundation, explained how dangerous the lack of species diversity could be in agricultural production, taking the example of bananas. Cavendish variants accounted for roughly 60 per cent of global banana production. But as all of them were genetically identical clones, Watkins explained, they were at high risk of being wiped out by pests and diseases. Integrating wild crop varieties in innovative crop breeding programmes could counter this.

Preserving seeds and biodiversity through deliciousness

Ghanaian chef and entrepreneur Selassie Atadika presented a very different approach to the meeting. She invited the participants to an – imaginary – culinary tour. They were asked to close their eyes and imagine a dish they especially liked to eat – the tasty ingredients, what it looked like and its smell. And precisely the moment they had gained a mental image of their favourite dish, they were to open their eyes and imagine that this dish no longer existed. For this was what had happened to the Ghanaian chef when, having spent several years in New York/USA, she returned to her country and noticed that a lot of foods and ingredients which she had eaten as a child were no longer available. Instead, imported food was dominating the shops and markets. "I was trying to figure out how we could bring these

traditional foods and ingredients onto the table, and I slowly ended up getting involved in finding the seeds myself and trying to understand what was happening with our food system." With the Midunu Insititute (in her mother's language, Ewe, Midunu means "Let us eat"), she has set herself the goal of preserving Africa's culinary heritage and thus giving back cultural foods the value that they deserve.

Alejandro Argumedo, the Coordinator of the International Network of Mountain Indigenous Peoples, also presented some of his childhood memories: waking up to the aroma of a dish cooked by his grandmother with differently coloured and shaped potatoes, mixed with herbs. "Nothing will change until we change our values and go back to the roots," he told the meeting, stressing the need to connect food to its source. Indigenous Peoples and local communities had accumulated thousands of years of knowledge and expertise on how to ensure food system diversity and resilience. And this had to be taken advantage of.

Ghanaian chef and entrepreneur Selassie Atadika invited the participants to an – imaginary – culinary tour.

Photos: Crop Trust/MIKA-fotografie

A plea for in situ and ex situ conservation

In the panel discussions, several speakers stressed that that crop diversity should be systematically used by farmers and local communities, thus being saved and maintained "outside the freezers". In other words, it ought to be ensured that seed banks "move from museums to the farm and the plate". One practical example of this came from Bhutan. Asta Maya Tamang, from the Bhutan National Biodiversity Centre, told the meeting about a revival of the production of buckwheat. Once a staple food, this crop was gradually dying out in the country. In order to stimulate not only production, but also consumption, her organisation was supporting farmers in developing a variety of buckwheat products. Bhutan's national gene bank contained 3,500 samples from 46 crop species, Tamang told the audience.

> Seed storage can be very unsexy to those who don't realise how important it is.
>
> Lise Lykke Steffensen, Director of NordGen

Francisca Azevedo, a consultant in the field of agrobiodiversity, pointed out that small-scale farmers not only produced food, but also contributed to breeding. Genebanks were important, but in situ conservation – i.e. conservation on the farms – was at least just as important. Here, she called on those responsible to ensure that small-scale farmers were not only research participants but also development partners and benefited from associated gains. Michael Windfuhr, Deputy Director of the German Institute for Human Rights, stated that farmers often lacked knowledge about how to access seed banks. Here, agricultural extension had a role to play.

Long-term funding needed

After this excursion to the emotional aspects of crop diversity and conservation, Lise Lykke Steffensen addressed a fundamental problem which all seed banks around the globe were struggling with: chronic underfinancing. In most countries, the banks don't enjoy any priority, as they are not seen as a resource power or knowledge base. "Seed storage can be very unsexy to those who don't realise how important it is!" Steffensen explained. And most actors were not aware that the process was not simply about placing seed collections in the fridge, added Zakaria Kehel, Head of Genetic Resources, Pre-Breeding and Genebank operations at the International Center for Agricultural Research in the Dry Areas (ICARDA). The seed had to be maintained and monitored to see if seeds could be germinated when sent to others. Energy supply was also an issue as it had to be ensured that the seed was kept in good condition. In addition, seed banks were responsible for making not only the seeds available, but also the information – in order to be able to quickly provide the corresponding material with the desired features in response to requests from farmers or another seed bank.

But who is responsible for financing all this? Even though funding comes from many places, with most seed banks being funded by donors, Steffensen clearly stated that it was first and foremost a national responsibility to conserve the genetic resources of one's country and our world. She reminded the meeting that all countries had committed to the targets from the Global Biodiversity Treaty after COP15. What she was hoping for was a gene bank with long-term funding which conducted innovative research on genomics and phenomics (the systematic study of traits that make up the set of observable characteristics, the phenotype) and ensured responsiveness to requests.

Silvia Richter, Rural 21

SDG TARGET 12.3 – WHERE ARE THE STUMBLING BLOCKS?

At the midpoint of the 2030 agenda, all of the Sustainable Development Goals are seriously off track. SDG 12, with its third target of substantially reducing global food loss and waste, is no exception in this respect. A look at backgrounds, facts, knowledge gaps and some myths.

By Silvia Richter

With the adoption of Agenda 2030 in September 2015, the international community set itself the target of ensuring "sustainable consumption and production patterns" in the context of Sustainable Development Goal 12. The third target under this goal (SDG 12.3) calls for "halving per capita global food waste at the retail and consumer levels and reducing food losses along production and supply chains (including post-harvest losses) by 2030". Then, just like today, it was assumed that globally, roughly a third of the food produced, i.e. 1.3 billion tons of food, did not get where they were meant to go, namely to the stomachs of the consumers. According to the latest available data from the Food and Agriculture Organization of the United Nations (FAO), the United Nations Environment Programme (UNEP) and the World Wildlife Fund (WWF), about 8 per cent of all food produced in the world is lost on the farm, 14 per cent is lost between the farm gate and the retail sector, and 17 per cent is wasted at the retail, food service and household stages of the food supply chain. These figures above all indicate one aspect: the inefficiencies in our food systems – with disastrous consequences for global food and nutrition security, for the economy and for the environment.

World-wide, more than 700 million people are chronically undernourished, and over three billion people cannot afford a healthy diet. Wasted food pushes up food prices, and quality losses cause valuable nutrients to go lost and put food safety at risk or at least reduce it, with both raising global food insecurity. Economic damage sustained by the countries in the form of lost revenue is put globally at one trillion US dollars annually.

Our food systems are a potential threat to nature. If agriculture is not performed sustainably, it results in habitat and biodiversity loss. Seventy per cent of the water from freshwater sources is consumed by agricultural production; at the same time, more and more people are living in regions suffering from


Photo: Sumy Sadurni/ FAO

Definitions

Food loss is the decrease in the quantity or quality of food resulting from decisions and actions by food suppliers in the chain, excluding retailers, food service providers and consumers. Empirically, the term refers to any food that is discarded, incinerated or otherwise disposed of along the food supply chain, which starts with harvest/slaughter/catch and reaches up to, but excludes, the retail level, and the food does not re-enter the supply chain for any other productive use, such as for feed or seed.

Food waste refers to the decrease in the quantity or quality of food resulting from decisions and actions by retailers, food service providers and consumers.

(FAO, 2019)

water scarcity. Areas under cultivation add up to a total of roughly 4.8 billion hectares, with around 1.6 billion hectares consisting of human or animal food crops and 3.2 billion hectares being used as pastureland. However, both the quantity and the quality of cropland and pastureland are declining. So with every gram of grain or rice rotting in the fields, in storage, or during transportation, with every banana or mango going bad in the supermarket, with every chunk of meat or fish consumers throw away, valuable and already scarce natural resources are wasted. Added to this are inputs such as fertilisers and pesticides, which not only pollute the environment but also require energy for their production. And then, of course, there is energy consumption needed for the production process as a whole, from cultivation through harvest and storage to processing and transport, which, if it does not come from sustainable sources, contributes to global warming.

But what is more, UNEP estimates that 8–10 per cent of all global greenhouse gas emissions can be ascribed to food loss and waste. When organic material, including food, ends up in garbage, it rots and releases methane (CH_4). In its first year in the atmosphere, this gas has a 120 times higher global warming potential than carbon dioxide (which, since methane is constantly degraded through natural processes, falls to the 85-fold amount over a period of 20 years). It was not without reason that more than 150 countries signed the Global Methane Pledge, launched at the November 2021 Conference of the Parties (COP26) in Glasgow, thus agreeing to take voluntary actions to contribute to reducing global anthropogenic methane emissions by at least 30 per cent from 2020 levels by 2030. These include measures directly addressing the agricultural and food systems with their familiar methane sources, such as improving dairy productivity, animal feed production, manure management and rice production, but also measures in landfill management, e.g. by capturing methane or covering landfills in cities.

What do we know about food loss and waste?

That there is urgent need for action has also been recognised by the G20 Agriculture Ministers who, at this year's meeting in Hyderabad, India, in mid-June, committed "to prioritise reduction in food loss and waste". Why is it that at least globally, the food loss and waste figures have hardly changed for years? One of the reasons is that there is still very little reliable data available on how much food is really wasted or lost, where exactly in the supply chain these losses occur, and why. This applies not only, but above all, for the Global South, where many smallholders are involved in the agri-food value chain and where little is known about losses beyond the farm level as well as quality losses. The other reason is that different

measuring methods are employed – and don't always yield meaningful results. All this makes it extremely difficult to prioritise interventions and choose the most suitable ones.

A wide range of research papers discuss the factors influencing food loss and waste. There is no doubt that climatic conditions, such as heat and drought, humidity and lack of or excessive rainfall, are one of the major causes of losses, both pre-harvest and post-harvest. In turn, certain climatic conditions – above all heat and moisture – tend to increase the prevalence of pests and diseases. In many countries, rodents also cause high post-harvest losses. Improper harvest and post-harvest crop management techniques, lack of proper storage, especially in fruit and horticultural crops, as well as lack of transportation have also been identified as important factors behind food losses, as have poor marketing options. And all the last-mentioned reasons are of course closely linked to access to information and financial resources.

If wasted food were a country, it would be the third-largest producer of carbon dioxide in the world after the USA and China. *(WFP)*

However, whereas some of these factors, such as unfavourable climatic conditions, clearly correlate with the extent of food losses, other links are less straightforward. For instance, studies of the effects on food losses of mechanisation and adoption of technology in harvesting in various value chains have yielded contradictory evidence. Studies on the influence of socioeconomic characteristics have shown that higher age levels and increasing production are frequently, albeit not always, positively correlated with food loss reduction. For gender, in turn, the results are extremely heterogenic – one survey demonstrated that being male is correlated with an increase in losses in the maize value chain, while another indicated the reduction of the same. What all these surveys do show is the importance of adequate knowledge and training when it comes to the adoption of tools and technologies. And they suggest that policies aiming at preventing and reducing food losses need to be developed context- and commodity-specific.

What can – and should – be done?

Over the last few years, most interventions to tackle food losses have concentrated on the post-harvest stage, and here, above all on storage technologies. However, the latest surveys assume that losses in production, in the harvesting process and during transportation are far higher. This can have technical reasons, for example if farmers no longer have the opportunity to dry their grain because it has been raining after the harvest, but also economic ones, if e.g. a farmer growing mango or papaya for exporting only harvests fruit meeting the quality standards of the purchasing company. If the prices on the local markets are very low, it will usually not be worthwhile for him to invest labour in harvesting the rest of the fruit.

For FAO Chief Economist Maximo Torero, one crucial aspect of successfully stemming food losses is, therefore, that the market recognises quality, which is already the case e.g. with milk or fruit. In other areas, too, observing quality standards ought to be rewarded with price premiums, for example when farmers supply maize free of aflatoxin. At retail level, economist Torero regards regulatory measures as the means of choice. Things get more difficult at consumer level, for here, behaviour change of people is crucial. Here, awareness raising is above all necessary so that consumers understand its benefits.

Improving circularity can also make a major contribution to mitigating food loss and waste, and to making our food systems more sustainable. "From waste to value" is the motto under which valuable biomass – leftovers and waste material – are converted into new raw materials. These can in turn be fed back into the agri-food systems – for instance as fertiliser, animal feed or a source of energy. In this context, "food upcycling" is also a term that is gaining popularity as a "green" consumer behaviour trend. It refers to two variants: avoiding wasting resources by putting food rests (e.g. stale bread or suboptimal fruit) to alternative use – which is commonplace in many poorer social strata in any case – or broadening the resource base by assigning parts of food which aren't used normally – such as husks and kernels of fruit and vegetables – a novel use. Here, the term "upcycling" is supposed to indicate that a value-enhancing process is involved – as opposed to "recycling", which, in its conventional sense, implies "downcycling". Very much along these lines, Pete Pearson, Senior Director, Food Loss and Waste at WWF, would like to see more people recognising

A labourer downloading and washing tomatoes in Bangar el Sokor, Nubaria, Egypt. Reducing food loss in the horticultural sector is critical to simultaneously supporting the transition towards a diet with higher consumption of vegetables.

Photo: FAO

that "food and organic material is not a waste which has zero value". If one trusts current statistics, only 10–12 per cent of organic material is put to circular economy or composted world-wide, while the rest goes to landfills. So here, Pearson is convinced, there is a potential to create a whole new marketplace.

Final reflections

It used to be assumed that food production, storage and transportation losses are mainly a problem of developing countries and that consumer food waste is concentrated in high-income countries. Very recent surveys by UNEP have put this assumption into perspective (see Box). One of the reasons for this is

> Reducing food loss and waste is one of the major drivers for making space for nature.
>
> Pete Pearson, Senior Director, Food Loss and Waste at WWF

A maize storage facility in Uganda .

Photo: Sumy Sadurni/ FAO

that economic development leads to changes in lifestyle and eating habits. So whereas locally adapted technologies in harvesting, food processing, (cold) storage and logistics, together with the corresponding information, capacity building and financing options are likely to reduce food losses in the countries of the Global South, various factors going hand in hand with the increasing development of precisely these countries will have a tendency to result in more waste. For example, rising income levels enable people to handle food more "generously", since not everything has to be used up for scarcity reasons. In addition, more affluent societies often have higher standards regarding food aesthetics. And frequently, they are also more aware of the risks food may bear and will perhaps prefer to throw food away for "safety reasons". Increasing urbanisation linked with the trend towards smaller households can lead to less time being left for targeted shopping and the tedious process of cooking food. Another trend this is linked to is eating out. Restaurants and canteens have to operate economically. Moreover, with regard to reducing food waste, they are confronted with conditions – as well as customers' expectations regarding sustainability. In addition, they are able to buy food in bulk quantities, combine it tailored to requirements and re- or upcycle it. While all this can help reduce waste, the trend towards eating out is also linked with consuming ultra-processed food, which in turn is associated with negative health outcomes.

However, higher income and more affluence are also coupled to a more sustainable lifestyle. Here the question arises what ultimately has a greater net effect – consumer enthusiasm and convenience or sustainability awareness and consciously doing without. Moreover, the encouraging trend towards a "green lifestyle" results in chemicals and plastic disappearing more and more from the food chain. But making do without packaging, in particular, can lead to higher losses in transportation when vulnerable crops are concerned. Here, the development of environmentally friendly packaging can make a crucial contribution, especially if organic waste material is used to produce it.

Last but not least, every intervention must consider which actors it benefits in the food value chain – and which ones could lose out. Rising food prices, which are regarded as one of the most important incentives to reduce waste, can lead to the food and nutrition security of the poorer groups in society worsening. So reducing food loss and waste is, and will remain, a multifaceted and complex issue requiring accurate cost-benefit and cause-and-effect analyses.

Silvia Richter is an editor of Rural 21. She would like to thank the members of the Rural 21 Editorial Board for their valuable input for this article.

Key findings from UNEP's Food Waste Index Report 2021

- Around 931 million tonnes of food waste was generated in 2019, 61 per cent of which came from households, 26 per cent from food service and 13 per cent from retail. This suggests that 17 per cent of total global food production may be wasted (11 per cent in households, 5 per cent in food service and 2 per cent in retail).
- Household per capita food waste generation is found to be broadly similar across country income groups, suggesting that action on food waste is equally relevant in high, upper-middle and lower-middle income countries. This diverges from earlier narratives concentrating consumer food waste in developed countries, and food production, storage and transportation losses in developing countries.
- Previous estimates of consumer food waste significantly underestimated its scale. While data doesn't permit a robust comparison across time, food waste at consumer level (household and food service) appears to be more than twice the previous FAO estimate.
- There is insufficient data on the edible fraction of food waste to allow comparative analysis across country income groups, but even if inedible parts (bones, pits, eggshells, etc.) predominate in lower-income countries, there is sufficient total food waste in these areas for circular approaches or other food waste diversion strategies to be important.

Measuring food loss and waste – instruments, challenges and global perspectives

Food loss and waste is a pressing global concern with significant environmental, social, and economic implications. Understanding its causes and scale is essential for creating effective strategies to reduce it. Our authors explore the diverse methodologies and instruments available for this purpose.

By Aditya Parmar, Sharvari Raut, Apurba Shee and Barbara Sturm

Measurement is the critical starting point for effective management, a well-worn principle echoed by the adage "If you cannot measure it right, you cannot manage it well." This also holds true for food loss and waste (FLW). Understanding the scale and sources of FLW is essential for creating effective strategies to reduce it. Quantitative measurement of FLW provides the data required to make informed decisions. It not only helps in achieving food security but is also a fundamental element of sustainability. Developing targeted interventions is challenging without accurate and comprehensive data on FLW.

An enumerator administering survey questions to record food loss and waste during the transportation of sweet potatoes in Ethiopia.

Photo: Aditya Parmar

Keeping an eye on quantity and quality

Until recently, there was no common methodology for assessing food loss and waste, leading to confusion, particularly at global and national levels. Efforts were made to standardise loss assessment methodologies, especially for durable products like cereals and pulses. A more precise estimation of (post-harvest) losses began with the counting and weighing method. Visual loss estimation methods, requiring less labour, were also developed. Initially, studies focused on storage losses, but by the late 1980s, a holistic system approach emerged, encompassing all stages of production, processing, marketing and consumption. Perishable products introduced complexity due to their quality-sensitive nature. To address this gap, the Food Loss and Waste Accounting and Reporting Standard was launched in 2016 by a multi-stakeholder partnership, offering comprehensive guidelines for measuring losses and enabling spatial and temporal comparisons. The Standard offers a decision tool to help organisations select appropriate methods.

The systematic measurement and quantification of FLW by actors in the food supply chain can help the public and private sectors contribute to finding viable and sustainable solutions to the food and environmental challenges of today. Here, the UN Food and Agriculture Organization (FAO) has developed a methodology for measuring and monitoring progress with Sustainable Development Goal 12 (Sustainable production and consumption), indicator SDG 12.3.1a – the food loss index (FLI). The FLI measures the percentage of food lost from the farm level up to – but not including – retail and compares it to percentage losses in the base year (2015).

At the organisational level, measuring food loss and waste helps an organisation understand the root causes and thus work to prevent it. The International Food Policy Research Institute (IFPRI) has developed a methodology that aims to improve the measurement of food losses across the value chain and includes stakeholders at each processing stage (farmers, intermediaries and processors). This approach not only measures the quantities of food lost but importantly takes into consideration deterioration in quality, which entails economic losses. The objectives of this methodology are to gauge the extent of food losses across a wide array of commodities in developing countries, measure both quantitative and qualitative economic losses, determine the nodes where losses are more prevalent, and identify particular production processes during which losses occur.

Quantifying FLW serves multiple academic and management objectives by providing baseline data, setting targets, monitoring progress, making comparisons, calculating costs, identifying critical areas, evaluating measures' effectiveness, creating statistical databases and modelling future trends. One such initiative is The African Postharvest Loss Information System (APHLIS), which models the future trends of food losses in the majority of African countries, with a particular focus on durables (cereals and grains).

