Chapter

# A New Paradigm in the Delivery of Modernizing Agricultural Technologies across Africa

*Paul L. Woomer, Welissa M. Mulei and Rachel M. Zozo*

## Abstract

This Chapter describes the approach and impacts of the Technologies for African Agricultural Transformation (TAAT) Program. TAAT is an operational framework based upon collaboration between the African Development Bank, the International Institute of Tropical Agriculture, and many other partners. This Program is designed to deliver modernizing agricultural technologies as a means of achieving food and nutritional security, and to boost employment and agricultural exports across Africa. TAAT consists of nine Commodity Compacts that have assembled technology toolkits for use in development programs and six specialized Enablers that help them to do so. These commodities are rice, maize, wheat, sorghum, millet, cassava, sweet potato, common beans, fish, and small livestock. The Enablers provide policy support, youth empowerment, capacity development, irrigation and soil fertility expertise, and control of invasive pests. Together these Compacts and Enablers design and conduct collaborative agricultural development projects in partnership with national counterparts. To date, TAAT has staged 88 interventions in 31 African countries, including the incorporation of customized technology toolkits within country loan projects of major development banks. Over three years, these efforts have reached about 10.6 million adopter households and increased food supply by 12 million tons worth over US $763 million, resulting in substantial improvements in smallholder farmer's food supply (0.75 MT $yr.^{-1}$) or income (\$128 $yr.^{-1}$). Environmental gains in terms of carbon offset average 0.74 MT $CO_2e$ $yr.^{-1}$ per adopter household, an outcome indicative of positive combined rural development and climate actions. This Chapter describes how these technology toolkits are designed, deployed and evaluated, and how TAAT is becoming a leading mechanism for agricultural innovation delivery across Africa. This evaluation is limited to eight critical field crops and does not consider animal enterprises or the strategic roles of TAAT Enablers, two other important activities within the larger Program.

**Keywords:** African Development Bank, agricultural transformation, COVID-19, food security, IITA, strategic investment, TAAT Program, technology delivery

## 1. Introduction

Agriculture is a major economic activity and source of income across Africa, but its untapped potential contributes to persistent poverty, rural stagnation and deteriorating food security. Also, increased food demand and changing consumption habits have led to rising food imports, including staple foods, and the value of these imports now exceeds US $35 billion per year [1]. At the same time, failure to commercialize agriculture is associated with massive rural unemployment; where over 120 million Africans are out of work, more than 672 million live on less than US $2 per person per day, and 60% of those unemployed are young people. Nonetheless, agricultural modernization serves as the critical engine for African economic growth and this transformation requires that a host of production and processing technologies become widely introduced and adopted by the region's smallholder farmers and entrepreneurs.

Technologies for African Agricultural Transformation (TAAT; https://taat-africa.org) is a recent program led by the International Institute of Tropical Agriculture (IITA) that has pioneered new approaches to deploying proven technologies to African farmers. TAAT arose as a joint effort of IITA and the African Development Bank (AfDB) and is a crucial component of the latter's Feed Africa Strategy [1]. TAAT is organized around 15 "Compacts" that represent priorities and partnerships to achieve Africa's potential in achieving food security and advancing its role in global agricultural trade. Nine of these Compacts relate to specific priority value chains of rice (*Oryza sativa*), wheat (*Triticum* spp.), maize (*Zea mays*), sorghum (*Sorghum bicolor*) and pearl millet (*Pennisetum glaucum*), cassava (*Manihot esculenta*), sweet potato (*Ipomoea batatas*), common bean (*Phaseolus vulgaris*), fish, and small livestock [2]. Weaknesses in producing these commodities are viewed as responsible for Africa's food and nutritional insecurity, the need for excessive importation of food, and the unrealized expansion of food exports. Six of these Compacts serve as Enablers, providing specialist services to the Commodity Compacts in policy support, capacity development, youth empowerment, soil management, water management, and response to invasive pests. Together these Compacts design interventions in collaboration with national programs to introduce technologies and management innovations that respond to country priorities for agricultural development. In many cases, these targets are addressed by implementing projects resulting from sovereign country loans awarded by development banks; and TAAT's role in the planning and execution of these loan projects is becoming a vital element of their success. This Chapter describes the range of technologies advanced through TAAT and the impact of their deployment through various mechanisms over the past three years (mid-2018 through early-2021).

TAAT's portfolio of proven technologies deemed ready for deployment is open-ended, meaning that all holders are welcome to work through the Program; however their inclusion is subject to scrutiny through different mechanisms [3]. The most abundant technology holders are Consultative Group on International Agricultural Research (CGIAR) Centers through their commitment to producing new knowledge and technologies necessary to meet several Sustainable Development Goals (CGIAR, 2018). Many of these innovations result from the 16 programs and platforms of the CGIAR Collaborative Research Program (CRP), mainly those eight addressing Agri-Food Systems [4]. The CGIAR has paid special attention to compiling and categorizing these innovations and projecting their impact [4, 5]. A review by TAAT in early-2019 indicated a 63% overlap between CGIAR technologies deemed ready for next users and the elements of the TAAT toolkits [3, 6], with the discrepancy mainly attributable to technologies related to CGIAR mandate commodities outside of TAAT's nine priority value chains.

TAAT is well-positioned to advance agricultural modernization across Africa, both as a developmental model and a mechanism forward. As a model, TAAT allows an open-ended flow of proven agricultural technologies to stream toward rural development planning. It redirects the technical expertise within its Compacts to the needs of others' programs in ways that correct for flawed designs of the past and that provides the technical assistance required to assure that more aggressive actions toward agricultural modernization result in the future. At the same time, it reorients research institutions to the expectation that simply novel ideas and innovative piloting are insufficient. Ultimately success is judged and rewarded by the widespread adoption and commercial appeal of the proven technologies that result. TAAT consists of four components: 1) Enabling Environment, 2) Rural Technology Delivery Infrastructure, 3) Technology Deployment, and 4) Program Management [2]. The first component promotes a common transformation agenda, proven technologies and supporting policies; the second organizes technology access and partnership around that agenda; the third conducts collaborative technology delivery at national and site levels; and the last creates an administrative and reporting structure for the first three. This simple model is proving to be quite effective. Furthermore, recent developments in "Scaling Readiness" permit innovations to be classified based upon their stage of development and range of applicability, serving as both a means to prioritize commitments and predict impact trajectories [7].

