KNOWLEDGE BRIEF

2

Biosolutions for improved farming systems

DeSIRA LIFT

Towards a shared research and innovation agenda for agroecological transitions of agri-food systems in Africa under AU/EU policy frameworks

Photo: CIAT/Georgina Smith

Introduction

Biosolutions such as those used for soil fertility, pest management and livestock disease management, offer a viable transition option for sustainable agri-food systems in Africa. The opportunities that biosolutions present, however, must be coupled with understanding the innovation gaps that stand in the way of large-scale adoption. This knowledge brief discusses specific biosolutions and the opportunities and challenges they face in sub-Saharan Africa. With the right investments and policies, biosolutions can become an invaluable tool in the effort to future-proof productive, socially inclusive and greener agri-food systems.

Setting the scene

The world's population is projected to reach nearly 10 billion people by 2050; by then, global and local food supply must increase to meet the growing demand for food while conserving and protecting natural resources to prevent further biodiversity loss and climate change. What was commonly known as the 'Green Revolution' in the 1970s was characterized by increased yield due to improved seeds, pesticides, fertilizers, and irrigation systems. However, the Green Revolution's success recorded in Asia and South America (in terms of production increase) was not necessarily felt in sub-Saharan Africa, where agricultural productivity remains low. Although agriculture accounts for between 50% and 70% of employment in African countries (AfDB, 2017; AGRA, 2018), it contributes to only 15% of the total GDP. The agricultural sector still struggles to feed the continent and create enough employment opportunities for a growing population. These challenges contribute to the continent's low economic performance, leading to migration, political instability, and ecosystem degradation. Rainfed agriculture could explain the so-called yield gap in Africa, but there is also a lack of vibrant public-private partnerships in the agricultural sector that can drive innovations. Consequently, Africa imports $35bn in food annually, according to the African Development Bank (AfDB), which could be used to produce food in-house and provide employment for many people.

To address biotic and abiotic, climate and non-climate stressors (e.g., pests and diseases; soil humidity and fertility), a large part of smallholder farmers use synthetic chemical pesticides and fertilizers to protect their crops and boost productivity. The overuse and misuse of these agricultural inputs affect biological diversity and human health (Perrin et al., 2017). This has heightened the need for more sustainable farming practices and growing demand for healthy and sustainably produced food for local consumers due to a rising middle class, food consciousness and importing countries such as those in the EU. The current pressure on our (global and regional) food systems and ecosystems implies an urgent need for a paradigm shift to greener, healthier, and more resilient approaches using nature-based solutions including 'biosolutions' (Willett et al., 2019).

A widely accepted definition to describe biosolutions in agriculture does not seem to exist. However, in this paper, we consider biosolutions in agriculture as any kind of management intervention using organisms found in nature, produced and applied instead of conventional methods, to enhance crop health, plant metabolism, yield, crop protection, nutrient use efficiency or to reduce stress effects. Definitions and regulations for the different biosolutions have been rigorously debated in Europe and Africa over the last decade. However, in general, in terms of classification, these can be listed in two broad categories, biostimulants (stimulating natural processes to improve nutrient uptake and efficiency and tolerance to abiotic stress) and biopesticides (substances derived from nature, such as microorganisms or botanicals or semiochemicals that may be formulated and applied in a manner similar to conventional chemical pesticides). Some examples of biostimulants in agricultural systems include biofertilizers, inoculants, micro- and macro-organisms, botanical substances, pheromones and treated seeds.

Biosolutions are essential for a viable transition option for sustainable agri-food systems in Africa (Day et al., 2022). Understanding the potential of this viable transition, also requires an enhanced understanding of the ecological and social barriers to large-scale adoption of biosolutions. It requires a deeper dive into currently piloted (or not yet piloted) 'bio-based' technologies and their potential to support the transformation towards more sustainable agri-food systems.

In the following sections, examples of specific biosolutions are addressed, each complemented by a short analysis of opportunities, challenges and gaps in knowledge. The selection of biosolutions is non-exhaustive, requiring further discussion and potential expansion of this brief.

1 Biosolutions for pest management

Integrated Pest Management (IPM)

IPM is one of the Biosolutions to combat pests in crops. The IPM strategy comprises multiple tactical and ecological processes for preventing, monitoring, and controlling pests. Furthermore, the use of IPM measures reduces the environmental impact quotient, human health, and environmental risk effects associated with insecticide use (Midingoyi et al., 2019). However, IPM is admittingly not the dominant practice in the African context to deal with pests compared to conventional pesticides and is usually applied at a small scale, with scalability being a challenge. Several successful cases using IPM have been reported. For example, in the case of mango, studies have shown that, when carefully combined, IPM suppresses the fruit fly pest population in an environmentally sound and cost-effective manner that generates higher mango yields that are chemical pesticide-free. The combined IPM package could result in an 80% reduction of mango infestation by fruit flies, increased mango revenues by up to 60%, and reduced insecticide use and their adverse health and environmental effects by 74% and 23–35%, respectively (Muriithi et al., 2016; Midingoyi et al., 2019). Due to the easier application in smaller fields, IPM has been applied more extensively in urban agriculture. Mondedji et al. (2021) report that about 40% of the farmers producing cabbage in Benin use botanical extracts as pesticides. However, the respective figures for other neighboring West African countries are considerably lower.

Some reasons for this low adaptability include the cumbersome on-field preparation needed (in case of in-house use) and the lack of affordability for available biopesticides from small-scale farmers. A review paper dealing with IPM for fruit flies from North Africa reveals some other constraints for broader IPM implementation that are applicable even in Sub-Saharan Africa. These are not very much related to the method's effectiveness, although funding for research and innovation programmes is comparatively limited, mostly due to i) lack of support by technical staff, and ii) high material costs (Boulahia-Kheder 2021).

Additionally, Day et al. (2022) admit that IPM must be seen as a key element of food-system transformation. However, pesticide and other input regulatory systems unintentionally constrain the adoption of IPM through expensive registration procedures, weak compliance monitoring and limited regional harmonisation. Other challenges to the broader adaption of IPM include, according to Day et al. (2022), lack of incentives and limited subsidies for, e.g. low-risk pesticides compared to subsidies covering fertilisers and seeds, as well as weak food safety regulations for domestic markets that do not allow growers to receive price premiums for improved quality. Additionally, lengthy and costly procedures related to the registration of biopesticides have been reported as a hinder to the broadly implemented IPM, and regional harmonisation measures need to be in place to tackle such challenges.