Finding the right approach

Achieving absolute precision in measuring food losses is a formidable task. Historically, two main approaches have been employed: precise measurements from representative product samples (weight scales, load tracking) and informed estimates considering variable dimensions (surveys and questionnaires). The challenge lies in determining the extent to which measurement techniques and methodologies should be applied, balancing the cost against the benefits.

Depending on the value chain, the food commodity in focus and geographical location, appropriate methods (i.e. direct or indirect) can be employed. Direct measurement including weighing, surveys and counting allows direct quantification of data, while indirect measurement, such as literature data, modelling, etc., includes information from a secondary set of sources. Each of these methods has its own set of advantages and disadvantages (also see Box). For example, surveys help collect data in a cost-effective manner as interviews can be conducted over different communication platforms. On the other hand, data obtained through surveys could also be biased (aspirational or participant), thus leading to inaccurate data. To obtain a useful data set of FLW, it is important to consider various criteria, including accuracy, costs and significance, and assess each measurement against these criteria. The accuracy of measurements is a decisive factor, as decisions and interventions are commonly based on acquiesced data. Furthermore, the chosen method should also align with the specific goals of FLW reduction i.e. be significant and relevant in this regard. Finally, depending on the context, cost-effective instruments can also be implemented for FLW measurement. Comparative studies and cost-effectiveness analyses can guide the selection of appropriate instruments for FLW measurement.

Commonly used FLW measurement and assessment methods – advantages and disadvantages

Weighing scales and data loggers (also sometimes referred to as load tracking) are the most accurate and precise way to measure FLW. They can be used to measure the weight of food at different stages of the supply chain, from production to consumption. This data can then be used to calculate the amount of food that is lost or wasted at each stage. However, weighing scales and data logger approaches can be expensive, and they require extensive time and effort to collect enough data. This makes them less suitable for large-scale FLW measurement or for small businesses with limited resources.

Surveys and questionnaires are a more cost-effective and versatile way to measure FLW. They can be used to collect data from many people, including consumers, businesses and other stakeholders. This data can then be used to estimate the amount of food that is lost or wasted at different stages of the supply chain. However, these instruments rely on self-reporting, which can be inaccurate. People may forget or exaggerate the amount of food they waste, or they may be reluctant to report food waste if they perceive it to be socially unacceptable.

Remote sensing and GIS technology can be applied to measure FLW on a large scale. This technology provides real-time data and can be used to track changes in crop yields, land use and other factors that can contribute to FLW. However, this technology requires a high initial investment in equipment and software, as well as technical expertise to operate and interpret the data. This makes it less accessible to small businesses and developing countries.

Literature data can be used to estimate FLW when there are no resources available for conducting other methods. It is a low-cost method for a rough estimation of FLW. However, available data is often skewed towards a few developed countries and a few stages in the food supply chain, while the extent of FLW in developing countries and other stages of the food supply chain remains largely unexplored.

Global collaboration for local solutions

The fight against FLW is a global endeavour. Currently, a large set of data is obtained through indirect measurements such as literature from secondary or inconsistent/ outdated data sources. Furthermore, the data is limited to only a few sets of countries and a few stages in the food supply chain, thus leading to a significant data gap. To overcome such challenges, data sharing and international collaboration on a multidisciplinary level are essential to achieving meaningful progress. It is crucial to establish databases and to create a global repository of knowledge and best practices that are consistent and follow a standardised framework for FLW measurement to address FLW's transboundary nature. Platforms and initiatives for data sharing, like FAO's "Save Food: Global Initiative on Food Loss and Waste Reduction", are connecting stakeholders world-wide. Furthermore, involving the public through initiatives such as citizen science can also support the collaborative goal of reducing FLW.

In the quest to reduce FLW and achieve sustainable food systems, quantitative measurement is a critical first step. Selecting the right instrument is not a one-size-fits-all process; it requires a thoughtful evaluation of accuracy, costs and significance. Sharing data as well as successes, challenges and lessons learnt from FLW measurement efforts can be beneficial on a global scale. Here, emerging and developing countries offer unique insights and solutions. As we navigate the path towards a world with less FLW, it is crucial to understand, measure and tackle FLW at local level, in particular among rural communities.

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Why we need to go beyond technology

Food loss and waste is a multifactorial phenomenon. Therefore, at least in the long term, one-dimensional efforts to mitigate it, such as providing storage technologies, will not prove successful, our authors maintain, and they call for a systemic approach.

By Sylvanus Odjo and Heike Ostermann

Food loss remains an important challenge nowadays and contributes to food insecurity, resource depletion (water, soil and biodiversity), greenhouse gas emissions, health risks and lost income, particularly in low- and middle-income countries. It is a systemic and multifactor issue, and addressing it is a powerful measure in tackling today's local and global food system problems. Minimising food loss is part of the international development agenda and is recognised as one of the Sustainable Development Goals (SDG 12.3) with the objective of achieving a 50 per cent reduction of global food loss and waste by 2030. Applying post-harvest technologies with supporting public policies is generally suggested to halve food losses, as in the EAT-Lancet *Food in the Anthropocene* report. So far, sustainable and structural reductions in food loss and waste have been meagre. It important to implement a systemic approach attending the following points.

Assessing loss points, making well adapted technologies available

An in-depth assessment of critical loss points often lacks and post-harvest interventions for cereals such as maize, wheat, and rice, which feed humanity and underpin civilisation, generally focus on storage interventions. However, significant post-harvest losses could occur upfront in the post-harvest system, for example, during harvesting, drying and threshing or at processing stage, and depending on the context, it might be more efficient to address those loss points. Technologies which are well adapted to the local context are a prerequisite for successful implementation. Many challenges arise when making technologies like small-scale combine harvesters, shellers and dryers accessible to farmers. Often, these devices must be imported, without a local supply of spare parts or the capacity for maintenance, not to mention training for farmers in their optimal use. In many cases, the equipment does not fit the local context, sometimes offering a working throughput far beyond what farmers actually need or can manage. Finally, some post-harvest management innovations require supporting equipment that is locally unavailable. Local sourcing and maintenance of material is critical for the longevity of the investments and for up-scaling. It also creates business opportunities for local input and service providers.

Women who process peanuts generally air-dry the produce, a long and tedious process that requires labour and constant monitoring to avoid soaking by rains or contamination by pets. The solar-powered small-scale dryer promoted by the Green Innovation Center Togo through women's cooperatives (see photo) addresses these issues and dries the peanuts four times faster than air drying, avoiding aflatoxin contamination and achieving a high-quality product. However, use of the dryer does not result in a visually identifiable (i.e. market valued) difference in the processed peanuts, and high profitability is yet to be achieved, even though the dryer reduces labour costs. The sustainability plan for the dryers includes diversifying their use (e.g. for drying medicinal plants) and offering drying services for other cooperatives and private companies.

Photo: Laré B. Penn/ University of Lomé, Togo

Photo: Albert Barro/ CNRST, Burkina Faso

The multifunctional thresher promoted by the Green Innovation Center Burkina Faso responded to the need to reduce grain losses during threshing and the lack of labour during peak post-harvest periods, which was causing delays in threshing that exacerbated grain spoilage. The thresher (see photo) can be used for various crops (maize, sorghum, millet, soybean) and is portable. It has been made available to farmers through a service provider approach, in which young people from rural areas are trained to offer threshing and other agricultural and post-harvest services for in-kind or cash remuneration. Challenges associated with the sustainability and scaling of this approach include the high acquisition costs for the equipment and lack of financing. The local provision of financial instruments to facilitate access to credit, but also anchoring this approach to local governments and NGOs, are among potential solutions.

Defining sustainable business models for post-harvest innovations

The economic effectiveness of post-harvest investments is crucial for long-lasting and well-targeted reduction measures. This calls for sustainable business models which consider key quantitative economic parameters, such as investment costs, running costs, opportunity costs, price impact, marketable quantity and eventually knowledge about the degree of loss reduction and critical loss points within the value chain. Only if value chain actors understand the potential of value creation will they engage in targeted investments in the long run.

Users' purchasing power needs to figure prominently in planning to scale post-harvest interventions for smallholders in low- and middle-income countries. Smallholders in these countries generally lack resources for the acquisition of the technologies. Microfinance institutions can provide crucial financial services, but their reach is limited by factors such as high transaction costs and farmers' lack of collateral or financial literacy. Particularly in this case, post-harvest technologies and the need to minimise losses generally fall outside the perceived purview of local financers.

A sustainable business model for post-harvest innovations should offer a roadmap for generating revenue, accounting for operational challenges, social and environmental impacts, and the diverse actors involved and how the innovation can create value for them in the short and long terms. In the pilot phase, this would include involving key stakeholders and creating an enabling environment that facilitates collaboration and partnership. Pay-per-use solar-powered cold storage for the preservation of fruits and vegetables (also see article on pages 18–19) are examples of sustainable business models. Machine hire centres and post-harvest service providers have also proven effective approaches, but any business model must be locally designed and validated, and in any case will be subject to fluctuating local and global markets.

Understanding market dynamics

Markets play a crucial role in mitigating post-harvest losses, and understanding market dynamics associated with a post-harvest technology – including fluctuating prices, linkages between the actors in the supply chains of products and consumer preferences – is critical for adoption and scaling. Poorly integrated markets, particularly fragmented value chains with weak linkages among farmers, intermediaries, wholesalers and retailers, limit the volume and quality of produce, while diminishing profits and timely delivery to consumers. Coordination between the value chain actors and enhanced market information can help bring farmers on board and foster delivery of high-quality produce. Improved post-harvest technologies can address these challenges but need to be profitable and incentivise investments associated with equipment and practices. Linking smallholder farmers to market niches – for example, connecting Mexican producers of blue maize with gourmet restaurants in large cities and ensuring the grain quality through hermetically sealed storage, or market diversification and premium prices for products such as aflatoxin-free maize also stored in sealed containers – are relatively simple strategies to encourage investment in post-harvest technologies.

Technological solutions are a key component of post-harvest management, but their success hinges on a host of factors that influence their adoption, effectiveness and sustainability. They may significantly reduce losses and be cost-effective, but potential stakeholders need to be made fully aware of the benefits and, as much as possible, their precise amount, and thus be willing to invest in, promote and help scale the technology. Overall, minimising post-harvest losses requires a systemic (value chain) approach involving all relevant stakeholders in the design, implementation and evaluation of any intervention.

Hermetic technologies

Hermetic technologies, such as hermetic bags and hermetic metal silos, are airtight grain storage containers. Any pests (insects, fungi) infesting the stored grain rapidly deplete the oxygen in the container and die. The effectiveness of such sealed containers also depends significantly on the moisture content of the grain, which needs to be below 14 per cent at the time it is stored. This can be challenging in smallholder conditions, particularly in areas with high relative humidity and for farmers lacking a device to measure grain moisture. Small-scale dryers and moisture meters (like the DryCard™, which includes an indicator strip that, when enclosed in a jar with a grain sample, changes colour when the grain is not sufficiently dry), as well as good open-air drying practices and alternative ways of checking grain moisture content, need to be promoted, along with sealed containers. The salt method, based on the hygrospic properties of salt (see photo), is one easy way to check moisture content.

Using the salt method to check maize grain moisture content; it consists of adding 2-3 spoons of dried salt to a jar filled three quarters with a grain sample and shaking it for 2 minutes; if the grain sample is not sufficiently dried (as on the left), the salt will stick to the wall of the jar; otherwise (as on the right), the grain is sufficiently dry and can be safely stored in hermetic technologies.

Photo: Jessica González/ CIMMYT, Mexico

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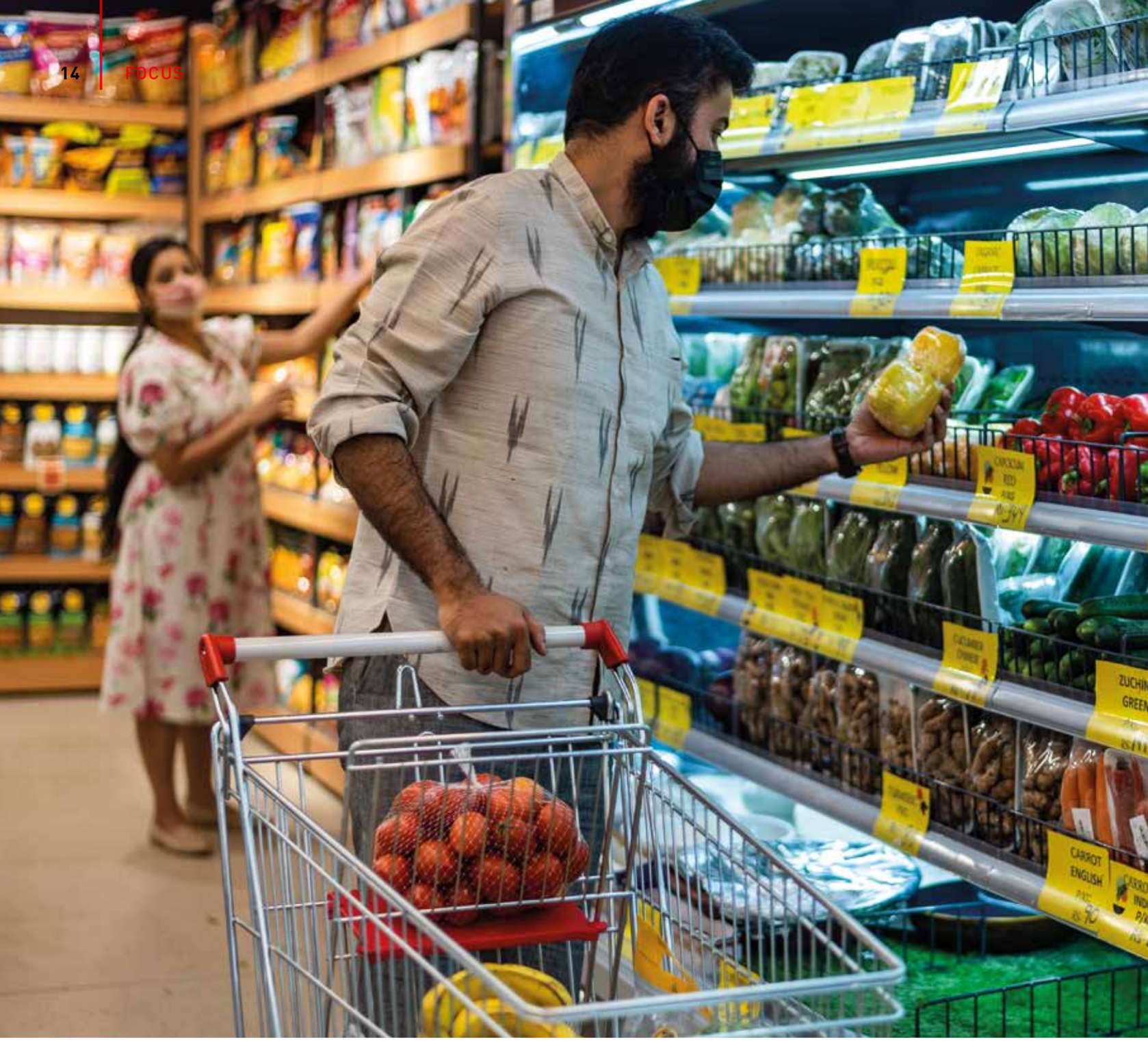

Motivation factors for food waste reduction

Lack of management and infrastructure are only two of the reasons why a substantial share of food ends up in the dustbin. Societal norms and acquired behaviour play a crucial role as well. Our authors have taken a look at what drives individuals to discard edible treasures and how change could be motivated both at consumer and industry levels.

By Neha Gupta and Manita Arora

Several factors contribute to the alarming rates of food waste at household level. One significant culprit is the modern lifestyle, where convenience often takes precedence over sustainability. Lifestyle choices are a factor in the development of habits. The latter are ingrained behaviours that can be performed with little to no thought due to previous reinforcement. They are the consequence of random events rather than more purposeful activities such as making a decision. This means that routine acts are governed by reflexes rather than intentional choices. Individual behaviours cause a huge part of food to be wasted. Several studies have revealed that people who waste food do it regularly. In this way, modern culture is much to blame since it prioritises short-term gratification over long-term sustainability far too often. The desire for perfection in aesthetics also plays a role – consumers tend to discard fruits and vegetables that don't meet stringent cosmet-

Photo: Alisha Vasudev/ shutterstock.com

ic standards. Moreover, the lack of awareness about expiration dates and proper storage techniques contributes to unnecessary disposal.

From numerous research papers on consumer behaviour, we figured out twelve key motivating factors that inspire individuals to actively reduce food waste. These include attitudes, perceived behavioural control, having experienced scarcity, past food waste behaviour, connection with food, awareness and knowledge about the food waste problem, subjective norms, financial motives, going for planned buying, lack of time, knowledge and skills about proper food management at home, and good household skills. Besides these, emotions also play a role. While qualitative research indicates that emotions could be associated with consumers' food waste behaviour, it is unclear whether the emotion is the cause of food waste or a consequence of it. The participants in such studies expressed regret at squandering food and felt guilty or concerned about avoiding wasteful behaviour. Several surveys have found that people feel awful about throwing away edible food. In India, cultural and religious values also play a crucial role. For instance, the practice of *annadanam* (donating food) in Hinduism fosters a sense of responsibility towards minimising food waste.

Tailoring strategies for India

In India, according the United Nations Environment Programme's Waste Index Report 2021, 50 kilograms of food is thrown away per household and year, causing the country to rank seventh in the world on overall food waste. Addressing food waste requires a nuanced approach. Given the above factors, it is above all awareness for the positive effects on society and the natural world which should be created or made use of. Educational initiatives could be employed to raise household awareness of food waste. Public awareness campaigns should emphasise the cultural significance of minimising waste and educate consumers about traditional practices that align with sustainability. Additionally, leveraging technology to disseminate information about proper storage and preservation methods can have a significant impact on household behaviour. Here, research could play a crucial role. For instance, nanotechnology offers promising approaches for the development of environmentally friendly and healthful applications for maintaining the freshness of agricultural produce and extending the shelf life of food.

There is no doubt that policy-makers hold a pivotal role in steering the ship towards a zero-waste future. In addition to promoting food education in schools and hastening research efforts, implementing and enforcing regulations that mandate clearer expiration labels and incentivising businesses to donate surplus food can create a conducive environment for change. However, eating establishments and grocery stores must also contribute to this. Some restaurants have already taken measures to track and cut down on food waste; but random and inconsistent effort never yields positive results in the long run. In order to lastingly and comprehensively lower food losses, it is important to determine which approach is going to be most successful. While some eateries have implemented programmes they identify with, others might reap financial, social, and ecological rewards by doing the same. In order to ensure that the measures are not haphazardly and inconsistently carried out, businesses need to provide their staff with training on the most effective methods for waste management and then strictly enforce the guidelines that they have established.

To reduce food loss and waste in the early stages of the supply chain, businesses must acknowledge the importance of technology. By fuelling innovation in areas like logistics and supply chain technology as well as blockchain, AI, data monitoring, storage and packaging, investments in India's growing start-up ecosystem can aid in the removal of systemic barriers. Implementing sustainable packaging practices, adopting technologies to extend shelf life and establishing partnerships with food banks for surplus redistribution are tangible steps which the food industry can take. Collaborative efforts, such as sharing best practices and success stories, can further catalyse positive change.