As a mechanism, TAAT represents a dynamic platform where those committed to advancing transformative agricultural technologies connect with those who need them most, particularly within government programs expected to improve their agricultural production, strengthen rural economies and advance the lives and livelihoods of farming households. It is a way for the development community to buy into technical advances under the assurance that offered technologies achieve expected levels of adoption and promised impacts. TAAT was quick to pivot in response to the COVID-19 pandemic [8] and its disruption of planting, harvesting, and marketing; and took quick action to mobilize improved seed and planting materials to national partners. In the larger view, TAAT recognizes that the world's most vulnerable, including women, youth, and the most impoverished farmers, are the hardest hit by the pandemic, that the African economy is particularly vulnerable to it [9], and that it has a vital role to play in support of Africa's recovering food systems. This Chapter describes the technologies that TAAT promotes, how they are advanced, and the impacts achieved by this Program over its first three years, with attention to eight priority crop commodities.

## 2. An enabling environment

An enabling environment is necessary for modernizing technologies to become better recognized and mobilized. The Enabling Environment offered as a Program component through TAAT is partly the result of its carefully considered design and implementation process. The design of TAAT started through dialog between IITA and AfDB and culminated in endorsement and buy-in from Regional Member Countries of the Bank. TAAT arose as a service to the AfDB Feed Africa Strategy by international centers holding proven but under-deployed technologies of importance to Africa's agricultural future [1]. Three alternative models were evaluated based upon alignment among different agro-ecologies, within recognized priority developmental interventions, and along key agricultural value chains, with the last option deemed the most promising in terms of ready linkage to national programs and the private sector. In the process, a comprehensive list of candidate technologies were examined, particularly those from the CGIAR, as being ready for the next users [4, 5]. A key step in this process was submitting letters of intent by national authorities from 25 African countries to participate in the Program [10]. Negotiations led to the release of US $40 million to the TAAT Program by the African Development Fund, primarily for three-year operations (2018 to 2021) of the 15 TAAT Compacts and the Program Management Unit; and an additional $7 million raised from the Bill and Melinda Gates Foundation in support of technology brokerage by the TAAT Clearinghouse. TAAT was officially launched through two events, one held at IITA, Ibadan, Nigeria to formalize its technical approaches, and another at AfDB HQ in Abidjan, Cote d'Ivoire to finalize administrative requirements and to announce the Program to the larger international community; both conducted during January 2018 [2]. The Program began its field operations shortly afterwards.

As a result of these preparations, the Enabling Environment fostered through TAAT then focused upon three areas; the promotion of agricultural modernization as a regional priority, the removal of bottlenecks preventing regional integration of its technologies, and an understanding of which trade and regulatory policies are required to advance its goals. Agricultural modernization is crucial to the achievement of numerous Sustainable Development Goals (SDGs) [11], starting with Goal 1-No Poverty, Goal 2-Zero Hunger, and Goal 13-Climate Action but extending into several other Goals as well (Section 3.2). TAAT also serves as a replicable mechanism within Goal 17-Partnerships to Achieve the Goals. Technologies associated with the various TAAT commodity Compacts are extremely relevant to this Chapter and appear in **Table 1**. This list covers only crop technologies, but information on TAAT's approaches to aquaculture, poultry, and small livestock are available elsewhere [12].

Note that all African countries are eligible to participate in TAAT based upon their willingness to enact policies that facilitate the uptake of food production technologies, to align national research and extension systems to it, and to participate in agreed-upon activities. This participation is often performed in conjunction with sub-regional programs and sovereign country developmental loans. This approach ensures that TAAT interfaces with a wide variety of agricultural value chain development programs to secure the deployment and adoption of recommended food production technologies by farmers, particularly dynamic seed systems, commercializable accompanying technologies, and backstopping information and extension campaigns.

The need to accelerate and harmonize technology release and registration across regions shapes TAAT's policy approaches, particularly when current situations restrict technology scaling across national boundaries within regional economic blocks. Policies and protocols for the release and registration of crop varieties are streamlined so that improved varieties available in one country are utilized in others within the same agroecological zone. In many cases, the policies needed to reinforce agricultural transformation are in place, such as the duty-free importation of agricultural equipment and inputs and reducing regulatory obstacles to the seed sector. However, in some cases regional cooperation is unenforced or lacking. It is not the purpose of this Chapter to review national and regional policies related to the fast-track release of technologies within and between countries, but the provision for policy support can indeed lead to faster uptake of modernizing technologies, and this became a primary concern of the Program's Enabling Environment.

## 3. A regional technology delivery infrastructure

TAAT operates a Regional Technology Delivery Infrastructure (RTDI) that offers a menu of proven food production technologies in nine priority commodities to all Program partners and stakeholders. These technologies are bundled into "technology toolkits" [3] that may be configured into elements of country projects and offered through knowledge sharing and extension campaigns. These technologies include improved varieties, seed systems innovations, accompanying soil fertility and pest management strategies, harvest and post-harvest management, digital

| Commodity value chain | TAAT Technologies ready for scaling |
|---|---|
| Rice | New Rice for Africa (NERICA), Hybrid Rice Varieties for Africa (ARICA), Aromatic rice varieties (ORYLUX), Engineered irrigation, Deep urea placement, Foliar micronutrient addition, Motorized weeders, RiceAdvice digital support, Axial flow threshers, GEM parboiling and flour production |
| Wheat | Heat and drought tolerant varieties, Yellow stem rust resistant varieties, Hessian fly resistance, Sahel “winter” production, Raised bed furrow irrigation, Hermetic grain storage, Conservation agriculture and zero tillage, Integrated pest, disease and weed management, Expansion of harvesting combine fleets, Flour milling and blending systems |
| Maize | Drought-tolerant varieties (DTMA, WEMA), Imazapyr resistance for striga management (IR-maize), Golden maize (Vitamin A fortification), TEGO seed licensing mechanism, Contract mechanization (Hello Tractor), Specialized pre-plant fertilizer blending and N topdressing, Maize-legume rotation and intercropping, Pre-emergent herbicides, Fall Armyworm control (e.g. Fortenza Duo®), Aflatoxin management (AflaSafe®) |
| Millet & Sorghum | Rust-resistant varieties, striga-tolerant varieties, Community-based seed production, Zai pits and contour bunds (water harvesting), Conservation agriculture, Fertilizer microdosing, Parasitoid wasps for Head Miner, Mobile stover choppers, Warrantage cereal banking, Flour production and wheat and barley substitution |
| Cassava | Resistance to Cassava Mosaic Virus, Golden Cassava (Vitamin A fortified), High dry matter and starch content varieties, Semi Autotrophic Hydroponics (rapid propagation system), Stem cutting enterprise, Integrated weed, pest and soil management, Cassava Business Connector (App), Chipping and livestock feed production, Mobile processing plant, High Quality Cassava Flour and industrial starches |
| Sweet Potato | Orange Fleshed Sweet Potato (OFSP, high Vitamin A), Drought- and virus-tolerant varieties, Purple sweet potato (high in antioxidants), Community-based cutting production, Greenhouse production of vines and cuttings, Raised bed production, Specially blended fertilizers, Relay intercropping with legumes, Silage production from vines, Puree production and products |
| Beans | High Iron Bean (HIB, also high Zn), Climbing bean with higher nitrogen fixation potential, Seed inoculation with rhizobia, Chemical seed dressing, Specialized fertilizer blends, Low-cost staking, Mechanical weeder & herbicide (integrated management), Hermetic grain storage, flour and flour products, Pre-cooked beans |

