Planet Friendly Home-Grown School Feeding

WFP
World Food Programme

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INITIATIVE ON
Fragility, Conflict, and Migration

What does it mean?

Teresa Borelli, Tabitha Nekesa, Emiliana Mbelenga, Mwarome Jumbale, Yasuyuki Morimoto, Raffaella Bellanca, Irmgard Jordan

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Annexes

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Contents

Acknowledgement.......... 2

List of abbreviations.......... 4

Methodology (as described in the report).......... 5

Annex 1: Supplementary information and additional evaluation criteria, indicators and tracking progress list related to the evaluation tool derived from literature and key informant interviews 7

Annex 2: Implication of agronomic practices at farm level.......... 12

Biodiversity through agronomic practices and their multifaceted benefits 12

Agronomic practices for improving soil organic carbon and soil-water management 14

Organic farming.......... 14

Water management practices in agriculture 14

Irrigation practices and implications..........15

Soil fertility management and nutrient leaching 17

Pesticide use and implications.......... 20

GHG emissions.......... 22

Plastic pollution in crop production.......... 23

Annex 3: Assessment of agronomic practices: Impacts and sustainable solutions 25

Annex 4: Background information on environmental impact along the supply chain 33

Annex 5: Background information on environmental impact of storage systems 36

Annex 6: Key Findings from the Key Informant Interviews among WFP staff 37

List of abbreviations

ASALs	Arid and semi-arid lands
BNF	Biological nitrogen fixation
CBC	Competency Based Curriculum
CO_2	Carbon dioxide
CSB++	Super Cereal Plus
DGLV	Dark Green Leafy vegetables
ECOWAS	Economic Community of West African States
ESG	Environmental, social, and governance
FAO	Food and Agriculture Organization of the United Nations
GHG	Green House Gas emissions
HFCs	Hydrofluorocarbons
HGSF	Home-Grown School Feeding
IPM	Integrated pest management
IRB	Institutional Review Board
ISFM	Integrated soil fertility management
KII	Key informant interview
KLU	Kühne Logistics University
LCA	Life cycle assessment
LMICs	Low- and middle-income countries
NESFAS	Northeast Society for Agroecology Support
NGO	Non-Governmental Organization
NORAD	Norwegian Agency for Development Cooperation
SMC	School Meal Coalition
SMEs	Small and Medium Enterprises
SOC	Soil organic carbon
SSA	Sub-Saharan Africa
WFP	World Food Programme

This document is related to the evaluation tool presented in the report on "Planet Friendly Home-Grown School Feeding – What does it mean?" published in July 2024. The tool includes 21 indicators and several agricultural, food processing, transport and storage practices associated with school feeding programs. The aim is to provide detailed information on why the practices presented in the tool have been categorized as planet hostile or planet friendly.

Methodology (as described in the report)

The research design, methodology and approach for this work was based on qualitative methods and approaches, including secondary data collection via a literature review, and key informant semi-structured interviews. These were both supported by the WFP global office. The regional focus for this work was on Sub-Saharan Africa.

The **literature review** focused on identifying practices withing the current procurement system that impact sustainability and provided insights and perspectives into the WFP-led acquisition of foodstuffs. Key documentation was provided by the WFP global and country offices. Additionally, a computerized search was undertaken using Google searching for appropriate keyword combinations in English including *home-grown school feeding*; *school meals*; *public* or *institutional food procurement*; *food procurement and climate change*; *agrobiodiversity*; *climate smart foods*; *planetary health*; *environmental impact*; *food processing*; *transport systems*; *food storage*; and *greenhouse gas emissions and public procurement systems*. Approximately 200 documents/reports/peer-reviewed papers published between 2009 and 2024 were fully analysed; 50% of these were peer-reviewed papers focusing on agronomic practices related to maize, bean and green leafy vegetable production and climate impacts published between 2011 and 2024.

Key informant interviews

To clearly understand the status and approaches used in school meal procurement to mitigate the environmental impact of the food supply chain, its activities, and associated value chain players, a round of stakeholder consultations was conducted from May 9th to June 16th, 2024. These consultations involved key informant, semi-structured virtual interviews with 10 different expert groups from various national and international institutions, including three schools, the Japan International Cooperation Agency (JICA), WFP, and the Alliance of Bioversity International and the International Center for Tropical Agriculture (CIAT). Key informants were comprised of:

1. Supply chain officers
2. Supply chain sustainability officers
3. Smallholder market access officers
4. School meals, social protection, and meal planning officers
5. Regional school feeding advisors
6. Nutrition data analysts
7. Homegrown school feeding procurement experts
8. Food systems and nutrition analysts
9. Food fortification and nutritious foods development officers
10. School officials, including the principal and teachers

The initial list of key stakeholders to be included was provided by WFP headquarters and was subsequently expanded using suggestions from the key informants. The virtual interviews were recorded following verbal consent from the participants. The semi-structured interviews sought to address information gaps around the impacts of school feeding programs, including HGSF, brought to light by the systematic literature review. They also aimed at identifying success stories on planet friendly considerations in past or ongoing school feeding and HGSF implementation efforts; good practices, and lessons learned, as well as revealing institutional/governance, operational, technical, and financial challenges.

Key assessment questions were developed by the evaluation team and guided the interviews. Transcribed raw data underwent processing, cleaning, and organization. Based on the identified key criteria, the transcripts were labelled by thematic coding and the development of an objective-specific framework for ease of presentation. This was done using MAXQDA version 24 (MAXQDA 2024). The quotes contained in the report have been annotated where necessary and supplemented by inserting information in [...] to provide contextual information and (...) to indicate sections that have been omitted to facilitate reading and understanding. In addition, case studies from past and ongoing school meal programs were identified and summarized to provide in-depth information about the diversity of settings under which school meal programs are operating.

At the start of the study, the focus was on three main foods —maize, beans, and green leafy vegetables—commonly procured in the countries where WFP operates. However, during the project, it became clear that a range of indicators relevant to planetary health apply to all foods. Consequently, the emphasis shifted from identifying differences between these specific foods to developing general criteria applicable to the procurement process for any food. Additionally, interviews underscored the need for a flexible tool capable of addressing various operational demands and predicting and mitigating the environmental impacts of both development and emergency operations. This tool would be adaptable for making daily decisions regarding WFP's local food procurement in its entirety.

The study adhered to the Institutional Review Board (IRB) of the Alliance of Bioversity and CIAT (2024-IRB39). The study also aligned with the norms and standards for evaluation as guided by the United Nations Evaluation Group (UNEG).

Annex 1: Supplementary information and additional evaluation criteria, indicators and tracking progress list related to the evaluation tool derived from literature and key informant interviews

Evaluation Criteria	Planet Friendly Indicators	Tracking Progress Checklist
Sustainable procurement practices that consider both social and environmental impacts will enhance local markets driving economic equity and linked to long term sustainability and healthy diets for school going children	▪ A clearly defined procurement policy and framework is outlining what planet friendly home-grown school feeding. ▪ Transparency and accountability in the procurement process ▪ Strengthened emphasis on sourcing from farmer cooperative groups or local and sustainable small and medium enterprise (SME) agri-food producers practicing sustainable production. ▪ Enable the implementation of tender processes that prioritize certain suppliers (e.g. local, smallholder farms that use sustainable practices ▪ Link to impact monitoring indicators	▪ Is there a set timeline clearly outlining key milestones towards the achievement of planet friendly HGSF procurement? ▪ Are there environmentally friendly minimum requirements and award criteria set out in procurement documents? ▪ Are key strategies and interventions needed to promote smallholder participation in the HGSF procurement process documented? ▪ Are local or smallholder farmers, small and medium food enterprises, or women, youth or other vulnerable producer groups practicing sustainable agriculture identified and mapped? ▪ Implement demand-side policy actions, such as helping farmers overcome barriers that prevent them from enhancing their productivity e.g., through small micro financing to ensure demand for local products. ▪ Establish rules and procedures to facilitate contract "lotting" (i.e., where large contracts are divided into smaller, more manageable lots), making it easier for small and medium enterprises (SMEs) to win tenders. ▪ Work in partnership with other stakeholders to stimulate the development of local markets which can provide regular and reliable source of income for smallholder farmers.

Evaluation Criteria	Planet Friendly Indicators	Tracking Progress Checklist
		▪ Greater consideration of sustainability issues associated with food procurement such as the impacts on human health and the environment) rather than awarding contracts based solely on the lowest economic cost. ▪ Document how food procurement is contributing to improvements to smallholder livelihoods, food security and nutrition outcomes and challenges involved in procuring food from smallholder farmers.
Promote sustainable procurement in HGSF programs considering planet-friendly production	▪ Clear definition of type of production procurement will purchase from (e.g. from agricultural production that ensures sustainable production. Strengthened planet-friendly procurement through knowledge sharing on sustainable farming practices among smallholder farmers and other farmers ▪ Community and stakeholder engagement to assess and promote local capabilities and potential for planet friendly agricultural production for supply to HGSF programs.	▪ Provide training and capacity building on sustainable agriculture for all relevant stakeholders, including policy makers, smallholder farmers and local communities in HGSF programs. E.g., through conferences, seminars, open days, field days ▪ Provision of public and private extension services for training and capacity building of smallholder farmers in sustainable farming practices ▪ Clear records of attendance for all extension services, and other training/capacity building fora along with pre- and post-training evaluation surveys maintained ▪ Clear records, such as minutes and reports, for community/stakeholder engagement, including the documentation of the integration of their feedback ▪ Investments and capacity building in information and technology for the promotion of sustainable farming practices e.g., databases, mobile applications
Reduce emissions from energy use in processing	▪ Promote and support farmers to acquire drying equipment from simple tarpaulins to shelters that protect from the rain. ▪ Support smallholder farmers to acquire appropriate machinery (e.g. maize shellers for threshing and shelling of grain crops).	▪ Monitor the promotion of low emissions drying technologies such as solar dryers ▪ Track the use of low emissions processing technologies e.g., canning, irradiation and dehydrating) that extend shelf life and eliminate or reduce the need for cold storage.

Evaluation Criteria	Planet Friendly Indicators	Tracking Progress Checklist
Packaging actions should be a shared responsibility to ensure overpacking is avoided and the necessary packaging has been produced responsibly. Procurement officers can work with suppliers and producers to increase their diligence in this area through reduction of packaging and recycling options in discussions at contract follow-up meetings	▪ Established food packaging standards for HGSF programs and awareness creation of these standards. ▪ Sourcing food products that are handled with low environmental impact packaging throughout the supply chain. ▪ Provide clear guidelines on discarding packaging correctly wherever possible, thereby helping to minimize unnecessary waste. ▪ Promote recycling, avoid overpacking and chemicals. ▪ Require packaging not to contain certain elements such as chemicals, polyvinyl chloride (PVC) or waste ▪ Require that packaging and other material coming into contact with food be free of PVC, phthalates and other known undesirable substances. ▪ Building awareness of the most effective packing techniques/technologies and promoting the development of skills necessary to implement these behaviours and technologies. ▪ Providing financial resources (e.g. subsidies) to actors along the school feeding supply chain who could benefit from implementing these practices/technologies.	Procurement officers may find it difficult to set measurable criteria for packaging food products, and criteria can be difficult to implement as products are often packaged at the producer level and packaging is necessary to avoid excessive waste during transport. However, procurement officers can work to minimize packaging; but this is difficult to navigate, as it can also have an impact on the durability of food items. ▪ Are there set technical procurement specifications that require that cardboard packaging should, as far as possible, consist of recycled cardboard and not cardboard combined with other materials? ▪ Are there technical specifications for plastic packaging, where the packaging should, as far as possible, consist of recycled plastics and not be composed of different types of plastics?
Reducing emissions from energy use in food storage and cold chains	▪ Invest in hermetic storage (HS), also known as "sealed storage" or "airtight storage" (e.g. metal drums and silos, and hermetic bags) as an effective storage method for cereals	▪ Is there a plan in place to phase-out the use of hydrofluorocarbons (HFCs), a type of highly potent GHG often used in refrigeration and promote other known low-emissions alternatives to HFCs in refrigeration, such as

Evaluation Criteria	Planet Friendly Indicators	Tracking Progress Checklist
	like the maize and pulses beans which will reduce the use of chemicals and pesticides. ▪ Promote lower-cost, off-grid cooling technologies (e.g. biogas- or solar-powered technologies) that offer a low-emission alternative to cold storage facilities. ▪ Invest in cold storage facilities with greater energy efficiency especially for perishable foods like the dark green leafy vegetables which will also have an impact on food loss and waste. Energy-efficient cold storage technologies include phase change material, thermal energy storage and phase change thermal storage units	natural refrigerants (e.g. ammonia, carbon dioxide, hydrocarbons, water and air)? ▪ Are suppliers and aggregators incentivized to buy more energy-efficient refrigerators through subsidies and/or labelling schemes? ▪ Have emissions embedded in food supply chains been quantified to identify where in food supply chains emissions are arising and thereby develop targeted interventions?
Reducing emissions from energy use in transport	▪ Include full life cycle costs when evaluating tender proposals to decrease carbon impact, by considering emissions that arise throughout the entire life cycle including for example transportation and packaging ▪ Use more GHG-efficient modes of transport for example, rail and barges are more energy-efficient per ton of cargo than air freight. Similarly, larger trucks are more emissions-efficient than smaller vehicles. ▪ Promotion of transportation materials that can safely transport crops to distant markets, such as natural and synthetic fibre sacks and moulded plastic boxes. This is especially relevant for high-perishability crops like the dark green leafy vegetables.	▪ Create information and communications technology to design the least emissions-intensive transportation routes and storage strategies. ▪ Conduct research that quantifies emissions embedded in food supply chains to identify where emissions in the HGSF supply chains are arising and thereby develop targeted interventions.
Reducing post-harvest food loss and food waste	▪ Adoption of a HGSF strategy for reducing food loss, including programs, policies, practices, incentives and/or related	Effective implementation of post-harvest food loss measures needs to be in tandem with national governance and policy reforms such as agricultural policies related to post harvest food loss reduction and research and development and will require collaboration with other actors. For example, PCMs

Evaluation Criteria	Planet Friendly Indicators	Tracking Progress Checklist
	measures to influence actions of farmers, aggregators, other suppliers and schools. ▪ Establishment of aggregation centres for storing and preserving food at multiple temperature levels. ▪ Support smallholder farmers and small and medium businesses with upfront investment costs of infrastructure and technologies to reduce post-harvest food loss. ▪ Promotion of proper handling practices along the supply chain that can reduce contamination of products. ▪ Use of phase change materials (PCMs) to maintain products within a desired temperature range and thus maintain the quality of the products as they move along the supply chain. ▪ Promotion of food monitoring and tracing technologies to reduce supply chain inefficiencies and improve knowledge of where food losses are occurring along food supply chains. ▪ Creating incentives for suppliers to measure food loss and waste and implement food loss and waste policies, for example through success cases demonstrating possible cost savings, company reporting and disclosure to investors, or third-party monitoring.	that range from more natural and/or organic materials such as gelatine to more synthetic materials such as polystyrene can reduce emissions associated with cold chains by increasing energy efficiency of and distribution operations as well as by reducing food loss ▪ Are technologies and practices to reduce food loss and waste being implemented? ▪ Is awareness and training of the HGSF supply chain actors on the best available technologies for reducing food loss being done? ▪ Are processing methods/technologies that can extend shelf life of products such as drying, smoking, salting, fermenting, pickling, canning and food irradiation being promoted? ▪ Are measures to build more efficient and intelligent value chains such as vertical integration; expanded contracting from retailers and wholesalers; computer-based modelling and monitoring systems that optimize transportation scheduling and routes; and funding methods to lessen information constraints and bottlenecks in place?