A prerequisite for food security

Tackling food waste is a complex challenge that demands a multi-faceted approach. By understanding the drivers behind wasteful habits and tailoring strategies to local contexts, we can foster a culture of mindful consumption. Minimising food waste will reduce ozone-depleting substance outflows, mitigate the obliteration of nature through land change and contamination, and enhance food accessibility, hence reducing hunger and saving money. With policy-makers and industry leaders leading the charge, we can aspire to build a world where every morsel is valued, and no one sleeps hungry. Preventing food loss and wasting less food ought to be an inherent aspect of any national or regional strategy for achieving food security in a country.

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Unleashing the power of innovation

The estimated share of food that goes to waste globally has remained unchanged for years. And yet there are numerous companies which have developed clever solutions to tackle the problem at the various stages of the value chain. The World Food Programme's Innovation Accelerator has set itself the goal of promoting these innovations and making them widespread.

By Nourdine Khalifeh and Jackie Negro

EcoRich founder and CTO Joyce Waithira presenting their innovative food waste solution, the WasteBot.

Photo: EcoRich

An urban hydroponic agriculture system from the WFP Innovation Accelerator Portfolio Innovation H2Grow.

Photo: Gulia Rakhimova/ WFP

The World Food Programme (WFP) has a presence in over 120 countries around the world to provide life-saving humanitarian assistance and build more resilient food systems. And yet, while up to 783 million people faced hunger in 2022, one-third of all food goes to waste. Food lost through poor farming, harvest and storage practices not only represents lost food security, nutrition and wasted resources but also lost opportunities to invest income in education, health and well-being. Imagine the potential impact of solutions should annual food loss – valued at 1 trillion US dollars – be reduced or eliminated and reinvested in achieving zero hunger and the Sustainable Development Goals (SDGs).

At each stage of the food value chain, innovators are developing solutions to optimise food production, distribution, storage, consumption and disposal in diverse contexts to reduce and manage food waste. The WFP Innovation Accelerator (see Box), which sources, supports and scales high-impact innovations to disrupt hunger and achieve the SDGs, has empowered several innovative solutions focused on these challenges to deliver greater impact around the globe. Two examples are presented in the following.

Reducing post-harvest waste for producers – Smartel Agro

Around half of total food waste (14 per cent of all food) occurs between harvest and retail. This post-harvest waste arises from various sources in production and supply chain inefficiencies. The Nigeria-based start-up Smartel Agro empowers farmers to cultivate fresh produce in urban areas through a climate-smart hydroponic system powered by interconnected data and technology. To date, 70 farmers are using this technology on their farm. Smartel Agro's unique model combines three tools to produce food more efficiently in urban-rural contexts:

Internet of Things. The utilisation of Internet of Things (IoT) allows for real-time monitoring and data-driven insights that enable precise control over environmental conditions, ensuring optimal plant growth and minimising the risk of spoilage. Smart irrigation efficiently manages resources, leading to a 90 per cent reduction in water usage compared to traditional farming methods. This not only addresses water scarcity concerns but also contributes to sustainable agriculture by mitigating the environmental impact of excessive water consumption.

Hydroponic farming. Hydroponic farming – farming without soil – contributes to a significant reduction in food loss. The portable and stackable design of the system allows for year-round cultivation, overcoming seasonal limitations and producing eight times higher yield than traditional farming. In the initial pilot, the Smartel team are exploring and planning to select three key crops to integrate into their hydroponic system based on their potential to positively impact farmers and improve food security. By cultivating crops in a controlled environment, the hydroponic technology ensures a consistent and abundant supply of fresh produce, while reducing the risk of pests and diseases. Additionally, the proximity of hydroponic systems to urban centres reduces the time and distance between harvest and consumption, further

decreasing the likelihood of spoilage during transportation.

Support for smallholder farmers. Smartel Agro is committed to making its technology accessible to smallholder farmers, its main consumer base. The primary sources of revenue involve selling hydroponic systems and related services. The customers, who include both rural small-scale farmers and city dwellers, purchase the portable hydroponic setups for cultivation purposes. Additionally, the team offer consultation and installation services to assist clients in establishing and effectively managing their hydroponic systems. This service provision generates income through associated fees. Moreover, Smartel introduced a pay-as-you-go subscription plan designed specifically for rural farmers who might encounter difficulties with upfront payments. This approach guarantees accessibility for individuals unable to cover the initial investment by allowing them to make periodic payments while still benefiting from the technology and expertise.

Managing household organic waste for consumers and producers – EcoRich

Once food reaches consumers, there are still opportunities for food to go to waste or for food waste to be mismanaged, which causes a variety of long-term health and environmental risks. The Kenyan start-up EcoRich Solutions has taken a transformative step here through its innovative WasteBot technology. At the heart of its mission is the development of an Artificial Intelligence-powered waste decomposer device that, using soil-based microorganisms, not only rapidly converts harmful waste into organic fertiliser but does so at a fraction of the cost of conventional fertilisers. The team operate in two business models: 1) direct-to-consumers (D2C): selling organic fertiliser at 25 US dollars for each 50kg bag; b) renting out the decomposer machine to large-scale farmers. The farmers utilise it to recycle farm waste into organic fertiliser, which they then apply in their farms for a monthly fee of 2 US dollars.

EcoRich's WasteBot efficiently transforms up to 50 kilograms of organic waste into nutrient-rich organic fertiliser in just 24 hours, disrupting the traditional timeline associated with waste disposal. Moreover, it addresses the issue of farm losses by providing an affordable and effective solution for farmers. The WasteBot's ability to turn waste into food also aligns with the broader goal of sustainable agriculture and climate change mitigation. The organic fertiliser, produced through AI-enabled recycling and robotics, reduces not only reliance on chemical fertilisers but also greenhouse gas emissions. It contains essential nutrients that improve soil quality, supplement nutritional requirements of the plants and enhance their ability to absorb nutrients optimally. The decomposer device is able to assess nutrient levels in the fertiliser, encompassing both macro and micronutrients. All this not only ensures food security for farming families but creates opportunities for surplus produce to enter the market as well, addressing broader issues of food shortages.

By producing organic fertiliser that is 70 per cent cheaper than normal fertilisers, the company has significantly expanded its reach. This affordability factor has resulted in a remarkable increase in the number of farmers who can now access and afford their fertiliser – EcoRich has reached 3,150 farmers in Kenya, who have reported a 36 per cent increase in yields and a 25 per cent income rise after switching to the organic fertiliser.

EcoRich's WasteBot technology is a holistic, affordable solution to food loss and waste. By seamlessly transforming household waste into a valuable resource for agriculture, the start-up is reducing the environmental impact of food waste and farming, improving sustainable farming practices, increasing farm production and supporting the overall well-being of farming communities.

Using innovation to end food waste and hunger

The amount of food that goes to waste each year could feed the world's population facing hunger four times over if the challenges that cause food waste are addressed more rigourously. The potential impact which innovation can have here should not be underestimated. In fact, innovators are uniquely positioned to forge new paths to zero waste and implement and scale solutions which, ultimately, contribute to the mission goal of zero hunger. With innovation, producers can optimise their resource usage and production chains, resulting in healthier, more resilient produce arriving at the market closer to the day of harvest and reducing spoilage. With longer-lasting produce, consumers are afforded more time to cook and create healthy meals, reducing their at-home waste. In addition, proper management of existing food waste can alleviate negative environmental impacts and produce fertiliser to improve farm production in turn.

At the World Food Programme Innovation Accelerator, we seek to enable innovations, like Smartel Agro and EcoRich, to reach new heights in their scaling and impact. Without innovation, the global food system will continue in its cycle of wasting one-third of the food it produces, with ongoing negative impacts in the context of a global hunger crisis. In order to break the cycle, we all should look to innovators for impactful solutions to the many food loss and waste challenges we face.

The WFP Innovation Accelerator

In 2015, the WFP Innovation Accelerator was launched to identify, support and scale innovations that can help make WFP's emergency response more efficient and effective and disrupt hunger globally. It has since become the world's largest social impact start-up accelerator, offering 15 acceleration programmes each year to address a wide range of global challenges, from hunger and climate change to primary healthcare, gender equality, and emergency response. In eight years, the WFP Innovation Accelerator has raised 200 million USD in co-funding with public and private entities and has designed its innovation programmes to accelerate social impact start-ups and companies. With its broad global network of Innovation Hubs and Units, the Innovation Accelerator serves a key role in connecting high-potential solutions to the resources and support necessary to reach greater impact for the most vulnerable communities.

In 2022 alone, the WFP Innovation Accelerator's portfolio of 150+ innovations reached 37 million people globally.

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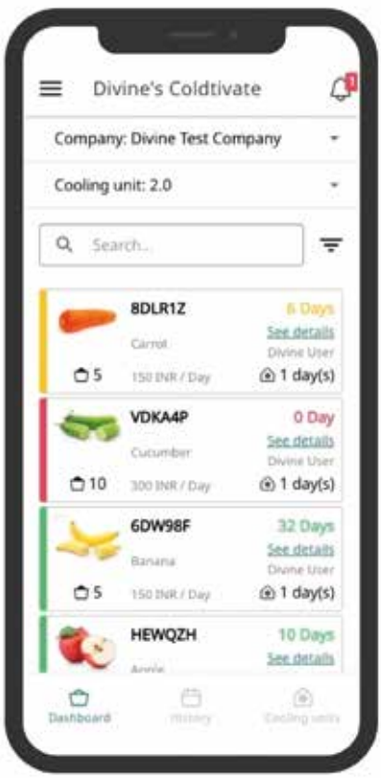
Bridging the cooling gap through digitalisation

When seeking reliable cooling solutions to preserve their harvested food, farmers encounter quite a lot of barriers. The initiative "Your Virtual Cold Chain Assistant" seeks to overcome this. It combines innovative business models, capacity building and digital tools. Insights from Nigeria and India.

By Simran Singh, Celina Schelle and Roberta Evangelista

Horticultural food loss is a significant issue in low and lower-middle income countries, with losses in India at 30-40 per cent and in Nigeria at 50-60 per cent. These losses are due to fragmented cold chains, poor post-harvest management and limited market access, resulting in crop damage and spoilage. Limited storage options force farmers into distress selling, particularly impacting women and marginalised farmers who lack access to storage, resources, and training. These access gaps lead to reduced productivity and profits, perpetuating cycles of poverty and dependence. Entrepreneurs are addressing these challenges by creating decentralised cold rooms with a Cooling-as-a-Service (CaaS) model. This approach removes financial and technological barriers, enabling users to pay a daily fee based on the amount of stored produce while the cooling companies handle equipment ownership and maintenance. However, a lack of awareness about cold storage benefits, inefficient cold room management to accommodate crop diversity and ineffective financial tracking hinder the scalability of these solutions.



A solution for inclusive access

In a bid to advance the adoption of cooling practices among farmers, in 2021, the Swiss not-for-profit BASE Foundation (formerly the Basel Agency for Sustainable Energy) and the SymBioSys Group of the Swiss Federal Laboratories for Materials Science and Technology (Empa) partnered to promote sustainable cooling in agriculture, launching "Your Virtual Cold Chain Assisstant" (also see Box). "Your VCCA" combines CaaS, digitalisation and awareness-raising efforts to combat post-harvest losses and enhance farmer livelihoods. One key pillar of the initiative is the design of a free-to-use, data science-based mobile application, "Coldtivate", which has been co-developed with the support of local cooling companies and users to ensure that operations in cold rooms are more efficient and transparent. The main components of the application are:

Digitalising inventory management. Coldtivate simplifies inventory management by replacing error-prone manual processes. Cold room operators, who assist farmers with crate storage and retrieval, enter crate details into the app, including commodity type, weight and harvest date. The app offers insights on commodity distribution within the cold room, optimal temperatures and occupancy rates. It calculates fees during check-out, ultimately optimising decentralised cold room management.

Digital twins and storage life prediction. To instil trust in cold storage solutions, farmers need to see how these facilities preserve their produce's quality. The Coldtivate app employs "digital fruit twins", artificial models developed by Empa that virtually simulate crop ageing (see Photo above). These models, fuelled by information about the crop initial quality and sensor data on room temperature, predict how long each crate can be stored, adjusting for temperature changes. The app displays this information on smartphones in local languages, indicating the days remaining until pickup. SMS notifications are used for farmers without smartphones, ensuring they are alerted before their produce spoils.

Market price predictions: Coldtivate empowers farmers to boost profits by using open-source market data to display historical prices and predict commodity prices in India and Nigeria. This enables strategic sales timing and location, and fair rate negotiations, and it reduces the risk of distress selling, with potential price drops of up to 75 per cent.

Levelling the playing field – your VCCA's gender-focused approach

Female smallholder farmers in the two countries face challenges in land ownership, wage equality, and financial access. They lack support, training, and recognition, with only eight per cent of female-headed households in Nigeria accessing extension services. Cultural barriers limit integration into the agricultural value chain and financial independence. The case studies in the Box on page 19 illustrate how "Your VCCA" helps improve access to sustainable cooling solutions for women. Female-staffed cooling rooms facilitate cultural inclusivity and knowledge sharing among their users. Additionally, the training materials developed as part of the initiative have been co-de-

Your VCCA's Partners

"Your Virtual Cold Chain Assistant" was launched in India with support from the Inclusive Growth and Recovery Challenge Initiative of the platform Data.org. It has since been replicated in Nigeria, financed with contributions from the Fund for the Promotion of Innovation in Agriculture (i4Ag), which is commissioned by the German Federal Ministry for Economic Cooperation and Development (BMZ). The development of the impact dashboard was supported by the Swiss-based Climate Ledger Initiative, with financial support from the Swiss Agency for Development and Cooperation (SDC).

Women self-help groups redefine cold room management

In India, the company Koel Fresh has been training members of a women's self-help group to operate a five metric tonne cold room near the VSS Market in Rourkela, Odisha, using tools like Coldtivate. This location was chosen to ensure women farmers' safety and convenient access. The initiative empowers women with technical skills and creates job opportunities within self-help groups. A study by Your VCCA and Koel Fresh revealed that before the intervention, female farmers in Odisha had sold less produce at market prices than their male counterparts (50.8 % vs. 60 %), incurring higher losses. In response, the self-help group launched a programme to aggregate crops stored in the cold room for fair wholesale deals, collaborating with local businesses. The presence of female operators in the cold room has enhanced its cultural accessibility, increasing usage among female farmers.

Regular female cold room users receive specialised training, becoming cold-room champions who educate the community on how and why to use a cold room. This peer-to-peer approach allows for equity in knowledge dissemination, and first-hand narratives experiences build trust in cooling solutions. Through this approach, the room's users have witnessed a drop in crop spoilage from 17 to 4 per cent, and a boost in revenues by 29.6 per cent. The significant increase in revenue for cold room users allows female farmers to gain better payment for their crops, a change from historical norms.

Community as a pathway to inclusivity

The cooling service provider ColdHubs, which offers modular, solar-powered walk-in cold rooms, primarily employs female cold room operators at its 58 facilities across Nigeria, collaborating with local female leaders, such as the *iyál ójà* in the Yoruba community, to identify women confronting socio-economic difficulties and facilitate their empowerment. The female operators are offered training on crop care and managing the cold rooms using Coldtivate. The trainers demonstrate cultural proficiency, integrating with the community and fostering a close working relationship for effective monitoring of the operators' needs.

In addition to targeted programmes for women, ColdHubs also holds joint gender sessions for knowledge exchange and to enhance women's visibility in the agricultural supply chain. These efforts have resulted in nearly 1,500 regular female cold room users.

Post-harvest management training in Aje Market, Osun State, Nigeria.

Photo: ColdHubs

signed with all involved stakeholders and translated into local languages to make them more accessible, with special care taken in depicting women as empowered market participants.

To date, more than 230 tonnes of produce (10,000+ crates) belonging to 400+ cooling users has been registered in the Coldtivate app. The solution has helped reduce post-harvest loss in the two countries by approximately 20 per cent, increase the revenue of farmers by 20 per cent and, thanks to the use of solar power technologies, as opposed to conventional fossil fuel-based technologies, avoid 193 tonnes of CO_2 emission a year.

The road to scalability

Companies face a challenge in achieving high utilisation rates to quickly recoup their cold room investments, ensuring business profitability and sustainability. Their primary revenue source is the daily storage fee charged to cooling users per crate, underscoring the importance of room utilisation. To recover costs for a 3 metric ton cold room in 1.5 to 2 years, companies charging around 0.5 USD/ crate/ day need an average room occupancy of approximately 60 per cent daily. However, farmers often face hurdles like uncertainty in sales and high transportation expenses when contemplating cold storage, leading them to choose immediate post-harvest sales through intermediaries at lower rates.

Expanding cold room capacity depends on a company's ability to secure additional funding for establishing new facilities. Small and medium-sized enterprises commonly struggle to attract impact investments because of their limited capacity to substantiate economic, environmental and social impact with reliable performance data. To accelerate the adoption of cold storage and address these challenges, Your VCCA is actively working to establish market connections for farmers and providing transparent tracking of company impact through data from Coldtivate. One significant effort includes the development of an impact dashboard, which allows cooling companies to oversee their business performance across different cold rooms and time periods. It also enables them to showcase key indicators to external stakeholders, demonstrating business viability and attracting investments.

Your VCCA's innovative solution enhances sustainable food systems, empowering smallholder farmers, improving food security, and reducing resource losses. The positive reception suggests potential for global application. Coldtivate streamlines multi-commodity cold storage for cooling companies world-wide, with ongoing efforts to open-source its code for seamless integration with third-party apps.

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References: **www.rural21.com**

Wolfgang Mittmann is the co-founder and CEO of Saving Grains. He previously worked for the innovation and programme division of the World Food Programme and with the Innovation Accelerator (see article on pages 16–17). He specialised in the area of grain storage and smallholder grain trade.
Photos: Saving Grains 301 GmbH

“If we only rely on safe bets, we will miss out on big opportunities”

The social business Saving Grains was founded in 2019 in order to improve the livelihoods of small farmers in Africa. Its aim is to establish a fully hermetic grain value chain from the farmer to the food industry. Company founder and CEO Wolfgang Mittmann on the logic of smallholdings, the value of transparent grain bags and his vision of a new kind of development cooperation.

Mr Mittmann, how did the Saving Grains idea evolve?

My work for the World Food Programme above all focused on smallholders and the grain trade. Here, I encountered the same structural problems again and again – problems which make it impossible for smallholders to get out of the poverty trap. While these problems may indeed be huge, some are also very easy to solve.

What are the problems?

Smallholders in sub-Saharan Africa, but also in South Asia and in many other countries, can't produce cheaply. While total production is limited by the small plot size, such tiny plots don't allow realising economies of scale. Let's take mechanisation, for example. It's often more expensive to take the tractor to the field than to plough the field by hand. This results in high prices. In Ghana, for instance, buying grain on the world market is cheaper than producing it at home.

Even so, most African countries are seeking food sovereignty …

This is a political and also sensible goal which development cooperation rightly supports. But achieving it requires structural transformation, which is associated with many politically sensitive topics, such as land reforms and subsidies, and therefore isn't easy to implement. And then there are dilemmas regarding its objective. While farmers are supposed to raise their production, mistakes which we have made in agriculture in the Global North, such as applying excessive levels of agro-chemicals, with their negative impacts on the environment and biodiversity, are to be avoided. And although there are many good and successful projects in this area, one has to concede that progress made over the last ten years hasn't exactly been gigantic.

What is your company doing differently?

We did not come from the production, yield and cost angle but looked at profits. The smallholder margin, in other words the sales price minus costs, is at a rough average around 15 per cent in Ghana. It's much lower in Kenya, where farmers produce their grain almost at cost.

Why is this the case?