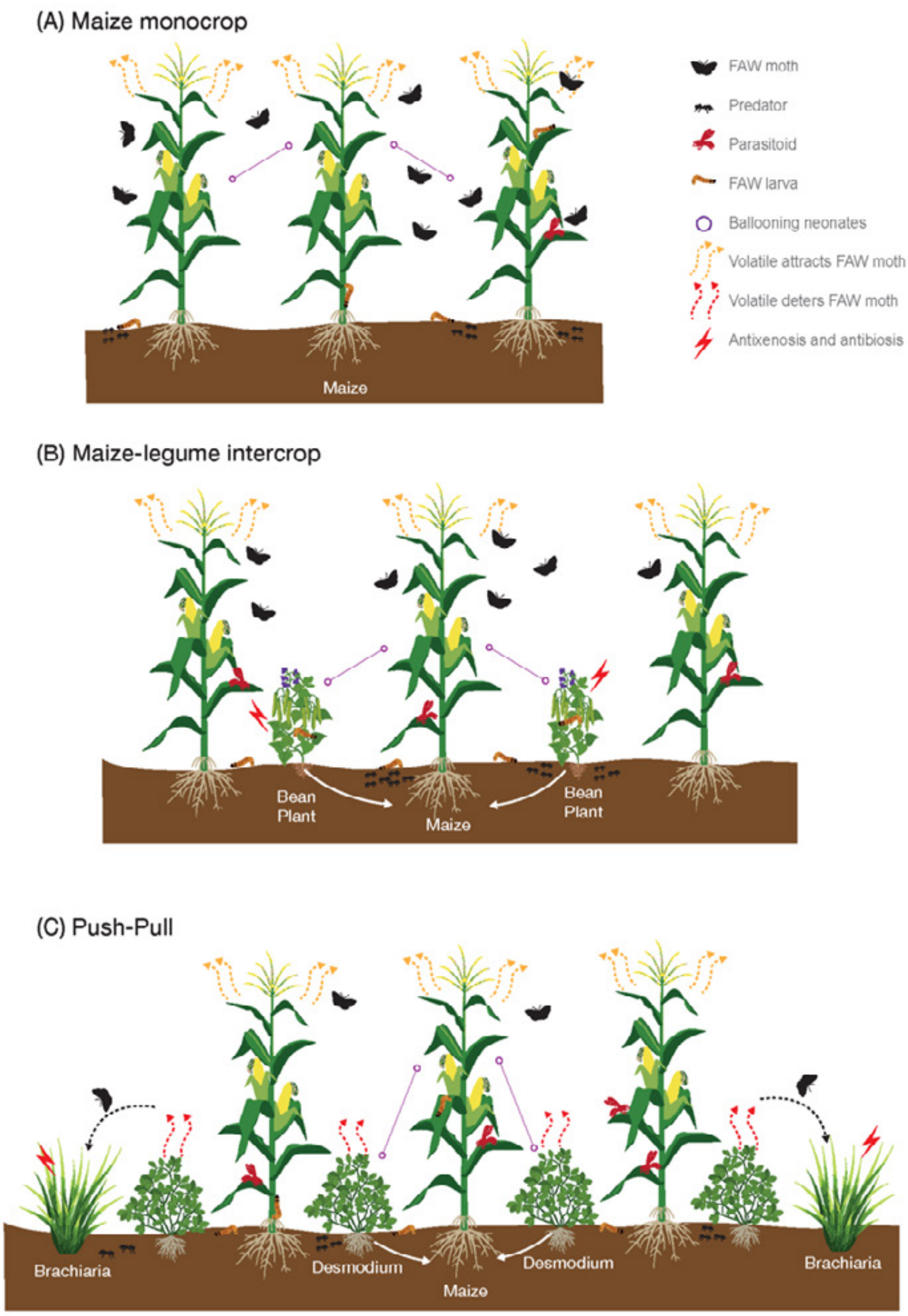
As a response to the structural challenges for broader IPM implementation, the extension of educational programmes before and during IPM implementation focusing on farmers, information access, and the integration of new technologies seem to be the key to future success (Srinivasan et al., 2022; Tamo et al., 2022), as well as research and innovation investments to reduce related costs. Trials to aim for upscaling seem to be needed (Harrison et al., 2019). Support for public-private partnerships to develop and commercialize biopesticides across Africa could also be a measure to contribute to broader IPM implementation and a transition from a pesticide-based approach in Africa (Srinivasan et al., 2022).

Finally, one main challenge for IPM practices and the way to develop in the future is the plethora of its definitions that cause confusion and different interpretations by members of the profession, also depicted inconsistencies between the concept of IPM and practices and public policies. The use of chemical control is considered only as a last resort in IPM; farmers implementing IPM seem to adopt unguided prophylactic chemical controls rather often, which can be a sign that IPM practices can be proved harmful to the environment (Deguine et al., 2021). Such risks can be avoided by, e.g., a more radical change in crop protection: instead of small adjustments to IPM that is pest-centred, adopting a more holistic approach that seeks to promote agroecosystem health, which is reflected in recent guidelines for IPM (FAO 2020). Such a shift opens many research questions related to the interaction of pest management, production, and environmental and socioeconomic issues.

Push-Pull technology

Fungal-based biopesticides or frass fertilizers are currently being promoted in Africa for the management of pests but also to counter the effects of climate change by improving soil health and nutrient uptake (Akutse et al. 2020; Beesigamukama et al. 2020a, b, c). Innovative integrated pest management (IPM) and agroecological practices such as maize legume intercroppings, including push-pull, can also be considered as biosolutions as they protect crops and enhance their productivity using natural processes (Hailu et al. 2018). The Push-Pull Technology (PPT) is one of the most successful and viable low-cost agroecological practices being promoted to help curb the problem of insect pests like stemborers and parasitic weeds such as Striga (Khan et al. 2008; Cook et al., 2007). PPT involves trapping stemborers on highly attractive border plants (pull), Napier grass Pennisetum purpureum Schumach or Brachiaria cv Mulato II and driving them away. On the other hand, Desmodium uncinatum Jacq. (Silverleaf) and Desmodium intortum Urb. (Greenleaf), planted between maize rows, repel ovipositing stemborer moths (push). In addition, Desmodium enriches the soil with nitrogen and protects it from erosion as it acts as a cover crop, leading to improved maize yields. In such a diversified and intensified system, farmers gain access to high-value animal fodder from the harvest of the companion crops, facilitating increased milk production and diversification of farmers' income sources. Lately, it has been discovered that

Figure 1: *Layout and mechanism of Push-Pull Technology*



the climate-adapted PPT effectively controls fall armyworm in maize (Midega et al., 2018; Hailu et al., 2018, Scheiddegger et al., 2021).