Annex 2: Implication of agronomic practices at farm level

Planet friendly agronomic practices serve as the foundation of sustainable agriculture; encompassing practices that reduce the environmental footprint of agriculture, enhance the efficient utilization of natural resources, and enhance the resilience to climate change and variability (Krall 2015a; Piñeiro et al. 2021a). Furthermore, sustainable agricultural production involves the implementation of sustainable land management (SLM) practices aimed at improving land productivity through restoration and increasing carbon sequestration for climate resilience (Tennigkeit, Okoli, and Brakhan 2023a). Sustainable agricultural and SLM practices include organic inputs use, agroforestry, crop rotation, crop residue management, cover cropping, multiple cropping, integrated cropping, integrated pest management, drip irrigation, and use of renewable energy sources, amongst others (Dubey et al. 2021; Krall 2015a; Tennigkeit, Okoli, and Brakhan 2023a). The implementation of planet-friendly agronomic practices mitigates environmental degradation and promotes food security and economic development.

Biodiversity through agronomic practices and their multifaceted benefits

Agroforestry, multiple cropping, and crop rotation systems enhance agricultural biodiversity for improved food and nutrition security, management of pests and diseases, soil and water conservation, improved crop yields, poverty alleviation, and enhanced resilience to climate change and variability (Mthembu, Everson, and Everson 2019; Mustafa, Mayes, and Massawe 2019). These integrated farming practices promote the sustainable use of natural resources by harnessing the complementary interactions between crops, trees, and other components of the agroecosystem. Directly, intercropping, crop rotation and agroforestry enhance species diversity, indirectly fostering genetic and ecosystem diversity, which are fundamental to maintaining the integrity and functionality of agroecosystems. These agronomic practices underpin SLM.

Continuous maize monocropping is associated with a continuous decline in crop productivity and soil fertility, and increased pest and disease incidences (Berdjour et al. 2020; Mthembu, Everson, and Everson 2019), as well as low soil microorganism populations (Nassary, Baijukya, and Ndakidemi 2020), contrary to diversified cropping systems. Incorporating legumes such as common bean, soybean, cowpea, groundnut, pigeon pea, and desmodium into intercropping and crop rotation systems is vital for SLM through improved soil health and productivity (Nekesa et al. 2024). A 7-year study in the lowlands of Kenya, Ethiopia, Malawi, and Mozambique recorded higher maize grain yields under similar maize-legume intercropping, contrary to maize monocropping (Table 1).

Table 1: Mean values of maize grain yields under different cropping systems in the lowlands of Kenya, Ethiopia, Malawi and Mozambique (Mupangwa et al. 2021)

Cropping system	Maize grain yield kg ha−1
Conventional practice + sole maize	2485
Conservation agriculture + sole maize	2658
Conservation agriculture + maize intercropping	2802

In the Northern Highlands of Tanzania, continuous maize-bean intercropping for two seasons resulted in bean grain yield increase from 1.5 to 2.3 t ha^{-1} in lower altitude, 2.0 to 2.3 t ha^{-1} in middle altitude, and 1.8 to 2.9 t ha^{-1} in upper altitude agroecological zones (Nassary, Baijukya, and Ndakidemi 2020). Incorporating leguminous crops into intercropping and crop rotation systems enhances biological nitrogen fixation (BNF) leading to improved soil fertility and the potential for better crop yield (Table 2) (Nekesa et al. 2024).

Push-pull technology is an intercropping agronomic measure that incorporates desmodium into cereal production to repel pests such as fall armyworm and stem borer, and improve soil fertility (Mwakilili et al. 2021; Nekesa et al. 2024). In a long-term study, maize-desmodium intercrop yielded more diverse and beneficial fungal communities relative to sole maize at the International Centre for Insect Physiology and Ecology (ICIPE), Mbita campus in Kenya (Mwakilili et al. 2021). The fungal communities consisted of functional groups such as mycorrhiza, endophytes, saprophytes, decomposers, and bioprotective fungi. These groups contribute to nutrient and water cycling, and pathogen suppression, amongst other ecosystem services. Push-pull technology creates favorable conditions boosting crop yields.

Intercropping or crop rotation systems with legumes enhance soil moisture conservation through their deep roots. The deep roots access moisture from deeper soil layers that would otherwise remain untapped by shallow-rooted crops. benefits can be attained from Additionally, the roots enhance access to nutrients in these zones, reducing competition among crops for resources. Such benefits can be attained from intercropping maize with dolichos lablab *(Lablab purpureus)* and pigeon pea *(Cajanus cajan)* (Mugi-Ngenga et al. 2023).

It is important to note that agronomic practices can be employed complementarily rather than singly. This approach promotes synergies between the different practices, leading to more holistic and effective solutions for SLM and agricultural production. In Eastern Kenya's dryland agroecosystems, a study recorded over 40 Mg N ha^{-1} increase in total N stocks under conservation tillage with *Calliandra calothyrsus* and *Gliricidia sepium* in maize-legume intercrops (Kisaka et al. 2023). Leguminous trees or shrubs in agroforestry systems offer the benefit of nitrogen fixation. Correspondingly, trials in the semi-arid regions of Ghana, Guinea, and the Savanna highlighted the positive impact of agroforestry parklands, with high decomposition and mineralization of leaf litterfall from white acacia *(Faidherbia albida),* enriching the soil with N for various annual crops such as maize, millet, sorghum, and vegetables (Akpalu, Dawoe, and Abunyewa 2020). This improved soil fertility holds significant potential for enhancing crop yields.

Agroforestry is an effective strategy for regulating soil moisture, improving soil fertility, increasing carbon stocks, and mitigating runoff and soil erosion in agricultural landscapes ultimately improving crop yields (Bogale and Bekele 2023; Kuyah et al. 2019). Integrating trees and shrubs into cropping systems helps stabilize soil, reduce surface runoff, and prevent erosion, thus enhancing soil and water conservation. In the Western highlands of Cameroon, a review identified various agroforestry systems, including alley cropping, improved fallow, shelter belts, living fences, and scattered trees on croplands, as suitable for soil and water management (Shidiki, Ambebe, and Awazi 2020). The benefits of agroforestry are further exemplified in the semi-arid region of Laikipia East, Kenya, where trials recorded significant increases in maize yield and rainwater use efficiency with the implementation of agroforestry, by 16% and 16.8% respectively (Waweru et al. 2024). Additionally, agroforestry trees as windbreaks, and litterfall from their leaves, potentially reduce wind erosion, and water erosion respectively (Bogale and Bekele 2023; Shidiki, Ambebe, and Awazi 2020).

Agronomic practices for improving soil organic carbon and soil-water management

Core to Sustainable Land Management is soil organic carbon, crucial for soil health and fertility, playing a significant role in supporting plant growth and ecosystem resilience. It further contributes to carbon sequestration by enhancing the storage of atmospheric CO_2. The integration of trees and shrubs into agricultural landscapes increases the input of organic matter into the soil through leaf litter, root biomass, and other plant residues. A review of agroforestry systems in the Congo basin showed that incorporating nitrogen-fixing trees (NFT) improves the soil health through C sequestration and nutrient restoration (Koutika et al. 2021).

Other agronomic practices such as tillage, cover cropping, and crop residue management also account for soil organic carbon levels. For instance, the study in Eastern Kenya's dryland agroecosystems yielded over 36 Mg C ha^{-1} increases in SOC under no-tillage with pigeon pea in maize production contrary to sole maize (Kisaka et al. 2023). Elsewhere, in low-altitude and mid-altitude areas in Malawi, conservation tillage (practiced over 10 years) with maize-legume intercropping yielded more total soil organic carbon over traditional tillage with sole maize (Simwaka et al. 2020). Conservation tillage potentially increases soil organic carbon by reducing soil disturbance and erosion, promoting the retention of organic matter, and enhancing soil aggregation, all of which contribute to the accumulation of stable carbon in the soil.

Agricultural field trials (2 to 26 years) in semi-arid areas of Namibia yielded 20% of soil organic carbon previously present in the woodlots before deforestation, leading to decreased simulated maize yields in the agricultural fields due to the shifting to low-input agriculture (de Blécourt et al. 2019). This implies the need for sustainable agronomic practices to boost soil organic carbon. At the semi-arid University of Fort Hare research farm, South Africa, crop residue retention and application of biochar yielded higher amounts of soil organic carbon contrary to residue removal for 6 cropping seasons (Nyambo, Chiduza, and Araya 2020a). As crop residues decompose, they release organic carbon and other nutrients into the soil, improving soil health.

Organic farming

Organic farming or using organic soil amendments such as manure enhances soil health and conservation. The organic materials are valuable sources of carbon and nutrients. A 2-year study in the tepid humid mid-highlands of Bedele district, Ethiopia recorded C and N stocks that were 86 % and 175 % higher under the combined use of 4 t ha^{-1} of compost along with 50% recommended inorganic fertilizer relative to the 100% recommended inorganic fertilizer (Mamuye et al. 2021). Decomposition of organic amendments releases organic matter into the soil, providing a continuous supply of nutrients to crops and supporting beneficial microbial activity.

Moreover, organic farming and associated practices, along with other soil conservation measures, are important for erosion control. For instance, the application of 10 or 15 t ha^{-1} of poultry manure in a maize-aerial yam intercrop yielded significantly lower bulk density and higher total porosity and saturated hydraulic conductivity relative to non-application (Udom, Wokocha, and Ike-Obioha 2024). The results imply better water movement for improved infiltration and water storage, preventing runoff and soil erosion. Conservation of soil and water in turn conserves nutrients and soil organic carbon.

Water management practices in agriculture

Poor water management practices in agriculture can lead to waterlogging and salinization (Kirui, Mirzabaev, and von Braun 2021), rendering land unsuitable for crop cultivation and exacerbating soil degradation. Moreover, agricultural runoff containing agrochemicals and sediment pollutants can contaminate water bodies enhancing eutrophication and polluting drinking water. Desertification, the expansion of arid and semi-arid lands (ASALs), poses severe challenges to agricultural livelihoods and food security. It reduces land productivity, limits agricultural expansion, and exacerbates soil erosion and water scarcity, exacerbating poverty and food insecurity in the ASALs.

Crop residue retention controls surface runoff and erosion. The residues act as a protective layer, shielding the soil from the impact of rainfall and reducing the erosive force of water thus preserving top fertile soil. In a forest zone in Ghana residue retention constituting of full tillage with maize-cowpea rotation with incorporation of plant residues, minimum tillage with maize-cowpea rotation and plant residues applied as mulch, and minimum tillage with continuous maize cropping with residue mulch recorded lower runoff in comparison with full tillage with continuous maize cropping and removal of crop residue (Dugan et al. 2022). Additionally, crop residues improve soil structure by promoting the formation of aggregates and enhancing soil stability. This, in turn, reduces soil compaction and increases infiltration rates, allowing water to penetrate the soil more easily and reducing the runoff.

Planet-friendly agronomic practices serve as the foundation of sustainable agriculture; encompassing practices that reduce the environmental footprint of agriculture, enhance the efficient utilization of natural resources, and enhance the resilience to climate change and variability (Krall 2015b; Piñeiro et al. 2021b). Furthermore, sustainable agricultural production involves the implementation of sustainable land management (SLM) practices aimed at improving land productivity through restoration and increasing carbon sequestration for climate resilience (Tennigkeit, Okoli, and Brakhan 2023b). These planet-friendly agronomic practices are important for climate change adaptation and mitigation. For instance, improved soil structure and water infiltration through reduced tillage and cover cropping reduce surface water runoff by increasing water infiltration, water storage in subsurface layers and aquifers as well as slow release of surface runoff from vegetated areas for flood control cases of heavy rainfall events (Saco et al. 2021; Antolini et al. 2020).

Implementing conservation tillage underpins reducing soil erosion, conserving soil moisture, and improving soil health. Minimal soil disturbance preserves the soil structure and organic matter, thereby conserving soil moisture. For instance, in Mkushi, Zambia, the production of maize under conservation tillage combined with biochar application, followed by conservation tillage, resulted in higher soil moisture levels compared to conventional tillage(Obia et al. 2020). Apart from enhanced infiltration (Akplo et al. 2022; Fatumah, Tilahun, and Mohammed 2020; Obia et al. 2020), conservation tillage maintains a protective soil cover through the presence of crop residues, reducing water evaporation and providing protection from wind and water erosion.

Biochar, a carbon-rich material produced from biomass pyrolysis, has gained attention for its potential to enhance soil and water conservation. When incorporated into the soil, biochar acts as a sponge-like material, absorbing and holding onto water, thus improving soil water retention capacity (Agbede and Adekiya 2020; Obia et al. 2020). Additionally, biochar has been found to enhance soil structure, promoting better soil aggregation and pore formation, which further aids in water infiltration and retention. In the forest-savanna transition zone at Rufus Giwa Polytechnic, Nigeria, the application of biochar reduced bulk density and penetration resistance, and increased porosity as well as moisture content, creating favorable conditions for maize production (Agbede and Adekiya 2020).

Irrigation practices and implications

Smallholder farmers in SSA rely on rainfed agriculture, however, with the changing climatic and weather patterns, irrigation becomes important for sustainable food production (Assefa et al. 2020). Irrigation can have both positive and negative impacts on soil and water quality, depending on how it is managed. On one hand, adequate irrigation can improve soil moisture levels, promoting better soil structure and aggregation. This can enhance soil fertility and nutrient availability, leading to increased crop productivity. Additionally, irrigation water can help flush out salts and other harmful substances from the root zone, preventing soil salinization and improving soil health.

Conversely, inefficient irrigation practices can lead to salinization or sodification (Daba and Qureshi 2021; Mohanavelu, Naganna, and Al-Ansari 2021), where excessive water use results in the accumulation of salts in the soil, rendering it infertile. Coupled with waterlogging, inefficient irrigation management exacerbates soil degradation, compromising its ability to support plant life. Salinity and sodicity challenges are severe in arid and semi-arid lands (ASALs) under irrigated agriculture due to limited rainfall and high rates of evaporation, leading to the accumulation of salts in the soil (Daba and Qureshi 2021).

The salinity and sodicity in irrigated agriculture potentially enhance both surface and groundwater (Figure 1) contamination exacerbating soil and water degradation. These factors lead to low crop yields and productivity by limiting the uptake of water and nutrients (Daba and Qureshi 2021; Hailu and Mehari 2021). This is supported by the review by Hailu & Mehari (2021)documenting that high sodium concentrations (sodicity) result in lower infiltration and hydraulic conductivity, as well as surface crusting due to sodium-induced dispersion. Water and nutrient stresses as a result affect crop growth and development.