Farmers sell at low prices during the harvest. Over the year, grain prices aren't really so low, but there are considerable seasonal dynamics. And whereas price fluctuations in Germany, for example, hover around two per cent, we're talking about roughly 80 per cent in Ghana, and in Kenya, which has two growing seasons, prices move between 50 and 90 per cent. Farmers sell during the harvest season, causing an immense oversupply which forces the price down towards the production price. This applies especially to commodities like maize and beans. Later, prices rise gradually again, and selling would become worthwhile, only that at this stage, the farmers usually no longer have any maize.

Because they lack storage facilities?

Yes, that's one of the reasons. If grain is stored in normal bags, which is the usual way of storing in the countries we're looking at, it is often eaten up by storage pests. Moulds producing aflatoxins are a further issue. In many African countries, this is a huge public health problem which contributes to high liver cancer rates and stunting among children. So with traditional storage, after a certain time, the farmer has less grain – weight loss being at around 25 per cent – which is of poorer quality as well. Therefore, since farmers are eager to sell good grain, they don't want to store grain for a longer period.

However, a further factor is often forgotten. Farmers need money. The harvest is needed, for instance, to pay back formal or informal agricultural loans and services provided on credit. Other costs are also incurred, such as school fees. Farmers are expected to have money at the time of the harvest, which also makes sense from the point of view of service providers. So farmers have to sell at least part of their harvest.

The partnership

Saving Grains 301 GmbH was founded in 2019 by Wolfgang Mittmann (CEO), Henning Vogt (CTO) and Kelvin Tyron (CPO/COO). The start-up has developed out of the World Food Programme Innovation Accelerator. Its social business model aims to allow farmers to benefit from future grain prices. The company recently started working with Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) in the context of the project "Reducing post-harvest losses and utilising agricultural residues". This project is commissioned by the German Federal Ministry for Economic Cooperation and Development (BMZ). It is part of the Fund for the Promotion of Innovation in Agriculture (i4Ag) and is carried out by Saving Grains on behalf of GIZ in Ghana and Kenya. Here, i4Ag seeks to increase the scale and impact of the solution. Specific aims include increasing female participation, offering training on wider post-harvest management and providing trading infrastructure to farming communities.

In November 2023, Saving Grains was awarded the German Entrepreneurship Award for Development.

How does Saving Grains intend to solve these problems?

We buy up the farmers' harvest at the time of the harvest and store it in safe, hermetic bags in community warehouses, so that the quality is maintained. We subsequently arrange off-take with industrial buyers at a point in time when prices are high. Farmers then get a kickback, a 10-20 per cent share of the profit. So we offer them a service via which they obtain part of the grain's future price. Should prices go up less than usual, or even fall, then there is little or no profit share – but neither is there any risk. This is of course a very popular model. Which farmer wouldn't be happy to sell his grain without any market risk and, six months later, get money again, just like that? And since the structural problems in most SSA countries are very similar, the model can be scaled.

That sounds straightforward …

Yes, but the question is whether it will be enough to get the farmers out of poverty – to promote health, education and all the other Sustainable Development Goals. And to be honest, no, that's not enough, even though the profit margin for the farmers increases significantly.

So, what has to happen?

The yields of many farmers are still at a third or a quarter of what the plots could generate. Here, development cooperation has invested a lot: trainings, the – incidentally unsustainable – distribution of free-of-charge seed, subsidies for marketing … But many farmers don't accept these offers. To understand this, you have to consider the situation a farmer is in. When I spread some corn in my field without further input, I will certainly have very, very poor yields. But the profit I generate isn't that bad because I have no costs. I might be able to feed my family with it for half a year and also sell a few bags to pay my debts. Now let's compare that with a farmer who makes a proper investment – land preparation, improved seed, fertiliser, pesticides, harvesting technology – which pays its way in terms of agricultural yield. But does it also pay off? In our experience, this is often not the case with low harvest prices. Nevertheless, the farmer bears a high risk. If there is no rain this year, a locust plague, or the plants are infested with the fall armyworm, a large investment is lost. The potential profits are not worth the risks.

And this means farmers stick with subsistence agriculture?

Exactly. What we hope is that if we increase profits, this will result in the farmers seeing that their risk-profit threshold shifts, and that it is worthwhile to invest. To start seeing farming as a business, invest a little more and perhaps care about soil erosion or try out crop rotation, intercropping, etc. With this approach, in the long term, we might be able to arrive at an integrated model in which profit sharing is paid out in the shape of inputs or an insurance policy. If you continue this logic, you arrive at a one-stop-shop incentivising farmers to sustainably raise their yields, and make money. This is a long-term vision, and for now, we are happy to be able to pay out profit shares. But we feel that business models with transformation at their core could crack the hard problems like the yield gap and rural poverty.

Coming back to post-harvest losses once more, why has so little happened over the last few years? Do the technologies lack maturity?

At least for grain, technology itself isn't the problem. Take hermetic bags, for instance. Insects and moulds need air and quickly die in hermetic bags. No weight or quality loss occurs. This is a simple technology that has been around for two decades, and the technical effectiveness is well documented.

And why aren't these bags in use across the board?

The bags do have one fundamental disadvantage: You can't look into them. Just imagine me trying to sell you such a bag full of grain. You can't open it to check the state of the grain, because then the bag would no longer be hermetic. So you probably wouldn't buy it. This is precisely the reason why you will find these bags used mainly for on-farm storage by farmers to feed the family. But if we want to tackle food losses on a large scale, we need hermetically packaged grain to move along the entire value chain, so that losses can be prevented at all stages. And it's precisely for this reason that we're developing a solution.

What does this solution look like?

The concept is quite simple. First of all, we asked our suppliers to provide us with transparent bags. This may not be a sensational innovation. But it is an initial step, enabling buyers to see which cereal the bag contains, the colour, kernel size, dirt, stones, etc. But to rule out any fermentation in the bag, which would spoil the grain, the grain must be dry. This is especially important in regions in which the harvesting and the rainy seasons coincide.

How do you ensure this?

In collaboration with Humboldt-Universität Berlin and a Fraunhofer Institute, we developed sensors detecting fermentation and insect damage. They can be read out with a free app that would alert the user to a quality problem. What is really exciting is that because any buyer has an incentive to read out the sensors, you can establish the route the bag has taken. This is interesting in terms of quality management, but also, and increasingly, with a view to supply chain requirements on social sustainability, the *Lieferkettengesetz* – the new German legislation on supply chains–, or the requirements of shareholders and other stakeholders.

So you could guarantee traceability …

Yes, and more. The food industry suffers from unstructured and often unpredictable supply in terms of quantity and quality. For instance, a brewery in Ghana might often not know if it will be able to fill its vats with local grain at a reasonable price in the coming three months. If not, it will have to order a cargo ship from Ukraine or the Gulf of Mexico. By using bag data we could provide market information or act as intermediary and enable the industry to plan its supply chain better.

Speaking of quality, you mentioned aflatoxins earlier on.

Aflatoxin is the key quality criterion for the

food industry. This applies in particular to breweries or the Nestlés of the world, and it has been the focus for regulators. Kenya is the leader in this respect, introducing and monitoring quite strict aflatoxin limits. While this is a positive development, it introduces uncertainty, both for the suppliers, who don't know if their goods could be turned down, and for the industry, which is not sure whether it can rely on planned consignments. Rejecting consignments won't cause a food company costs directly, but it could run out of raw material.

Here too, we are working on a solution that relies on traceability. While aflatoxin is infamous for high variability, this is not random. Aflatoxin occurs in certain locations, depends on the weather, on the post-harvest treatment and so on. So we believe that we can predict aflatoxin. This would be very valuable for the food industry, for public health and for agricultural interventions.

How would you predict aflatoxins?

A lot is unknown about which factors drive aflatoxin in a smallholder context. Aflatoxin testing is expensive, and its high variability means it is prone to sampling errors. This is what makes it so tricky. However, there is a wealth of data. The food industry already has to perform aflatoxin tests. We are working with industry to make this data usable through machine learning. Our aim is to develop an aflatoxin warning system with which we can spatially and temporally forecast the aflatoxin risk. This would allow forecasting safe zones for each season as well as zones with high risk.

But for the farmers concerned, this would mean no longer being able to supply ...

Yes, for the time being. But there are ways to reduce aflatoxin contents, for example via decontamination with ozone or low-temperature plasma. With the aid of the warning system, one could target where such measures make economic sense – basically where aflatoxin is high. Of course, it is much more sensible to tackle aflatoxin where it arises. There are solutions for soil treatment, such as the biocontrol technology Aflasafe, with which the *aspergillus* moulds are gradually ousted by other moulds. But naturally, it is very difficult to convince farmers to make such an investment over several years, especially if nobody cares whether their grain contains aflatoxin and treatment doesn't provide them any added value. Even so, if we could apply such interventions in a targeted way, this would also be a big step for food losses and public health.

Insect damage in maize results in quality and quantity losses.

The transparent hermetic bags allow buyers to see which cereal is inside.

How confident are you that such a system can establish itself?

We design systems to solve problems for the industry, which ultimately bears the cost. And these are the businesses of the food industry at the end of the grain value chain. This is the seat of power, this is where the money is, and this is where the decisions are taken. It is important to exactly understand their processes. How is quality management performed, how is it recorded? Are batches tracked? What are the costs when consignments have to be rejected? How often are aflatoxin limits exceeded in intermediary or final products? We need to demonstrate how much money is lost and how our solution makes economic sense. Henning Vogt, our CTO, is running the development and is confident that the costs for the sensors will be just a few cents, and the corresponding IT will be very cheap at significant volumes. This makes such a system so attractive, considering the value created in avoided food losses, quality, traceability and aflatoxin management.

One requirement for hermetic storage is dry grain. Is this something that the farmers can basically handle well?

This depends very much on the climate zone and, of course, also on the price. In the West of Kenya, for instance, depending on the altitude, harvesting is done between August and October, when dry weather conditions prevail. But there are also many countries and regions in Africa where drying is a huge problem. For example, in Ghana's middle belt, harvesting takes place right in the middle of the rainy season. At this time, farmers can no longer dry the grain on a tarpaulin in the sun. Here, dryers are the normal solution, but they aren't usually available. And drying is expensive. Again, farmers have to work out if they can find a buyer for wet grain or if they can make more money selling dry grain. Here, the respective capacities have to be created – and this is a volume game requiring a lot of capacity, which means it needs to be an economically viable venture for the farmer and the drying business.

Is that also part of your concept?

We have a commercial dryer available. But most dryers are diesel-, charcoal or gas-powered, so they aren't environmentally friendly. This is why we are collaborating in a pilot project with the agricultural engineering department of Kwame Nkrumah University of Science and Technology in Ghana and the Fund for the Promotion of Innovation in Agriculture, i4Ag. With this cooperation, we are looking at biomass dryers in order to find out if we can operate these dryers ecologically and economically, and if this is also worthwhile from a material cycle angle. We want to see if enough biomass is available when cultivating maize. Do the cobs and the entire plant provide enough energy? Is there enough other biomass around without cutting down trees?

When can the first results be expected?

The dryer should be ready for the harvest season in Ghana next year. We would then operate it alongside a diesel-driven dryer to compare capacities. Of course, many other factors have to be considered, such as transportation costs of grain to the dryer and labour costs.

Does it makes sense to get the governments on board in your ventures?

We see only little support. With tight budgets, perhaps quite rightly, it is more tempting for

A village demonstration of the Saving Grains App.

Onboarding of market women in the North of Ghana.

Photos: Wolfgang Mittmann

governments to invest in high-value products. Exports to help their country's economy are more important than supporting a small company with big ideas. So far, we have seen little potential for cooperation. Maybe that will change once we have reached a certain size.

And what about other partners?

Just like any other start-up, we are looking for investments. This applies in particular to Africa and to start-ups which are still in the seed phase. We have been working with a grant from the Accelerator of the World Food Programme and the Austrian Development Agency and are grateful to Bayer's corporate giving. The "Deutsche Bundesstiftung Umwelt" supported our technology development. Now we have entered a larger partnership with Deutsche Gesellschaft für Internationale Zusammenarbeit and its i4Ag for three years until August 2026. As a social business, we seek to achieve impact, but we cannot, for example, run farmer trainings at a large scale or develop a lot of infrastructure in the villages. This is where we meet our limits. In this partnership, we benefit from GIZ infrastructure and advance our scale and corporate goals. So, this is a mutually beneficial partnership and a big opportunity for us.

What can a social business do better than conventional development cooperation?

It is natural for development cooperation organisations to have political goals and processes, all of which make sense in the given context. Their nightmare is taxpayer's money being embezzled, and they build their processes accordingly. But these organisations don't work along free market lines. We have a company's orientation on profit, which keeps costs lean, and are at the same time guided by social aspects, where the impact I am having is clearly measured. And whereas one dollar in development cooperation can only amount to one dollar, a dollar invested in a social business can generate ten, a hundred or even a thousand dollars in transfer performance, depending on how efficiently the business model spreads and how much investment is needed later on.

Now this is a bird's eye view, as no development agency we know of just gives money to build a business. It is always linked to specific targets and activities. But still, I think it explains the growing interest on the part of development cooperation to invest in innovative start-ups, social businesses, investment funds and the wider start-up ecosystem. It isn't long until 2030. And we are nowhere near reaching the Sustainable Development Goals. This is why we are very happy to work with pioneers from i4Ag.

What would you like to see regarding international cooperation?

A structured political dialogue on what a new type of development cooperation should look like. We need to look at risk and the way we deal with failure. If we only rely on safe bets, we will miss out on big opportunities. Learn from venture capitalists. If they make seed investments they know most will go bust. A few will return their investments, but they make money from the one or two investments that scale a hundredfold. This is a difficult conversation to have – can we invest taxpayer's money in risky ventures? What if they really do go bust? What if they change their business model? What if they actually succeed and make lots of money having been funded for free? For development cooperation, every project must be a success. But for all these successes, when I travel in rural Africa, I still see the hoe more often than the tractor. So, I believe this is the time to have a dialogue addressing all these issues.

What is important in a partnership between a social business and government development cooperation?

It is trust. Trust that you can work with each other and sort out problems. It is openness to work with a focal point that you can tell about the real challenges. It is the degree of freedom that you allow companies. If the development agency follows the logic of supporting a scaling business that creates impact, it is important that goals align. The development agency should demand results towards its goals. On the other hand, the development agency and its support may move the start-up further and further from its core business preventing the desired scaling. A balance has to be sought, and the development agency should be mindful of the power dynamics.

What is your long-term vision? Upscaling by private investors?

We are very proud of our growth so far, but we are still small. We focused on getting our model right, so it is profitable, impactful and scalable. Our third co-founder, Kelvin Tyron, is really the huge champion of this and has made dozens of changes. Our next milestone is solid market proof of our business model in Ghana and Kenya. We aim to reach 20,000 farmers. However, if we can show solid market proof for impact, for profits and for scalability, why can't we leapfrog to a much higher scale? There are impact investors but also institutions, such as the International Finance Corporation or the World Bank, the IFAD and foundations like Rockefeller and Gates. Why wouldn't they put big money behind a proven solution to one of the world's problems? There are so many capable founders in Africa – we could set up businesses in five new countries through a franchising model. Or we could bring in corporate partners, like major grain traders or breweries, and scale through their footprint. Again, it boils down to proving profitability, impact and scalability. And we are not far off. Then, everything will be possible. Together, we can solve a big problem at scale!

Interview: Silvia Richter

Metal silo, beyond minimising food losses – Ethiopian experience

Ethiopia loses between 10 and 22 per cent of grains during storage because a large share of the country's farmers still use traditional structures. A study by the United Nations Food and Agriculture Organization based on a project implemented in different regions of Ethiopia shows that much awareness raising as well as other measures, such as policy development, are needed to change this. Our author summarises the most important findings on the impact of post-harvest loss management on social, economic and environmental aspects, and develops recommendations for the future.

By Aresawum Mengesha

Ethiopia's agricultural production is unable to meet the country's total food needs. The reasons for this include food losses, limited access to, and availability of, suitable storage units and inefficient institutional and legal frameworks. Therefore, the project "Reducing Food Losses through Improved Post Harvest Management in Ethiopia" was implemented between 2013 and 2023 by the UN Food and Agriculture Organization (FAO) in collaboration with Swiss Development Cooperation and the Federal Government of Ethiopia via the Ministry of Agriculture. The project was carried out in the following five regions: Amhara, Oromia, Southern Nations, Nationalities and Peoples' Region (SNNPR), Sidama and Central Ethiopia (according to the new rearrangement of the regional states). Its overall goal was to contribute to improved food security of smallholder farmers in Ethiopia through reducing post-harvest losses (PHLs).

The findings of the study show that there is a shift in the attitudes of the government and policy-makers. Continuous awareness on the issues regarding post-harvest losses made by FAO and the Ministry of Agriculture has led to the development of a grain post-harvest management strategy. While this policy is yet to be operationalised in totality, it is certainly a step in the right direction.

Farmers have also become aware of the PHLs and are taking steps to mitigate them. Albeit very slow, there is a shift from the traditional structures such as *Gotera* (above-ground-bins), underground pits and roof or ceiling storage towards hermetic storage technologies such as hermetic bags and metal silos. Prior to the post-harvest loss management (PHLM) project, 4 per cent of farmers had stored their produce in metal silos and 8 per cent in hermetic bags, while 94 per cent had used traditional structures. After the implementation of the project, farmers storing their produce in metal silos were estimated to account for 44 per cent of all farmers, while 34 per cent were storing it in hermetic bags and 79 per cent in traditional structures. Since farmers keep their produce in several types of store, the percentages here do not add up to 100.

Why are many farmers still preferring traditional storage structures?

Despite all successes, the amount of grain which is stored in traditional structures is still high. Why do so many farmers continue to prefer these structures? Several reasons are at the forefront here, as shown in the study. For example, farmers indicated that traditional structures are cheap to construct. Metal silos, for example, are more expensive and difficult to transport, especially for farmers in remote rural areas, so that this can inhibit their purchase and use. And in their opinion, traditional structures maintain cultural values as well as minimising theft and misuse of grains stored for use during the emergencies. For instance, farmers in SNNPR pointed to conflict as one of the influencing factors for continued use of underground pits. Enemies who would oth-

Photo: Daniel Valenghi/ SDC

erwise burn all the stored food do not easily locate these pits. Moreover, underground pits do not offer easy access to the stored food as it is strenuous to get the food out, and this prohibits unnecessary sales, unlike metal silos and hermetic bags.

Several factors drive the adoption of PHLM practices. These include the level of income and the farmers' age. Participation in trainings, demonstrations and exchange visits also have a positive impact on the adoption of new technologies. Moreover, households headed by males were more likely to adopt hermetic bags and metal silos, perhaps thanks to better access to resources and ease of decision-making. Access to auxiliary services, including extension services, media and credit, was found to lead to changes in behaviour. PHLM sustainability will hinge on the training and capacity building that has taken place so far.

The assessment indicated that farmers can save up to 22 per cent of the grain which would otherwise be lost. This is thought to be 0.28 tons per farmer, or 15 per cent of the typical 1.8 tons of grain kept in conventional storage facilities. It was also found that storage of grains enables quality preservation and provides a farmer with the chance to profit from temporary price fluctuations between the periods of harvest and the times of sales. Although there may be variances depending on the crops and storage facilities, farmers often receive a better price when selling their grains after storage instead of straightaway. Grains stored in hermetic bags and metal silos cost significantly more than those stored in conventional structures.