Similar examples of biosolutions that protect and stimulate crop production (e.g., management of fruit fly pests in fruit production) are being researched, but a wide-scale application of known solutions remains limited. Despite efforts to promote biosolutions, the uptake is low despite the high demand. For example, in the horticultural system in Africa, it was estimated that only 20% (~100 million) of potential beneficiaries had been reached in the last 20 years of fruit fly management. The remaining 80% (~500 million) of beneficiaries are unaware of or have no access to the IPM tactics to control these pests in fruit production (Niassy et al., 2022).

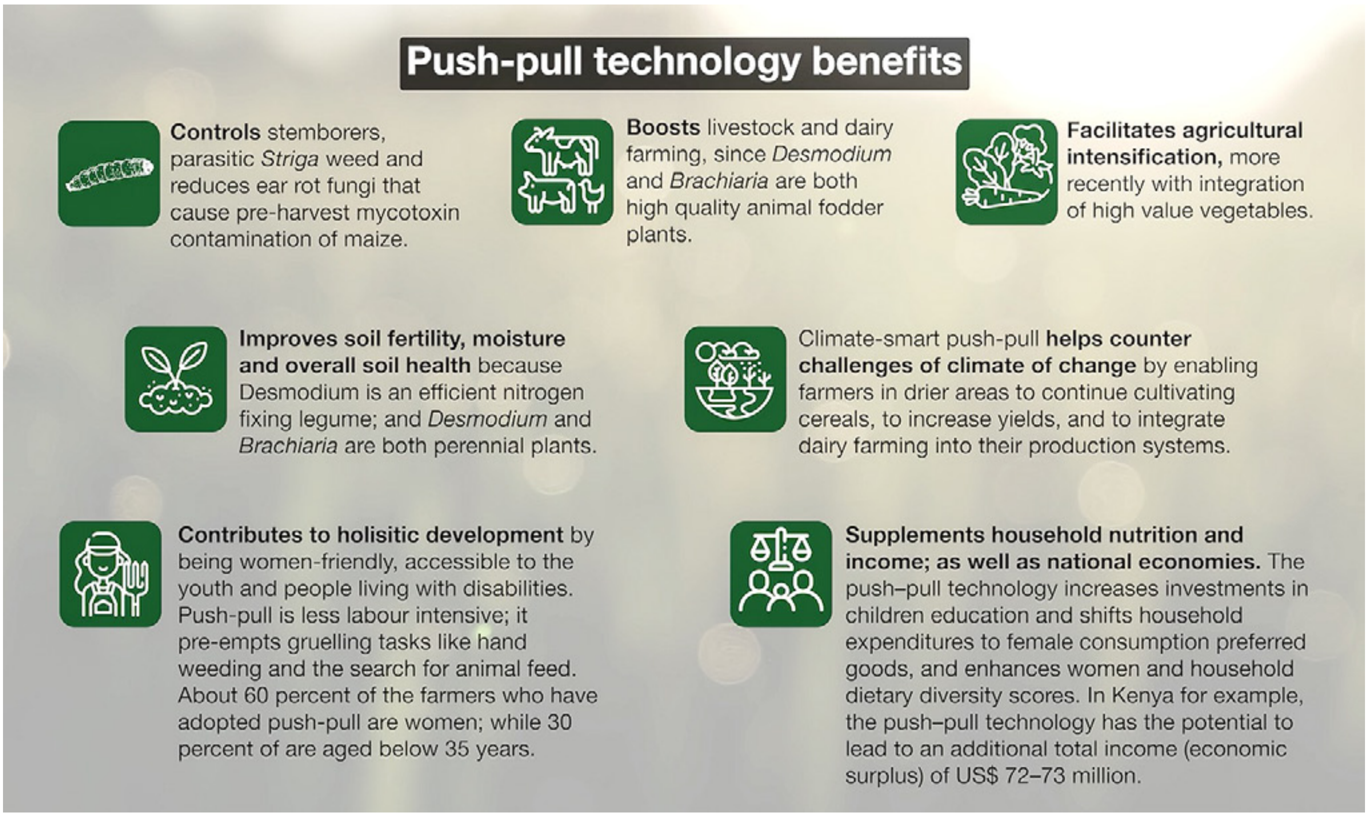
Certain biosolutions are more popular than others due to their availability, the presence of local manufacturers and ease of application. Others require technical know-how and investment from governments and the private sector. One of such biosolutions in IPM is producing and releasing natural enemies (parasitoids and predators). Although few companies (DuduTech, RealIPM and Kenya Biologics) produce these natural enemies, availability to smallholder farmers is low. The reason for this is the lack of access to infrastructures by national research services and the lack of reliable markets for private investments.

Day et al. (2022) reported that pesticide and other input regulatory systems constrain the adoption of IPM through expensive registration procedures, weak compliance monitoring and limited regional harmonisation. The PPT, developed years ago, is facing challenges due to a weak seed system unable to satisfy the demand for plants in push-pull systems and lengthy bureaucratic processes.

Biosolutions to combat pests during storage

The quest to increase food production has to include a reduction of food losses and attention for food safety during storage. For example, mycotoxins such as aflatoxins[1] are known to cause acute, chronic and irreversible health effects on people and livestock; exposure through food should be kept as low as possible. Aflatoxin exposure is frequent and widespread in most African countries (Udomkun et al., 2017) due to fungal contamination before and after harvest. Grain and legume crops are often treated with insecticides to avoid food loss, but these also create health risks. Alternative solutions such as bio-pesticides (e.g., Aflasafe for aflatoxin) or hermetic storage technologies (e.g., PICS bags) are available and seem to be effective (Magembe et al., 2016; Mutegi et al., 2013) but not yet applied at large scale. However, higher levels of aflatoxins in groundnuts were seen even in plastic bags (compared to jute bags), which were attributed to heat development in the bags (Meijer et al.,

Figure 2: *Benefits of Push-Pull (Source: International Centre of Insect Physiology and Ecology bulletin, June 2022)*



1] Source and more information: https://www.efsa.europa.eu/en/topics/topic/aflatoxins-food

2021). Therefore, using plastic bags raises questions about their effectiveness, considering that plastic bags are not environmentally friendly. The addition of grain protectants during storage of maize and groundnuts has proven to offer adequate protection, such as with antifungal dried neem leaf powder (Magembe et al., 2016), but more research to cover other stored agricultural products and to identify and use more antifungal biomaterials should be applied.