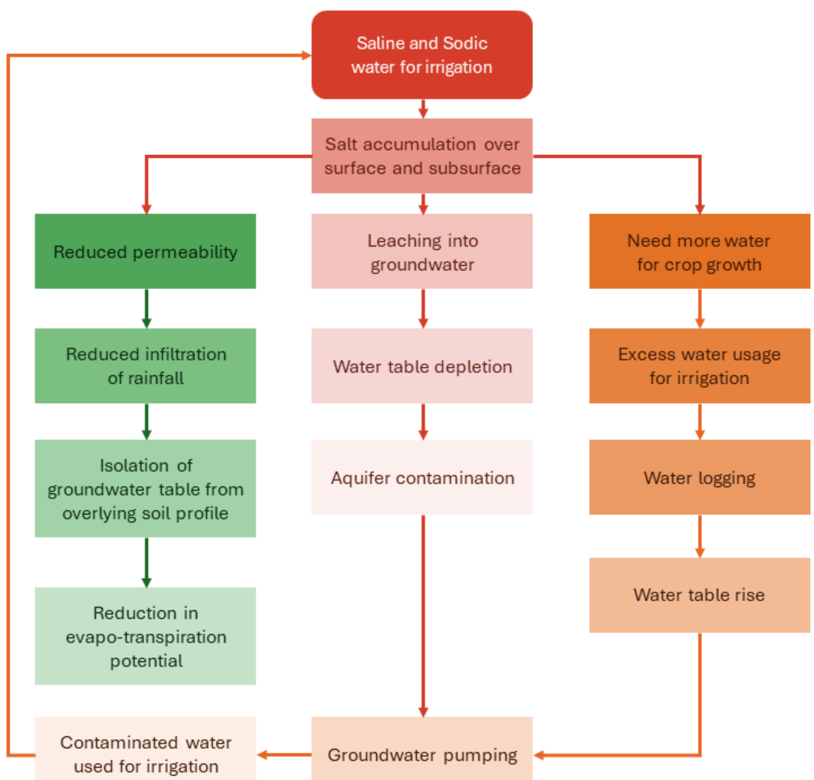

Figure 1: Groundwater impacts caused by irrigation-induced salinity and sodicity hazards (Mohanavelu, Naganna, and Al-Ansari 2021)

Irrigation methods can also influence water quality. Improper irrigation methods, such as flood irrigation, can exacerbate nutrient runoff and sedimentation, leading to eutrophication and contamination of water bodies. Excessive or improper application of fertilizers and pesticides in irrigated areas can further exacerbate water quality issues, as these agrochemicals can leach into groundwater or runoff into surface water, posing risks to aquatic ecosystems and human health.

Adopting sustainable irrigation practices is imperative to mitigate these negative impacts. Salt scrapping from the soil surface followed by leaching should be done on salt-affected soils (Gelaye et al. 2019; Omar et al. 2023). Leaching, however, is recommended in areas with deep groundwater tables as it increases salinity in areas with shallow water tables (Gelaye et al. 2019). Precision irrigation techniques, such as drip or sprinkler systems, can minimize water wastage and reduce the risk of soil erosion and salinization. Following a review of studies in Ghana, Tanzania, and Ethiopia, conservation tillage coupled with drip irrigation was found to be effective in soil and water conservation, contrary to traditional tillage, to produce vegetables such as cabbage, nightshade, and tomato, amongst others (Assefa et al. 2020).

Irrigation systems need proper drainage to help manage excess water, preventing waterlogging and salinization. Moreover, removal of excess water from the root zone, promotes optimal soil aeration and root growth, thereby enhancing crop productivity. Implementing soil and water conservation measures, such as minimum tillage, mulching, organic matter, and crop residue management can improve soil structure and water infiltration in irrigated agriculture (Daba and Qureshi 2021). Ripping, for instance, is recommended for saline-sodic soils to improve soil porosity and infiltration, preventing waterlogging and surface accumulation of salts on the soil surface (Omar et al. 2023). Additionally, agroforestry and deep-rooted crops further improve drainage in irrigation systems for salinity management (Mohanavelu, Naganna, and Al-Ansari 2021).

Buffer strips and riparian zones along water bodies can serve as natural filters, trapping sediment and pollutants before they reach waterways. Mulching and cover cropping create a protective layer on the soil, reducing salt concentrations on the soil surface resulting from evaporation. Lastly, the application of organic soil amendments, such as biochar and manure, in salt-affected soils can improve soil structure and drainage for irrigation management (Mohanavelu, Naganna, and Al-Ansari 2021; Omar et al. 2023). Integration of these solutions is sustainable. The review by Omar et al. (2023) noted that integrating ripping with organic and inorganic soil amendments yields improved long-term soil physical conditions for irrigation management.

Soil fertility management and nutrient leaching

Addressing the complexity of maintaining both soil fertility and environmental sustainability necessitates the adoption of comprehensive soil fertility management practices. While soil fertility is the foundation for plant production (Park et al. 2023), its depletion is a major form of land degradation in Sub-Saharan African countries due to continuous nutrient mining without adequate replenishment (Falconnier et al. 2023; Otieno 2023). Reducing or preventing nutrient decoupling becomes imperative.

Agronomic measures such as crop rotation, conservation tillage, agroforestry, intercropping, crop residue retention, mulching, and cover cropping, amongst others, are integral for Integrated soil management (ISFM). Incorporating legumes into diversified crop systems under ISFM enhances soil fertility (Nekesa et al. 2024; Otieno 2023). Utilizing deep-rooted legumes enhances soil fertility and reduces nutrient leaching, as the crops utilize any N or P leached below the root zone. However, N needs cannot be met fully through legume BNF and the use of animal manure (Falconnier et al. 2023). Moreover, organic amendments such as compost manure are usually available in small quantities that fail to meet recommended application rates (Job Kihara et al. 2022). Hence there is a need to integrate several soil fertility measures to fulfill fertility needs.

The utilization of inorganic fertilizers is recommended to enhance soil fertility (Jjagwe et al. 2020; Mamuye et al. 2021; Omar et al. 2023). The application of these fertilizers across varying AEZs in

Tanzania and Malawi has been shown to increase maize productivity (Job Kihara et al. 2022). The fertilizers supply essential nutrients including N, P, and K for the growth and development of crops.

Table 2: Advantages of inorganic fertilizers for improved maize productivity (Kihara et al. 2022)

Nutrient application	Agroecosystem	Average rainfall (mm/year)	Increase in productivity (Grain yield, %)	Gross margin (US$/ha)
P (20 kg/ha) + N (60 kg/ha)	Highlands of northern Tanzania	845	210 (153–444)	685–1,245
	Medium altitudes of northern Tanzania	743	215 (74–470)	820–1,215
	Lowlands of northern Tanzania	769	120 (63–300)	740–1,435
P (15 kg/ha) + N (60 kg/ha)	Semi-arid central Tanzania	408	57 (22–84)	102–357
P (18 kg/ha) + N (69 kg/ha)	Semi-arid central Malawi	855	128 (30–290)	n/a1
P (18 kg/ha) + N (69 kg/ha)	Semi-arid southern Malawi	723	187 (50–300)	263% (net income

Notes: for northern Tanzania, work was undertaken in Babati district using DAP and Minjingu Mazao fertilizers. For semi-arid central Tanzania, work was done in districts of Kongwa and Kiteto using DAP, Minjingu, and YaraMila CEREAL fertilizers. Both YaraMilaTM and Minjingu supply additional nutrients needed by plants in small doses (micro-nutrients) and reduce soil acidity due to the presence of basic cations in their formulation. In Malawi, the work was conducted in Machinga and Dedza districts using NPS fertilizer and urea.

1 | n/a = not applicable.

While the use of inorganic fertilizer improves crop productivity, adoption in Sub-Saharan Africa is constrained as resource-poor smallholder farmers can barely purchase these inputs (Badu et al. 2019; Dimkpa et al. 2023; Job Kihara et al. 2022; Otieno 2023). Moreover, fertilizer use in Sub-Saharan Africa is characterized by imbalanced nutrient composition and substandard quality materials (Dimkpa et al. 2023). Coupled with N and P losses through runoff and leaching contributing to eutrophication, fertilizer use efficiency in the region is low (Dimkpa et al. 2023; Falconnier et al. 2023).

One possible solution to increasing nutrient use efficiency and reducing nutrient losses is the 4R fertilizer management strategy, consisting of the right source, right rate, right time, and right place (Falconnier et al. 2023; Job Kihara et al. 2022). The right source assures balanced nutrient composition and can involve soil testing to establish the precise application rate. Timing fertilizer application should coincide with crop nutrient demand and avoid periods of heavy rainfall to reduce losses through runoff and leaching. Lastly, precision placement techniques ensure that nutrients are applied directly to the root zone of plants, maximizing their availability for uptake (Job Kihara et al. 2022), while minimizing environmental risks.

Considering using inorganic fertilizers is already constrained in SSA, alternative and complementary solutions are needed. Integrated soil fertility management (ISFM), involving the incorporation of organic and inorganic fertilizers with other improved production practices (Dimkpa et al. 2023), offers great potential for soil fertility and health improvement. The strategy further involves improved germplasm (Hörner and Wollni 2021; Mugwe, Ngetich, and Otieno 2019) and locally adapted soil fertility measures as well as improved agronomic measures for boosting soil fertility and crop productivity (Hörner and Wollni 2021).

Research trials in Yilmana Densa district, Ethiopia recorded a significant increase in organic C, total N, and available P under combined compost and inorganic fertilizer application relative to sole inorganic fertilizer use in maize production (Table 2) (Ejigu et al. 2021). ISFM enhances nutrient and fertilizer use efficiency for improved crop performance (Mugwe, Ngetich, and Otieno 2019). In Ghana, the utilization of either organic, inorganic fertilizers, or both, has been shown to increase cabbage and lettuce productivity relative to non-application (Amfo and Baba Ali 2021). Additionally, a review of maize production in Northern Ghana by Boansi et al. (2024) indicated that ISFM, through combining crop rotation, inorganic fertilizer, and farmyard manure, has the potential to increase yield gain by 86.52 % and decrease the yield gap by 10.22 %. In Southern Africa, this strategy shows the potential to enhance productivity and fertilizer use efficiency by 10-60% across diverse soil fertility conditions in maize-based systems (Zingore 2023).

Table 3: Effect of compost and inorganic fertilizer use on selected soil properties under maize production in Yilmana Densa, district, Ethiopia (Ejigu et al. 2021)

Compost (t/ha)	**Urea/NSPB (kg/ha)**	**OC (%)**	**TN (%)**	**AP mg kg1**
0	0/0	1.45	0.10	3.92
	50/50	1.43	0.13	5.08
	100/100	1.41	0.13	5.79
5	0/0	1.65	0.15	4.35
	50/50	1.67	0.16	6.15
	100/100	1.71	0.18	7.48
10	0/0	1.89	0.17	5.65
	50/50	1.92	0.19	9.04
	100/100	1.96	0.22	10.90

NSPB: Nitrogen, phosphorus, sulfur, boron blended fertilizer (18.1N+ 36.1 P_2O_5 + 6.7S + 0.71 B); TN: Total nitrogen; OC: Organic carbon; AP: Available phosphorus

Improving nutrient use efficiency (NUE) also helps minimize environmental pollution and degradation through leaching and volatilization of nutrients (Dimkpa et al. 2023). This reduces the risk of nutrient runoff into water bodies, contamination of groundwater, and eutrophication of aquatic ecosystems. The 4R strategy of fertilizer management further contributes to improved NUE.

Incorporating biochar into ISFM enhances crop productivity while minimizing the environmental impacts. A 10-year study in Siaya and Embu, sub-humid areas of Kenya noted an increase in N supply of about 45 kg N ha^{-1} yr^{-1} and increased water holding capacity in a maize-soy bean crop rotation following biochar application (Kätterer et al. 2019). This resulted in better grain yields and reduced variations in the yields. Increased water holding capacity can help mitigate the impact of water scarcity with the current challenges of droughts owing to climate change and variability. Biochar can also enhance slow-release capacity by coating inorganic fertilizers such as urea thus reducing N leaching (Dimkpa et al. 2023).

Pesticide use and implications

Pesticides are widely used across Sub-Saharan Africa in crop production to control pests and improve crop yields, with South Africa being the largest user (Horak, Horn, and Pieters 2021). Poverty, weak regulatory systems, illiteracy, food insecurity, and rapid population growth have driven the increased use and misuse of pesticides in Africa (Larramendy and Soloneski 2019). As a result, environmental implications have become a major concern, including soil degradation, water contamination, airborne drift, and harm to non-target species. Excessive and improper use of pesticides, coupled with improper disposal of pesticide packaging material, potentially result in these environmental concerns.

A survey of market gardening (cabbage, onion, beetroot, chili pepper, and carrot) around Kalsom dam in Togo revealed that most of the farmers disposed of expired pesticides and pesticide packaging material by burning, followed by disposal in the soil and dam (Kpiagou et al. 2023). Similarly, another study in South Africa found current-use pesticides in the soil and air of two agricultural sites in the Western Cape indicated in Table 3 (Degrendele et al. 2022).

Elsewhere in Ethiopia, organophosphates and pyrethroid pesticides were found in water samples from Lake Ziway attributed to agricultural and urban activities (Merga et al. 2021). Air, water, and soil contamination by pesticides potentially disrupts and destroys the ecosystems' health and functionality. For instance, their persistence in air, water, and soil contributes to biodiversity loss (Horak, Horn, and Pieters 2021; Larramendy and Soloneski 2019; Yahyah, Kameri-Mbote, and Kibugi 2024), further compromising the provisioning of ecosystem services. Pesticide residues in agricultural soils can reduce soil fertility over time, making crops more susceptible to diseases and pests and creating a cycle of dependency on chemical inputs.

Table 4: Current-use pesticides found in Hex River and Grabouw agricultural sites of Western Cape, South Africa (Degrendele et al. 2022)

Soil	Air	
Atrazine	Acetochlor	Malathion
Carbary	Alachlor	Simazine
Chlorpyrifos	Atrazine	Tebuconazole
Diazinon	Azinphos methyl	Terbuthylazine
Isoproturon	Diazinon	Carbendazim
Pirimicarb	Dimathachlor	Propiconazole
Simazine	Metazachlor	S-metolachlor
Tebuconazole	Carbaryl	
Terbuthylazine	Chlorpyrifos	

Pesticide contamination harms soil organisms including earthworms, bacteria, and fungi that enhance nutrient cycling and soil fertility (Yahyah, Kameri-Mbote, and Kibugi 2024). This implies depreciated soil health in turn contributing to low crop productivity. Water contamination affects aquatic organisms, with the pesticide mixtures having grave effects on fishes and arthropods (Merga et al. 2021). These pesticides threaten biodiversity and ecosystem functioning, ultimately impeding sustainable food and agricultural systems (Table 3).

Table 5: Pesticides with chronic risks on aquatic and terrestrial organisms in South Ghana (Onwona-Kwakye, Hogarh, and Van den Brink 2020)

Aquatic organisms		**Terrestrial soil organisms**	
Lambda cyhalothrin	Carbendazim	Glyphosate	Carbendazim
Chlorpyrifos	Sulphur	Chlorpyrifos	Maneb
Cypermethrin	Maneb	Imidacloprid	Copper hydroxide
Dimethoate	Copper hydroxide	Dimethoate	Cuprous oxide
Mancozeb		Mancozeb	

Note: First-tier environmental risk assessment

The use of pesticides in agriculture often leads to a vicious cycle of dependency and escalating environmental damage. Initially, pesticides effectively control pests, but over time, pests can develop resistance, necessitating the use of higher doses or more potent chemicals (Larramendy and Soloneski 2019). This increased use further degrades soil health and harms beneficial organisms essential for crop production, such as bacteria important for nutrient cycling and pollinators like bees. As soil health declines, farmers become more reliant on chemical inputs to maintain crop yields, perpetuating a cycle of dependency that exacerbates environmental harm and undermines sustainable agricultural practices.

Integrated pest management (IPM) is a possible solution to these environmental concerns. IPM is a holistic approach that combines biological, cultural, physical, and chemical methods to control pests in an environmentally sustainable manner (FAO 2024). Unlike conventional pesticide-heavy practices, IPM emphasizes understanding local conditions and using a combination of strategies to minimize pest damage while reducing reliance on chemical pesticides (FAO 2024; GIZ 2018).