**Table 1.**
*Technologies ready for bundling and scaling arranged by TAAT commodity value chain.*

applications and value addition processes. These technologies represent Regional Public Goods that offer broad public interest and recognizable benefits, strong alignment with development bank strategic orientation and regional objectives, and higher impact through cooperation [10]. For the most part, these technologies are available to all stakeholders for free. TAAT is not a research program intended to develop new technologies, instead it serves as a mechanism to advance proven approaches that warrant massive up-scaling. In some cases, applied research is needed to customize toolkits for specific conditions and clients.

### 3.1 The TAAT top 100 technologies

Compilation and interpretation of the technologies described in **Table 1** resulted from the assembly and analysis of a TAAT Top 100 Technologies database. This database consists of 10 leading technologies for each of TAATs priority commodities and contains three main categories and 13 descriptive variables (data not presented). To a large extent, these technologies are based upon achievements of the CGIAR [4, 5] where many of the technologies from its CRPs are described as either ready for next user or in an advanced stage of innovation. In terms of technical approach

(**Figure 1a**), the technologies are divided among those involving improved genetics and plant and animal breeding (23%), those based upon the distribution of digital information (3%) [13], production input products of proven efficacy (21%), crop and animal management technologies of utility within agricultural extension messaging and campaigns (27%) and the availability of appropriately designed labor-saving

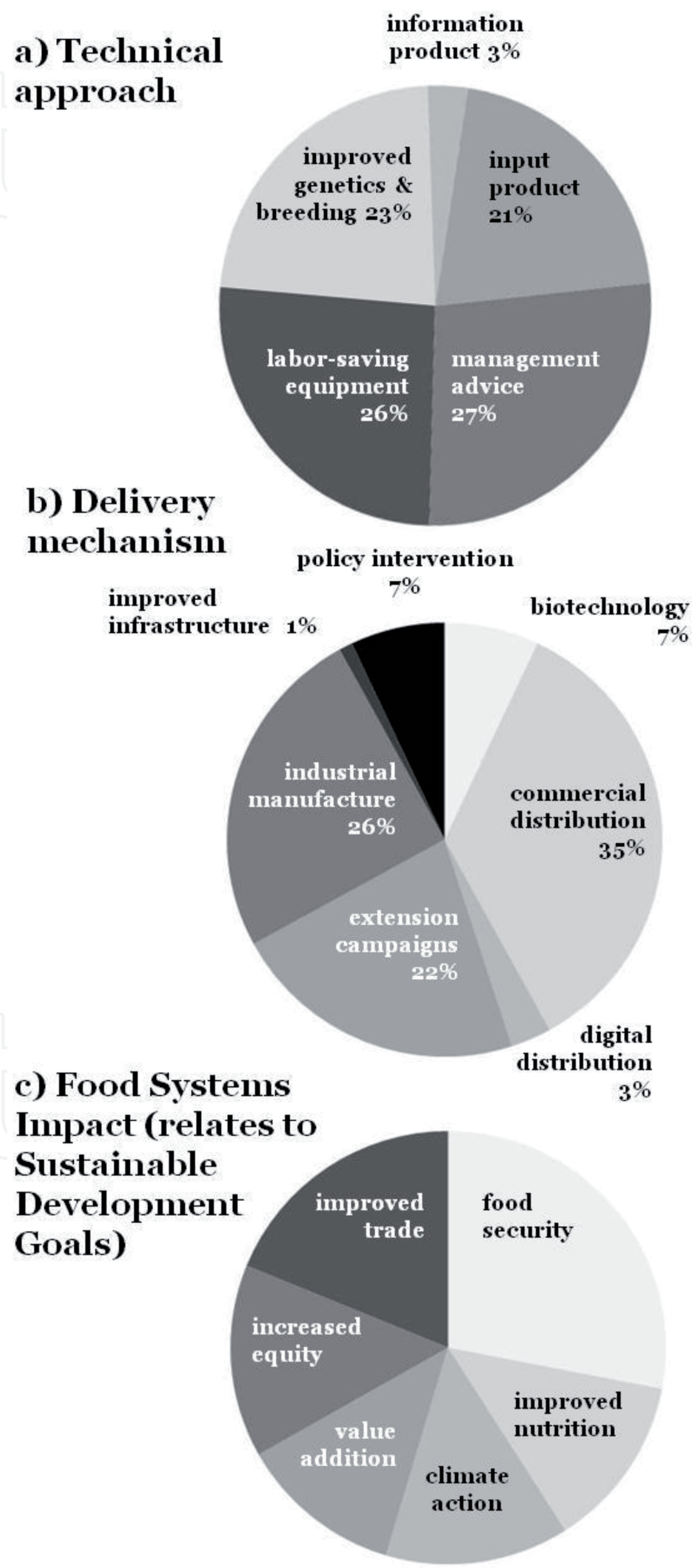


**Figure 1.**
*The technical approach (a), delivery mechanism (b) and food systems impacts (c) of the TAAT top 100 technologies.*

equipment (26%). These approaches are balanced, suggesting enormous scope for the deployment of diverse and accompanying technologies. This symmetry may be attributable to how the various Compacts were encouraged by TAAT to design their technology toolkits along entire value chains in the first place [3, 6].