Social and environmental impact

There is a close link between PHLM technologies and health issues because most of the farmers who store their grain in traditional structures apply storage chemicals to reduce losses. Thus, 76 per cent of farmers in Amhara and 25 per cent in Oromia and SNNPR report health problems caused by the use of chemicals. Widely reported illnesses include eye problems, sneezing, coughing and stomach problems. In addition, when applied, these chemicals remain on the produce, and taste and smell are evident at the time of consumption. Despite the illnesses reported by farmers, they continue to use chemicals since they cannot afford to purchase the metal silos. Also, pesticides like Malathion are readily available at the local agro-dealers stores and offer a cheaper alternative to reduce PHLs.

Despite the patriarchal nature of Ethiopian society, men and women share roles along the production value chains. However, the use of post-harvest loss management technologies had noticeable effects on women, particularly in terms of labour saved from constructing traditional structures and the release of women from daily management of the grains kept in these structures. The study shows that women save almost 75 per cent of the time and drudgery they would have spent. Importantly, the study revealed that domestic disputes brought on by damaged grains had decreased, which contributed to a decrease in gender-based violence. The time saved by women was used in other economic activities including strengthening social relationships within the community and spending more time caring for children.

Post-harvest losses have an impact on the environment. Agricultural production always involves the use of natural resources. According to the study's findings, for every tonne of grain saved through post-harvest losses, 0.81 tonnes of greenhouse gas emissions would otherwise have been released into the atmosphere. In terms of cultivated land, for every hectare used for grain production, an average of 0.22 hectares is used to produce grains wasted through PHLs. And in terms of water footprint, 1 tonne of wasted food is equivalent to 192 cubic metres of water. Consequently, PHLs of 0.288 tonnes per farmer correspond to a water loss of 55 cubic metres.

Recommendations for the future

The survey has demonstrated that especially training and capacity building positively influence the likelihood of adoption and should therefore be continued. With 79 per cent of the storable produce still finding its way into traditional structures, efforts must carry on to further promote and support PHLM technologies and practices. Awareness of the negative effects and consequences of pesticides must be raised through training. Moreover, experience sharing that exposes farmers to practical learning sessions, especially from model farmers, has to be supported and facilitated.

Extension services play an important role in demystifying the technical aspects of technologies and encouraging farmers to trust them. There is need to widen extension outreach to involve more farm households. This should be coupled with increased information supply via various media channels – radio, television and social media if available.

Another way to encourage farmers to adopt improved storage structures is to develop a grading standard mechanism and develop a price-reward system for quality grains. This can be implemented in the form of price premiums or quality certificates.

Also, it is necessary to develop and customise the credit market to meet the demand for the post-harvest loss management technology sector. The majority of the small-scale farmers may not be able to afford the silo without financial assistance. As such, in order to stimulate demand, it will be important to create market linkages between the artisans, farmers and financial institutions in the respective regions. The micro-finance institutions must create products relevant to PHLM. The cost of the credit product must consider the fluctuations of demand for the technologies in the market, fluctuations in food prices and the collateral requirements.

Policy development has been good so far, with strategies being created to deal with PHLs. However, these need to be operationalised down to the lowest administrative level with requisite human resources and facilitation. The strategy on agricultural extension needs to incorporate PHLM in the national extension system.

The PHLM technology agenda has to be deepened along the value chains. Although there are losses at the storage stage after harvest, more losses are presumed to take place at the harvesting stage, with food being lost through poor harvesting techniques. Widening the PHLM agenda to include the harvesting stage is likely to save farmers more losses. Moreover, there is need to incorporate pre-harvest practice technologies such as drying, transporting and threshing.

The study has shown that better post-harvest management contributes significantly to improving food and nutrition security as well as increasing the income of smallholder farmers in Ethiopia. However, extensive efforts still need to be made for the techniques to find their way into farmers' everyday practices.

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Transforming by-products into resources – circular economy approaches for agricultural products

In today's world, where environmental sustainability and resource conservation are paramount, the concept of the circular economy has gained significant traction. It represents a shift away from the linear model of "take, make, and dispose" towards a system where resources are kept in cycles and thus more available to the global poor as well as waste is minimised. While this approach is often associated with manufacturing and industrial processes, it is equally relevant to the agricultural sector. The following article explores how circular economy principles, inspired by cradle-to-cradle ideas, can be applied to agricultural products.

By David Bexte and Jens Soth

The cradle-to-cradle (C2C) philosophy, introduced by the US American architect William McDonough and the German environmentalist Michael Braungart in the late 90s, challenges the traditional linear economy by advocating for two distinct types of materials: biological nutrients and technical nutrients. Biological nutrients are materials that can safely return to the environment, nourishing ecosystems, while technical nutrients are those that can be perpetually recycled without loss of quality. Applying these principles to agriculture means rethinking how we use and manage by-products to minimise waste and maximise value.

In former times and poorer societies, the full use and circularity of products were not merely a fancy sustainability idea but a practical response to economic scarcities. Every resource and material was regarded as valuable, and nothing was wasted. This historical perspective underscores the deep roots of circular economy thinking, highlighting that it is not just a contemporary concept but a reflection of age-old practices born out of necessity. Furthermore, in a world of rising population and limited resources, access to these raw materials should be possible for everyone, including those living in poverty. Circular economy approaches aim to democratise resource access and ensure that even marginalised communities can benefit from the efficient use and repurposing of materials, contributing to greater equity and shared prosperity. By reducing waste and maximising resource efficiency, circularity can help address the challenges posed by resource scarcity and offer a more sustainable future for all.

The fibres of the banana stems are a valuable raw product for home textiles and packaging.

Photo: CRED/ Banana project

Contributing to sustainable and resilient food systems

Before looking into the practical examples, it is essential to understand how circular economy approaches align with modern perspectives on food systems. In today's world, where food waste is a global concern, it is crucial to minimise waste and ensure that all parts of agricultural products are used to their fullest potential. Circular economy principles optimise resource use, ensuring that every component of an agricultural product is put to good use. This is not only environmentally responsible but also contributes to more sustainable and resilient food systems. Some examples:

Banana stems – a fibre-rich opportunity for textiles and packaging

Banana cultivation is a significant agricultural activity in Vietnam. While the fruit is the primary focus, the banana stem, often considered a waste product, presents an untapped resource. Helvetas Germany and the Vietnamese civil society organisation CRED have taken an innovative approach to this by-product, applying circular economy principles to transform banana stems into valuable fibre raw material for home textiles and packaging. The process involves harvesting banana stems after the fruit has been harvested. These stems are then processed to extract fibres, which are subsequently woven into textiles or used as sustainable packaging material. Not only is value added to what was once considered waste but the need for more resource-intensive materials like cotton or synthetic fibres is also reduced.

This circular approach has several environmental and social benefits:

- By utilising banana stems, the demand for virgin materials is reduced, lessening the environmental impact of textile and packaging production.

- Banana stems that would have otherwise been discarded are transformed into useful products, reducing waste and its associated environmental problems.
- Local communities can benefit from this endeavour by participating in the processing and production, creating employment opportunities, and income generation.
- The use of local, renewable resources in the production of textiles and packaging materials can result in a reduced carbon footprint compared to traditional materials.

The outlook for employment benefits is impressive. For the stem material of 1,000 banana farmers, the by-product processing as described is underway to create 200 jobs for workers in cooperatively processing the stems to fibres and a further 250 jobs for handicraft women and men producing home textile products from these fibres (see photo on the right).

Rice rusks – from by-product to sustainable building material

Rice is a staple crop in many parts of the world and its production generates a significant amount of waste in the form of rice husks. However, with the right approach, these rice husks can be turned into a valuable resource. In a bid to expand the application of circular economy principles to different regions, Helvetas commissioned a study to identify the most reasonable uses for rice by-products in West Africa. The study evaluated potential uses for their employment effects, environmental performance, and the investment required to initiate production. Among the analysed options, particle boards from rice husks emerged as a suitable and easily transferable option.

The technology required to process rice husks into particle boards is relatively simple and can be implemented in both urban and rural settings. This presents an opportunity to not only reduce waste but also create local industries that produce affordable building materials. The resulting particle boards are lightweight, durable, and resistant to pests and moisture, making them an excellent choice for construction. A small-scale rice mill with a capacity of around five tonnes of paddy per day will have an average volume of one tonne of rice husks per day. This is sufficient raw material to add two more jobs to the milling operations just for valorising the husks in form of simple particle boards. With very basic board pressing machinery and some natural ingredients as binder (any starches from cereals mixed with caustic soda, with cassava starch being especially suitable), one can create particle boards with sufficient durability for small constructions like hen houses or stables for smaller livestock.

The benefits of this circular approach with rice husks are numerous:

- Rice husks, which would otherwise be discarded or burned, are transformed into a valuable construction material, reducing waste and air pollution.
- The use of locally sourced rice husk particle boards can lower construction costs, making housing more affordable in impoverished areas.
- Producing these boards can stimulate local economies by creating jobs and fostering entrepreneurship.
- The particle boards offer a sustainable alternative to traditional construction materials, contributing to more environmentally friendly building practices.

Cocoa pod husks – beyond soap and fertiliser

Shifting the perspective to view agricultural by-products as valuable raw materials rather than mere wastes transforms them into assets. The example of cocoa pod husks is particularly eye-opening: empty pods, which are left over after extracting the beans used in chocolate production. Surprisingly, the empty pods represent a much larger biomass by volume compared to the beans themselves. The ratio of bean weight to empty pod weight can range from 1:1 to 1:10.

Traditionally, in West Africa, there are established recipes for making various types of soap from cocoa pod husks, although this only utilises a small fraction of the total volume. An additional simple and noteworthy application emerges with the growing interest in biochar as a soil additive. This method becomes particularly relevant for replenishing soils that have lost their organic matter, offering a practical way to make the most of these abundant cocoa pod husks. This dual approach not only minimises waste but also contributes to the enhancement of soil quality, showcasing the untapped potential of these often overlooked agricultural by-products.

These two pathways of utilisation can be implemented very easily with lowest investments. But more sophisticated approaches with very high intended value added are also on the drawing board. Helvetas Germany and Helvetas Vietnam are collaborating on a project with key players in the Vietnamese cocoa value chain to develop environmentally friendly chocolate packaging made from cocoa pod husks. By combining these husks with poly-lactic acid (PLA – a widely recognised biodegradable polymer derived from various sugars), the resulting packaging becomes both more affordable and quicker to degrade compared to pure PLA foils. However, this type of packaging is currently more expensive than conventional plastic-based materials. Nevertheless, the potential for change is on the horizon, driven either by regulatory measures banning plastics (as already initiated by some sub-Saharan countries) or by increased consumer demand. These factors present a significant opportunity for broader implementation in the near future.

Handicraft made of banana stem fibre. The circular approach offers numerous employment opportunities for local communities.

Photo: CRED/ Banana project

Circular economy approaches for agricultural products hold immense promise, particularly from a development perspective. They offer a pathway to enhance social and environmental sustainability while generating numerous opportunities for employment, attractive jobs for younger people and new businesses in the Global South. By embracing these innovative strategies, we can not only reduce waste but also contribute to more sustainable and resilient agricultural systems.

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Turning cocoa waste into a high-quality product for confectionery

Every year, the extraction of cocoa beans generates tonnes of waste products that just rot away unused. The founders of the Swiss start-up Koa found this terribly squanderous. In the south of Ghana, they have established a value chain that provides income and jobs in the region and also improves the carbon footprint of cocoa production.

By Angelika Wilcke

The West African countries of Ghana and Cote d'Ivoire grow roughly 64 per cent of the cocoa beans used for global chocolate production. The climatic conditions in this region of West Africa are ideal for cocoa: not too much sun and not too much rain, as well as sufficient rainforest cover below which the cocoa trees can thrive. Ghana is the world's second largest exporter of cocoa after Côte d'Ivoire. The cocoa beans are mostly grown by smallholder farmers. Ageing plantations, viral diseases of the cocoa trees and climate change-induced increasing droughts make life difficult for the farmers. And it is not an easy life to begin with, for on average, the smallholder farmers earn only about two US dollars a day. In order to better compete on the world market, the Ghanaian government, through the Ghana Cocoa Board, retains the monopoly and sets producer and sales prices. The Cocoa Board provides the smallholder farmers with a level of security because it pays fixed prices for the harvest and supplies them with fresh trees as well as fertiliser and pesticides. But for every Euro that European consumers pay on average for a 100g bar of chocolate, the smallholder farmers receive only 7 cents. Four cents go to the Cocoa Board, 2 cents to transport companies, 8 cents to mills, 35 cents to chocolate manufacturers and 44 cents to retailers.

Cocoa farming is a hardscrabble existence. The farming families usually live remotely in the rainforest, often without access to public road networks, which means that they have extremely limited access to markets and children can only attend school with great difficulty. Moreover, cocoa cultivation brings with it environmental hazards. When the beans are harvested, crop residues accumulate, such as the husks and the pulp that coats the beans. The pulp seeps into the soil, negatively impacting soil quality. The husks rot, releasing CO_2 in the process.

Designing new products – from idea to implementation

A young team from Ghana and Germany realised that these adverse processes can not only be avoided but that new products can be developed from the unused parts of the cocoa fruit, which can yield additional income for the farmers. The idea was realised in July 2017 with the establishment of the start-up Koa in Zurich, Switzerland (see Box). One year later, the subsidiary Koa Impact Ltd. was established in the Ghanaian capital Accra. The idea was to process the cocoa pulp into a variety of raw materials for quality products in the confectionary industry and catering. The first production plant opened in September 2019, in Akrofuom in the Ashanti Region. In August 2023, a second factory opened in Achiase in the Eastern Region. As of August 2023, Koa had 100 employees – 82 in Ghana and 18 in Zurich.

Only 30 per cent of the pulp is needed for fermentation of the beans. The rest can be processed into a fruit juice, syrup and powder to be used in the chocolate industry.

Photo: Angelika Wilcke

Together with Swiss and Ghanaian universities, Koa developed the solar-powered "Community Mobile Processing Unit", or CMPU. It allows for the fruit pulp to be collected and pressed directly on site, on the local farms. The farmers can follow the extraction process in the press to be sure that the beans are not damaged and that they get back the very beans they have grown. The pulp is then processed into juice and juice concentrates in the nearby factory. There are two crucial aspects to this process: Firstly, the pulp has to be processed immediately post-harvest, as it starts to ferment quickly in the hot and humid climate. Secondly, the process used to separate the pulp from the beans must be particularly gentle. It has to guarantee that around 30 per cent of the pulp remains on the beans, as this is crucial for the cocoa beans' fermentation and determines their ultimate quality.

Koa's fruit juice is used either in its "pure" form or concentrated. For example, a Dutch start-up called "Kumasi Drinks" has brought various tropical fruit juice drinks based on "Koa pure" onto the market. Bulk purchasers from the chocolate industry and confectioners, also in Switzerland (Lindt, Sprüngli, Felchlin), France (Valrhona) and Luxembourg (Oberweis Confiserie) use the juice, processed into powder or syrup, for "refined" sweetening of their chocolates and cakes, small tarts, desserts, etc. The fine cocoa aroma of the Koa products appeals to chocolate manufacturers, and they can advertise that their chocolates have been produced "vegan" and sustainably.

How it all started

Originally, Anian Schreiber and Benjamin Kuschnik, who for several years had worked for the Chinese solar energy company Yingli in Africa, wanted to set up their own enterprise selling solar home systems in West African countries. They saw cocoa farmers in Ghana as potential clients, but soon realised that these smallholder farmers, who usually lived in the tropical rainforest, often without road access, did not have the means to buy such systems. It was Anian Schreiber who during his visits to the villages observed how the cocoa fruit was harvested and how the beans, which are surrounded by a gelatinous pulp, were detached from the husks and placed onto a mat to drain. The husks were thrown onto a heap to rot at a distance from the cocoa trees. Schreiber also saw some of the pulp dripping into the soil. He realised that this juice from the pulp was extremely tasty. So he considered that it might be a good idea to put this waste product from the cocoa bean harvest to good use and at the same time create an additional income for the cocoa farmers.

Decent prices and training for farmers

As of August 2023, Koa worked with some 5,000 smallholder farmers (2,200 in Akrofuom and roughly 2,800 in Achiase). The Akrofuom plant produces around 300 tonnes of cocoa fruit juice annually. Upon selling the pulp, farmers immediately receive 16 Ghanaian Cedi (GHS) per bucket of pulp via mobile banking, which amounts to 3,520 GHS per tonne (12 Cedi equals 1 Euro). This means that farmers have extra money at hand immediately post-harvest and do not have to wait for two to three months until they receive their payments for the cocoa beans via the Cocoa Board. For 2023, this translates into an additional income of 307 USD per tonne of pulp for the farmers. The partner farmers receive additional training in the management of cocoa trees, in pollination techniques to improve tree productivity and in soil improvement with organic fertilisers, for which the cocoa husks can be utilised among other materials.

An additional goal the company aims to achieve is to get to a CO_2-free cocoa economy. The start-up is currently working on the development of a process with which the cocoa fruit husks can be converted into biochar in a closed pyrolysis process. So far these have been rotting into the ground unused, releasing CO_2 and also acting as hosts for fungal and other crop diseases. The smallholder farmers of West Africa are being challenged by decreasing soil fertility and the risk of longer drought periods. The application of biochar could increase soil fertility and enhance the cocoa farmers' capacity to adapt to climate change. In January 2023, the company launched a pilot project to this end. The aim was to determine the availability of cocoa pod husks and their conversion factor into biochar. Encouraged by the results, Koa is now preparing the launch of a bigger pilot project in order to determine the feasibility of the business model over the next two years. The pilot project is supported by a grant from the Swiss government (SECO) under the Swiss Platform for Sustainable Cocoa.

Both the Community Mobile Processing Unit and the two processing plants in Akrofuom and Achiase are powered by solar energy. The vehicles used to transport the buckets of pulp from the farms to the factory and back to the farms have so far run on conventional fuel. Since February 2023, initial trials have been underway to test a solar-powered tricycle which is being developed by a small start-up in Germany called AMC – African Motor Company. These tricycles are made of robust parts and can easily be assembled in different locations, including rural areas of Africa. The vehicles can transport a load of up to one tonne up to 100 kilometres, even in rough terrain. Koa aims to replace its Chinese tricycles with these solar-powered vehicles. To this end, a workshop is currently being built on the factory premises in Achiase. The first locally built small e-transporter is to be assembled there by the end of 2023.

The future of cocoa farming – a win-win-win story?

"Improving income for cocoa farmers, boosting economic growth, creating more jobs, aiming for less or even zero food waste, making use of solar energy" – this is the company's vision. With the opening of the processing plant in Achiase, roughly a four-hour drive from the capital Accra, Koa is a big step closer to realising this vision. In the near future, the start-up aims to increase the production of cocoa fruit juice tenfold, i.e. from 300 tonnes so far in Arkofuom to 3,000 tonnes per year in Achiase and Akrofuom. It is envisaged that in the Achiase region, 10,000 cocoa farmers will become involved in the project. The training measures are to be passed on in a snowball system from Koa staff to the partner farmers, who in turn will be enabled to train the latter in their communities.

Agricultural ecologist Abubakar heads the extension programmes in Achiase.

Photo: Angelika Wilcke

The mobile pressing unit is powered with solar energy.

Photo: KOA

What began with a compelling idea six years ago has developed into a sustainable development concept benefiting all: the cocoa farmers and their families, whose living conditions are improved by the additional income, the environment through an improved carbon footprint and the sustainable cultivation of cocoa trees, Koa's investors, and last but not least the chocolate industry, which has committed to making its own contribution to the Sustainable Development Goals. And then of course, at the very end of the supply chain, there are the end consumers who can enjoy sustainably produced confectionery.