Integral to IPM are biological control agents, such as beneficial insects, fungi, and bacteria, that naturally suppress pest populations. For instance, ladybugs and parasitic wasps can be introduced to control aphid infestations (GIZ 2018), reducing the need for chemical insecticides. Greenhouse trials in Tanzania found that a mixture of predatory ladybird beetles (*Hippodamia variegata* Goeze, *Chilocorus calvus* Chiccl, and *Cheilomenes propinqua* Mulsant), an entomopathogenic fungus (*Aspergillus flavus)*, and a parasitoid *(Aphidius Colemani)* effectively controlled bean aphid in kalanchoe crops (Nordey et al. 2021). This suggests their potential for aphid management in crops such as beans and green leafy vegetables.

Additionally, IPM encourages the inclusion of cultural practices such as crop rotation, intercropping, and the use of pest-resistant crop varieties, which help to disrupt pest life cycles and reduce their impact (FAO 2024; GIZ 2018). IPM further incorporates physical methods including traps, barriers, and manual removal. These techniques can effectively manage pest populations without introducing harmful chemicals into the environment. A review indicated that integrating crop rotation, push-pull technology, pheromone traps, biological control methods, and cultivating resistant varieties is effective in controlling fall armyworms in Africa (Akinyemi 2021). Fall armyworm is common in maize, millet, and sorghum, among other crops, and it causes an estimated yield loss in maize in Cameroon ranging from 15% to 78% annually (Akeme et al. 2021). Considering the gravity of fall armyworm damage to maize in Africa (Tambo et al. 2023), this has implications for increased use and misuse of pesticides with detrimental environmental effects. This highlights the significance of IPM. Chemical controls are used in IPM as a last resort and are applied in a targeted and judicious manner (Akeme et al. 2021; GIZ 2018). In this case, farmers should use less toxic and more selective pesticides that have minimal impact on non-target species and the environment. This selective approach helps to preserve beneficial organisms and reduce the risk of pesticide resistance and accumulation in the environment. IPM helps to protect soil health, water quality, and biodiversity, contributing to sustainable agriculture and environmental conservation.

GHG emissions

Greenhouse gas (GHG) emissions are a major concern with agronomic practices in Sub-Saharan Africa. Agriculture is a major contributor to GHG emissions, primarily through CH_4, N_2O, and CO_2. The emissions are largely emitted from livestock digestion, manure management, rice production, and soil management, including the use of synthetic and organic fertilizers (Ntinyari and Gweyi-Onyango 2021). Moreover, soil degradation, exacerbated by unsustainable agronomic practices, contributes to GHG emissions (Musafiri et al. 2020) and reduces the soil's ability to sequester C.

The application of nitrogen-based fertilizers (organic and inorganic) is a major source of N_2O and CH_4 emissions (Atedhor 2023; Falconnier et al. 2023; Musafiri et al. 2020; Ntinyari and Gweyi-Onyango 2021), with indirect contributions to CO_2 emissions (Ntinyari and Gweyi-Onyango 2021). In Sub-Saharan Africa, overuse or inefficient use of fertilizers can exacerbate these emissions. Trials in the Central Highlands of Kenya recorded the highest N_2O and CO_2 emissions under synthetic fertilizer use, compared to the combined use of synthetic fertilizer with manure and the sole application of manure in maize cultivation (Musafiri et al. 2020). This could be attributed to increased NUE with the combining of organic and inorganic fertilizers. A global meta-analysis review by Shakoor et al. (2021) concluded that manure application, especially poultry manure, significantly increases GHG emissions. This has implications for the need for proper management of manures and fertilizer.

The 4R strategy of fertilizer application has the potential to reduce these emissions by increasing N use efficiency (Falconnier et al. 2023). Proper management of animal manure, such as covering it or digesting it using anaerobic digesters before use potentially reduces emissions. Furthermore, incorporating organic farming practices and using leguminous cover crops can naturally improve soil fertility, reduce the need for synthetic fertilizers, and thus lower GHG emissions.

Agronomic practices that alter the soil have a significant contribution to GHG emissions. For example, in a semiarid area in the Eastern Cape of South Africa, conventional tillage increased CO_2 fluxes by roughly 26.3% and resulted in lower carbon stocks at the topsoil compared to no-tillage in maize cropping systems (Nyambo, Chiduza, and Araya 2020b). Similarly, findings by O'Dell et al. (2020) in Harare, Zimbabwe recorded lower CO_2 emissions under conservation tillage with cover cropping relative to conventional tillage and fallow in maize production. Conservation agriculture practices, including minimal soil disturbance, maintaining soil cover, and crop rotation, can enhance soil carbon sequestration (Nyambo, Chiduza, and Araya 2020b; O'Dell et al. 2020), which offsets some of the emissions from agricultural activities.

Various forms of soil degradation in agricultural production enhance GHG emissions. These include deforestation, overgrazing, and improper irrigation, which lead to soil compaction, erosion, loss of SOM, and depleting soil fertility. This degradation diminishes the soil's ability to sequester C, thus increasing emissions. Deforestation and burning of fossil fuels increase CO_2 concentrations in the atmosphere (Shakoor et al. 2021). Expanding agricultural land through deforestation and using fossil fuels in agricultural machinery like tractors and irrigation pumps, thus contribute to GHG emissions.

Moreover, soil compaction increases N_20 emissions by reducing oxygen supply in the soil (Pulido-Moncada, Petersen, and Munkholm 2022). Agricultural practices such as using heavy machinery, intensive grazing, and repeated or intensive tillage contribute to soil compaction. This compaction limits root growth, reduces water infiltration, decreases the soil's ability to store C, and enhances GHG emissions. Implementing practices like controlled traffic farming, reduced tillage, and maintaining soil cover can help alleviate soil compaction and its associated negative impacts on GHG emissions (Pulido-Moncada, Petersen, and Munkholm 2022).

Plastic pollution in crop production

Plastics have become an integral part of modern agronomic practices, offering benefits in terms of efficiency and productivity, but also posing significant environmental challenges. Plastics are widely used as mulch films (Dube and Okuthe 2024), greenhouse covers, irrigation pipes (Ragoobur, Huerta-Lwanga, and Somaroo 2021), pesticide containers, fertilizer bags, and seedling trays. These plastic materials offer several benefits, including conserving soil moisture, controlling weeds, enhancing plant growth, and improving the overall management of soil and water resources. Plastics may be introduced into agricultural soil unintentionally, for instance, through plastic-contaminated compost and sewage sludge (UNEP 2021). The environmental impacts of plastics in agricultural soil and beyond the soil ecosystem are substantial.

Primarily, the persistence of plastic in the environment is of concern. Plastics often break down into smaller particles known as microplastics and nanoplastics (MNPs) (Dube and Okuthe 2024; UNEP 2021), which can remain in the soil for decades. This breakdown starts on the surface of the plastic soon after exposure to the environment (UNEP 2021) and is aggravated in Sub-Saharan Africa due to the harsh environmental conditions (Dube and Okuthe 2024). The MNPs can disrupt soil structure, affect soil organisms, and potentially enter the food chain, raising concerns about food safety and human health. Walker (2021) records that plastic contamination may impede progress in the implementation of the sustainable development goals (SDGs).

While Africa is an emerging market for controlled-release fertilizers (Farmers Review Africa 2022), including polymer-coated NPK (Mordor Intelligence 2024), it's crucial to consider the potential impact of plastic pollution. Polymer-coated fertilizers target production of cereals and grains, pulses and oilseeds, turf and ornamentals, and fruits and vegetables (Mordor Intelligence 2024). In addition, plasticizers like polyethylene and polyvinyl acetate are included in coating materials for urea fertilizer to enhance slow-release capacity, for improved NUE, and reduced leaching and evaporative losses of N (Beig et al. 2020). According to UNEP (2021) the plastic polymer encapsulation of controlled-release fertilizers can lead to soil contamination through microplastics. Farmers can use biodegradable options, including coating these fertilizers with biochar.

The accumulation of plastic debris in agricultural fields can hinder soil health and productivity. Over time, plastic residues can impede root development and water infiltration, leading to reduced soil fertility and crop yields. This necessitates regular removal and proper disposal or recycling of agricultural plastics, which can be costly and labour-intensive. Moreover, the production and disposal of plastics contributes to greenhouse gas emissions, exacerbating climate change (Shen et al. 2020). The disposal of plastics through burning or landfilling can release toxic substances and further contribute to soil, water, and air pollution.

The use of plastics in agriculture requires significant investments in research for long-term sustainability. The Food and Agriculture Organization (FAO) is working on a Voluntary Code of Conduct on the sustainable use of plastics in agriculture (VCoC), which aims to strengthen policies and strategies in the agricultural chain (FAO 2023). Considering the current use, the implementation of plastic circular measures consisting of repair, recycle, and reuse underpin environmental conservation (Dube and Okuthe 2024). To further reduce plastic waste, biodegradable mulch films are currently being developed (Shah and Wu 2020); however, accessibility may be limited by financial constraints. Coupled with plastic circular measures, smallholder farmers should integrate other soil and water conservation measures such as crop residue retention and the use of live mulch during production.

Annex 3: Assessment of agronomic practices: Impacts and sustainable solutions

Planet hostile (unsustainable) practices	Environmental degradation implications	Planet-friendly agronomic practice (Solution)	Mechanism
Deforestation for agriculture	Habitat destruction and biodiversity loss Soil erosion (Kirui, Mirzabaev, and von Braun 2021) Soil moisture loss Soil organic carbon loss (de Blécourt et al. 2019) Soil fertility decline (Kirui, Mirzabaev, and von Braun 2021) Water pollution Greenhouse gas emissions (Ntinyari and Gweyi-Onyango 2021; Shakoor et al. 2021)	Agroforestry (with leguminous shrubs) (Akpalu, Dawoe, and Abunyewa 2020; Amadu, Miller, and McNamara 2020; Bogale and Bekele 2023; Koutika et al. 2021; Kuyah et al. 2019; Shidiki, Ambebe, and Awazi 2020)	Agroforestry enhances soil organic matter and nutrient cycling, reduces soil erosion, conserves soil/water through improved root systems and canopy cover, and lowers GHG emissions by sequestering carbon in trees and soil. It creates diverse habitats for plants and animal species
Slash and burn agriculture	Habitat destruction and biodiversity loss Greenhouse gas emissions (Alhassan 2021) Soil organic carbon loss Soil fertility decline	Agroforestry (with leguminous shrubs) (Akpalu, Dawoe, and Abunyewa 2020; Bogale and Bekele 2023; Koutika et al. 2021; Shidiki, Ambebe, and Awazi 2020)	Agroforestry enhances soil organic matter and nutrient cycling, reduces soil erosion, conserves soil/water through improved root systems and canopy cover, and lowers GHG emissions by sequestering carbon in trees and soil. It creates diverse habitats for plants and animal species

Planet hostile (unsustainable) practices	Environmental degradation implications	Planet-friendly agronomic practice (Solution)	Mechanism
Conventional/traditional tillage	Soil erosion/runoff (Obia et al. 2020; Simwaka et al. 2020)	Conservation tillage (Obia et al. 2020; J. Kihara et al. 2020) e.g., No-tillage (Fatumah, Tilahun, and Mohammed 2020) reduced tillage (Adimassu, Alemu, and Tamene 2019)	Conservation tillage reduces runoff and erosion by maintaining a protective cover of crop residues that absorb rainfall and slow water movement, while also conserving soil moisture by minimizing soil disturbance and reducing evaporation
		Agroforestry (Bogale and Bekele 2023; Kuyah et al. 2019; Shidiki, Ambebe, and Awazi 2020; Waweru et al. 2024)	The extensive root systems of trees and shrubs bind soil particles, the protective canopy cover intercepts rainfall and reduces surface runoff, organic matter from tree litter enhances soil structure and infiltration (this enhances soil moisture storage), and windbreaks decrease wind erosion
		Poultry manure application (Udom, Wokocha, and Ike-Obioha 2024) Biochar application (Agbede and Adekiya 2020; Obia et al. 2020)	The practices improve soil structure by enhancing soil hydraulic properties, which leads to better water infiltration, consequently controlling runoff and erosion.
	Soil moisture loss (Obia et al. 2020)	Crop residue retention (Dugan et al. 2022) Mulching (Akplo et al. 2022; Dugan et al.	The practices maintain a protective cover on the soil surface, reducing evaporation, increasing infiltration, and slowing down water movement to protect the soil from being washed away. They also build

Planet hostile (unsustainable) practices	Environmental degradation implications	Planet-friendly agronomic practice (Solution)	Mechanism
		2022; Fatumah, Tilahun, and Mohammed 2020)	organic matter, enhancing the soil's water-holding capacity
		Intercropping/ crop rotation systems with deep-rooted legumes (Maya and Maphosa 2020; Mugi-Ngenga et al. 2023)	The deep roots access moisture from lower soil layers, improving soil structure and porosity for better water infiltration, the legumes provide soil cover to reduce evaporation and contribute organic matter to enhance the soil's water-holding capacity
	Soil organic carbon loss	Conservation tillage (Kisaka et al. 2023) Intercropping with legumes (Kisaka et al. 2023; Simwaka et al. 2020) Crop residue retention (Nyambo, Chiduza, and Araya 2020a) Biochar application (Nyambo, Chiduza, and Araya 2020a) Combined use of compost and inorganic fertilizers (Mamuye et al. 2021) Organic farming/manure	The practices preserve or build soil structure and organic matter, and the decomposition of this organic matter releases nutrients and carbon into the soil

Planet hostile (unsustainable) practices	**Environmental degradation implications**	**Planet-friendly agronomic practice (Solution)**	**Mechanism**
	Soil fertility decline	Conservation tillage (Kisaka et al. 2023)	Minimizes soil disturbance, preserving soil structure, and enhancing the accumulation of organic matter and nutrients in the soil
		Integrated soil fertility management (Boansi, Owusu, and Donkor 2024; Otieno 2023; Zingore 2023)	Combining organic and inorganic fertilizers with other conservation practices builds soil fertility and health
		Combined use of compost and inorganic fertilizers (Ejigu et al. 2021; Mamuye et al. 2021) Inorganic fertilizers (Amfo and Baba Ali 2021; Jjagwe et al. 2020; Job Kihara et al. 2022; Mamuye et al. 2021; Omar et al. 2023) Organic fertilizers (Amfo and Baba Ali 2021; Jjagwe et al. 2020)	The supply macro and micronutrients to the soil
		Biochar application (Agbede and Adekiya 2020)	The practice enhances soil organic matter, whose decomposition supplies macro and micronutrients to the soil

Planet hostile (unsustainable) practices	Environmental degradation implications	Planet-friendly agronomic practice (Solution)	Mechanism
		Agroforestry with leguminous shrubs (Akpalu, Dawoe, and Abunyewa 2020; Amadu, Miller, and McNamara 2020; Koutika et al. 2021; Kuyah et al. 2019) Intercropping with legumes (Kisaka et al. 2023; Mugwe, Ngetich, and Otieno 2019)	Legumes enhance biological nitrogen fixation and soil organic matter boosting soil fertility
	Greenhouse gas emissions (Nyambo, Chiduza, and Araya 2020a; O'Dell et al. 2020)	No tillage (Nyambo, Chiduza, and Araya 2020a) Minimum tillage (O'Dell et al. 2020)	The practices reduce GHG emissions owing to minimal or no soil disturbance
Excessive or improper use of inorganic fertilizers	Water pollution, eutrophication	Integrated soil fertility management (ISFM) 4R strategy of fertilizer application (Right source, right rate, right time, right place) (Falconnier et al. 2023; Job Kihara et al. 2022)	The approaches improve nutrient use efficiency which reduces leaching
		Coating inorganic fertilizers with biochar (Dimkpa et al. 2023)	Enhances slow release of nutrients, minimizing nutrient excesses in the soil and reducing chances of leaching