2 Biosolutions to boost soil fertility

Soil fertility has been consistently identified as the primary limiting factor of agricultural production in sub-Saharan Africa (Stewart et al. 2020). Inorganic fertilizers to boost soil productivity have become popular as they used to be due to specific subsidy schemes, and thus relatively affordable (pre-Covid-19 pandemic and pre-Ukraine war times). However, excessive application of inorganic fertilizer has led to adverse side effects such as pollution, salt burn, soil acidification, or health issues (e.g., Itelima et al., 2018, Shanka and Moral, 2020). Furthermore, a focus on inorganic fertilizer use alone has had limited success in improving soil fertility of degraded soils (Stewart et al. 2020).

Soil health is crucial for crop performance and the ability to defend itself against pests and diseases. Many farmers use organic manure from cattle, but the lack of adequate amounts of animal manure poses great challenges. Innovative biological solutions (such as biofertilizers, biochar, green manure, and vermiculture) can also play an important role in restoring soil quality. The availability of biomass feedstock as raw material is a pre-requisite and needs to be investigated at farmer and territorial levels; waste streams from, e.g., urban areas (municipal and industrial wastes with nutrient value), but also from rural areas, e.g., from processing companies but also households, need to be recycled. The production of compost or other biosolutions that will boost soil fertility, requires knowledge and skills, and investments to build capacities need to be ensured.

For example, organic waste recycling uses bioconversion as an ecosystem service offered by insects. Insects such as the Black Soldier Fly (BSF) can transform organic wastes (kitchen waste, manure, market wastes) into organic fertilizer, and the BSF maggots generated can be used as feed for livestock. The larvae protein also results in a parallel increase in frass - a residue left after rearing the larvae and selling them as a biofertiliser (Gebremikael et al., 2022; Lopes et al., 2022). Today BSF farming may become a game changer in Africa; several youth groups have engaged in the business. Increases in yields and nutrient quality of maize, as well as increases in soil organic matter when BSF has been applied as fertilizer, have been reported (Anyega et al., 2021; Tanga et al., 2022). However, many aspects related to frass are still unknown, such as its varying composition of nutrients, microorganisms and bioactive compounds, its post-processing requirements for improved biological stabilization, its behavior in the soil and action in the plants' metabolism, among other aspects (Lopes et al., 2022; Besigamamana, Abiya et al. 2022). As insect farming is taking up in Africa, it is expected that Insects for Food and Feed (IFF) will also become an important biostimulant by-product of bioconversion.

Vermiculture biotechnology uses earthworms as natural bioreactors for effectively recycling nontoxic organic wastes into the soil, resulting in vermicompost. It can be effectively used to increase vegetable production in horticulture (Ranaivoarisoa et al., 2017, Shanka and Moral, 2020), but its overall use compared to other compost methods is not as wide (Ranaivoarisoa et al., 2017). Vermicompost can be produced at the household level and offer an alternative to inorganic fertilizers. However, upscaled production will be needed to produce larger amounts of compost, and several aspects remain unanswered. Additionally, in rural areas, support will be needed to demonstrate to farmers the technical and economic value that organic farming brings using vermicompost.

Recently, farmers have discovered that rabbit urine combines pest management and foliar fertiliser properties for many pests (Kemunto et al., 2022). Other products, such as local botanicals, are also important but still require extensive research for optimization. All these are new research areas that need serious attention in the conceptualization of the ecological transition in Africa.

To inoculate or not to inoculate?

On-farm experiments have shown that the effective application of microbial inoculants in integrated soil fertility management (ISFM) can improve nutrient availability and water and nutrient use efficiency. Inoculating legumes with rhizobia (i.e., the group of soil bacteria that infect the roots of legumes to form root nodules) can result in increases in legume nodulation generating nitrogen fixation and post-crop soil nitrate levels and, therefore, an increase in grain and biomass yield. This can be a cost-effective solution, particularly for resource-constrained smallholder farmers, doubling grain yields in legume-based cropping systems (Agropolis, 2021). However, in the case of non-responsive soils when e.g. there are N-limiting conditions, the limiting factors and how to address them show that there is still work to be done on the integration of biological nitrogen fixation in crop breeding schemes and on the benefits to associated crops and soil fertility in rotational crop systems (Van Lauwe et al., 2019).

3 Biosolutions and livestock

Peer-reviewed literature only provides limited information regarding the use of plant-derived products in the management of (re)emerging vector-borne diseases (i.e. caused by parasites, viruses and bacteria) in animal husbandry or pastoral farming systems. The animal health system has relied on vaccines and serums, and using nature-based or bio-substances to keep the vector burden low is being researched. For the longest time, most findings are results from 'in-vitro' experiments (Kumar et al., 2020 in: Van der Aa and Groot, 2021).

Bio repellents inspired by animal smells have been developed to keep away certain vectors, including biting flies. Biting flies constrain animal agricultural production in Africa, seriously affecting the sector's potential for growth. Compared to animals kept in trypanosomiasis-free areas, animals kept in areas of moderate risk of trypanosomiasis have lower calving rates, lower milk yields, higher rates of calf mortality, and require more frequent treatment with preventive and curative doses of trypanocidal drugs. At the herd level, trypanosomiasis reduces milk offtake, live animal offtake and the work efficiency of oxen used for cultivation. It is estimated that a 50% increase in the livestock population would increase the total value of agricultural production by 10%. The potential benefits of trypanosomiasis control thus appear to be highest in areas with good potential for integrating livestock into profitable and sustainable mixed crop-livestock farming systems. In most arid and semi-arid areas, pastoralists suffer from access to solutions such as diagnostic tools, making them more vulnerable. A better understanding of livestock–trypanosome interactions is the key to control trypanosomiasis effectively. Interdisciplinary cooperation is pivotal (as many of the diseases are zoonotic and animals are potential reservoirs for disease in humans) to understand the interaction of vectors/parasites and their habitats and to assess the effect of natural substances, mainly because of the resistance in conventional antiparasitic drugs (Van der Aa and Groot, 2021). Recently, the International Centre of Insect Physiology and Ecology (ICIPE) developed a biomarker-based livestock diseases diagnosis, a kit designed to assess animal status using urines (Getahun et al., 2022). One example is using a tsetse fly repellent collar inspired by the waterbuck smell, synthesized to protect herds and pastoralist communities. Likewise, biopesticide-based products have also been developed to control ticks and tick-borne diseases. In most countries, the regulation and registration process of biosolutions in animal health is lacking or obsolete and requires serious attention.