Within the TAAT Theory of Change, a modern African farmer is encouraged to acquire the best varieties for their growing and market conditions, raise them with recommended accompanying production inputs, conduct their production through sound management advice, and do so in a labor- and cost-effective manner [2, 3, 6, 12]. It also encourages clients to add value to agricultural products in a way that addresses upper-end markets. TAAT is also examining the policy implications of its Top 100 transformative technologies. While this area remains under development, preliminary results suggest that very few technologies (12%) have no immediate policy implications or may otherwise be advanced through the national legislative process involving enactment or repeal of laws (23%) (data not presented). In contrast, technology deployment is best facilitated through the agendas of African regional organizations (46%) or requires progressive regulatory adjustments (rather than lawmaking) by national authorities (58%).

### 3.2 Technology delivery strategy

Of equal importance to TAAT and its mission are the mechanisms through which its targeted technologies are delivered (**Figure 1b**). TAAT operates under the assumption that there are seven separate delivery mechanisms in support of its technologies but also recognizes that they are complementary and overlapping. These delivery mechanism categories and the proportion of technologies belonging to them are applications reliant upon biotechnologies (7%); commercial production and distribution along supply chains (35%), digital applications (3%), government and private extension services (22%), industrial manufacture and distribution (26%), inclusion within infrastructure development projects (1%) and through policy reform (7%). The main sources of overlap in delivery strategy exist between biotechnologies, industrial advancement, and commercial distribution.

The technologies and their relationship to food systems (**Figure 1c**) advanced by TAAT clearly relate to the Strategic Development Goals [11]. Of the Top 100 Technologies: 76% intend to increase farm productivity, improve food security, and reduce hunger (relates to SDG 2-No Hunger); 35% improve the quality of food, household nutrition, and diets (relates to SDGs 2 and 3-Good Health); 37% represent climate-smart innovation and reduced risk of environmental extremes (impact upon SDG 13-Climate Action); 33% add value and provide opportunity for cottage-scale and commercial processing (relates to SDG 1); 39% improve equity by providing special opportunity to women, youth or vulnerable stakeholders (relates to SDG 5-Gender Equity); and 51% impact upon trade imbalances and provide opportunity for agribusiness and exports (relates to SDG 8-Economic Growth). The total percentages are more than 100% because a given technology can contribute to more than one SDG. In this regard, the TAAT technology portfolio represents a balanced approach to food systems improvement.

Of the Top 100 transformative technologies, 76% were extensively deployed by TAAT Compacts to African farmers. Of these same technologies, 64% are sufficiently established for widespread adoption, whereas the remaining 36% require further fine-tuning or site adjustment (**Table 2**). From these characteristics, it is evident that almost 2/3 of the transformative technologies advanced by TAAT are mature in that they are ready for immediate adoption by clients. This applicability is in keeping with its mandate as a leading element of the AfDB Feed Africa Strategy. At the same time, the technology identification process by TAAT must also be

| Technology category | No. | Comment |
|---|---|---|
| Included within current Compact workplans | 76 | Over 3/4 of these Top 100 transformative technologies are currently advanced through TAAT's country-level deployment |
| Based upon Advanced R&D technologies | 27 | Many of the technologies advanced by TAAT require further refinement and site-specific adjustment |
| Based upon Established technologies | 49 | About 2/3 of the technologies currently advanced by TAAT are fully established and ready for widespread adoption |
| Plans for future inclusion | 24 | Several additional Top 100 technologies warrant attention during future stages of TAAT |
| Based upon Advanced R&D technologies | 9 | There are some key areas of technical Research & Development that require future attention among TAAT partners |
| Based upon Established technologies | 15 | Several additional established technologies could be rapidly included within existing TAAT technology toolkits |

**Table 2.**
*Categories of current TAAT technologies, their proportions and current status.*

forward-looking, and 24 of them show potential to make future contributions to the TAAT agenda. Nine of these candidates are at an advanced stage of Research and Development but requires additional attention, and 15 of them exist as innovations that are ready for the next users but remain weakly distributed. In this way, the nine candidates represent a research agenda for the institutions leading these Compacts in the following areas and include 1) Imazapyr resistance in maize for striga (*Striga spp.*) management; 2) Golden maize for vitamin A fortification; 3) Improved, hardy, duo-purpose breeds of poultry for smallholders; 4) release of purple-fleshed sweet potato that is high in antioxidants; 5) Hessian fly resistance in wheat; 6) Aflatoxin management of maize and other crops using Aflasafe® atoxigenic fungi; 7) refinement of integrated vegetable-aquaculture systems; 8) water quality protection and aeration of fish ponds, and 9) expansion of harvesting combine fleets of wheat. Over 50% of these topics are related to improved crop varieties and animal breeds, making the CGIAR particularly well-positioned to contribute to their achievement through genetic innovation [4, 5].

Of the 15 underutilized off-the-shelf technologies, one is a biotechnology (preventative antibiotics for poultry bio-security), another is a commercial product (pond lining in fishpond construction), and four are well-established management interventions related to different forms of crop rotation and value addition to manure and composts. Six technologies involve underutilized industrial devices and applications including semi-automated poultry hatcheries, mechanized de-feathering and egg sorting, motorized weeders and choppers for field operations, hide curing and secondary leatherworks, and sorghum flour milling and blending for wheat and barley substitution. Three underutilized technologies have strong policy dimensions related to the clustering fish farmers within aquacultural parks, and the humane slaughtering and meat inspection of both poultry and small ruminants. RTDI requires that TAAT technologies be recognized and appreciated through a variety of information resources offered by the Program [2, 3] including numerous adoptive case studies [12].

### 3.3 Relationship to resilience and climate action

Agricultural resilience describes the ability to absorb and overcome constraints to agricultural production and livelihoods, whether short-term or long-term, sudden or chronic. This ability responds to complex and accumulating economic, social,

| | frequency |
|---|---|
| **a. Resilience factors (technologies offer …)** | |
| Overall climate-smart effects | 53% |
| Increased carbon sequestration | 34% |
| Increased drought tolerance | 30% |
| Management of biotic interactions | 25% |
| Greenhouse gas emissions reduction | 14% |
| Resistance to extreme weather events | 14% |
| **b. Resilience pathway (delivered through …)** | |
| System-level transformation | 13% |
| Increased crop biomass | 9% |
| Improved water use | 8% |
| Improved biotic relations | 8% |
| Reduced gaseous loss | 4% |
| Drought tolerant germplasm | 3% |
| Enterprise diversification | 3% |
| Increased animal hardiness | 2% |
| Improved animal sheltering | 2% |
| Reduced fuel use | 1% |