Planet hostile (unsustainable) practices	Environmental degradation implications	Planet-friendly agronomic practice (Solution)	Mechanism
Application of nitrogen-based fertilizers	Greenhouse gas emissions (Falconnier et al. 2023; Ntinyari and Gweyi-Onyango 2021)	Integrated soil fertility management (ISFM) 4R strategy of fertilizer application (Right source, right rate, right time, right place) (Falconnier et al. 2023; Job Kihara et al. 2022)	The practices improve nutrient use efficiency which reduces volatilization of nutrients
Application of organic fertilizers		Improved animal manure management e.g. covering during storage/ anaerobic digestion	The practices reduce the generation of GHG emissions. Nutrient-rich digestate from anaerobic digestion reduces the need for inorganic fertilizers which are associated with significant GHG emissions
Monocropping	Biodiversity loss (Mwakilili et al. 2021; Nassary, Baijukya, and Ndakidemi 2020) Increased pest vulnerability (Berdjour et al. 2020) Soil fertility decline (Berdjour et al. 2020; Mthembu, Everson, and Everson 2019) Soil organic carbon loss (Kisaka et al., 2023)	Intercropping (Nekesa et al. 2024) Push-pull technology (Mwakilili et al. 2021; Nekesa et al. 2024) Crop rotation (Mustafa et al., 2019) Agroforestry (Mustafa, Mayes, and Massawe 2019)	The practices enhance habitat diversity and/or species diversity and increase soil organic carbon and fertility by improving nutrient cycling, soil structure, and microbial activity
Inefficient irrigation practices (Daba and Qureshi 2021;	Salinization (Daba and Qureshi 2021;	Precision irrigation methods e.g. drip irrigation	The practices improve soil structure and infiltration, preventing/reducing

Planet hostile (unsustainable) practices	Environmental degradation implications	Planet-friendly agronomic practice (Solution)	Mechanism
Mohanavelu, Naganna, and Al-Ansari 2021) e.g., flood irrigation	Mohanavelu, Naganna, and Al-Ansari 2021)		waterlogging and Salt buildup on the soil surface, and the runoff of these salts. Mulching and crop residue retention further protect the soil from evaporation, reducing salt buildup even more
	Sodification (Daba and Qureshi 2021; Mohanavelu, Naganna, and Al-Ansari 2021)	Minimum tillage (Daba and Qureshi 2021) e.g., ripping (Omar et al. 2023)	
	Surface water contamination, eutrophication	Mulching (Daba and Qureshi 2021)	
	groundwater contamination (Mohanavelu, Naganna, and Al-Ansari 2021)	Crop residue management (Daba and Qureshi 2021)	
	Waterlogging	Agroforestry (Mohanavelu, Naganna, and Al-Ansari 2021) Planting deep-rooted crops (Mohanavelu, Naganna, and Al-Ansari 2021) Biochar application (Omar et al. 2023) Manure application (Omar et al. 2023)	The practices improve soil structure and drainage for waterlogging and salinity management
Excessive/ improper pesticide use	Water pollution (Kpiagou et al. 2023; Merga et al. 2021)	Integrated pest management (IPM) (FAO 2024; GIZ 2018)	IPM utilizes chemical pesticides as the last option for reducing the environmental impacts

Planet hostile (unsustainable) practices	Environmental degradation implications	Planet-friendly agronomic practice (Solution)	Mechanism
	Soil and air pollution (Degrendele et al. 2022)		
Disposal of pesticides and packaging by burning or in the soil or water	Biodiversity loss (Horak, Horn, and Pieters 2021; Larramendy and Soloneski 2019; Onwona-Kwakye, Hogarh, and Van den Brink 2020; Yahyah, Kameri-Mbote, and Kibugi 2024) Soil fertility decline (indirectly) (Yahyah, Kameri-Mbote, and Kibugi 2024)		

Note: Planet-friendly practices encompass sustainable production technologies, approaches, or cropping systems. These practices can be implemented concurrently within a crop production cycle to enhance synergies among them.

Annex 4: Background information on environmental impact along the supply chain

The transport systems and processing mechanisms impact both anthropogenic-based emissions as well as chemical, biological, and physical interactions (González, Frostell, and Carlsson-Kanyama 2011). An increase in the world's energy demand increases environmental damage due to growth in fossil fuels.

Globally, bioenergy provides approximately 10% of energy supplies with 80% of it coming from renewable sources (Popp et al. 2014). With an average energy demand of 20% of the global scale, the shipment and transportation sector is one of the fastest-growing biofuels representing 3% to 4% of road transport and a total of 5% of bioenergy use. This trend incorporates shipping and aviation which have a comparatively lower projection to the road with projections of less than 30% by 2050, with a current 2% of CO_2 emission.

Consequently, the transport system, based on a case study of Canada accounts for one of the highest pollution levels, contributing 24% of all greenhouse gas emissions, a trend that is closely followed by the United States (Olia et al. 2016). These findings are in congruence with the average global contribution which averages 23% of CO_2 emissions and 15% of greenhouse gas emissions (Wang, Zhuang, and Lin 2016).

In Sub-Saharan Africa, the lack of formal public transport systems, lax regulations of vehicle importations, increasing urbanization and increase in gross-product per capita is associated with an increase in vehicle ownership. Mbandi et al. (2023) emphasizes that in addition to the increasing number of vehicles, emissions from road transport are exacerbated by the high average age of the fleet which is mainly composed of imported second-hand vehicles (accounting for ~90% of vehicles in SSA), poor fuel quality, poorly maintained roads, lack of vehicle emission regulations and inadequate implementation of vehicle inspection and maintenance programmes (Mbandi et al. 2023).

According to estimates done by Mbandi et al. (2023) "The contribution of Kenya's transport sector emissions from road transport, domestic shipping, railway and domestic aviation for 2010, are shown in Figure 2. International shipping and international flights were not accounted for in the national emissions inventories. Road transport dominates transport emissions of all pollutants. However, the contribution of different modes of road transport varies. Heavy-duty vehicles and urban buses account for 62% of NO_X and 49% of BC road transport emission estimates. Motorcycles dominate NMVOC, OC, CO and $PM_{2.5}$ road transport emissions, while passenger cars contribute most to estimated NH_3, CH_4, and CO_2 road transport emissions."

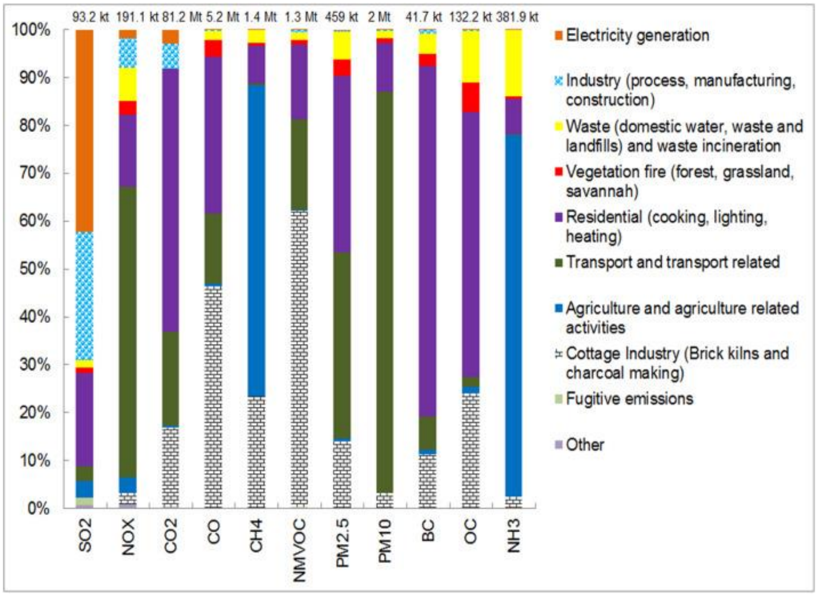

Figure 2: Fractional sectorial contribution by emitted species in 2010 in Kenya (Mbandi et al. 2023)

While food production plays a significant role in environmental footprints, the transportation of food, especially perishable products, contributes to planetary well-being. Informed by the increased vulnerability to shocks and risks that include the increasing cost of food, conflict, and climate change today's food systems negatively affect the environment by exposing its vulnerability to these stressors, especially in fragile contexts which are inhabited by over 23% of the world's population (WFP 2022).

Half of the energy usage in the production and delivery of fruits and vegetables that travel long distances is associated with transportation (Wikoff, Rainbolt, and Wakeland 2012). In the UK, it was reported that food transport accounts for 1.8% of total greenhouse emissions with a further 18,444 kt of CO_2 emissions (Tassou, De-Lille, and Ge 2009). These emissions and the magnitude of energy from transportation vary from one food product to another.

Consumer behaviors and food choices are determining factors in environmental health by impacting the amount of CO_2 emissions. This is informed by the different extent of emissions by food products. Between 7% and 1.3% emission was recorded when transporting 1kg of beef from Argentina to Gothenburg (González, Frostell, and Carlsson-Kanyama 2011). Comparatively, when grains were transported from Brazil to Sweden, about 60% of total emissions and energy were recorded.

Most of these GHGs emitted from value addition and processing are a result of natural gas, electricity, coal, and diesel, among other sources. Additionally, boilers, cookers, and furnaces emit CO_2. On the other hand, methane and nitrous oxide are by-products of wastewater.

The choice of the mode of transportation of food is primarily dependent on the shelf life of the food product, the cost of fuel, and the distance to be covered (Hammond et al. 2015). Due to the high interdependence between efficiency and speed, air transport is preferred for foodstuffs with a shorter shelf-life. As a result, airplanes are used to transport products such as meat, fresh seafood, and green leafy vegetables. However, this transport mode is costly.

Elsewhere, foodstuffs such as grains and beans do not have a perishability concern making travel time a non-issue and transportable by rail, ship, or road. Furthermore, collaborative findings have shown that the climatic impact of the transport system is ascribed to intrinsic product factors including the moisture content of the product as observed in the transportation of legumes (Tidåker et al. 2021).

Hammond et al. (2015) visualized the evolution of the transport of foodstuffs over time showing that distance food was transported has significantly increased over time (Figure 2).

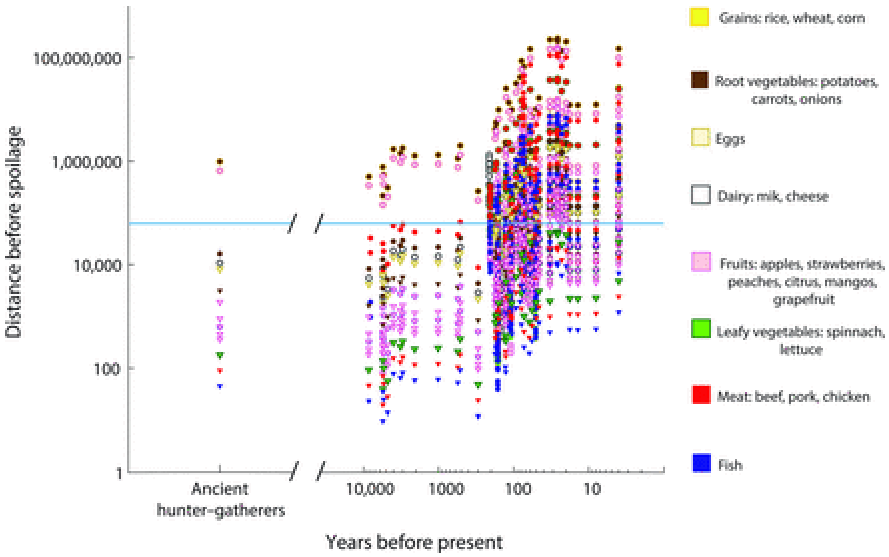

Figure 3: The evolution of the human capacity to transport food before it spoils throughout history (Hammond et al. 2015)

Annex 5: Background information on environmental impact of storage systems

The outcomes of the United Nations Climate Change COP 28 underscore the importance of pursuing sustainable food systems and climate action through the adoption of a holistic whole-of-system approach. Although storage technologies contribute to reducing postharvest food losses and waste, they significantly impact greenhouse gas emissions. Even though a lot of focus has been on food production and distribution, storage of home-grown foods plays a key role in environmental quality and safety. With warehousing becoming an important pillar in the food value chain, warehousing emissions are attributed to air conditioning, cooling, heating, and lighting (Fichtinger et al. 2015). These factors are influenced by stockholding levels, inventory management, and warehouse design among other convergent elements including the type of equipment, and warehouse throughput.

Cold storage systems have a significant environmental impact. Ranging from bulk cold stores, multi-purpose cold stores, small cold stores, frozen food stores, walk-in stores, and controlled atmosphere cold stores are designed for post-harvest handling by temperature reduction of fresh produce. This procedure is underpinned by the cooling design which reduces the respiratory rate, minimizes water loss, and therefore boosts the shelf stability of the raw produce through decelerating the rate of decay. The refrigeration system is associated with the consumption of half of the energy used in supermarkets (Mylona et al. 2017). Thus, a notable environmental footprint has resulted from this mode of storage. In the UK, food chain refrigeration was reported to emit 13,720 kt of CO_2 with 35% coming from direct emissions and 65% indirectly exuded. With the global electricity consumption through refrigeration estimated at 440 kWh/year/capita, fluorocarbons subscribe to 20% of greenhouse gas emissions (Burek and Nutter 2020). Reducing emissions requires cutting down energy consumption and optimizing the efficiency of storage systems. This can include but is not limited to utilizing LED lighting, using closed display cabinets, and energy-saving anti-sweat heaters and defrosts (Mylona et al. 2017).

Annex 6: Key Findings from the Key Informant Interviews among WFP staff

The study adhered to the Institutional Review Board (IRB) of the Alliance of Bioversity and CIAT. A comprehensive value chain assessment involved conducting key informant interviews (KII) as the primary data collection methodology. This provided insights and perspectives into the WFP-led acquisition of foodstuffs. For a clear understanding of the current work in reducing the environmental impact of the supply chain, its activities, and associated value chain players, focal persons from different professional backgrounds within the supply chain in WFP, both at the headquarters and regional offices, were engaged through virtual interviews (KII). These included the following:

- Supply chain officer
- Supply chain sustainability officer
- Smallholder market access officer
- School meals, social protection, and meal planning officer
- Regional school feeding advisor
- Nutrition data analyst
- Homegrown school feeding procurement expert
- Food systems and nutrition analyst
- Food fortification and nutritious foods development officer

Key assessment questions were developed by the evaluation team. Interviews were adopted based on the area or work of the interviewed person. Interviews were recorded and transcribed automatically. Transcribed raw data underwent processing, cleaning, and organization. Based on the identified key criteria, the transcripts were labelled by thematic coding and the development of an objective-specific framework for ease of presentation. This was done using MAXQDA version 24. Table below shows the thematic coding overlay as per the outcome of the discussions with the key informants in the different levels of the supply chain.

Table 6: Code frequence by professional area of engagement

	Food fortify-cation and Nutritious Foods Develop-ment	Food Systems and Nutrition Analyst	Home-grown School Feeding Procure-ment Expert	Nutrition Data Analyst	Regional School Feeding Advisor	School Meals, Social Protection Service, and Meal Planning	Small-holder Market Access	Supply Chain Officer	Supply Chain Sustain-ability Officer	Total
Sustainability Segmentation	4	6	2	10	9	6	0	6	4	47
Intersecting Policies, Processes, and Actors	10	2	5	0	11	12	17	7	2	66
Sustainability Criteria and Standards	2	4	4	4	6	2	3	6	4	35
Technology and Innovation	0	6	0	5	2	7	1	6	2	29
Environmental Impact Assessment	2	0	0	2	1	1	1	9	8	24
Planetary Health Indicators	2	7	5	0	4	5	17	10	5	55
Supply Chain Management	8	4	12	9	14	26	25	9	5	112
SUM	28	29	28	30	47	59	64	53	30	368
N = Documents	1	1	1	1	1	1	1	1	1	9

*The intersecting figures represent the number of times a given thematic code appeared in the discussion.