4 Perspective(s) for Biosolutions: addressing innovation gaps

Crop production is heavily dependent on inputs, including fertilizers and pesticides. Over the past two decades, biopesticides (viruses, bacteria and fungus), endophytes and organic fertilizer applications have been critical in integrated pest management to control disease and boost productivity. The concept revolves around the fact that any pest management intervention can effectively work when necessities for crops are met (e.g., good soil fertility, water availability and selection of certified seeds). Biobased products such as fungal-derived biopesticides and biostimulants have been proposed as sustainable alternatives with less damage to human, animal and environmental health. Although these products have been taken up by commercial farmers who are constrained by Maximum Residue limits (MRLs) and other quarantine requirements before export to Europe, local demand for safer and healthier produce is also increasing due to mass awareness and food consciousness among producers and consumers. Almost in all regions of Africa, private sector companies are investing heavily in these important biosolutions despite heavy competition with conventional production systems which promote synthetic pesticides. However, smallholder farmers are still limited with resources and lucrative markets to solidify the industry thoroughly. Economic trade-offs and cost-benefit studies are limited for many value chains, and the impact of these biostimulants and biopesticides on production income needs to be demonstrated to growers.

The strategy for scaling biosolutions in Africa should consider the supply-environment-consumer nexus (Lundqvist et al., 2015). Moreover, the availability, affordability, accessibility, and acceptability of biosolutions within this complex nexus are critical. On-farm production of new technologies, but also the entire supply chain -from production, to storage, processing and marketing- of biosolutions is extremely important. If the agri-food system is to perform with desired social, economic and environmental impact, political leadership implemented by multiple institutions will be required. Despite a rich portfolio, the industry (the production and marketing of bio-solutions), its services (distribution), and the entire chain need a comprehensive strategy. The biosolutions must be available, accessible, and affordable, but most importantly, farmers must know how they work. Biosolutions must fit their socio-economic and cultural contexts. These are critical to support agroecological solutions for planetary health.

Innovation questions that need to be considered include e.g., what are the best scaling pathways for biosolutions in Africa? Are farmers aware and ready to use these biosolutions, and what is the cost-benefit ratio? What are the socio-economic drivers on a wide scale? How do we incentivize the use of biosolutions? Who are the major players in the biosolutions value chains? What are the social and ecological indicators of success for biosolutions?

Below, several innovation gaps for a selection of focus areas are being highlighted. This selection of focus areas, including the innovation gaps and questions raised, is a non-exhaustive one, requiring further discussion.

Boosting bio-based technologies in sub-Saharan Africa

Technology development to boost biological solutions for a larger variety of crops, a mixture of cropping systems, for a variety of farm and farming systems to improve productivity and address (a)biotic stressors in different agroecological zones requires interaction between stakeholders along the value chain and new partnerships and should not exclude technology development with farmers and local entrepreneurs to develop local solutions. Precision agriculture could boost new bio-based or nature-based solutions, but it requires calibration with biosolutions that consider multiple-cropping systems (intercropping, relay cropping, sequential cropping) using quality seeds, biopesticides, and natural enemies. Most African countries have various agroecological zones, and the performance of biosolutions needs to be assessed accordingly. For example, the success of the PPT is attributed to the stimulo-deterrent performance of companion crops, which in turn relies on the physicochemical properties of the soil. Thus, the suitability of Desmodium species depends on various climatic factors such as temperature and soil type, while the incidence of Striga and other insect pests such as the stemborer and the fall armyworm varies according to the agro-ecological zones. Therefore, it is paramount to determine the technology's performance in various ecoclimatic zones, which is an important supporting or limiting factor for any innovation. The expected benefits of any technology, including biosolutions, play an important role in its acceptance (Yeboah et al., 2021).

Investments need to be made in the circular systems through recycling and valorizing organic streams such as crop residues, brewery and kitchen wastes and other refusals into animal feed and biofertilizers to improve soil health. Insects are an excellent source of protein, fatty acids, vitamins and minerals (Rumpold and Schlüter, 2013). The increasing demand for alternative sources of nutrients for humans and animals has fuelled the need to farm edible insects. The use of insects as bioconversion agents is a potential area of future investment as it reduces environmental footprints in the food, feed and vegetable sectors while creating jobs for the youths (FAO, 2021; Tanga et al., 2021; Verner et al., 2021).

In the case of push-pull technology, smallholder farmers often raise the issue of labour as a barrier to large-scale adoption. Since most food crops are not high-value crops, the effort deployed on the farm must recoup the ultimate gain. This can only happen if the seed is affordable, and staple crops such as grains produced from push-pull are sold at a premium price, considering they have been produced without chemicals and are free of Aflatoxin. These aspects have been often overlooked yet are critical for scaling the technology.

The use of biofertilizers is limited in Africa because of constraints such as lack of suitable storage (short shelf life), lack of suitable strains and carrier materials to produce bio-fertilizers, inadequate and inexperienced staff in the supply chain (biofertilizer producers, agro-dealers, extension agents, farmers), or environmental constraints in certain soil types and locations (Itelima et al. 2018).

Capacity development

Awareness creation is the most critical step as biosolutions are usually nature-based solutions, often slow in action and knowledge-intensive, adding more burden to the farmer. Muriithi et al. reported that African farmers could adopt fruit fly IPM technologies that are affordable and easier to apply out of the bundle of biosolutions. They also showed that about 47% of mango-growing households were willing to pay for fruit fly IPM technology in Ethiopia. Similar findings have also been reported in Kenya. It is therefore essential to guide farmers and demonstrate the effectiveness and superiority of biosolutions. The weak extension systems, poor linkages between research and extension, and lengthy technology verification and release systems require serious attention.