**Table 3.**
*Relationship of the technologies advanced by TAAT to agricultural and environmental resilience.*

environmental, and institutional shocks and stresses. Resilience is often considered within the context of climate change and its relationship to food security [14]. In this sense, the TAAT technologies are classified in terms of their potential contributions to resilience as related to 1) increased carbon sequestration, 2) reduction of GHG emissions, 3) performance during drought, 4) protection against extreme weather events, and 5) fostering beneficial biodiversity. These factors were evaluated to assess their roles in climate-smart agricultural practice. The relationship of these technologies was examined in two ways; the types of resilience they infer, and the pathway through which their benefits are achieved (**Table 3**) with one of five different sorts of climate-smart features expressed among 53% of the different technologies (**Table 3a**). Within the context of agricultural transformation, the pathways to adoption are extremely relevant. This analysis revealed ten different pathways ranging from 1–13% of the individual technologies. These pathways included (in descending order): system-level transformation, increased crop biomass, improved water use, improved biotic relations, reduced gaseous loss, drought-tolerant germplasm, enterprise diversification, increased animal hardiness, improved animal sheltering, and reduced fuel use (**Table 3b**). This diversity of pathways reinforces the advantages and complexity of bundling technologies into toolkits for application within climate-responsive rural development projects [3, 15].

## 4. Technology deployment

The TAAT Program mobilizes a wide range of agricultural technology providers to assemble flexible menus of proven food production technologies related to

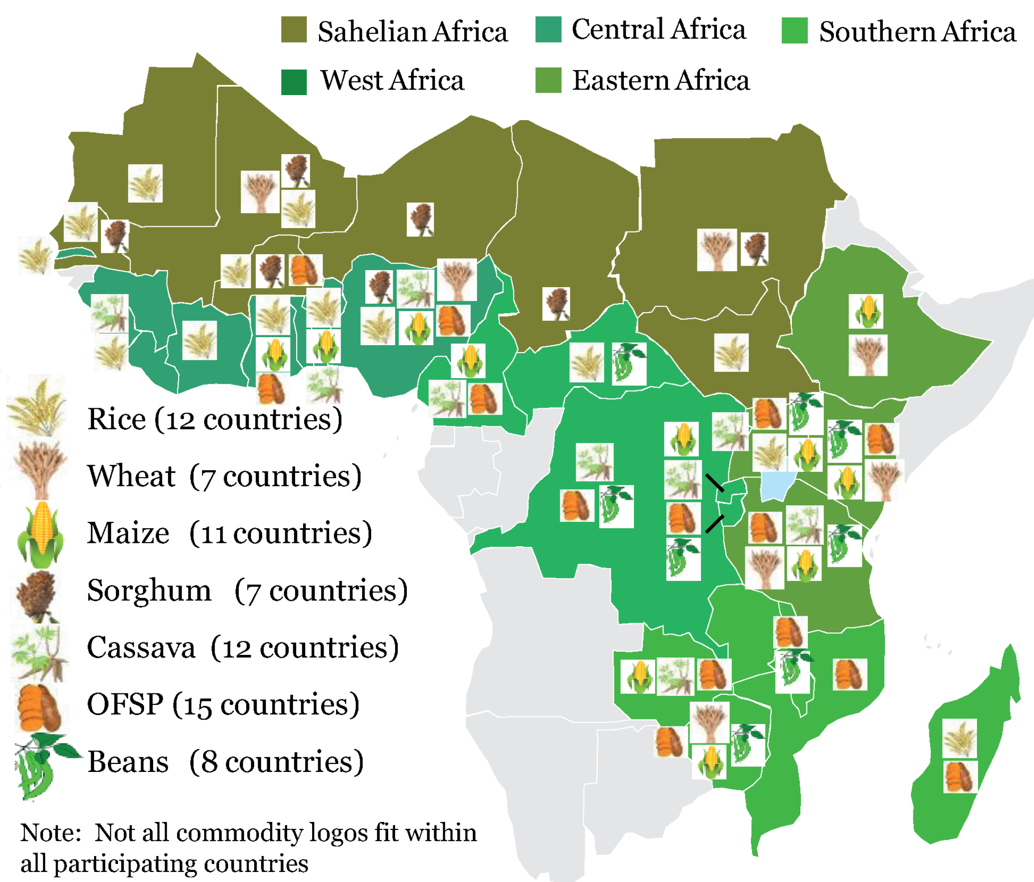


**Figure 2.**
*TAAT activities include commodity compact interventions across 31 African countries.*

improved seed and breeding systems and their accompanying management and input products. These bundles are referred to as toolkits [3] intended for large-scale deployment through promotional and outreach campaigns, usually in conjunction with the country projects of development banks and humanitarian organizations. For the most part, these efforts are linked to country-level extension campaigns and with existing community-based innovation platforms. This approach allows for efficient outreach actions. As a result of these efforts, TAAT Commodity Compacts have performed 88 technology deployment interventions in 31 countries (**Figure 2**) over the past three years (mid-2018 through early-2021). Some highlights of these interventions grouped by their respective commodity Compacts follow, and further information about them is available through https://taat-africa.org/compact-briefs/.

### 4.1 The rice compact

This Compact is coordinated by AfricaRice and operates in 12 countries, with concentrated activities in West Africa and the Sahel (10 countries). Its focus is to reduce massive rice imports into Africa and produce a quality product that rivals those imports. In all, this Compact worked through 41 partnerships and delivered 162 MT of certified seed through its cooperators. It introduced climate-smart rice varieties with potential yields reported to be 4–7 MT $ha^{-1}$, but its reported yield results were far less. This discrepancy suggests that these improved rice varieties were inconsistently accompanied by recommended Good Agricultural Practices (**Table 1**). In some cases, however, outstanding yields were achieved with harvests up to 4.2 MT $ha^{-1}$. A total of 69.1 MT of breeder seeds was produced for multiplication into certified seeds by seed companies. In some cases, deep placement of large urea pellets was introduced to reduce the loss of ammonia to the atmosphere. In terms of rice utilization, a parboiling system and substitution of firewood with rice husk briquettes as cooking fuel resulted in substantial energy savings.