Planetary Health Indicators

Finding 1.1: The World Food Programme (WFP) incorporates standards in its procurement system to address food safety and minimally on climate-friendly practices. These standards include microbial analysis of procured grains and focus on reducing solid waste and greenhouse gas emissions. Key indicators such as water footprint, greenhouse gas emissions (measured in kilograms of CO2 equivalents per kilogram of food), and land use (measured in square meters) are of interest. Despite the potential to mitigate environmental impact, there is a lack of defined procurement methodologies for a climate-smart supply chain approach. Suggestions for improvement include using drought-tolerant crops and investing in regenerative agriculture.

> *So, when we're talking about, for example, Cambodia, there was a high interest in talking about greenhouse gas emissions and minimization and mitigation of greenhouse gas emissions. And this is something we have had an interest in.*

Finding 1.2: Factors such as food storage, handling, and preparation also influence environmental impact, particularly through energy consumption in refrigeration and cooking. Traditional cooking methods using firewood emit smoke, impacting air quality. Introducing clean energy solutions for cooking, as seen in Rwanda's pilot project in providing clean energy cooking for schools, offers sustainable alternatives. However, achieving widespread adoption of clean cooking energy requires improving access, especially in rural areas, to fully realize its benefits for planetary health.

> *For example, the Government of Rwanda even did a study last year to look at clean energy for cooking in schools……..Rwanda is looking at what type of energy they can integrate into the school feeding programme.*

Finding 1.3: The transportation system and modes used significantly impact environmental change, primarily assessed by the distance traveled in kilometers. The World Food Programme (WFP) manages transportation for food acquisition in school feeding programs, which typically involves the use of fossil fuels and thus contributes to greenhouse gas emissions. These emissions are a concern across various transport modes including road, shipping, and aviation. Reducing these emissions is crucial for mitigating environmental impact in WFP's operations.

> *For GG emission, we cover production, upstream transport, warehousing processing (if there is any processing), and downstream transport up to the distribution.*

Finding 1.4: Waste management in food systems involves addressing both postharvest loss and waste. Various stakeholders, including farmers and cooperatives, play roles in minimizing environmental impact through proper energy use, including energy-saving and clean energy sources, and efficient cold storage facilities. Food processing, which involves complex conversions, often includes drying produce before storage to improve shelf stability and reduce perishability, particularly for highly perishable items like leafy vegetables. These practices serve planetary health goals by giving an operational opportunity to reduce waste and improve resource efficiency in the food supply chain.

Intersecting policies, activities, and actors

Finding 2.1: Homegrown school feeding programs have far-reaching impacts on planetary health through various enterprises. Grain fortification, championed by the Whole Grain Alliance and Rockefeller initiative, is a key initiative. John Hopkins University assesses the environmental impact of food systems. Additionally, Capgemini, a tech company from the Netherlands, contributes digital solutions expertise.

Finding 2.2: Food monitoring and inspection are covered under the second layer of assessment. This is conducted by WFP inspectors or third parties in processing units for the case of highly processed commodities. The testing is done in countries with ISO 17025-accredited laboratories. To preserve the quality and safety of the processed foodstuffs, they are distributed for utilization within a period of two weeks. The current focus is on building digital solutions with comprehensive team efforts.

> *That is the second layer and the third layer is inspection and monitoring in case of highly processed commodities. WFP also deploys their inspectors or a third party in the processing unit throughout the process, but that is for the very highly processed commodities for this kind of commodities like maize and rice, which are the staples.*

Finding 2.3: The choice of suppliers is on a need basis as well as their production, processing capacity, food safety, quality system capacity, storage capacity, and logistical approaches. While large-scale processors are considered big players in procurement, medium-scale capacity, and small-scale vendors are appreciated by WFP. However, there is much work to be done in terms of food safety, quality implementation, and capacity strengthening to bring them to par with the large-scale players.

Finding 2.4 WFP collaborates with FAO and other networks for homegrown school feeding programmes. This includes supporting South-South cooperation, capacity strengthening and working across sectors including health, education, agriculture, and finance. Furthermore, there is involvement of local governments and various stakeholders in school feeding initiatives with an emphasis on sourcing food commodities from smallholder farmers and supporting strategic planning and coordination in school feeding programs. Partnerships include the Rockefeller Foundation and Nova Nordisk for sustainability focusing on enhancing smallholder market access and improving agricultural practices.

> *So, we have all these sectors, health, education, agriculture, finance you know, to some extent, even local government and water and sanitation and all these other key sectors involved in the programmes.*

Supply chain management

Finding 3.1: WFP's involvement and support in school meal programs vary by country, sometimes leading them, and also by offering technical support in the development of procurement policies and guidelines. This is done by designing and implementing school feeding programs aligned with national priorities. In some countries, WFP engages in procurement from smallholders for school meals. The transition of school meal program management from WFP to government is at an advanced stage in some countries like Benin.

> *However, for Benin, I can inform you that for now, this is WFP that is leading the school meal programme, but it is planned to be transferred to the government by the end of this year. The policy is ready but it has not yet been implemented which is to be handed over.*

Finding 3.2: In WFP-led school feeding programmes, WFP emphasizes food safety and quality through joint assessments with suppliers. The organization works closely with governments and other partners to enhance program effectiveness and sustainability. Additionally, vendor management committees at WFP oversee procurement processes. WFP further uses a centralized or decentralized model for school meal programs based on local contexts. Under this modality, WFP maintains rosters of approved vendors for procurement.

Finding 3.3: Once there is a self-sustainable and sufficient establishment, the school-feeding programmes are transferred to the respective governments. Local procurement policies aim to support regional agricultural economies. Examples from Rwanda highlight successful procurement from fortification processors. Nevertheless, challenges include scarcity of data and emerging technical fields as well as ensuring food safety standards are met when procuring locally.

> And Rwanda is a good case, you know because it is a national programme at the moment if I remember correctly, the government already invested, and took over at least 3.8 million children under the homegrown school feeding

Finding 3.4: There is an interest in integrating environmental considerations into supply chain management tools within WFP. Collaboration with governments and regional offices is crucial for programme alignment.

Sustainability criteria and standards

Finding 4.1: The verification process for procured foodstuffs ensures nothing is distributed until confirmed. This further constitutes packages that include WFP beneficiary desk numbers for consumer complaints. However, quantitative monitoring of environmental impact is limited. Evaluation of nutrition targets across energy, macronutrients, and micronutrients is enhanced through the use of secondary data for assessing nutrition indicators and deficiencies.

Finding 4.2: There are opportunities in designing nutrition-sensitive food systems supporting smallholder farmers. These initiatives can further be enhanced through fostering collaboration with FAO, IFAD, and South-South Triangle for school feeding.

Finding 4.3: There exists an emphasis on fitting sustainability within national procurement standards by integrating environmental considerations in response to climate change. Some of these discussions in existence touch on centralized steam kitchens for urban school meal preparations. Furthermore, there is a need for advocacy for budget allocations in national budgets for school feeding.

> *In recent years, we've seen increased discussions around the contributions of school feeding, maybe to some of the environmental negative impacts that we are seeing predominantly in Africa most use firewood to prepare school meals. In Kenya, there are discussions on centralized steam kitchens right where they can prepare 30,000 meals in each kitchen for redistribution, but it's like I said, that works in the urban area or the cities.*

Finding 4.4: WFP local procurement policy aims to promote local economic development. Criteria include farming practices, intervention balance, and quality variables. Considerations for food production, land use, water use, and fertilizer use with a focus on economic, social, and environmental aspects of sustainability.

Sustainability segmentation

Finding 5.1: Maize and rice utilized for school feeding are sourced from approved suppliers who have to meet international standards. In the case of Burundi and Rwanda, they receive fortified maize meal using premix as per international standards. Samples undergo rigorous testing in WFP regional laboratories in Nairobi to ensure fortification compliance.

Finding 5.2: Within homegrown feeding programmes, local production is emphasized over imports. Capacity building for smallholder farmers is a priority. Similarly, WFP focuses on filling nutrient gaps in school feeding through cost-effective diet analysis through advocacy and analytics aimed at improving nutrition in school feeding programs.

> *We try to assess nutrient gaps by estimating the minimum cost of the diet and then the affordability of diets, and we interface with the school, feeding colleagues, and programs by modeling the school feeding, essentially assessing how nutritious they are and how they can be improved.*

Finding 5.3: WFP assesses nutrient adequacy of distributed rations globally. Life cycle assessments are being considered for commodity procurement. Although not adequately carried out, life assessment of Beans, which is a prominent component in school feeding programmes in countries like Rwanda has been done. Nutrition diversity, affordability, and environmental impact are key considerations.

Finding 5.4: Increased budget allocations in countries like Burundi for school feeding programs have the potential to contribute to climate impact mitigation efforts. While targeting sustainable approaches for meal preparation and procurement, context-specific challenges are addressed in different regions for effective implementation. Furthermore, WFP should ensure that sustainability criteria are integrated into its procurement processes while aiming to maintain community and humanitarian context in its operations.

> *When it comes to the stability question, it's not an answer that we can necessarily come to yet, but the idea is that we provide an equal playing field for everyone.*

Technology and innovation

Finding 6.1: Using new technologies and approaches such as linear programming, WFP is developing software for calculating the minimum cost of diets previously outsourced, now developed in-house. Furthermore, this constitutes nutrient adequacy and diet cost analysis which intersects planetary health considerations. However, these rely on secondary data including a database of food composition. Currently, there is an existing software piloted in Cambodia, expanding with multi-objective algorithm integration.

> *We have systems analysis tools that we use to gauge where a government is at, whether they are ready to begin to transition, and we come up with milestones together with governments, for example, that you know every year you have maybe 100,000 kids offloaded to the government programme.*

Finding 6.2: Collaborations in fostering technology and innovation include those with Johns Hopkins, and Tilburg University for data analytics and platform development. The primary focus is on economic access to nutritious diets and environmental footprint considerations.

Environmental impact assessment

Finding 7.1: Maize meal distributed in certain countries uses environmentally friendly packaging. WFP policy emphasizes environment-friendly packaging solutions. Plastic and non-environmentally friendly packaging materials are discouraged.

Finding 7.2: WFP aligns its actions with the UN environmental strategy through an Environmental Plan of Action. As a result, it considers greenhouse gas emissions and water footprint in its operations. In particular, there is concern about the impact of climate change on rice production and nutritional quality.

Adimassu, Zenebe, Getachew Alemu, and Lulseged Tamene. 2019. 'Effects of Tillage and Crop Residue Management on Runoff, Soil Loss and Crop Yield in the Humid Highlands of Ethiopia'. *Agricultural Systems* 168 (January):11–18. https://doi.org/10.1016/j.agsy.2018.10.007.

Agbede, T. M., and A. O. Adekiya. 2020. 'Influence of Biochar on Soil Physicochemical Properties, Erosion Potential, and Maize (Zea Mays L.) Grain Yield under Sandy Soil Condition'. *Communications in Soil Science and Plant Analysis* 51 (20): 2559–68. https://doi.org/10.1080/00103624.2020.1845348.

Akeme, Cyril Njume, Christopher Ngosong, Sally Alloh Sumbele, Aslan Aslan, Aaron Suh Tening, Courage Yaw Krah, Blair Moses Kamanga, Asep Denih, and Okolle Justin Nambangia. 2021. 'Different Controlling Methods of Fall Armyworm (Spodoptera Frugiperda) in Maize Farms of Small-Scale Producers in Cameroon'. *IOP Conference Series: Earth and Environmental Science* 911 (1): 012053. https://doi.org/10.1088/1755-1315/911/1/012053.

Akinyemi, A. O. 2021. 'Exploring Integrated Pest Management Strategies in the Control of the Fall Armyworm in Smallholder Organic Agriculture Farms in Africa'. *Agro-Science* 20 (3): 65–70. https://doi.org/10.4314/as.v20i3.9.

Akpalu, Stephen Edem, Evans Kwasi Dawoe, and Akwasi Adutwum Abunyewa. 2020. 'Effects of Faidherbia Albida on Some Important Soil Fertility Indicators on Agroforestry Parklands in the Semi-Arid Zone of Ghana'. *African Journal of Agricultural Research* 15 (2): 256–68. https://doi.org/10.5897/AJAR2019.14617.

Akplo, Tobi Moriaque, Félix Kouelo Alladassi, Mahougnon Charlotte Carmelle Zoundji, Julien Avakoudjo, Pascal Houngnandan, Dieudonné Gustave Dagbénonbakin, Aliou Saïdou, et al. 2022. 'Impact of Conservation Tillage on Runoff, Soil Loss, and Soil Properties on Acrisols and Ferralsols in Central Benin'. *Canadian Journal of Soil Science* 102 (3): 659–71. https://doi.org/10.1139/cjss-2021-0080.

Alhassan, Hamdiyah. 2021. 'The Effect of Agricultural Total Factor Productivity on Environmental Degradation in Sub-Saharan Africa'. *Scientific African* 12 (July):e00740. https://doi.org/10.1016/j.sciaf.2021.e00740.

Amadu, Festus O., Daniel C. Miller, and Paul E. McNamara. 2020. 'Agroforestry as a Pathway to Agricultural Yield Impacts in Climate-Smart Agriculture Investments: Evidence from Southern Malawi'. *Ecological Economics* 167 (January):106443. https://doi.org/10.1016/j.ecolecon.2019.106443.

Amfo, Bismark, and Ernest Baba Ali. 2021. 'Beyond Adoption: The Interaction between Organic and Inorganic Fertilizer Application, and Vegetable Productivity in Ghana'. *Renewable Agriculture and Food Systems* 36 (6): 605–21. https://doi.org/10.1017/S1742170521000235.

Antolini, Federico, Eric Tate, Brent Dalzell, Nathan Young, Kris Johnson, and Peter L. Hawthorne. 2020. 'Flood Risk Reduction from Agricultural Best Management Practices'. *Journal of the American Water Resources Association* 56 (1): 161–79. https://doi.org/10.1111/1752-1688.12812.

Assefa, T., M. Jha, M. Reyes, A. W. Worqlul, L. Doro, and S. Tilahun. 2020. 'Conservation Agriculture with Drip Irrigation: Effects on Soil Quality and Crop Yield in Sub-Saharan Africa'. *Journal of Soil and Water Conservation* 75 (2): 209–17. https://doi.org/10.2489/jswc.75.2.209.

Atedhor, Godwin Oghenebrozie. 2023. 'Greenhouse Gases Emissions and Their Reduction Strategies: Perspectives of Africa's Largest Economy'. *Scientific African* 20 (July):e01705. https://doi.org/10.1016/j.sciaf.2023.e01705.

Badu, Eunice, James S. Kaba, Akwasi A. Abunyewa, Evans K. Dawoe, O. Agbenyega, and Rex V. Barnes. 2019. 'Biochar and Inorganic Nitrogen Fertilizer Effects on Maize (Zea Mays L.) Nitrogen Use and Yield in Moist Semi-Deciduous Forest Zone of Ghana'. *Journal of Plant Nutrition* 42 (19): 2407–22. https://doi.org/10.1080/01904167.2019.1659347.