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From innovation to upscaling – circular economy in the rural-urban nexus

Recycling organic waste into soil amendments and animal feed through a transdisciplinary approach – this is what the RUNRES project, launched in four sub-Saharan African countries four years ago, seeks to achieve. Now the promising results of the first phase are to be upscaled.

By Leonhard Späth, Sharon Migeri, Johan Six, and the RUNRES Team

Examples of the RUNRES innovation technologies deployed in phase 1: co- and composting used for coffee plantlets (top left), cassava peels transformed into animal feed supplement (top right), black soldier flies' larvae (bottom left) and mechanised windrow composting (bottom right).

Photos: Leonhard Späth

The RUNRES project – in full, The Rural-Urban Nexus: Establishing a Nutrient Loop to Improve City Region Food System Resilience – aims to set a key step in the transformation towards a circular and more sustainable agriculture and waste management in four city regions of sub-Saharan African countries: DR Congo, Ethiopia, Rwanda and South Africa. It is funded by the Swiss Agency for Development and Cooperation (SDC) and entails two main phases: a piloting phase (2019–23) and a scaling-up phase (2023–27). The aim of the first phase was to pilot a set of innovations and evaluate their ability to contribute to a circular economy by linking organic waste management to agriculture. For this, we took a transdisciplinary research approach, where we co-produced the different innovations with different actors: waste collectors, farmers' cooperatives, collection and treatment companies, and regulators. This approach made it possible to co-develop innovations between science and practice that are tailored for the local context.

The innovations co-developed in phase 1 can be classified in three types: recycling organic and food waste; recycling human waste, faeces and urine; and supporting small-scale processing in relation to the flows of recycled organic waste. For each of these innovations, we ensured that they were technically feasible, that regulatory standards were met and that the output would have a meaningful impact in terms of circular economy. In addition, we evaluated how the different actors and their respective sectors integrated along with the project.

Circulating organic waste back to agriculture

By circulating organic waste back to agriculture, the innovations contribute to improved environmental and human health, one of our main objectives. For example, organic waste collected from urban centres of the city regions, transported and processed into compost, have the capacity to provide critically needed organic soil inputs for farmers in rural areas. These innovations simultaneously alleviate environmental and human health challenges in these urban centres, while also improving soil health and fertility in the adjacent agricultural zones.

In RUNRES, we used an array of technologies that we co-developed with different local actors to make them viable to the realities on the ground. The technologies that proved to be viable during our piloting phase are (see examples on the left):

- composting and co-composting of organic and human waste through thermophilic compost and vermi-compost production (DR Congo, Ethiopia, South Africa and Rwanda),
- rearing black soldier flies' larvae with organic waste to produce animal feed (Rwanda),
- treating cassava peels through fermentation (to remove aflatoxins and cyanides), drying, and grinding for animal feed supplement (Rwanda),
- deactivating pathogens in urine through long-term storage for urine-derived fertiliser (Rwanda and DR Congo).

In addition, we supported small-scale food production, for instance through producing banana flour as a substitute for cereal-based flour, also adapted as baby-food (Ethiopia). Piloting these innovations enabled us to see what bottlenecks exist to their application at a larger scale, given the local context of the four participating countries.

Ensuring quality standards

The use of organic and human waste by farmers poses a number of risks due to possible pathogen and pollutant accumulation in the products. Therefore, we set up a quality

assurance programme aiming to measure the following parameters to guarantee the quality of the products: the agronomic parameters, for instance nitrogen, phosphorus, potassium and carbon, the level of pathogens, for example *Escherichia coli* or Helminths' eggs, and the amount of heavy metals, for instance lead or cadmium. Overall, it has become apparent that soil inputs produced through the project have agronomic parameters similar to compost which can be found on the market. We could also show that the processes set in place deactivated harmful pathogens. The remaining challenge is the level of some heavy metals, which exceeded the norms in some places, although these cases were rather exceptional.

Settings for upscaling

The innovations piloted during the first project phase were, inter alia, selected according to their potential viability for scaling. The different innovations will have three different settings to allow an upscaling in capacity and space:

Upscaling: this setting will be the next step for existing consortia which we piloted in Phase 1, and which are already working on RUNRES innovations. In this setting, the existing innovations will continue to grow, aiming to reach a larger output with a strongly decreased intensity of financial contribution through the project.

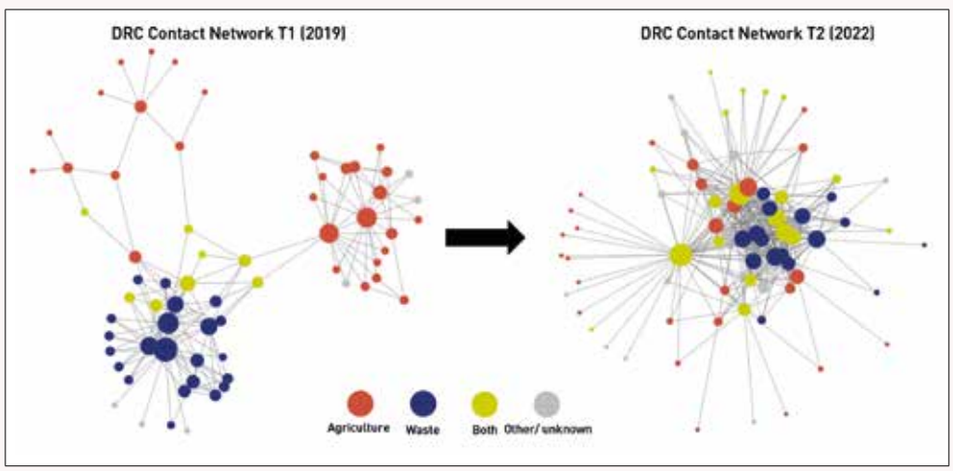
Replicating: In this setting, most of the innovations will be replicated through other transdisciplinary consortia, i.e. implemented in other places by other actors. The development of these innovations is to be directly supported through technical backup and co-financing by the RUNRES core team. However, the project's financial contribution for this setting will be significantly lower per unit of output compared to Phase 1, since the expertise has already been developed through the piloting.

Supporting: This last setting will take place in the form of indirect support to implement RUNRES innovations by other actors who have their own financial means for implementation. The actors we target are already active in organic waste recovery, but may be in a different area of the countries we focus on. The project will not directly financially support these innovations but will provide indirect support by making available its acquired knowledge in the successful implementation of the innovations.

The different innovation settings of the second phase will be deployed timely over four years. While the initial focus is to be on upscaling the innovations from Phase 1 that have been evaluated as suitable for upscaling, we aim in parallel at replicating these innovations in different places with new actors. This will take place through public-private partnerships and through the co-development of business plans with the new actors, with the aim of leveraging financial resources from existing business development institutions. While some innovations are to be upscaled through the private sector, others will require committed support from the public sector, for instance for organic-waste sorting and collection at a household level. Finally, later in time, we aim at supporting any actors interested in recovering organic waste through the quality assurance capacity developed along with the project. In this way, we will be able to first scale up and then scale out to make a substantial contribution to sustainability through a large deployment of circular economy solutions.

Creating capacity by fostering social networks

A transdisciplinary approach often involves collaboration among researchers from different disciplines, as well as practitioners, like farmers, waste collectors and waste transformers. To observe the evolution of the collaboration between different actors, we used Social Network Analysis (SNA), which is based on the concept that social relationships are not isolated entities but are part of a larger network of connections and interactions. An example of how collaborations evolved over time in the RUNRES network of DRC from 2019 to 2022 is shown in the Figure. The nodes represent individuals who are to some degree involved in the project or its topics. The networks are contact networks; hence, if two nodes are connected with an edge, they share information related to RUNRES topics. The colour of the nodes indicates whether the respective individual is part of the agriculture sector (red), the waste sector (blue) or both sectors (grey).



The size of the nodes represents the degree of centrality: a bigger node means that this individual has more connections in the network. For the DRC network, we observe substantial changes between the periods 2019 (T1) and 2002 (T2). While for T1 the agriculture and the waste sectors only have some connections, the two sectors are now integrated. The new linkages show exchange of knowledge and dialogue, and therefore allow for learning – a prerequisite for transformation.

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From waste to wealth – biomass solutions (not only) for India's food loss challenge

Many innovations have been developed in recent years in the field of biomass conversion technologies that enable food waste and agricultural surpluses to be converted into various valuable products. This article presents innovative solutions from India that could help address the country's food loss and waste problem and at the same time help protect the environment and create energy security.

By Vandit Vijay and Santosh Saraswat

India has been working hard to find solutions to the problem of food loss and waste and to reduce its extent of post-harvest losses, which amounted to a substantial 926.51 billion rupees (USD 15.19 billion) in 2014. In its efforts to make its food systems more sustainable while covering the rapidly growing energy demand, the country is increasingly opting for using biomass. Research and innovations in the respective technologies have opened doors to convert food waste and agricultural surplus into different valuable products. In the following, we highlight some of the prominent technologies that can harness the power of biomass, offering a sustainable path towards reducing food waste, bolstering food and energy security, and nurturing a circular economy.

Promising approaches

Bioenergy generation for enhancement of food production. Crop productivity in India remains low due to significant reliance on rain-fed agriculture and manual cropping practices, unavailability of advanced irrigation techniques and dependence on expensive fossil fuels such as diesel, coal-based power for transport and power applications. The bioenergy generated in the form of solid, liquid and gaseous biofuels can be used to locally power the critical on-farm energy applications such as irrigation, farm mechanisation, biomass supply chains, fuel for tractors and farm machinery to boost agricultural productivity, and thus overall food production. India has about 228 million tons of annual surplus biomass availability with a biomass power potential of 28 gigawatts (GW). With significant progress thanks to support under several schemes from the Government, the country has already achieved an installed biomass-power capacity of 10.8 GW and more than 300 tons per day of bio compressed natural gas (BioCNG) production.

Reducing food loss and waste by powering the grain storage, cold storage, and preservation infrastructure. A significant portion of food produce perishes because of inadequate post-harvest care. The cold storage options are usually few and far between, leading to horticultural crop wastage and economic losses. With the advances in bioenergy research, decentralised biomass-based cold storage and dryer options are now commercially available which could be owned and operated by local farmers or service providers in rural areas. In the last two to three years, farmers in a few locations in India have started to utilise these biomass-based cold storage solutions. So far, however, not enough farmers have been using these technologies. Further dissemination would be important, for it would help to reduce wastage and loss which in turn would increase farmers' profitability and overall rural economy while adhering to sustainability principles, as they could store and sell their products year-round.

Organic approaches for boosting sustainable food production and mitigating climate change. In the quest to increase food production, the use of chemical fertilisers on farms has increased significantly in the last few decades. This adversely affects soil health as well as human and livestock health in the long run, along with other harmful effects on the environment because of the fertilisers' production and transportation processes being highly energy-intensive and emission-emitting. Here, nutrient-rich bio-fertiliser slurry produced along with biogas during anaerobic digestion can be an important organic substituent to the chemical fertilisers as it can lead to enhancement in crop productivity for farmers while restoring soil health and also saving the huge import costs (more than approximately five billion USD a year) of chemical fertilisers for the nation. Biochar, which is gained from plant material via pyrolysis, is a further interesting option to replace chemical fertilisers, for it can be used to enhance both soil health, harvest yields and wastewater treatment. And finally composting is another well-established method that turns organic waste into nutrient-rich compost, improving soil quality and crop yields. Recognising the importance of biofertilisers from biogas plants, the Government of India launched the Market Development Assistance scheme in September 2023, with a budget of 14.518 billion rupees (approximately 181 million USD) to promote organic fertilisers, and thus sustainable and organic agricultural practices, throughout the country.

Moreover, biomass from food waste finds several other applications in agro-industrial contexts, producing bioplastics, bio-based chemicals, nutritious and sustainable animal feed source, and animal bedding materials. These innovative biomass solutions also tackle urgent problems such as the loss of soil nutrients and the burning of crop residues, which contribute to air pollution. It is important to highlight that burning one ton of paddy straw, for instance, releases 60 kilograms of carbon monoxide (CO), 1,460 kg of carbon dioxide (CO_2), 199 kg of ash, 3 kg of particulate matter and 2 kg of sulphur dioxide (SO_2), causing significant global warming while also killing important microorganisms in the soil. It also depletes the soil of essential nutrients i.e., nitrogen (5.5 kg), phosphorous (2.3 kg), potassium (25 kg) and sulphur (1.2 kg), as well as other micro-nutrients besides organic carbon.

Numerous options for application

Thus, by reducing the need for burning crop residues and enriching the soil, biomass solutions can provide many useful eco-friendly alternatives. Several important incentives for farmers from the Government of India indicate the support and seriousness which is being emphasised for encouraging the adoption of bioenergy and organic fertiliser options. Government schemes like the National Bioenergy Programme (NBP) and others offer financial assistance and support for bioenergy, bio-fertilisers and sustainable farming practices. One such example is the Lambra Kangri Multipur-

Biogas powering prosperity – the Lambra Kangri village story

Lambra Kangri, a village in Punjab, India, stands as an example of how biogas can be used to achieve rural innovation and sustainable development. At the centre of this transformation is the Lambra Kangri Multipurpose Cooperative Service Society Ltd., which got partial financial support from India's Ministry of New and Renewable Energy (MNRE).

In Lambra, the society collects approximately 2,500 kg of cattle dung from the rural residents daily and compensates the farmers at a rate of 8 rupees per 100 kg (approximately 0.1 USD per 100 kg) for this waste. The cattle dung is used to produce biogas and is distributed to more than 40 households every day for cooking applications with the help of pipelines in the village, for daily fixed slots between 5:00 a.m. and 9:00 p.m. The economic benefits are striking, with an average monthly expenditure of only 200 to 300 rupees (approximately 3 USD), significantly lower than the cost of liquefied petroleum gas (LPG). Biogas has emerged as a popular choice in the village for both economic relief and environmental sustainability. In addition, the biofertiliser is used on the village's fields, which contributes to holistically enhancing the soil health and food production, and brings in an income of approximately 800 rupees (roughly 10 USD) for each tanker load.

Lambra exemplifies how a simple idea, fuelled by collective determination and supported by governmental initiatives, can not only address energy needs but also create economic opportunities, reduce environmental impact and foster sustainable rural development..

The Lambra Kangri Society Biogas Plant.

A cow dung collection trolley.

Biogas being used for cooking.

A tractor trolley for spraying bio-fertiliser.

Photos: Jaswinder Singh/ Lambra Kangri Cooperative Society

pose Cooperative Service Society which provides an entire village with biogas generated from local cow dung (see Box). It is worth mentioning here that while rural areas have very limited kitchen and food waste, as it is a major feed for livestock, in urban areas, similar biogas systems can be installed at the household level to locally manage kitchen waste, in residential societies, offices, hotels and restaurant complexes at community level, so that large amounts of food waste don't end up in landfills and are locally managed sustainably. The biofertiliser produced thereby can also be used for gardening applications. In recent years, large BioCNG plants with 300 and 550 tons of municipal solid waste treatment capacity per day have also been installed in cities like Pune and Indore respectively, and the BioCNG is used to fuel the public transport buses.

To summarise, biomass is a promising way for India to combat food losses and waste. With the technologies presented, several challenges can be tackled simultaneously. They will prevent food waste, promote sustainable agriculture, improve soil fertility, increase local productivity and reduce the environmental footprint of agriculture.

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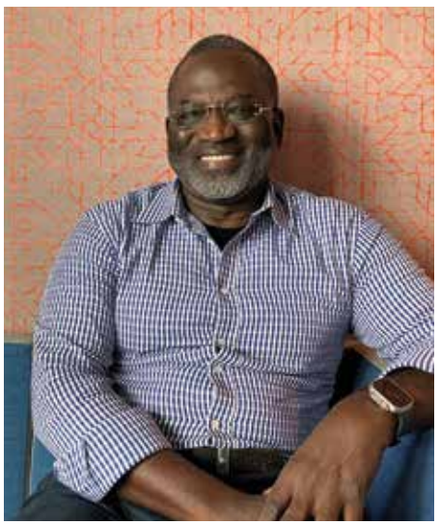


Ousmane Badiane is the Executive Chairperson and Acting Managing Director of the Rwanda-based research organisation AKADEMIYA2063. He is a Distinguished Fellow of the African Association of Agricultural Economists, recipient of the Africa Food Prize in 2015 and member of the World Academy of Sciences. Ousmane has over 30 years of experience in international development.
Photo: Claudia Jordan

“We have to align the transformation agenda with African realities”

Per capita growth had slowed down in Africa years before the Covid crisis and the war in Ukraine. Also, the number of people going hungry has been on the rise again for some years. These and other factors have to be borne in mind when discussing food systems transformation on the continent, argues Ousmane Badiane of AKADEMIYA2063.

Dr Badiane, how can a transformation of agricultural and food systems succeed in Africa?

I guess it will succeed if the agenda is broad enough to address the most burning questions around food system development. Firstly, comprehensiveness is important: that all the different components are taken into consideration and dealt with: health, nutrition, equity, inclusions as well as adapting to and mitigating climate change, production, processing and technologies. Science, innovation and the environment require a comprehensive approach. Secondly, such an approach has to be rooted in the African agenda. The question should be: Where do we find ourselves today in terms of food systems and approaches and development in Africa? Where are we strong, where are we weak, and where are the gaps that need to be filled? That’s where our partners can find the biggest opportunity to make a contribution. Thirdly, we need to align the agenda with African realities, constraints and opportunities. It’s not going to be one size fits all, although we are all dealing with the same food systems.

What relevant transformational activities, initiatives and processes are already taking place on the African continent?

We have the Malabo Agenda. When the agenda was developed around ten years ago, the emphasis of food systems wasn’t there. You would find that food security and nutrition were really strong then, but the complexity of an approach to nutrition and dietary health was missing. Similarly, there is a strong focus on gender and youth which you could expand to the equity and inclusion part of the food system agenda. As the African Union now gets ready for the Post-Malabo Agenda, it’s time to engage and see where there are opportunities for cooperation and technical assistance in forging a much stronger food system-oriented agricultural agenda.

What role do you see for an institution like AKADEMIYA2063 in contributing to the transformation agenda?

If we want to do things better, more efficiently, at lower cost within a shorter time and with better outcomes in Africa, we need to understand the challenges better in all their nuances. That requires data and analytics to provide the information that can guide action. And to do that we need to deploy the existent African expertise. ACADEMIYA2063 has focused on this from its beginning. It’s a 20-year agenda that attempts to improve the data, analytics and evidence base, which will allow Africa to improve the quality of the planning and implementation of policies. We mobilise, strengthen and deploy local expertise but also serve as a bridge to connect with the global science communities. Our role is right in the middle of data and includes innovation. To generate data and foresight capacities, we are investing heavily in trade data and in tracking the Biennial Review (BR) Report of the African Union Commission on the Implementation of the Malabo Declaration, which we are supporting. We are also investing a lot in remote sensing and artificial intelligence, in order to improve the data and analytics environment.

Where do you see the role and potential of the African Continental Free Trade Area in driving the transformation of agricultural and food systems?

People often talk about the huge import bill in Africa, and they tend to see this as a problem, even as an issue with a negative connotation. What we are missing here is that the import bill is not synonymous with stagnating agriculture. Import is surging, while agriculture is growing faster than it ever has in the continent’s history. What is driving the rapid increase in imports is two decades of strong economic growth coupled with rising populations. The two combined are fuelling demand

for food at a pace that is higher than the rate at which agriculture, as a biological process, can sustainably grow.