Moreover, investigating the acceptance and use of the technology is a critical aspect of adoption and scaling. These two components are mainly driven by performance and effort expectancy and are influenced by gender, age, and experience.

Institutional arrangements to support innovation and governance

Though technologies for biosolutions are known, making these technologies available at scale remains a challenge. There is a need for public-private partnerships (collaborations between national research organizations, public extension, SMEs, and farmer organizations) that can jointly bring biosolutions to scale. Too often, such attempts are limited to temporary pilot projects.

Political will and private sector investment are still weak, as well as the extension systems that do not have the capacity for knowledge and household coverage. The role of political leadership and private partnerships is essential to support the availability and affordability of greener agricultural solutions, promote healthy diets, and fund research while adding levies or taxes or even banning unsustainable agricultural technologies and practices. Standards should be promulgated for agroecologically produced commodities for local and international markets. Advocacy for promoting biosolutions and agroecologically produced foods is necessary, and strong policies should accompany this. Access to biosolutions is to be improved, but dissemination strategies and policy harmonization across regions and continents also need improvement. Regulatory frameworks must be revised to prioritize environmentally-friendly solutions over destructive ones. This may include a revision of incentives and subsidies currently promoting the use of (imported) inorganic inputs rather than alternative biosolutions that can be produced locally.

Gender & youth

The African youths are one of the greatest assets of the continent, which has been so far untapped. Investing in technology development, business incubation for biosolutions and youth employment will popularize and liberalize biosolutions among value chain actors, enhance yield and export market and profits, create jobs, and provide social peace and justice in a healthy environment. This requires a coordinated effort of training youth in technical and entrepreneurial skills, investments in the research and development of biosolutions, de-risking of startups through financial support and a conducive enabling environment.

Little is known to what extent women are involved in, or have access to, biosolutions. Including gender dimensions is a knowledge gap to be addressed. Some practices may result in an additional labour burden for women while they may not have access to the required training. Development and promotion of biosolutions need to consider the division of roles, tasks and access to resources within smallholder farm households to avoid adverse effects on women (or other individuals).

Finance

The private sector has a huge role to play in developing, producing and disseminating biosolutions, but SMEs in biosolutions struggle to expand due to a lack of finance. Though investments in nature (in the form of nature-based solutions) make sense to safeguard future well-being, global finance flows are primarily directed towards damaging and extractive industries. Funding gaps for biodiversity protection or climate change mitigation are enormous. A diverse set of financial mechanisms is required to close the finance gap for investments. Public-private partnerships for blended finance mechanisms can reduce the risk for private investors to compensate for environmental benefits which do not currently have market payment mechanisms. Regulatory frameworks should place the currently narrow focus on economic profit alongside the need for social and ecological returns on investment. This means including multiple values of nature within standard accounting methods and embedding methods for valuing nature within the finance departments of companies (NbS, 2020).

Market access

Market access is an important driver if there is a market for it and a premium price for agroecologically produced foods. A clearly defined demand for such agroecological foods with biosolutions that are affordable to most producers is needed. Currently, a handful of growers (involved in exports) buy most of the biosolutions. Market access and market linkages are critical as the demand for biosolutions will be addressed by the need for healthy and greener produce, which will create a market niche for the private sector with limitless growth potential. The incentive for farmers to adopt biosolutions is to have higher profit margins, reduced cost of input, labour and higher selling prices. This implies shorter commodity value chains with improved storage, transport, and processing to minimize losses at the disposal of smallholder farmers or cooperatives. However, through all of it, the demand for agroecologically produced food is a societal issue. Each segment of the production chain has a role to play. Although food consciousness is due to health and environmental concerns, awareness creation and policy engagement is critical to create demand, which will create a market. Biosolutions and agroecological practices are often costly; however, farmers are willing to produce if there is a guaranteed assurance. The main challenge is when producers do not have market access and are forced to sell under the same conditions as those who put in minimal investments.

References

Abiya, Andrew Agrey, David Mfuti Kupesa, Dennis Beesigamukama, Menale Kassie, Dennis Mureithi, Daniel Thairu, John Wesonga, Chrysantus M. Tanga, and Saliou Niassy. 2022. "Agronomic Performance of Kale (*Brassica oleracea*) and Swiss Chard (*Beta vulgaris*) Grown on Soil Amended with Black Soldier Fly Frass Fertilizer under Wonder Multistorey Gardening System" Agronomy 12, no. 9: 2211. https://doi.org/10.3390/agronomy12092211

AfDB (2017). Multinational - Technologies for African Agricultural Transformation - Framework Program in Support of "Feed Africa", African Development Bank Group, Agriculture and Agro-Industry (AHAI). Pp:26
AGRA. (2018). Africa Agriculture Status Report: Catalyzing Government Capacity to Drive Agricultural Transformation (Issue 6). Nairobi, Kenya: Alliance for a Green Revolution in Africa (AGRA)

Agropolis. (2021). Agroecological transformation for sustainable food systems : Insight on France-CGIAR research. Les dossiers d'Agropolis International. Special Partnership Issue, n° 26. Montpellier (France): Agropolis International 147 p. ISSN: 1628-4259

Ajayi M.T, Fatunbi AO and Akinbamijo O. O (2018). Strategies for Scaling Agricultural Technologies in Africa. Forum for Agricultural Research in Africa (FARA), Accra Ghana

Akutse KS, Subramanian S, Maniania NK, et al. (2020) Biopesticide Research and Product Development in Africa for Sustainable Agriculture and Food Security – Experiences From the International Centre of Insect Physiology and Ecology (icipe). Frontiers in Sustainable Food Systems 4

Anyega, A.O., Korir, N.K., Beesigamukama, D., Changeh, G.J., Nkoba, K., Subramanian, S., Van Loon, J.J.A., Dicke, M., Tanga, C.M., 2021. Black soldier fly-composted organic fertilizer enhances growth, yield, and nutrient quality of three key vegetable crops in Sub-Saharan Africa. Front. Plant Sci. 12, 680312. https://doi.org/10.3389/fpls.2021.680312.