Beig, Bilal, Muhammad Bilal Khan Niazi, Zaib Jahan, Arshad Hussain, Munir Hussain Zia, and Muhammad Taqi Mehran. 2020. 'Coating Materials for Slow Release of Nitrogen from Urea Fertilizer: A Review'. *Journal of Plant Nutrition* 43 (10): 1510–33. https://doi.org/10.1080/01904167.2020.1744647.

Berdjour, Albert, Ibrahim Yakamba Dugje, Israel Kwame Dzomeku, and Nurudeen Abdul Rahman. 2020. 'Maize–Soybean Intercropping Effect on Yield Productivity, Weed Control and Diversity in Northern Ghana'. *Weed Biology and Management* 20 (2): 69–81. https://doi.org/10.1111/wbm.12198.

Blécourt, Marleen de, Alexander Gröngröft, Stephan Baumann, and Annette Eschenbach. 2019. 'Losses in Soil Organic Carbon Stocks and Soil Fertility Due to Deforestation for Low-Input Agriculture in Semi-Arid Southern Africa'. *Journal of Arid Environments* 165 (June):88–96. https://doi.org/10.1016/j.jaridenv.2019.02.006.

Boansi, David, Victor Owusu, and Emmanuel Donkor. 2024. 'Impact of Integrated Soil Fertility Management on Maize Yield, Yield Gap and Income in Northern Ghana'. *Sustainable Futures* 7 (June):100185. https://doi.org/10.1016/j.sftr.2024.100185.

Bogale, Girma Asefa, and Solomon Estifanos Bekele. 2023. 'Sustainability of Agroforestry Practices and Their Resilience to Climate Change Adaptation and Mitigation in Sub-Saharan Africa: A Review'. *Ekológia (Bratislava)* 42 (2): 179–92. https://doi.org/10.2478/eko-2023-0021.

Burek, Jasmina, and Darin W. Nutter. 2020. ‘Environmental Implications of Perishables Storage and Retailing☆’. *Renewable and Sustainable Energy Reviews* 133 (July 2019): 110070–110070. https://doi.org/10.1016/j.rser.2020.110070.

Daba, Ashenafi Worku, and Asad Sarwar Qureshi. 2021. ‘Review of Soil Salinity and Sodicity Challenges to Crop Production in the Lowland Irrigated Areas of Ethiopia and Its Management Strategies’. *Land* 10 (12): 1377. https://doi.org/10.3390/land10121377.

Degrendele, Céline, Jana Klánová, Roman Prokeš, Petra Příbylová, Petr Šenk, Marek Šudoma, Martin Röösli, Mohamed Aqiel Dalvie, and Samuel Fuhrimann. 2022. ‘Current Use Pesticides in Soil and Air from Two Agricultural Sites in South Africa: Implications for Environmental Fate and Human Exposure’. *Science of The Total Environment* 807 (February):150455. https://doi.org/10.1016/j.scitotenv.2021.150455.

Dimkpa, Christian, William Adzawla, Renu Pandey, Williams K. Atakora, Anselme K. Kouame, Martin Jemo, and Prem S. Bindraban. 2023. ‘Fertilizers for Food and Nutrition Security in Sub-Saharan Africa: An Overview of Soil Health Implications’. *Frontiers in Soil Science* 3 (March). https://doi.org/10.3389/fsoil.2023.1123931.

Dube, Edith, and Grace Emily Okuthe. 2024. ‘Plastic and Micro/Nanoplastic Pollution in Sub-Saharan Africa: Challenges, Impacts, and Solutions’. *World* 5 (2): 325–45. https://doi.org/10.3390/world5020018.

Dubey, Pradeep Kumar, Ajeet Singh, Rajan Chaurasia, Krishna Kumar Pandey, Amit Kumar Bundela, Rama Kant Dubey, and Purushothaman Chirakkuzhyil Abhilash. 2021. ‘Planet Friendly Agriculture: Farming for People and the Planet’. *Current Research in Environmental Sustainability* 3 (January):100041. https://doi.org/10.1016/j.crsust.2021.100041.

Dugan, Emmanuel, Roland Issaka, Mohammed Buri, Ephraim Sekyi-Annan, Hide Omae, and F Nagumo. 2022. ‘Influence of Tillage, Crop Rotation and Crop Residue Management on Soil Erosion and Maize Yield’. *West African Journal of Applied Ecology* 29 (January):59–74.

Ejigu, Workineh, Yihenew G.Selassie, Eyasu Elias, and Matebe Damte. 2021. ‘Integrated Fertilizer Application Improves Soil Properties and Maize (Zea Mays L.) Yield on Nitisols in Northwestern Ethiopia’. *Heliyon* 7 (2): e06074. https://doi.org/10.1016/j.heliyon.2021.e06074.

Falconnier, Gatien N, Rémi Cardinael, Marc Corbeels, Frédéric Baudron, Pauline Chivenge, Antoine Couëdel, Aude Ripoche, et al. 2023. ‘The Input Reduction Principle of Agroecology Is Wrong When It Comes to Mineral Fertilizer Use in Sub-Saharan Africa’. *Outlook on Agriculture* 52 (3): 311–26. https://doi.org/10.1177/00307270231199795.

FAO. 2023. ‘Towards the Development of a Voluntary Code of Conduct on the Sustainable Use of Plastics in Agriculture’. 6 September 2023. https://www.fao.org/fsnforum/call-submissions/voluntary-code-conduct-sustainable-use-plastics-agriculture.

———. 2024. ‘Integrated Pest Management (IPM) | Pest and Pesticide Management’. 2024. https://www.fao.org/pest-and-pesticide-management/ipm/integrated-pest-management/en/.

Farmers Review Africa. 2022. ‘The Controlled Release Fertilizer Market to Cross USD 3.9 Bn by 2024’. *Farmers Review Africa* (blog). 14 July 2022. https://farmersreviewafrica.com/the-controlled-release-fertilizer-market-to-cross-usd-3-9-bn-by-2024/.

Fatumah, Nakiguli, Seifu A. Tilahun, and Ssemwanga Mohammed. 2020. ‘Effect of Tillage Systems and Tillage Direction on Soil Hydrological Properties and Soil Suspended Particle Concentration in Arable Land in Uganda’. *Heliyon* 6 (12): e05616. https://doi.org/10.1016/j.heliyon.2020.e05616.

Fichtinger, Johannes, Jörg M. Ries, Eric H. Grosse, and Peter Baker. 2015. ‘Assessing the Environmental Impact of Integrated Inventory and Warehouse Management’. *International Journal of Production Economics* 170:717–29. https://doi.org/10.1016/j.ijpe.2015.06.025.

Gelaye, Kidia K., Franz Zehetner, Willibald Loiskandl, and Andreas Klik. 2019. ‘Effects of Soil Texture and Groundwater Level on Leaching of Salt from Saline Fields in Kesem Irrigation Scheme, Ethiopia’. *Soil and Water Research* 14 (4): 221–28. https://doi.org/10.17221/137/2018-SWR.

GIZ. 2018. ‘Integrated Pest Management in International Cooperation Projects with Partner Countries. A Guideline’. https://www.giz.de/en/downloads/giz2018-en-IPM-guideline-web.de.pdf.

González, Alejandro D., Björn Frostell, and Annika Carlsson-Kanyama. 2011. ‘Protein Efficiency per Unit Energy and per Unit Greenhouse Gas Emissions: Potential Contribution of Diet Choices to Climate Change Mitigation’. *Food Policy* 36 (5): 562–70. https://doi.org/10.1016/j.foodpol.2011.07.003.

Hailu, Birhane, and Hagos Mehari. 2021. ‘Impacts of Soil Salinity/Sodicity on Soil-Water Relations and Plant Growth in Dry Land Areas: A Review’. *Journal of Natural Sciences Research*, February. https://doi.org/10.7176/JNSR/12-3-01.

Hammond, Sean T., James H. Brown, Joseph R. Burger, Tatiana P. Flanagan, Trevor S. Fristoe, Norman Mercado-Silva, Jeffrey C. Nekola, and Jordan G. Okie. 2015. ‘Food Spoilage, Storage, and Transport: Implications for a Sustainable Future’. *BioScience* 65 (8): 758–68. https://doi.org/10.1093/biosci/biv081.

Horak, Ilzé, Suranie Horn, and Rialet Pieters. 2021. 'Agrochemicals in Freshwater Systems and Their Potential as Endocrine Disrupting Chemicals: A South African Context'. *Environmental Pollution* 268 (January):115718. https://doi.org/10.1016/j.envpol.2020.115718.

Hörner, Denise, and Meike Wollni. 2021. 'Integrated Soil Fertility Management and Household Welfare in Ethiopia'. *Food Policy* 100 (April):102022. https://doi.org/10.1016/j.foodpol.2020.102022.

Jjagwe, Joseph, Keneth Chelimo, Jeninah Karungi, Allan John Komakech, and Jakob Lederer. 2020. 'Comparative Performance of Organic Fertilizers in Maize (Zea Mays L.) Growth, Yield, and Economic Results'. 2020. https://www.mdpi.com/2073-4395/10/1/69.

Kätterer, Thomas, Dries Roobroeck, Olof Andrén, Geoffrey Kimutai, Erik Karltun, Holger Kirchmann, Gert Nyberg, Bernard Vanlauwe, and Kristina Röing De Nowina. 2019. 'Biochar Addition Persistently Increased Soil Fertility and Yields in Maize-Soybean Rotations over 10 Years in Sub-Humid Regions of Kenya'. *Field Crops Research* 235 (April):18–26. https://doi.org/10.1016/j.fcr.2019.02.015.

Kihara, J., P. Bolo, M. Kinyua, S. S. Nyawira, and R. Sommer. 2020. 'Soil Health and Ecosystem Services: Lessons from Sub-Sahara Africa (SSA)'. *Geoderma* 370 (July):114342. https://doi.org/10.1016/j.geoderma.2020.114342.

Kihara, Job, Mateete Bekunda, Vimbayi Chimonyo, Anthony Kimaro, Bekele Kotu, Stephen Lyimo, and Wezi Mhango. 2022. 'Management of Soil Fertility through Application of Fertilizers'. *Sustainable Agricultural Intensification*, CABI Books, , April, 48–61. https://doi.org/10.1079/9781800621602.0004.

Kirui, Oliver K., Alisher Mirzabaev, and Joachim von Braun. 2021. 'Assessment of Land Degradation "on the Ground" and from "Above"'. *SN Applied Sciences* 3 (3): 318. https://doi.org/10.1007/s42452-021-04314-z.

Kisaka, M Oscar, Chris Shisanya, Laurent Cournac, J. Raphael Manlay, Harun Gitari, and Jonathan Muriuki. 2023. 'Integrating No-Tillage with Agroforestry Augments Soil Quality Indicators in Kenya's Dry-Land Agroecosystems'. *Soil and Tillage Research* 227 (March):105586. https://doi.org/10.1016/j.still.2022.105586.

Koutika, Lydie-Stella, Kalulu Taba, Martin Ndongo, and Martin Kaonga. 2021. 'Nitrogen-Fixing Trees Increase Organic Carbon Sequestration in Forest and Agroforestry Ecosystems in the Congo Basin'. *Regional Environmental Change* 21 (4): 109. https://doi.org/10.1007/s10113-021-01816-9.

Kpiagou, P, S Tchegueni, D Sama, T Tchacondo, and Gnandi. 2023. 'Chemical Family of Pesticides Used in Market Gardening around the Kalsom Dam in the Didagou Watershed Area (Dapaong, Northern-Togo)'. https://www.jmaterenvironsci.com/Document/vol14/vol14_N8/JMES-2023-14085-Kpiagou.pdf.

Krall, Stephan. 2015a. 'What Is Sustainable Agriculture?' *GIZ*.

———. 2015b. 'What Is Sustainable Agriculture?' *GIZ*.

Kuyah, Shem, Cory W. Whitney, Mattias Jonsson, Gudeta W. Sileshi, Ingrid Öborn, Catherine W. Muthuri, and Eike Luedeling. 2019. 'Agroforestry Delivers a Win-Win Solution for Ecosystem Services in Sub-Saharan Africa. A Meta-Analysis'. *Agronomy for Sustainable Development* 39 (5): 47. https://doi.org/10.1007/s13593-019-0589-8.

Larramendy, Marcelo L., and Sonia Soloneski. 2019. *Pesticides: Use and Misuse and Their Impact in the Environment*. BoD – Books on Demand.

Mamuye, Melkamu, Amsalu Nebiyu, Eyasu Elias, and Gezahegn Yadessa. 2021. 'Combined Use of Organic and Inorganic Nutrient Sources Improved Maize Productivity and Soil Fertility in Southwestern Ethiopia'. *International Journal of Plant Production* 15 (June). https://doi.org/10.1007/s42106-021-00144-6.

MAXQDA. 2024. 'MAXQDA | All-In-One Qualitative & Mixed Methods Data Analysis Tool'. MAXQDA. 2024. https://www.maxqda.com/.

Maya, Mthulisi, and Mcebisi Maphosa. 2020. 'Current Status of Chickpea Production: Opportunities for Promoting, Adoption and Adapting the Crop in Zimbabwe: A Review'. *Journal of Dryland Agriculture* 6 (1): 1–9. https://doi.org/10.5897/JODA2019.0029.

Mbandi, Aderiana Mutheu, Christopher S. Malley, Dietrich Schwela, Harry Vallack, Lisa Emberson, and Mike R. Ashmore. 2023. 'Assessment of the Impact of Road Transport Policies on Air Pollution and Greenhouse Gas Emissions in Kenya'. *Energy Strategy Reviews* 49 (September):101120. https://doi.org/10.1016/j.esr.2023.101120.

Merga, Lemessa B., Alemayehu A. Mengistie, Miresa T. Alemu, and Paul J. Van den Brink. 2021. 'Biological and Chemical Monitoring of the Ecological Risks of Pesticides in Lake Ziway, Ethiopia'. *Chemosphere* 266 (March):129214. https://doi.org/10.1016/j.chemosphere.2020.129214.

Mohanavelu, Aadhityaa, Sujay Raghavendra Naganna, and Nadhir Al-Ansari. 2021. 'Irrigation Induced Salinity and Sodicity Hazards on Soil and Groundwater: An Overview of Its Causes, Impacts and Mitigation Strategies'. *Agriculture* 11 (10): 983. https://doi.org/10.3390/agriculture11100983.

Mordor Intelligence. 2024. 'Polymer Coated NPK Fertilizers Market - Size, Share & Industry Analysis'. 2024. https://www.mordorintelligence.com/industry-reports/bio-degradable-polymer-coated-npk.

Mthembu, Bonginkosi E., Terry M. Everson, and Colin S. Everson. 2019. 'Intercropping for Enhancement and Provisioning of Ecosystem Services in Smallholder, Rural Farming Systems in KwaZulu-Natal Province, South Africa: A Review'. *Journal of Crop Improvement* 33 (2): 145–76. https://doi.org/10.1080/15427528.2018.1547806.

Mugi-Ngenga, E., L. Bastiaans, N. P. R. Anten, S. Zingore, F. Baijukya, and K. E. Giller. 2023. 'The Role of Inter-Specific Competition for Water in Maize-Legume Intercropping Systems in Northern Tanzania'. *Agricultural Systems* 207 (April):103619. https://doi.org/10.1016/j.agsy.2023.103619.

Mugwe, Jayne, Felix Ngetich, and Erick Oduor Otieno. 2019. 'Integrated Soil Fertility Management in Sub-Saharan Africa: Evolving Paradigms Toward Integration'. In *Handbook of the Historiography of Biology*, 1:1–12. Historiographies of Science. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-69626-3_71-1.