Since we had managed to import, fewer people went to bed hungry. Africa was feeding itself through production and import. It's going to be like that as long as we continue growing for the next couple of decades. If we can produce and compete in the domestic markets and grab a share of that demand, we're creating a market for our farmers. The growing demand is for food that is ready to cook and ready to eat in most urban centres. That means it has to go to the processing sector. Competitive processing sectors require access to skills, technologies and investment to enable micro-enterprises to mature and become medium to large enterprises ready to compete in these markets.

2025 marks the target year for the African Union's Malabo Declaration on Accelerated Agricultural Growth and Transformation. To what extent is the continent on track to achieve the ambitious goals of the Declaration?

The Malabo agenda and especially the Biennial Review which is tracking its achievement represent a set of ambitions. They don't necessarily measure progress taking place on the ground. In other words, failing to achieve the Biennial Review outcome doesn't mean that there is no progress on the ground. But neither does progress on the ground mean that we're achieving the Malabo Declaration. We can distinguish between the two. The results framework for the Biennial Review wasn't put together in an open and rigorous process to get the best indicators and the best matrix suited to support the agenda. That has actually resulted in ever fewer countries achieving the goals, because it has been practically impossible to achieve them. Such realism lacked when the results framework was being set up. Nevertheless, a number of countries are making progress, although not enough to achieve the goals set.

What worries me is that everybody is seeing Covid and Ukraine as the source of the deceleration of progress in Africa. But already three years before Covid, there had been something going wrong after almost 20 years of solid growth. Expenditures were flat or didn't increase as they should have. The pace of per capita GDP growth has slowed, and the number of hungry people and the level of public debt have started rising after a decade

“What worries me is that everybody is seeing Covid and Ukraine as the source of deceleration of progress in Africa. But already three years before Covid, there had been something going wrong after almost 20 years of solid growth.

long decline. That debate has to take place now so that we can again create the conditions that assured us the longest period of economic recovery in Africa's history.

How is the continent currently preparing for the post-Malabo decade?

The ambition is a post-Malabo agenda that is much more reflective of the need for food system transformation. There are lot of issues that need to be clarified around health and healthy diets, nutrition, climate mitigation and adaptation, inclusivity and equity in addition to what we already have in the current Malabo agenda. It's also going to be important to coordinate this process. It cannot be that each and every organisation is throwing something into the pot. We should seek the right ideas and expertise for the products and services intended for the African Union.

Who could take up coordination in your opinion?

In the early years of the Comprehensive Africa Agriculture Development Programme, there was a good partnership between the African side and the development partners' side. The CAADP donor platform worked well, and the CAADP Partnership Platform was a very good vehicle in coordinating and was better managed than it has been in later years. Donors and development partners were well organised in coordinating among themselves. The African Union Commission brought in the African side, and the non-state actors were well organised too. Most of the work happened at country level. Development partners will have to find ways of aligning locally, meaning to support the same goals using the same indicators to track progress at local level. They also have to coordinate among each other, while using the same targets and goals. If we can achieve that, we will have the synergies to give us better outcomes going forward.

In its efforts to support the transformation of agri-food systems on the African continent – which actors and processes should German development cooperation pay more attention to?

There are several levels where German development cooperation can link up with the CAADP process and connect with actors that are driving the agenda. At the continental level, it is with the African Union Commission, in particular the commission in charge of agricultural development in blue economy. There are also opportunities to work with the regional economic communities as well as, and more importantly, with stakeholders at the country level, not just in government, but also with non-state actors. This will require that German development cooperation aligns with the goals and priorities of the agenda, at continental, regional and country levels. It will also need to embrace the same review and evaluation processes and find space as much as possible to participate in the mutual accountability processes around the agenda.

Are farmers' organisations already included enough in these processes?

It's not sufficient to just sit around the table. You must have the capacity and the opportunity to contribute. In terms of principles, we need farmers' organisations to find a voice when we are planning and executing programmes and policies. And it's not a once-off, it's a continuous process. It has to be refined and improved as we go. So, no matter how much influence they have, farmers' organisations need continued support.

Interview: Claudia Jordan

Biodiversity-smart agriculture – the role of labour requirements

Governments across the Global South invest heavily in agricultural development to combat poverty and hunger. But while crucial for improving the livelihoods of millions, agricultural development can undermine biodiversity. Our authors explain how these issues relate to one another and demonstrate why reconciling agricultural production and biodiversity conservation only works if it also takes issues of farm labour into consideration.

By Thomas Daum, Frédéric Baudron, Regina Birner, Matin Qaim and Ingo Grass

Biodiversity is declining rapidly in both the Global North and South, a trend that an article in *Science Advances* from 2015 referred to as the sixth mass extinction. The Living Planet Index of the World Wide Fund for Nature (WWF) and the Zoological Society of London shows an average decline in the population sizes of more than 5,000 key vertebrate species by 69 per cent since 1970. A recent review published in *Biological Conservation* confirms this, showing that 40 per cent of insect species are facing a decline, with one-third of them on the brink of extinction. This rapid loss of biodiversity could have significant consequences for food security, warn the authors of the report on the *State of the World's Biodiversity for Food and Agriculture* issued by the the UN Food and Agriculture Organization (FAO). This is because biodiversity is key for ecosystem services like pollination, soil formation, nutrient cycling, water maintenance, and pest and disease control – all of which are important for food production. The authors also warn that biodiversity loss can weaken farmers' ability to cope with climate shocks and limit the access of rural communities to wild food sources such as animals, honey, vegetables, fruits, tubers and nuts.

How agriculture impacts biodiversity

Agriculture impacts biodiversity through two main avenues: the expansion of agricultural land and the intensification of farming practices. Farmland expansion can lead to the destruction and fragmentation of habitats, threatening the survival of species that rely on large habitats. Avoiding farmland expansion is therefore key to biodiversity conservation. Alas, pristine nature is lost rapidly across the world. In Africa, agricultural growth has been significant in the last two decades, but 75 per cent of it has stemmed from converting forests and savannahs into farmland, as shown in a recent study by Thomas Jayne and Pedro Sánchez in *Science*.

Intensification makes it possible to produce more food on existing farmland, thus preserving land for natural habitats, as long as rebound effects can be curtailed. India is a success story. FAO data shows that it tripled cereal production in the last decades as part of the "Green Revolution" – without significantly expanding farmland. In Africa, the potential for intensification is still large – studies show that farmers achieve only 25 per cent of what would be possible under their agro-ecological conditions. However, intensification is a double-edged sword. In particular, when badly managed, it can lead to environmental harm due to increased pesticide use and simplification of landscapes to facilitate mechanised farming, among others. This is why the Indian agronomist Mankombu Swaminathan, one of the architects of the "Green Revolution", now calls for an "Evergreen Revolution".

The heavy toil of farming has been a driving force behind humankind's relentless strive to develop smart technologies.

Photo: Thomas Daum

Researchers, policy-makers and farmers are increasingly recognising the importance of finding a balance between promoting agriculture and protecting biodiversity. However, when discussing ways to make agriculture more biodiversity-friendly, the focus tends to be on conservation goals and, to some extent, on minimising the trade-offs with land productivity. This is important because low yields are bad for farmers and can lead to more land being used for farming. However, one aspect is often neglected in discussions about biodiversity-friendly agriculture: agricultural labour. This oversight is very problematic, considering the heavy toil of farm work for the world's 550 million family farms. Moreover, neglecting farm labour needs could ultimately hinder efforts to conserve biodiversity.

Agricultural labour – the neglected factor

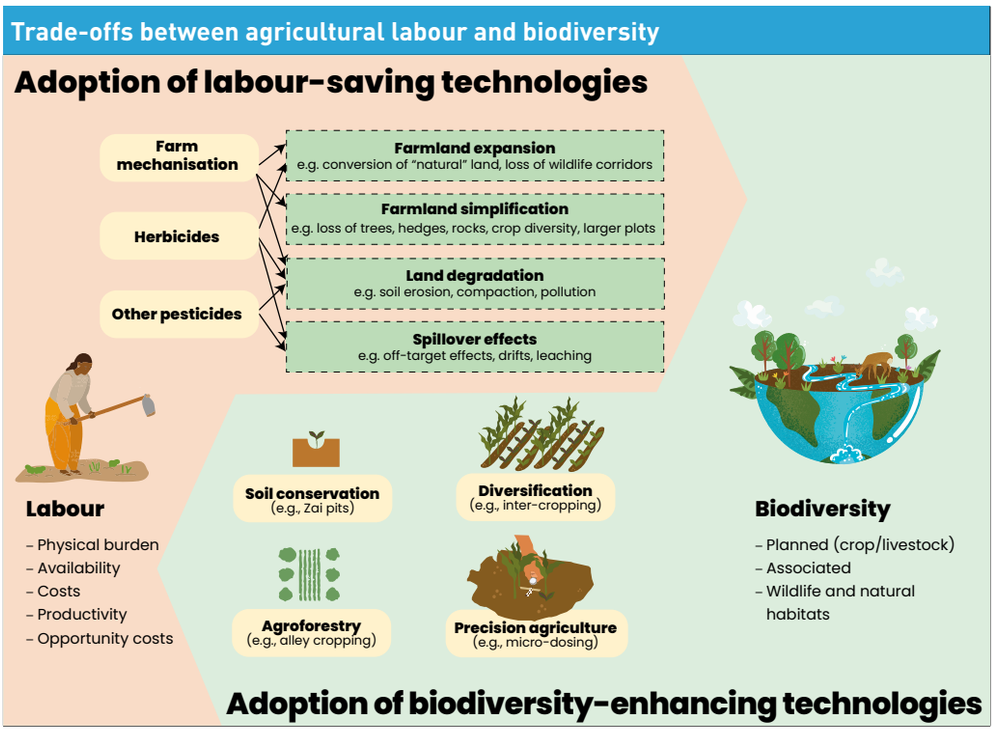
Addressing agricultural labour issues is crucial for achieving the Sustainable Development Goals of the United Nations. Across the world, around 10 per cent, and in Africa roughly 35 per cent, of the population live in extreme poverty, mostly in rural farming communities. This is largely because of low labour productivity, which is a key determinant of farmers' income. Cultivating one hectare of land with manual labour often takes smallholder farmers 800-1,500 hours, depending on the crop. Most of this heavy work has to be done under the harsh (sub)-tropical sun. Climate change will make things worse. Agricultural labour affects men, women and children. The International Labour Organization (ILO) estimates that 70 per cent of child labour occurs in agriculture, affecting the well-being and livelihood opportunities of 112 million children. Moreover, while there is a persistent

belief that labour is abundant in the Global South, many regions actually face acute agricultural labour shortages due to ageing, outmigration and structural transformation.

The heavy toil of farming has been a driving force behind humankind's relentless strive to develop smart technologies. Ox-drawn ards were already used 6,000 years ago in Mesopotamia, while water-powered mills emerged 3,000 years ago in China. In present days, modern technologies such as tractors and herbicides are "gifts from heaven" for many farmers, allowing them to almost decouple agricultural production from agricultural labour. In the USA, farmers obtain 1,470 kg of maize per hour worked, in Kenya, they produce only 1 kg – as shown by Douglas Gollin from the UK's Oxford University.

The desire to reduce the heavy toil of farming also explains why herbicides are spreading rapidly in the Global South, a trend that Steven Haggblade from Michigan State University, in the USA, calls a "herbicide revolution". In a study in Mali, he shows that herbicides reduce weeding workloads – one of the most time-consuming and arduous tasks of farming – by up to 90 per cent. In their fieldwork in Burkina Faso, William Moseley from Macalester College and Eliza Pessereau from the University of Wisconsin-Madison, both in the USA, found that herbicides are often referred to as "mother's little helpers". In a recent paper, Ghislain Aihounton and Luc Christiaensen from the World Bank show that "modern" production packages including tractors and herbicides allow farmers in Côte d'Ivoire to reduce labour use from 1,568 to 432 hours per hectare.

But while appealing to farmers, such technologies can negatively affect biodiversity through farmland expansion, simplification, land degradation, and spillover effects (also see Figure). In Zambia, for instance, a study by Ferdinand Adu-Baffour and co-authors from Germany's University of Hohenheim found that tractors enable farmers to cultivate more land, which increases their incomes but harms the African savannah. Similarly, a comparative study conducted as part of the "Program of Accompanying Research for Agricultural Innovation" in Benin, Kenya, Nigeria and Mali suggests that farmers often remove trees and other landscape elements and enlarge and reshape plots to facilitate the use of tractors. These changes ultimately result in a loss of diversity within farms and the overall landscape. Similar trends have long been observed in many parts of the Global North. The use of agrochemicals can also be detrimental. Pesticides, especially when unregulated or poorly managed, as is often the case, can harm insect populations, soil organisms, groundwater, lakes and rivers.



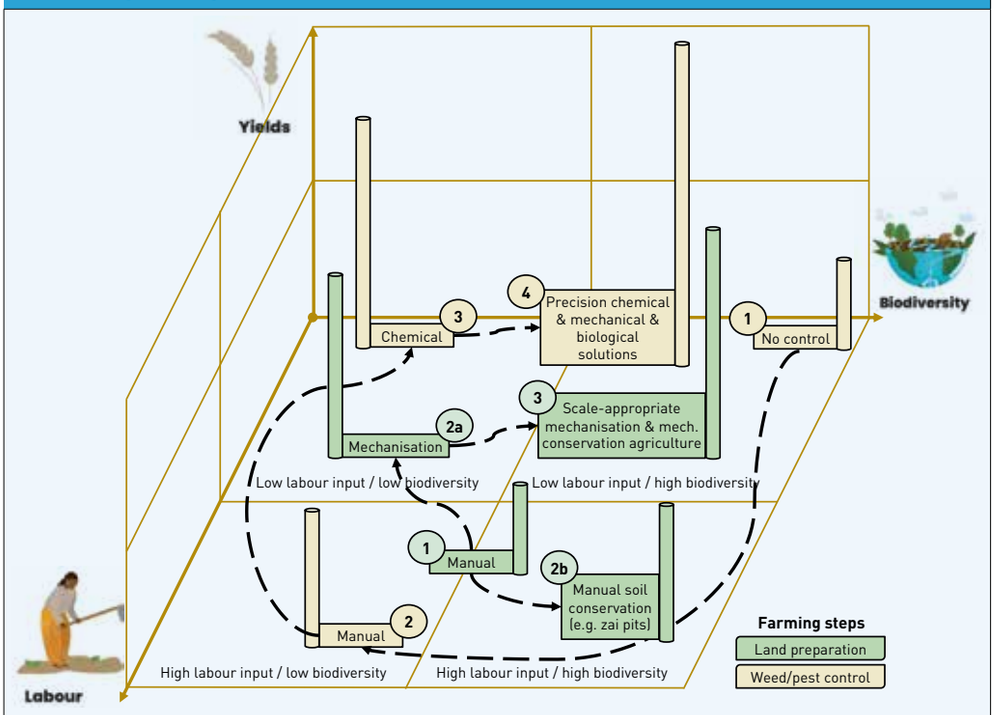
The downside of agroecological practices

At the same time, as shown in our framework (see Figure above), approaches aimed at promoting biodiversity in agriculture often face resistance from farmers. Despite the potential benefits for local biodiversity, many agroecological practices are not widely adopted because of their high labour requirements. A recent meta-analysis by Sigrun Dahlin from the Swedish University of Agricultural Sciences and Leonard Rusinamhodzi from the International Maize and Wheat Improvement Center (Cimmyt) provides an overview of the labour requirements of various such technologies. For example, they find that planting basins increase the agricultural labour for land preparation by 702 per cent. In earlier work in Mozambique, Rusinamhodzi and co-authors found that intercropping increased yields and reduced risks – but also increased the labour demand for weeding: by 36 per cent. A study by Til Feike, now with the Julius Kühn-Institute (JKI), suggests that intercropping is reportedly experiencing a "slow death" in China due to its high labour requirements and increasing labour shortages. Studies also show that the increased labour burden of agroecological practices is often shouldered by women.

Considering such labour dynamics, it is not surprising that farmers often adopt technologies and practices that ultimately result in a situation of low labour input and low biodiversity. The Figure on page 38 illustrates the typical trajectory of farms. This framework utilises a three-dimensional matrix with four quadrants, where only the quadrant representing low labour requirements and high biodiversity is truly sustainable. In addition to labour and biodiversity, yields also play a crucial role in our optimisation matrix, as low yields are bad for farmers and can raise overall farmland requirements, impacting wild biodiversity.

Many farming systems across the world have followed such a trajectory, initially in the Global North and now increasingly in the Global South. For example, plantation agriculture in Indonesia has transitioned towards oil palm monocultures that rely heavily on mechanical and chemical methods for nutrient and weed, and pest management. Such farming systems are characterised by low labour intensity and high yields, but they have adverse effects on biodiversity. In another case study from Arsi-Negele (Ethiopia), we find that farming systems have also evolved towards the low labour input, low biodiversity, and high productivity scenario. However, more recently, some farms have moved to the optimal low labour input, high biodiversity, and high productivity scenario by using labour-saving technologies compatible with high biodiversity (e.g. small combine harvesters) and reforestation efforts.

Synergies and trade-offs between labour, biodiversity, and yields and typical evolution pathways – from 1 to 3/4



While the diagram focuses on land preparation and weed/pest control, the technologies employed for other activities like planting, nutrient management, and harvesting also influence the positioning of farms within the matrix. The placement of farming steps within the matrix is only an approximation.

Approaches for the future

The big question is how we can enable agricultural development pathways that reconcile biodiversity, yields and labour. There is a range of technological, agronomic and institutional solutions. At the farm level, such solutions need to reduce the biodiversity trade-offs of labour-saving technologies such as mechanisation and pesticides. One potential approach is to adopt scale-appropriate mechanisation, utilising small two-wheel and four-wheel tractors that can manoeuvre around trees, hedges and other landscape features. Looking ahead, using fleets of small agricultural robots may one day help to alleviate the high labour requirements associated with agroecological farming and allow smaller and more diverse plots, potentially leading to an "ecological utopia", as discussed in a recent article in *Trends in Ecology and Evolution*. When it comes to pesticides, a promising path involves integrating biological approaches, such as crop rotations, with mechanical solutions like precision sprayers, following the idea of integrated pest management. Completely abstaining from pesticides may benefit local biodiversity but lower yields, undermining land sparing, and increase labour demand. A recent review in the *Annual Review of Resource Economics* suggests that organic farming, which refrains from synthetic pesticides, typically yields 19-25 per cent less compared to conventional agriculture.

Next to reducing the biodiversity trade-offs of labour-saving technologies, we must strive to reduce the labour trade-offs connected with biodiversity-friendly farming practices such as production-integrated measures (e.g. patch cropping, intercropping) and set-aside measures (e.g. trees, hedges, flower strips). For example, mechanised strip-cropping could help to harness the benefits but minimise the labour burden associated with inter-cropping.

A recent study published in *Nature* also shows that set-aside measures such as tree islands can improve biodiversity in oil palm plantations in Indonesia – even without compromising yields. But more research is needed on how such measures have to be designed to minimise trade-offs regarding agricultural land and labour productivity.

By paying more attention to yields and labour needs, biodiversity-smart agricultural solutions are more likely to be adopted by farmers. This is especially important in the Global South, where many governments have limited resources to compensate farmers for environmentally friendly farming practices. However, in situations where biodiversity conservation is more costly than beneficial for individual farmers, it may still be necessary to implement innovative certification or payment systems for ecosystem services. To effectively preserve biodiversity, farm-level solutions should be accompanied by landscape-level efforts such as managing land use to protect biodiversity hotspots, diverse habitats and connections between different areas.