Beesigamukama D, Mochoge B, Korir N, et al. (2020a) Nitrogen fertilizer equivalence of black soldier fly frass fertilizer and synchrony of nitrogen mineralization for maize production. Agronomy. https://doi.org/10.3390/agronomy10091395

Beesigamukama D, Mochoge B, Korir NK, et al. (2020b) Biochar and gypsum amendment of agro-industrial waste for enhanced black soldier fly larval biomass and quality frass fertilizer. PLoS ONE. https://doi.org/10.1371/journal.pone.0238154

Beesigamukama D, Mochoge B, Korir NK, et al. (2020c) Exploring Black Soldier Fly Frass as Novel Fertilizer for Improved Growth, Yield, and Nitrogen Use Efficiency of Maize Under Field Conditions. Frontiers in Plant Science. https://doi.org/10.3389/fpls.2020.574592

Day, R., Haggblade, S., Moephuli, S., Mwang'ombe, A., Nouala, S. (2022). Institutional and Policy Bottlenecks to IPM. *Current Opinion in Insect Science*, 100946, ISSN 2214-5745, https://doi.org/10.1016/j.cois.2022.100946

Deguine et al. (2021) Integrated pest management: good intentions, hard realities. A review. Agronomy for Sustainable Development, 41 (38)

FAO (2020) NSP – Integrated Pest Management, FAO definition. http://www.fao.org/agriculture/crops/thematic-sitemap/theme/pests/ipm/en/

Gebremikael, MT. Wickeren, NV, Hosseini, PS, De Neve, S (2022) The Impacts of Black Soldier Fly Frass on Nitrogen Availability, Microbial Activities, C Sequestration, and Plant Growth. FRONTIERS IN SUSTAINABLE FOOD SYSTEMS 6, 95950-95950.

Hailu, G., Niassy, S., Zeyaur, K., Ochatum, N., & Subramanian, S. (2018). Maize–Legume Intercropping and Push–Pull for Management of Fall Armyworm, Stemborers, and Striga in Uganda. Agronomy Journal.

Harrison et al (2019) Agro-ecological options for fall armyworm (Spodoptera frugiperda JE Smith) management: Providing low-cost, smallholder friendly solutions to an invasive pest, 243:318-330

Itelima, J.U., Bang, W.J., Onyimba, I.A. et al. (2018). A review: biofertilizer; a key player in enhancing soil fertility and crop productivity. J Microbiol Biotechnol Rep. 2(1):22-28.

Kemunto, Diana, Evanson R. Omuse, David K. Mfuti, Amanuel Tamiru, Girma Hailu, Ignath Rwiza, Yeneneh T. Belayneh, Sevgan Subramanian, and Saliou Niassy. 2022. "Effect of Rabbit Urine on the Larval Behavior, Larval Mortality, Egg Hatchability, Adult Emergence and Oviposition Preference of the Fall Armyworm (*Spodoptera frugiperda* J.E. Smith)" *Agriculture* 12, no. 8: 1282. https://doi.org/10.3390/agriculture12081282

Kibira, M.; Affognon, H.; Njehia, B.; Muriithi, B.; Ekesi, S. Economic Evaluation of Integrated Management of Fruit Fly in Mango Production in Embu County, Kenya. Afr. J. Agric. Resour. Manag. 2015, 10, 343–353.

Lopes, IG, Yong, JW, Lalander, C (2022) Frass derived from black soldier fly larvae treatment of biodegradable wastes. A critical review and future perspectives. WASTE MANAGEMENT 142, 65-76, DOI 10.1016/j.wasman.2022.02.007

Lundqvist, J., Liu, J. and Lundberg, J. (2015). Consumers, food supply chain and the nexus. In K. Hussey, J. Pittock and S. Dovers (Eds.). Climate, Energy and Water: Managing the Holy Trinity. Cambridge: Cambridge University Press
.
Magembe, KS., Mwatawala, MW., Mamiro, DP. (2016). Mycotoxin Contamination in Stored Maize and Groundnuts Based on Storage Practices and Conditions in Subhumid Tropical Africa: The Case of Kilosa District, Tanzania. J Food Prot 79(12):2160-2166. doi: 10.4315/0362-028X.JFP-15-550.

Mbow, C., C. Rosenzweig, L.G. Barioni, T.G. Benton, M. Herrero, M. Krishnapillai, E. Liwenga, P. Pradhan, M.G. Rivera-Ferre, T. Sapkota, F.N. Tubiello, Y. Xu, 2019: Food Security. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D.C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. In press.

Meijer, N., Kleter, G., de Nijs, M., Rau, ML., Derkx, R., van der Fels-Klerx, HJ. (2021). The aflatoxin situation in Africa: Systematic literature review. Comprehensive Reviews in Food Science and Food Safety. 20 (3): 2286-2304, DOI: 10.1111/1541-4337.12731

Melesse B. (2018) A Review on Factors Affecting Adoption of Agricultural New Technologies in Ethiopia. J Agri Sci Food Res 9: 226.

Michael Danquah (2018). Technology transfer, adoption of technology and the efficiency of nations: Empirical evidence from sub–Saharan-Africa, Technological Forecasting and Social Change, Volume 131, 2018, Pages 175-182, ISSN 0040-1625,

Midega, C.A.O.; Pittchar, J.O.; Pickett, J.A.; Hailu, G.W.; Khan, Z.R. A climate-adapted push-pull system effectively controls fall armyworm, Spodoptera frugiperda (J E Smith), in maize in East Africa. Crop Prot. 2018, 105, 10–15.

Midingoyi, S.K.G.; Kassie, M.; Muriithi, B.; Diiro, G.; Ekesi, S. Do farmers and the environment benefit from adopting integrated pest management practices? Evidence from Kenya. J. Agric. Econ. 2019, 70, 452–470.

Mondedji et al., Cabbage Production in West Africa and IPM with a Focus on Plant-Based Extracts and a Complementary Worldwide Vision. Plants 2021, 10(3), 529.