Mupangwa, W., I. Nyagumbo, F. Liben, L. Chipindu, P. Craufurd, and S. Mkuhlani. 2021. 'Maize Yields from Rotation and Intercropping Systems with Different Legumes under Conservation Agriculture in Contrasting Agro-Ecologies'. *Agriculture, Ecosystems & Environment* 306 (February):107170. https://doi.org/10.1016/j.agee.2020.107170.

Musafiri, Collins M., Joseph M. Macharia, Milka N. Kiboi, Onesmus K. Ng'etich, Chris A. Shisanya, Jeremiah M. Okeyo, Daniel N. Mugendi, Elizabeth A. Okwuosa, and Felix K. Ngetich. 2020. 'Soil Greenhouse Gas Fluxes from Maize Cropping System under Different Soil Fertility Management Technologies in Kenya'. *Agriculture, Ecosystems & Environment* 301 (October):107064. https://doi.org/10.1016/j.agee.2020.107064.

Mustafa, M. A., S. Mayes, and F. Massawe. 2019. 'Crop Diversification Through a Wider Use of Underutilised Crops: A Strategy to Ensure Food and Nutrition Security in the Face of Climate Change'. In *Sustainable Solutions for Food Security : Combating Climate Change by Adaptation*, edited by Atanu Sarkar, Suman Ranjan Sensarma, and Gary W. vanLoon, 125–49. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-77878-5_7.

Mwakilili, Aneth David, Kilaza Samson Mwaikono, Sebastian Larsson Herrera, Charles A. O. Midega, Francis Magingo, Beatrix Alsanius, Teun Dekker, and Sylvester Leonard Lyantagaye. 2021. 'Long-Term Maize-Desmodium Intercropping Shifts Structure and Composition of Soil Microbiome with Stronger Impact on Fungal Communities'. *Plant and Soil* 467 (1): 437–50. https://doi.org/10.1007/s11104-021-05082-w.

Mylona, Zoi, Maria Kolokotroni, Konstantinos M. Tsamos, and Savvas A. Tassou. 2017. 'Comparative Analysis on the Energy Use and Environmental Impact of Different Refrigeration Systems for Frozen Food Supermarket Application'. *Energy Procedia* 123:121–30. https://doi.org/10.1016/j.egypro.2017.07.234.

Nassary, Eliakira Kisetu, Frederick Baijukya, and Patrick Alois Ndakidemi. 2020. 'Assessing the Productivity of Common Bean in Intercrop with Maize across Agro-Ecological Zones of Smallholder Farms in the Northern Highlands of Tanzania'. *Agriculture* 10 (4): 117. https://doi.org/10.3390/agriculture10040117.

Nekesa, Tabitha, Stéphanie Jaquet, Teodardo Calles, Stephanie Katsir, and Vivian Vollmann Tinoco. 2024. 'Fields of Harmony: Pulses and Sustainable Land Management', February. https://hdl.handle.net/10568/139357.

Nordey, Thibault, Simon Boniface Boni, Mawufe Komi Agbodzavu, Robert Mwashimaha, Nickson Mlowe, Srinivasan Ramasamy, and Emilie Deletre. 2021. 'Comparison of Biological Methods to Control *Aphis Fabae* Scopoli (Hemiptera: Aphididae) on Kalanchoe Crops in East Africa'. *Crop Protection* 142 (April):105520. https://doi.org/10.1016/j.cropro.2020.105520.

Ntinyari, Winnie, and Joseph P. Gweyi-Onyango. 2021. 'Greenhouse Gases Emissions in Agricultural Systems and Climate Change Effects in Sub- Saharan Africa'. In *African Handbook of Climate Change Adaptation*, edited by Nicholas Oguge, Desalegn Ayal, Lydia Adeleke, and Izael da Silva, 1081–1105. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-45106-6_43.

Nyambo, Patrick, Chiduza, and Tesfay Araya. 2020a. 'Carbon Dioxide Fluxes and Carbon Stocks under Conservation Agricultural Practices in South Africa'. *Agriculture* 10 (9): 374. https://doi.org/10.3390/agriculture10090374.

Nyambo, Patrick, Cornelius Chiduza, and Tesfay Araya. 2020b. 'Carbon Input and Maize Productivity as Influenced by Tillage, Crop Rotation, Residue Management and Biochar in a Semiarid Region in South Africa'. *Agronomy* 10 (5): 705. https://doi.org/10.3390/agronomy10050705.

Obia, Alfred, Gerard Cornelissen, Vegard Martinsen, Andreas Botnen Smebye, and Jan Mulder. 2020. 'Conservation Tillage and Biochar Improve Soil Water Content and Moderate Soil Temperature in a Tropical Acrisol'. *Soil and Tillage Research* 197 (March):104521. https://doi.org/10.1016/j.still.2019.104521.

O'Dell, Deb, Neal S. Eash, Bruce B. Hicks, Joel N. Oetting, Thomas J. Sauer, Dayton M. Lambert, Christian Thierfelder, et al. 2020. 'Conservation Agriculture as a Climate Change Mitigation Strategy in Zimbabwe'. *International Journal of Agricultural Sustainability* 18 (3): 250–65. https://doi.org/10.1080/14735903.2020.1750254.

Olia, Arash, Hossam Abdelgawad, Baher Abdulhai, and Saiedeh N. Razavi. 2016. 'Assessing the Potential Impacts of Connected Vehicles: Mobility, Environmental, and Safety Perspectives'. *Journal of Intelligent Transportation Systems: Technology, Planning, and Operations* 20 (3): 229–43. https://doi.org/10.1080/15472450.2015.1062728.

Omar, M. M, M. J Shitindi, B. H. J Massawe, K. G Fue, J. L Meliyo, and O Pedersen. 2023. 'Salt-Affected Soils in Tanzanian Agricultural Lands: Type of Soils and Extent of the Problem'. *Sustainable Environment* 9 (1): 2205731. https://doi.org/10.1080/27658511.2023.2205731.

Onwona-Kwakye, Michael, Jonathan N. Hogarh, and Paul J. Van den Brink. 2020. 'Environmental Risk Assessment of Pesticides Currently Applied in Ghana'. *Chemosphere* 254 (September):126845. https://doi.org/10.1016/j.chemosphere.2020.126845.

Otieno, Hillary M. O. 2023. 'A Review of the Current State and Potential Benefits of Using Herbicides by Smallholder Farmers in Sub-Saharan Africa'. *American Journal of Agricultural Science, Engineering, and Technology* 7 (3): 5–11. https://doi.org/10.54536/ajaset.v7i3.1712.

Park, Taewan, Sahrah Fischer, Christine Lambert, Thomas H Hilger, Irmgard Jordan, and Georg Cadisch. 2023. '(PDF) Combined Effects of Drought and Soil Fertility on the Synthesis of Vitamins in Green Leafy Vegetables'. 2023. https://www.researchgate.net/publication/370376449_Combined_Effects_of_Drought_and_Soil_Fertility_on_the_Synthesis_of_Vitamins_in_Green_Leafy_Vegetables.

Piñeiro, Valeria, Joaquin Arias, Pablo Elverdin, Ana María Ibáñez, Cristian Morales Opazo, Steve Prager, and Máximo Torero. 2021a. 'Achieving Sustainable Agricultural Practices: From Incentives to Adoption and Outcomes'. International Food Policy Research Institute (IFPRI). 2021. https://doi.org/10.2499/9780896294042.

———. 2021b. 'Achieving Sustainable Agricultural Practices: From Incentives to Adoption and Outcomes'. International Food Policy Research Institute (IFPRI). 2021. https://doi.org/10.2499/9780896294042.

Popp, J., Z. Lakner, M. Harangi-Rákos, and M. Fári. 2014. 'The Effect of Bioenergy Expansion: Food, Energy, and Environment'. *Renewable and Sustainable Energy Reviews* 32:559–78. https://doi.org/10.1016/j.rser.2014.01.056.

Pulido-Moncada, Mansonia, Søren O. Petersen, and Lars J. Munkholm. 2022. 'Soil Compaction Raises Nitrous Oxide Emissions in Managed Agroecosystems. A Review'. *Agronomy for Sustainable Development* 42 (3): 38. https://doi.org/10.1007/s13593-022-00773-9.

Ragoobur, Doorgha, Esperanza Huerta-Lwanga, and Geeta Devi Somaroo. 2021. 'Microplastics in Agricultural Soils, Wastewater Effluents and Sewage Sludge in Mauritius'. *Science of The Total Environment* 798 (December):149326. https://doi.org/10.1016/j.scitotenv.2021.149326.

Saco, P. M., K. R. McDonough, J. F. Rodriguez, J. Rivera-Zayas, and S. G. Sandi. 2021. 'The Role of Soils in the Regulation of Hazards and Extreme Events'. *Philosophical Transactions of the Royal Society B: Biological Sciences* 376 (1834): 20200178. https://doi.org/10.1098/rstb.2020.0178.

Shah, Farooq, and Wei Wu. 2020. 'Chapter Five - Use of Plastic Mulch in Agriculture and Strategies to Mitigate the Associated Environmental Concerns'. In *Advances in Agronomy*, edited by Donald L. Sparks, 164:231–87. Academic Press. https://doi.org/10.1016/bs.agron.2020.06.005.

Shakoor, Awais, Saba Shakoor, Abdul Rehman, Fatima Ashraf, Muhammad Abdullah, Sher Muhammad Shahzad, Taimoor Hassan Farooq, et al. 2021. 'Effect of Animal Manure, Crop Type, Climate Zone, and Soil Attributes on Greenhouse Gas Emissions from Agricultural Soils—A Global Meta-Analysis'. *Journal of Cleaner Production* 278 (January):124019. https://doi.org/10.1016/j.jclepro.2020.124019.

Shen, Maocai, Wei Huang, Ming Chen, Biao Song, Guangming Zeng, and Yaxin Zhang. 2020. '(Micro)Plastic Crisis: Un-Ignorable Contribution to Global Greenhouse Gas Emissions and Climate Change'. *Journal of Cleaner Production* 254 (May):120138. https://doi.org/10.1016/j.jclepro.2020.120138.

Shidiki, Abubakar Ali, Titus Fondo Ambebe, and Nyong Princely Awazi. 2020. 'Agroforestry for Sustainable Agriculture in the Western Highlands of Cameroon'. *Haya: The Saudi Journal of Life Sciences* 5 (9): 160–64. https://doi.org/10.36348/sjls.2020.v05i09.002.

Simwaka, Pacsu, Eyob Tesfamariam, Amos Ngwira, and Paxie Chirwa. 2020. 'Carbon Sequestration and Selected Hydraulic Characteristics under Conservation Agriculture and Traditional Tillage Practices in Malawi'. *Soil Research* 58 (October). https://doi.org/10.1071/SR20007.

Tambo, Justice A., Bellancile Uzayisenga, Idah Mugambi, David O. Onyango, and Dannie Romney. 2023. 'Sustainable Management of Fall Armyworm in Smallholder Farming: The Role of a Multi-Channel Information Campaign in Rwanda'. *Food and Energy Security* 12 (2): e414. https://doi.org/10.1002/fes3.414.

Tassou, S. A., G. De-Lille, and Y. T. Ge. 2009. 'Food Transport Refrigeration - Approaches to Reduce Energy Consumption and Environmental Impacts of Road Transport'. *Applied Thermal Engineering* 29 (8–9): 1467–77. https://doi.org/10.1016/j.applthermaleng.2008.06.027.

Tennigkeit, Timm, Adaugo Okoli, and Alexis Brakhan. 2023a. 'Guidebook for Project Developers. Best Practice for Agricultural Carbon Project Development Targeting Voluntary Carbon Markets (VCM)'. GIZ.

———. 2023b. 'Guidebook for Project Developers. Best Practice for Agricultural Carbon Project Development Targeting Voluntary Carbon Markets (VCM)'. GIZ.

Tidåker, Pernilla, Hanna Karlsson Potter, Georg Carlsson, and Elin Röös. 2021. 'Towards Sustainable Consumption of Legumes: How Origin, Processing and Transport Affect the Environmental Impact of Pulses'. *Sustainable Production and Consumption* 27:496–508. https://doi.org/10.1016/j.spc.2021.01.017.

Udom, B. E, C. C Wokocha, and J Ike-Obioha. 2024. 'Effects of Organic Manures on Soil Properties and Performance of Maize and Aerial Yam Intercrop'. https://www.iiardjournals.org/abstract.php?j=IJAES&pn=Effects%20of%20Organic%20Manures%20on%20Soil%20Properties%20and%20Performance%20of%20Maize%20and%20Aerial%20Yam%20Intercrop&id=1751.

UNEP. 2021. 'Plastics in Agriculture: Sources and Impacts'. https://www.papillons-h2020.eu/wp-content/uploads/2021/12/Plastics-in-agriculture-sources-and-impacts-UNEP-GRID-Arendal.pdf.

Walker, Tony R. 2021. '(Micro)Plastics and the UN Sustainable Development Goals'. *Current Opinion in Green and Sustainable Chemistry* 30 (August):100497. https://doi.org/10.1016/j.cogsc.2021.100497.

Wang, Jenhung, Herhome Zhuang, and Pei Chun Lin. 2016. 'The Environmental Impact of Distribution to Retail Channels: A Case Study on Packaged Beverages'. *Transportation Research Part D: Transport and Environment* 43:17–27. https://doi.org/10.1016/j.trd.2015.11.008.

Waweru, Geofrey, Florence Lenga, Mathew Gicheha, and George Ndegwa. 2024. 'Effect of Tillage, Mulching, Herbicide Application, Intercropping and Agroforestry on Soil Moisture Maize Yield and Rainwater Use Efficiency in Semi-Arid Kenya: A Case Study of Laikipia East'. *JOURNAL OF AGRICULTURE, SCIENCE AND TECHNOLOGY* 23 (1(1)): 26–62. https://doi.org/10.4314/jagst.v24i1.3.

WFP. 2022. 'WFP's Contribution to Resilient Food Systems in Vulnerable and Shock-Prone Settings - A Practical Framework and Orientation Note for WFP Programme Teams'. Rome, Italy: World Food Programme. https://www.shareweb.ch/site/Agriculture-and-Food-Security/news/F2F%20Rome%202023%20%20All%20slides/Resilient%20Food%20Systems%20Framework_LV_NOV2022.pdf.

Wikoff, Robin, Gretchen Nurse Rainbolt, and Wayne Wakeland. 2012. 'Measuring the Longitudinal Effects of Food Carbon Footprint Training on Consumers: Knowledge, Attitudes, and Behavioral Intentions'. *Sustainability* 5 (5): 317–22. https://doi.org/10.1089/SUS.2012.9925.

Yahyah, Hadijah, Patricia Kameri-Mbote, and Robert Kibugi. 2024. 'Implications of Pesticide Use Regulation on Soil Sustainability in Uganda'. *Soil Security* 16 (September):100133. https://doi.org/10.1016/j.soisec.2024.100133.

Zingore, Shamie. 2023. 'Integrated Soil Fertility Management: A Basis for Sustainable Intensification of Maize-Based Cropping Systems of Southern Africa'. In *Towards Sustainable Food Production in Africa*, edited by Morris Fanadzo, Nothando Dunjana, Hupenyu Allan Mupambwa, and Ernest Dube, 39–57. Sustainability Sciences in Asia and Africa. Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-99-2427-1_3.

Authors: Teresa Borelli, Tabitha Nekesa, Emiliana Mbelenga, Mwarome Jumbale, Yasuyuki Morimoto, Raffaella Bellanca, Irmgard Jordan.

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Contact:

Teresa Borelli, MSc, Associate Scientist, T.Borelli@cgiar.org

Irmgard Jordan, PhD, Senior Researcher, I.Jordan@cgiar.org

Yasuyuki Morimoto, PhD, Scientist II Y.Morimoto@cgiar.org

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