### 4.2 The wheat compact

This Compact is coordinated by The International Center for Agricultural Research in the Dry Areas and operates in seven countries. It focuses upon reducing massive wheat imports into Africa and advancing cool-season, irrigated production in the Sahel. The improved varieties delivered through TAAT have two key characteristics; some varieties are heat tolerant, allowing wheat production across a broader range of growing conditions, including lower elevations. Others are tolerant of stem rust, a constraining fungal disorder. This Compact operates through 129 partnerships and delivered 131,211 MT of certified seed through its cooperators. As a result of this strategy, wheat self-sufficiency is becoming a realizable national agenda item. In terms of outreach, grain and seed production, and value addition have impacted the lives of about 1.8 million beneficiaries, with 44% of them being women and youth.

### 4.3 The maize compact

This Compact is co-managed by The African Agricultural Technology Foundation and IITA and operates in 11 countries. It focuses on greater reliance upon 35 high-yielding and drought-tolerant maize hybrids and their adoption by commercial seed companies. It builds upon TEGO®, an innovative mechanism to accelerate the commercial acceptance of new maize varieties. The Maize Compact operates through 60 partnerships reaching 5,337,003 beneficiaries. It delivered 20,111 MT of certified seed through its seed system network. It also deployed 6,598 tons of certified seed treated with Fortenza Duo™ to counter the invasion of Fall Armyworm, an outbreak that directly preceded the initiation of TAAT's activities in 2018.

### 4.4 Millet and Sorghum compact

This Compact is coordinated by The International Crops Research Institute for the Semi-Arid Tropics and operates in seven countries of the Sahel. Promotion of pearl millet and sorghum is combined within a single Program unit because both of these crops are critical staple cereals of Africa's cultivated drylands, with millet assuming importance in the driest cultivated areas of the Sahel. This effort primarily focuses upon the achievement of food security among some of the most vulnerable farmers in the world. In all, this Compact worked through 16 partnerships reaching 83,629 beneficiaries and delivered 1,391 MT of certified seed through its cooperators. The Compact also addresses the substitution of sorghum and millet grains for imported ones, particularly in blended porridges and brewing.

### 4.5 Cassava compact

This Compact is directed by IITA and operates in 12 countries spread over Central, East, Southern and West Africa. Its focus is upon the distribution of improved virus tolerant varieties, accompanying sound management practices, and the elevation of cassava as an agro-processed export commodity. The Compact delivered 20,457,130 cuttings of this vegetatively cultivated crop through its cooperators. Its integrated approaches have resulted in substantial improvement of cassava yield. For example, in two countries, Tanzania and Nigeria, farmers relying upon TAAT technologies increased yield from an average of 8 MT to 29 MT per ha, similar to levels reported in commercial plantations in S.E. Asia. Critical to that increase is adopting improved vegetative propagation systems that ensure virus-free planting material (see Section 7.1). One of these technologies, Semi-Autotrophic Hydroponics, has produced and distributed 47,065 plantlets used to establish cutting operations. One problem confronted by the Compact is the low cost and weak marketability of cassava. Post-harvest (e.g. tuber waxing to extend shelf life) and agro-industrial processing (e.g. manufactured starch) technologies address this problem. These efforts intend that African countries become suppliers of cassava products on international markets.

### 4.6 Orange fleshed sweet potato compact

This Compact is coordinated by The International Potato Center and operates in 15 countries across Central, East, Southern and West Africa. Its focus is upon the introduction of Orange Fleshed Sweet Potato (OFSP), rich in pro-vitamin A, its accompanying propagation and management technologies, and the use of OFSP in human nutrition and localized value-added processing. This Compact worked through 18 partnerships and delivered 32,995,950 cuttings and vines of this vegetatively cultivated crop through its cooperators. This Compact promoted 93 improved varieties with high-yielding, virus-tolerant, and climate-resilient characteristics based on their adaptation within different agro-ecological zones [16] and through national approval mechanisms. Localized vegetative propagation systems that provide affordable, virus-free cuttings and vines are central to this approach and the Compact established more than 500 propagation enterprises. Value addition to OFSP is also pivotal, with about 18,659 individuals trained in enterprise development [17], 555 small-scale enterprises established, and over 40 industrial food processors now offering OFSP products. It also promotes sweet potato vines as a source of nutritious livestock feed and silage.

### 4.7 High Iron bean compact

This Compact is directed by the Alliance of Bioversity International and the International Center for Tropical Agriculture (ABC) and operates in eight countries of Central, East and Southern Africa. It focuses on the distribution and use of improved High Iron Bean varieties that may also be high in zinc. It operates through 10 partnerships that reached 1,150,929 beneficiaries. To date, 5,006 MT of seed, both bush and climbing types, were disseminated through public-private partnerships and community-based actions. A suite of improved agricultural practices accompany these varieties that increase yields from 0.8 MT to 1.25 MT per ha for bush types, and even more for climbers. Many of its beneficiaries also engage in value-adding pursuits, including the production of pre-cooked beans and the milling of bean flour.

Not included in this section is a description of the TAAT Aquaculture and Small Livestock Compacts led by WorldFish and the International Livestock Research Institute, respectively (see Section 7.4).

## 5. Larger outcomes and impacts

The deployment of technologies by TAAT has resulted in substantial impacts among eight of the Program's commodities; rice, wheat, maize, sorghum, millet, cassava, sweet potato and bean (**Table 4**). Productivity has increased an average

| TAAT commodity compact | Increased productivity[1] | Crop coverage[2] | Increased production | Increased value[3] |
|---|---|---|---|---|
| | MT $ha^{-1}$ (%) | $km^2$ | MT $y^{-1}$ | \$ $y^{-1}$ x $10^{\wedge 6}$ |
| Rice | 0.21 (10%) | 7,058 | 148,223 | 55.9 |
| Wheat | 0.80 (36%) | 18,000 | 1,440,000 | 290.9 |
| Maize | 0.75 (50%) | 8,412 | 630,930 | 107.3 |
| Millet | 1.0 (133%) | 237 | 23,765 | 4.5 |
| Sorghum | 1.75 (140%) | 1001 | 175,172 | 37.7 |
| Cassava | 27.5 (262%) | 3,441 | 9,462,750 | 217.6 |
| Sweet Potato[4] | 5.3 (106%) | 198 | 104,927 | 34.6 |
| High Iron Bean | 0.45 (56%) | 588 | 26,471 | 14.7 |
| Total (*mean*[5]) | *1.33* (58%) | 38,936 | 12,012,238 | 763.2 |

[1]*Based upon improved vs. baseline yields (% increase in parentheses).*
[2]*1 $km^2$ = 100 ha.*
[3]*Based upon January 2021 international prices.*
[4]*Promotion of the Orange Fleshed Sweet Potato.*
[5]*Mean (0.133) is normalized by dry matter content and coverage-weighting, Standard Error of the Mean ± 0.76.*