Nature-based Solutions Initiative. 2020. Financing NbS: overcoming obstacles and mobilizing investments for successful, sustainable NbS. Nature-based Solutions Digital Dialogues. DD S5.pages (naturebasedsolutionsinitiative.org)

Niassy S, Murithii B, Omuse ER, et al. (2022) Insight on Fruit Fly IPM Technology Uptake and Barriers to Scaling in Africa. Sustainability (Switzerland) 14:. https://doi.org/10.3390/su14052954

Perrin, A., Basset-Mens, C., Huat, J., & Gabrielle, B. (2017). The variability of field emissions is critical to assessing the environmental impacts of vegetables: A Benin case-study. *Journal of Cleaner Production*, 153. https://doi.org/10.1016/j.jclepro.2017.03.159

Ranaivoarisoa H., Ravoninjiva S., Ramananarivo S., Ramananarivo R. (2017) Vermiculture for Sustainable Organic Agriculture in Madagascar. Horticulturae 2017, 3(1), 2; https://doi.org/10.3390/horticulturae3010002

Rumpold, B.A. and Schlüter, O.K. (2013). Nutritional Composition and Safety Aspects of Edible Insects. Molecular Nutrition and Food Research, 57, 802-823. https://doi.org/10.1002/mnfr.201200735

Shanka, D., Moral, M.T. (2020). Roles of eco-friendly low input technologies in crop production in sub-Saharan Africa, Cogent Food &Agriculture,6:1, https://doi.org/10.1080/23311932.2020.1843882

Stewart, Z.P., Pierzynski, G.M., Middendorf, B.J., Vara Prasad, P.V. (2020). Approaches to improve soil fertility in sub-Saharan Africa, *Journal of Experimental Botany* 71:2(632–641) https://doi.org/10.1093/jxb/erz446

Srinivasan et al. (2022) The case for integrated pest management in Africa: transition from a pesticide-based approach. Current Opinion in Insect Science 54; 100970, https://doi.org/10.1016/j.cois.2022.100970

Tamo et al. How does IPM 3.0 look like (and why do we need it in Africa, Curr Opin Insect Sci, 2022, 53:100961. https://doi: 10.1016/j.cois.2022.100961

Tanga CM, Egony u JP, Beesigamukama D, Niassy S, Emily K, Magara HJ, Omuse ER, Subramanian S, Ekesi S. Edible insect farming as an emerging and profitable enterprise in East Africa. Curr Opin Insect Sci. 2021 Dec;48:64-71. doi: 10.1016/j.cois.2021.09.007. Epub 2021 Oct 11. PMID: 34649017.

Tanga CM, Beesigamukama D., Kassie M., Egonyu P.J., Changeh J. Ghemoh, Kiatoko Nkoba, Subramanian S., Anyega A.O., Ekesi S. (2022) Performance of black soldier fly frass fertiliser on maize (Zea mays L.) growth, yield, nutritional quality, and economic returns, Journal of Insects as Food and Feed 8:2, 185-196.

Udomkun, P. Wiredu, A.N., Nagle, M , Müller, J., Vanlauwe, B., Bandyopadhyay, R. (2017). Innovative technologies to manage aflatoxins in foods and feeds and the profitability of application – A review. Food Control, Vol. 76, 2017, Pages 127-138, ISSN 0956-7135, https://doi.org/10.1016/j.foodcont.2017.01.008

Van der Aa, A. and M. Groot (2021). Climate change related (re)emerging diseases in cattle in the Netherlands; The possible use of natural (plant) substances in an integrated approach. Wageningen, Wageningen Food Safety Research, WFSR report 2021.017. 30 pp.; 2 fig.; 2 tab.; 83 ref. https://doi.org/10.18174/556961

Vanlauwe, B., Hungria, M., Kanampiu, F., Giller, K.E. (2019). The role of legumes in the sustainable intensification of African smallholder agriculture: Lessons learnt and challenges for the future. *Agriculture, Ecosystems & Environment* 284:106583. https://doi.org/10.1016/j.agee.2019.106583

Willett W, Rockström J, Loken B, Springmann M, Lang T, Vermeulen S, Garnett T, Tilman D, DeClerck F, Wood A, Jonell M, Clark M, Gordon LJ, Fanzo J, Hawkes C, Zurayk R, Rivera JA, De Vries W, Majele Sibanda L, Afshin A, Chaudhary A, Herrero M, Agustina R, Branca F, Lartey A, Fan S, Crona B, Fox E, Bignet V, Troell M, Lindahl T, Singh S, Cornell SE, Srinath Reddy K, Narain S, Nishtar S, Murray CJL. Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems. Lancet. 2019 Feb 2;393(10170):447-492. doi: 10.1016/S0140-6736(18)31788-4. Epub 2019 Jan 16. Erratum in: Lancet. 2019 Feb 9;393(10171):530. Erratum in: Lancet. 2019 Jun 29;393(10191):2590. Erratum in: Lancet. 2020 Feb 1;395(10221):338. Erratum in: Lancet. 2020 Oct 3;396(10256):e56. PMID: 30660336.

Yeboah, S., Ennin, S.A., Ibrahim, A., Oteng-Darko, P., Mutyambai, D.M., Khan, Z.R., Mochiah, M.B., Ekesi, S., & Niassy, S. (2021). Effect of spatial arrangement of push-pull companion plants on fall armyworm control and agronomic performance of two maize varieties in Ghana. Crop Protection.

Acknowledgements

This brief has been prepared in the framework of the European Commission's funded DeSIRA-LIFT project. A particular focus of DeSIRA-LIFT's advisory work is to support and promote agroecological pathways as a viable transition option for sustainable agri-food systems in Africa. This knowledge brief, inspired by a multitude of sources, is a concrete follow-up of the 'Deep Dive Dialogue on Biosolutions' held on 6 July 2022 and will feed into the formulation of activities or research and innovation projects funded by DG INTPA.

The feedback from the participants of the online deep-dive dialogue on 6 July 2022 has been incorporated into the paper. Participants included: Olugbenga AdeOluwa (University of Ibadan), Ermias Betemariam (CIFOR & ICRAF), Ioannis Dimitriou (DeSIRA-LIFT), Morris Egesa (AFAAS), Julius Ecuru (BioInnovate Africa), Guy Faure (DG INTPA), Gary Klugman (Afrinat), Esther Koopmanschap (DeSIRA-LIFT), Christophe Larose (DG INTPA), Jaco Marais (Philagro), Futhi Magagula (CCARDESA), Sylvanus Mensah (University of Abomey-Calavi), Prean Naido (IITA), Gian Nicolay (FiBL), Saliou Niassy (ICIPE), Helena Posthumus (DeSIRA-LIFT), Pierre Silvie (CIRAD), Darrell Sexstone (DG INTPA), Martin Sekeleti (AFAAS), Knud Tybirk (Food & Bio Cluster Denmark).

Funded by the European Union

Website:
https://www.desiralift.org/
LinkedIn:
https://www.linkedin.com/company/desira-lift
Email:
info@desiralift.org

Address:
Wageningen Centre for Development Innovation

P.O. Box 88
6700 AB Wageningen
The Netherlands