Biodiversity-smart agriculture necessitates paradigm shifts in policy-making and research and development. For instance, conservation ecologists must place greater emphasis on economic and social sustainability. Without explicitly considering labour issues, conservation efforts are unlikely to achieve success. And agricultural scientists must consider multiple objectives beyond maximising yields. Many solutions for biodiversity-smart agricultural development already exist, but they must still be scaled. If successful, we can feed the growing global population, enhance the livelihoods of millions and safeguard the world's remaining biodiversity before it is too late.

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References: **www.rural21.com**

Zero soil movement – adopting new techniques in potato production

In many South Asian countries, rice straw burning is a common practice, resulting in bad air quality. In addition, agricultural production is often characterised by the overuse of natural resources as well as gender imbalances, with men frequently controlling the production of main agricultural commodities. An innovative conservation agricultural practice could change all this. Our authors give an account of initial experience with potato zero tilling and mulching in rice-based production systems in the Indian State of Bihar.

By Anushka Rose, Namita Singh, Jan Kreuze and Marcel Gatto

Bihar, the third most populous State in India, is home to over 100 million people, 36 million of whom are poor. Despite these challenges, Bihar is one of the faster-growing Low-Income States. Rice and wheat are the dominant crops, but Bihar is also a significant producer of potatoes. The state grows potatoes on 0.32 million hectares, with an annual production of 5.74 million metric tons. As a "sandwich crop", early maturing potato varieties fit in between the typical rice-wheat rotation cropping systems (also see Box on page 40), thus sustainably intensifying agricultural systems and providing an additional source of nutritious food and income.

A multipurpose project

In 2021, the International Potato Centre (CIP), the global not-for-profit organisation Digital Green (DG) and the Bihar Rural Livelihoods Promotion Society JEEViKA came together to introduce a new agricultural practice in the region: potato production through zero tillage and rice straw mulch (PZTM). Here, potatoes are brought out on the unworked soil and covered with rice straw after the rice has been harvested. The potatoes then mature within a mulch bed of rice straw rather than in the soil. The technique has yielded promising results in countries like China, India and Vietnam.

Photo: Anushka Rose/ Digital Green

In Bihar, the PZTM intervention focuses on increasing the gross margins of farmers who have been cultivating rice and potatoes by efficiently using crop residues and reducing input needs. For farmers without prior potato experience, the introduction of PZTM into a rice-based system is to allow them to cultivate an additional crop to increase food production and profits. Another important objective is to improve soil quality and carbon sequestration by minimising soil operations. Further, the intervention targets to elevate the status of women by reducing manual labour (such as ploughing, weeding and digging out potatoes during harvesting) and improving their decision-making agency. Women make up nearly 60 per cent of employment in the region's agricultural sector, although they enjoy hardly any land ownership or decision-making power. Discriminatory social practices and restricted access to information restrain their participation in agri-food systems. The fact that India ranked 132nd out of 191 countries in the Gender Development Index in 2021 underscores the need for gender focused agricultural innovations. Working with collectives of women farmers wherein the groups are introduced to the technique aims at women gaining knowledge, self-confidence and authority through participation in PZTM training so that they can eventually take on the role of promoters. Finally, the intervention is designed to increase adoption rates of new technologies by using video-mediated extension services.

The first project cycle

The project sites included four districts in Bihar State, Nalanda, Patna, Rothas and Vaishali, which are also the most important potato producing areas. In each district, 30 villages (120 villages in all) were identified to receive training on PZTM. Many farmers in the region cultivate rice and potatoes. For the first year, a total of 461 smallholder farmers were encouraged to adopt PZTM in smaller plots or kitchen gardens, given the ongoing cultivation season and farmers' reliance on the rented farmland for income. Trying PZTM on smaller plots was aimed at reducing risks with new techniques. Further, this approach was to empower women farmers, since the kitchen gardens are seen as their domain. To demonstrate the technique's impact, the farmers were encouraged to cultivate potatoes using conventional techniques (ploughing the land, making furrows and then planting the seed beneath the soil) and PZTM methods on the same plot, allowing for a direct comparison of the process and results.

In order to test the effectiveness of digital extension services (DES) with the aim to increase the adoption of the new technologies, DG supported the creation of six short agronomic videos on the PZTM technique by local farmers. In collaboration with JEEViKa and its network of extension agents, the videos were disseminated to farmers through public viewings utilising women self-help groups in every village. In addition to these digital capacities, the extension workers underwent comprehensive training both on technical skills (like PZTM practice, data collection, dissemination) and soft skills (presentation skills, facilitating group discussions, guiding the farmers and providing handholding support to them through the process of PZTM) along with site visits, all with support from CIP's experts in Bihar.

Findings from the field

As part of the overall study and project, focus group discussions were conducted to get a better understanding of farmers' initial experiences by using PZTM. A total of five discussions were held including 13 farmers (11 female, 2 male) and 8 extension agents (6 female, 2 male) from five villages across Maner in Patna district, Noorsarai and Harnaut in Nalanda, and Muhua in Vaishali. Guided questionnaires were used to facilitate the discussions to gain insights into farmers' journey through the adoption process, challenges faced, lessons learned along the way and the advantages and disadvantages of implementing PZTM. The following results draw from the discussions with the women farmers and extension workers from using PZTM during the November 2022 potato season.

A farmer planting the potato seed.

Photo: Shams Tarique/ Digital Green

After planting, the plot is covered with mulch.

Photo: Shams Tarique/ Digital Green

A farmer inspecting the growth of the sapling.

Photo: Shams Tarique/ Digital Green

Kitchen gardens well suited as demonstration sites. When Sushila Devi, an extension agent from Maner and farmer herself, introduced PZTM in her region, disbelief was the initial response, especially from men who doubted growing potatoes on the surface. Six women farmers adopted PZTM. Over two months, as potato saplings emerged, farmers thronged to witness accelerated growth and better quality of leaves, recognising PZTM as a better practice. Once harvested, the shinier, spotless, larger potatoes with thinner peels tasted pleasantly different than the traditionally cultivated ones of the same seed variety. Using their plots as demonstration sites, Sushila used this opportunity to discuss the techniques with the six farmers. The group reported reduced labour input, with no reliance on men for tilling, furrowing, and harvesting – which was particularly beneficial for women without male members in their household because of work migration. Furthermore, sowing seeds shortly after rice harvest retained soil moisture, resulting in less irrigation and prolonging potato shelf life. All farmers used the ZTM potatoes for self-consumption. Sushila believed that transforming kitchen gardens into local demonstration sites would result in more farmers adopting PZTM in the next season.

The opportunity cost of rice straw. As mentioned above, initially, the respondents could not believe potatoes could grow without soil burial. The seven farmers in Nursarai, Nalanda who tried PZTM were surprised to find that not only did the potatoes grow better but that their plots even retained moisture from the previous rice crop so the need for irrigation was reduced.

Extension agent Sangeeta Kumari explained that the adoption rates were to rise as farmers experienced the technique. The group noted accelerated growth of the saplings with reduced input needs, labour and fertilisers. As the news about the technique spread, farmers inquired about the group members' experience, even in markets. However, the PZTM plots were often attacked by rodents like field rats. In winter, dogs tend to rearrange mulch to create warm spots for themselves. Moreover, the farmers were faced with the dilemma of straw being needed for other purposes, such as cattle feed, additional income from the sale of straw and cooking fuel. Additionally, for scaling up, the farmers estimated that they would need to acquire straw – entailing further costs.

The challenges of upscaling the technique. In Vaishali, Mahua, the opportunity to try PZTM was limited because of the ongoing cultivation season when the PZTM dissemination began in November 2022. Extension

PTZM in Bihar – background information

Cereal systems, and in particular rice-based systems, are the dominant type of cropping system in the Indo-Gangetic Plains. Frequently, the season after rice (November–March) is left fallow. Adding an early-maturing potato variety (75-90 days to maturity) after rice allows farmers to intensify their cropping systems in a sustainable way – by making more efficient use of land – and get an additional nutritious crop for food and income. In the study region in Bihar, the project targeted potato farmers who have rice as their preceding crop in order to encourage them to change from conventional production to conservation potato production. The new technique allows farmers to sow seed shortly after harvesting rice when soil moisture is still relatively high, whereas with the conventional method, farmers first have to wait longer for the soil moisture to drop considerably to allow for ploughing of the fields. In many areas, without alternative uses for rice straw, the crop residues (and stubble left in the field) are burned, which is avoided under PZTM. Crop residue burning (stubble and straw) is a major issue mainly in the Western parts of the Indo-Gangetic Plains (mainly Punjab and Haryana), but is increasingly observed in Bihar and other States as well. It is usually connected with higher levels of commercialisation (and thus use of machinery) and larger areas of land.

As rice is one of the dominant crops in the region, farmers usually plant much less area with potato. About 1 hectare of rice produces rice straw for 0.5 hectare of potato (the ratio is 1:2). So if farmers cultivate 1 hectare of rice, they would use only some land/plots (and frequently different plots) for potato production. Even given the competing uses of rice straw, initial observations suggest that there should be sufficient rice straw for PZTM. Nevertheless, jointly with local research institutes, CIP explores what other alternatives could be used for mulching, such as jute gunny bags, turmeric leaves, water hyacinth, banana leaves and other leaf litter freely available to the farmers.

The project is part of an ongoing randomised controlled trial study designed by CIP and the University of Witwatersrand, South Africa. The intervention in Bihar is funded by the German Federal Ministry for Economic Cooperation and Development (BMZ), commissioned and administered through Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

Emerging potato saplings.

Photo: Shams Tarique/ Digital Green

Harvesting in progress.

Photo: Shams Tarique/ Digital Green

A farmer showing his harvest from PTZM technology.

Photo: Anushka Rose/ Digital Green

agent Sharmila Khushwaha faced challenges in convincing both men and women to come for dissemination screenings. Eventually, she was able to convince four women to adopt PZTM.

The group reported several benefits, including no need for tilling, furrowing or weeding. Irrigation could be done through sprinklers or drip irrigation, with less pesticides. Other farmers closely observed the PZTM plots. Given the positive experience of the four farmers, many more were keen to adopt the technique in their kitchen gardens' next cycle that starts in November 2023.

However, the respondents noted challenges for farmers with fragmented landholdings. Concerns included monitoring threats from field rats, nilgai (the largest antelope in Asia), other wild animals and pre-harvest tuber theft. Uneven terrain could result in the stagnation of water, and additional straw mulch was another challenge. The group stated that while PZTM seemed viable for smaller plots or kitchen gardens, its large-scale implementation had its own set of challenges.

Gender implications. The project aimed to address gender imbalances by empowering women as knowledge holders, practitioners and PZTM advocates across villages. The technique's introduction in Bihar's rice-potato systems placed women at the intervention's core. Dissemination through self-help groups played a vital role in empowering women in decision-making within agriculture. Insights from the first year highlighted the gender implications:

- PZTM reduced labour input, enabling women farmers to reduce reliance on men and eliminate the need to hire extra labour during men's absence.
- Dissemination through self-help groups made women both primary recipients and disseminators of knowledge, fostering their empowerment by enabling them to acquire knowledge, authority, and self-confidence through training.
- By the transformation of kitchen gardens into demonstration sites, women farmers were empowered as initiators and promoters of PZTM.
- Efforts were directed at convincing men, who were primary decision-makers in major agricultural production. The extension agents and women farmers were further challenged to demonstrate PZTM's efficiency and productivity to other farmers.

Overcoming barriers to behaviour change

Despite initial scepticism, a few farmers did adopt PZTM thanks to the persistent efforts of the extension agents. Access to digital extension service resources and support from field officers and experts provided constant assurance to them. Here, the extension agents played a critical role, using public screening discussions dispersed with personal experiences and training to encourage farmers.

After the first PZTM season, increased motivation and confidence among farmers was observed. Role model farmers shared their experience, anticipating a higher adoption rate in the next season. The implementation programme for the next cultivation includes a detailed dissemination strategy set to commence prior to the plantation season. This includes comprehensive training of the extension agents (in data collection, a refresher in dissemination skills along with the skills to operate PICO projectors that are used for video-mediated discussions in the villages) and extending dissemination through WhatsApp groups along with constant support and guidance from extension agents, field officers, and expert teams.

Changing behaviour takes time, but witnessing PZTM's positive impacts will encourage farmers towards adoption. By addressing the specific needs of farmers, the barriers to adoption can be overcome, leading to broader implementation of PZTM and amplifying its benefits to farmers, especially women farmers.

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References: **www.rural21.com**

Woody weeds – the underestimated threat to biodiversity

Biodiversity is critical for life on Earth. But human activity is damaging essential habitats. Our author looks at how invasive woody weeds are harming biodiversity in East Africa and how sustainable weed control approaches can help to restore delicate but vital ecosystems.

By Hariet Hinz

Biodiversity loss is happening at an unprecedented rate. The Earth.org Movement reports that "biodiversity is declining faster than at any time in human history. The average abundance of native species in most major land-based habitats has fallen by at least 20 per cent since 1900." But what does this mean for life on Earth? The uncomfortable truth, as explained in *The Lancet*, is that it "undermines ecosystems' abilities to function effectively and efficiently and this undermines nature's ability to support a healthy environment". Without this, we and other species cannot survive.

Biodiversity loss increases our vulnerability to climate change and limits options for climate adaptation. Ultimately, it threatens nature-based systems that are fundamental to our survival, like food production. Rural communities around the world that produce food are at most risk of biodiversity loss. Although the world's poorest countries are home to the greatest array of biodiversity, they are now the ones bearing the brunt of the threat. We must take action today.

Prosopis juliflora – from a useful plant to a pest

Invasive species are one of the major drivers of biodiversity loss. After habitat loss, they are the second greatest threat to biodiversity. Invasive species are living organisms, including plants, that have been moved without their natural enemies from one part of the world to another, where they then spread and thrive. They can have devastating effects on ecosystems. Take the woody shrub *Prosopis juliflora* (see Box), for example. In the 1970s, Prosopis was brought into Eastern Africa from the Americas as a source of fodder and wood, as well as being considered a solution to reducing erosion on degraded land. Today, it poses a significant threat to grasslands in East Africa. Its introduction has had unforeseen consequences as it has spread and crowded out native biodiversity.

In the Afar region of Ethiopia, CABI scientists have researched the spread of Prosopis and discovered that the weed has encroached upon 1.2 million hectares of land during the past 35 years. This represents more than 14 per cent of the region's total area, and the plant is expected to continue to spread. In Afar, this growth has caused a 25 per cent decrease in grasslands, which are critical ecosystems for wildlife and for absorbing carbon dioxide. The weed also consumes 50 per cent of the average rainfall in the area; this thirsty plant worsens the effects of climate change.

Huge monocultures of Prosopis have harmed natural habitats and the people who rely on them. Impacts include the loss of grazing land and access to water, a decline in biodiversity, reduced human health and more conflicts between humans and wildlife, as well as among humans themselves. In East Africa, the proliferation of woody weeds has had a significant negative impact on the livelihoods of pastoralists in Baringo County, Kenya.

Controlling woody weeds naturally

Farmers and land managers often turn to pesticides to try to control the spread of invasive weeds. But use of chemicals can have equally devastating effects on the environment. They can also harm human health. Manual removal of the weeds – of woody shrubs like Prosopis especially – can be incredibly difficult and labour-intensive. Sometimes, manual control can cause weeds to spread even further. But there is another way to handle the problem. Nature-based solutions, like the use of living organisms, such as insects or pathogens, are effective alternatives to chemical controls and can address biodiversity loss. They can control specific pests, diseases and weeds in a way that minimises environmental harm. By contributing to cataloguing and conserving global biodiversity, we can safeguard ecosystems for the benefit of human and environmental well-being.

In the case of woody weeds, CABI is spearheading the Woody Weeds+ project. Initiated in 2021, the project builds upon previous project work by its predecessor Woody Weeds which generated and shared knowledge on the impacts of woody invasive alien species in Ethiopia, Kenya and Tanzania. Woody Weeds+ involves supporting the implementation of Kenya's recently adopted National Prosopis Strategy. The project generates and shares evidence-based knowledge about the impact and spread of invasive plants on landscapes, as well as co-developing sustainable land management strategies to control them.

Woody weeds in Baringo Country, Kenya.

Photo: Sven Torfinn for CABI

By collectively addressing land degradation caused by woody weeds, the project supports communities, arming them with information to build local adaptive capacity and restore ecosystem services that are essential for coping with climate impacts.

Depending on the size of invasion and land assets, different management objectives (prevention, early detection rapid response [EDRR] or management) and different management techniques (surveillance, mechanical, chemical or biological control) will be implemented. While individual trees or small invasions can usually be best removed mechanically, biological control is the method of choice when the tree is already widespread. When biocontrol is unavailable, targeted use of chemical herbicides becomes necessary. In order to provide the knowledge needed for this, the Woody Weeds+ project is setting up herbicide efficacy trials in Kenya's Baringo and Isiolo Counties, applying them in very targeted ways.

A visit to communities in Baringo County, where woody weeds have caused them to consider management strategies for the invasive Prosopis tree.

Photo: Sven Torfinn for CABI

In Tanzania, CABI is helping to protect habitats around Lake Manyara and Lake Natron from the Prosopis invasion. Invasions around the Lake Natron basin are just starting, and visits to pastoralist communities here reveal just how important it is to prevent the spread of woody weeds to pasturelands.

A comprehensive approach to help preventing biodiversity loss

Many solutions exist that can help to prevent biodiversity loss. An important first step is to understand the spread of invasive weeds. This can be done with field-based research that helps us to monitor changes in species distribution over time. Minimising the disruption of ecosystems by invasive species is another option. By documenting the spread of and threat from these species, we can help countries produce plans for their management. This means working across various landscapes with a range of organisations and stakeholders. The Woody Weeds+ project is a good example of bringing together people from local women's groups to forestry researchers and land conservancies. In the Merti plateau of Kenya's Isiolo County, for example, the women' groups have routines to clear prosopis. They use dry cow dung to burn the trees at the base, thus killing them, which results in lasting removal.

Through the identification, development and release of new and safe biological control agents, we can help to protect biodiversity both by reducing the need for toxic pesticide use in agro-ecosystems and by supporting the restoration of ecosystems that have been degraded by invasion. By working in partnership with governments, we can develop and implement landscape-scale invasive species management strategies that reduce negative effects on biodiversity and ecosystem service delivery, while sustaining livelihoods. To achieve resilience, for example, the Woody Weeds+ project emphasises the importance of inclusive governance approaches.

In relation to agriculture, we can promote nature-based solutions, including Integrated Pest Management (IPM). We can also increase the availability and use of low-risk bioprotection products – such as biopesticides and invertebrate biocontrol agents – that conserve biodiversity. Recent research by CABI scientist has shown that cut stump and basal bark herbicide application and manual uprooting were highly effective in between 85-100 per cent of cases where the woody weeds were removed.

Further down the line, the Wood Weeds+ project will continue to support the implementation of the National Prosopis Strategy jointly with relevant stakeholders, in a target area stretching from West to East along the southern edge of Kenya's northern rangelands, targeting areas in Baringo, Isiolo and Tana River counties. This also aligns with the Darwin Initiative project which is currently active in Tanzania and compliments the National Invasive Species Strategy and Action Plan (NISSAP). This is a nationwide sectoral document aimed at protecting Tanzania's biodiversity, ecosystem services, and livelihood assets from invasive species and their negative impacts.

Prosopis

Prosopis has been rated as one of the most invasive plant species world-wide. It is a very drought- and salt-tolerant shrub or small tree which binds nitrogen. *Prosopis juliflora* has adapted to a wide range of soils and types of habitat. A mature plant can produce hundreds of thousands of seeds, which are capable of germinating for years. The seed is spread by grazers. The thorns and bush growth enable *P. juliflora* to rapidly block paths and make entire areas impenetrable.

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