**Table 4.**
*Increased crop productivity, production and value resulting from technology deployment by the TAAT program.*

of 58% ± 25% in response to these technologies, ranging between only 10% for rice and 262% for cassava. When adjusted for moisture contents and coverage, these gains amount to 1.33 ± 0.76 MT $ha^{-1}$. These technologies were extended across 3.9 million ha and resulted in an additional 12.0 million tons of food worth over US $763 million. At the beneficiary household level (**Table 5**), these technologies were applied to an average 0.37 ± 0.16 ha with the least areas devoted to bean (0.13 ha per household) and the largest to millet (1.92 ha). In large part, these scaling dimensions reflect the design and complexity of the technology packages themselves, with open-pollinated seed-based cereals appearing the least complicated and vegetatively propagated crops (cassava and sweet potato) more so. Wetland rice represents an intermediate case because of its complex field preparation and irrigation requirements.

The return in terms of increased food and income reflects the areas devoted to those crops, the magnitude of yield increase, and the commodity value. On average, adoption of TAAT technologies resulted in an average of 0.75 ± 0.41 MT of additional food per household per year (**Table 5**), with bean offering the least (0.05 MT) and cassava the most (3.6 MT) when expressed on a dry weight basis. Among the five kinds of cereal, food supply increased by an average of 0.94 MT per household, a substantial amount in terms of household food security. Alternatively, these gains could be marketed for an average of $128 ± $72 per household with the greatest returns realized in the order sweet potato >sorghum or millet> cassava >wheat>bean >rice > maize (**Table 5**).

In all, the various technology toolkits reached 10,616,372 households. If we assume equal division of project resources and services between these commodities, the expenditures by the three-year Program reached these beneficiaries at an average cost of $3.28 per household. This estimate does not take into account co-financing and in-kind contributions of TAAT's many partners. The Benefit to Cost Ratio of TAAT's program investment is about 22:1, an impressive return on developmental investment to that part of the Program directly supporting these eight crop commodities and accompanying Program services. The COVID-19 pandemic coincided

| TAAT Commodity compact | Beneficiary households (hh) | Adoption area | Increased food supply[1] | Increased Income[2] |
|---|---|---|---|---|
| | no | ha $hh^{-1}$ | MT $y^{-1}$ | \$ $hh^{-1}$ |
| Rice | 2,257,987 | 0.31 | 0.06 | 25 |
| Wheat | 1,777,845 | 1.01 | 0.70 | 164 |
| Maize | 5,174,965 | 0.16 | 0.11 | 21 |
| Millet | 12,403 | 1.92 | 1.69 | 364 |
| Sorghum | 71,217 | 1.41 | 2.16 | 529 |
| Cassava | 817,314 | 0.42 | 3.62 | 266 |
| Sweet Potato[3] | 54,641 | 0.36 | 0.67 | 634 |
| High Iron Bean | 450,000 | 0.13 | 0.05 | 33 |
| Total (*mean*) | 10,616,372 | *0.37 ± 0.16* | *0.75 ± 0.41* | *128 ± 72* |

[1]*Dry matter yield increase takes different Compact adoption areas and moisture contents into account, overall mean is weighted by coverage, ± Standard Error of the Mean.*
[2]*Based upon January 2021 international prices, overall mean is weighted by the number of adopters, ± Standard Error of the Mean across eight commodities.*
[3]*Promotion of the Orange Fleshed Sweet Potato.*

**Table 5.**
*Adoption and household impacts resulting from technology deployment by the TAAT program.*

with TAAT's third year of operations, and it is difficult to assess to what extent the momentum of the Program was impeded by the contagion despite its timely adjustments to it (see Section 6).

Projections of carbon sequestration resulting from TAAT interventions may also be made (**Table 6**). These projections are based upon Compact reports of increased yield, coverage (**Table 4**), numbers of adopters (**Table 5**), and assumptions concerning biomass yield, moisture content, Harvest Index, crop

| TAAT Commodity Compact | Increased system $CO_2e$ | Annual increased $CO_2e$[1] | Value of annual increase in $CO_2e$[2] | Annual reduction per adopter[3] |
|---|---|---|---|---|
| | MT $ha^{-1}$ | MT $y^{-1}$ | \$ $y^{-1}$ x $10^{\wedge 6}$ | MT |
| Rice | 1.06 | 186,882 | 4.11 | 0.08 |
| Wheat | 2.92 | 1,753,606 | 38.6 | 1.9 |
| Maize | 3.10 | 869.284 | 19.1 | 1.5 |
| Millet | 5.71 | 22,611 | 0.50 | 1.8 |
| Sorghum | 9.27 | 154,668 | 3.40 | 2.2 |
| Cassava | 26.1 | 1,498,159 | 33.0 | 1.8 |
| Sweet Potato | 5.24 | 25,944 | 0.57 | 0.1 |
| High Iron Bean | 1.63 | 48,079 | 1.06 | 0.1 |
| Total (*mean*) | *4.8 ± 2.3* | 4,559,213 | 100.3 | *0.74 ± 0.44* |

[1]*Mean weighted by coverage from **Table 5**, ± Standard Error of the Mean.*
[2]*Based upon US \$22 per MT $CO_2e$.*
[3]*Based upon the annual increase of $CO_2e$ and overall mean weighted by beneficiary households from **Table 6**, ± Standard Error of the Mean.*

**Table 6.**
*Carbon sequestration resulting from TAAT intervention.*

carbon content, $CO_2e$:crop C ratio, planning horizons, and the price of $CO_2e$. This approximation allows for the expression of realizable gains of $CO_2e$ associated with increased biomass and residual benefits in terms of $CO_2e$ gain per ha and as total average gain per project year. Realizable gains were achieved based upon increased focus upon climate-smart field practices and products within the technology toolkits employed by country agricultural development projects (see Section 3.3). This approach results in estimated $CO_2e$ gains averaging 4.8 ± 2.3 MT $ha^{-1}$ across these eight commodities and a total of 4.6 million MT of $CO_2e$ per year worth about US $100 million. When the number of adopters is considered, this amounts to per capita emissions reductions of 0.74 ± 0.44 MT $CO_2e$ per household per year, very similar to the targets established by Branca et al. [18] and Lipper et al. [19] when like sorts of climate-smart technologies are described. The possibility of organizing small-scale African farmers into a legion devoted to carbon sequestration is an exciting option for the future, but one that does not greatly benefit individual climate-smart practitioners from the standpoint of direct financial benefit. The gains they achieve are worth only $16 per household per year at current prices of $CO_2e$ (calculated from **Table 6**). For this reason, the benefits of climate-smart technologies are perhaps better promoted in terms of improved yield and land care and then factored in terms of realizing national commitments rather than being presented to farmers as a separate and tangible income opportunity.

## 6. COVID-19 pandemic disruption and adjustments

The COVID-19 pandemic has strongly affected TAAT's plans for technology deployment, and attempts at adjustments to the contagion were only partly successful. TAAT's deployment strategy was initially based upon travel to partnering countries by technology holders and physical gathering among stakeholders adopting their technologies. Most of this travel and participation within the missions of development banks was curtailed during 2020, prompting rounds of discussion on alternative ways forward. The TAAT Policy Support Compact offered a quick response through a position paper describing the threat to food security and economic growth, and raising some useful policy support options [8]. Another response considered the implications of COVID-19 safety precautions at the farm level and among potential adopters of TAAT technologies. This latter approach formed the basis for COVID-safe agricultural practices distributed to many project partners and stakeholders.

COVID-safe agricultural practices mitigate the risk of contracting the disease among farming household members while providing essential services as food producers during the pandemic. COVID-safe farming considers that contagion within a farm household is a function of the frequency of encounters with others and the risks they pose. There are two basic risks of exposure, external risk based upon exposure to others while away from the farm and internal risk from infected persons coming onto the farm. There are four main mitigation measures related to COVID-safe agricultural practice: 1) adherence to recommended social precautions, 2) adjustments in the management of farm labor, 3) increased use of small-scale machinery allowing for greater social distancing, and 4) greater reliance upon digital applications. Social precautions include personal distancing, wearing protective gear, and avoiding unnecessary contacts. The farm household should practice these precautions as the pandemic spreads deeper into rural communities. Greater reliance upon digital applications for farm planning, routine diagnostics and market intelligence may allow fewer outside contacts.

The gloomiest forecasts of food system disruption due to the pandemic [20] have fortunately not come to pass. Causes for these reduced impacts across Africa are still under study but they may be related to quick and decisive lockdown actions by governments, inherent resistance to viral infection within communities, and reduced frequency and range of travel among the poor. In many ways, small-scale farmers already operate in a socially distanced fashion. Nonetheless, the effect of the pandemic on TAAT's plans to widely disseminate its proven technologies through ever-growing partnership mechanisms during its third year was profound, and it is intriguing to consider how the Program can "build back better" in the aftermath of the pandemic [21]. TAAT's widespread multiplication of improved crop varieties preceded the pandemic by two years and effectively carried over into it to great advantage among earlier beneficiaries.

## 7. Technologies and African agricultural transformation

The promotion and adoption of improved technologies have an essential role in the modernization of African agriculture. In this sense, technologies include production input products and equipment distributed through commercial channels, improved management strategies advanced through extension and information campaigns, and to a lesser extent, agro-industrial processes that add value to commodities. This very applied concept of technologies overlaps with offered innovations and proposed solutions but are not necessarily synonymous with them. Innovations often lead to technologies of these sorts but may also include partnership arrangements, policy interventions, and novel operating assumptions beyond the reach or influence of farmers [7]. Solutions may also be expressed as broader knowledge management systems, disruptive paradigm shifts, and alternative guiding ideologies [15, 22–24]. From the practical context of how African smallholders and agricultural entrepreneurs can change their operations, the narrower definition of technology seems more appropriate. At the same time, development strategies are necessarily influenced by larger issues and regard new technologies as only one element of a more complex equation. Nonetheless, the need to establish proven technologies from research products is an important function and one that increasingly drives the agendas of research institutions and their donors toward more impact-oriented designs [4, 5].

### 7.1 Technology bundles

Throughout its short project lifetime, TAAT has recognized several trends in terms of technology selection and deployment. Among crop commodities, improved varieties usually serve as a lead technology that is backstopped by accompanying products and managements [3, 12]. The need for genetic innovation as a replacement for traditional varieties is well established, particularly lines that are better suited to biotic and edaphic stress, including climate-induced extremes. This trend explains why TAAT's priority technologies listed by commodity in **Table 1** all start with improved germplasm and then include additional products and managements that ensure their increased genetic potential. Genetic improvement was hard-earned across Africa and the result of concentrated breeding efforts over the past decades, resulting in disease-tolerant rice, wheat, maize, cassava, and other crops. At the same time, breeders also focused upon biofortification to develop crops with higher nutritive value, such as sweet potatoes, maize, and cassava rich in pro-vitamin A or beans containing more iron and zinc. Technology promotion by

TAAT has resulted in much wider recognition of these new varieties and its technology toolkits link these genetic advantages to regional and country rural development programs, as well as nest them into climate adaptation efforts. There is also the advantage that commercial and community-based mechanisms often co-exist and aid in the accelerated deployment of these new varieties, and this entered into TAAT's scaling strategy.

At the same time, excessive focus upon improved varieties and their breeding objectives may also pose disadvantages. For the most part, TAAT's advancement of hybrid rice has yielded little gains because of its complexity. So too, over-reliance upon drought tolerance in maize can lead to lower yields during years of better rainfall because of its quicker maturity. Across much of Africa, parasitic striga limits maize production more than drought, and TAAT's efforts have not adequately addressed this massive constraint. Similarly, the trait of higher iron and zinc contents in common beans appears inadequately combined with disease resistance and greater symbiotic capacities in biological nitrogen fixation. Vegetatively propagated crops such as cassava and sweet potato are more challenging to scale than crops propagated by seed, limiting early deployment by greater complexity and expense (see Sections 4.5 and 4.6). Nonetheless, the interactions within TAAT toolkits allow for customization to specific conditions in ways that can guide the design and implementation of development projects, including optimal scaling of new crop varieties, and this is a particular strength of the TAAT Program.

This strength requires that TAAT also be flexible in terms of its partnership arrangements [25] if its toolkits are to become widely recognized and adopted. An important partnership mechanism exists through the assisted design of sovereign country loans during their planning stage and buy-in from existing loan projects. TAAT had limited success in this area over the past three years because the formulation and approval process of these loan projects is longer than the project has been operating. Besides, existing loan projects are understandably unable or reluctant to redirect funding toward technical directions and partners not considered in their original, approved designs. Nonetheless, TAAT has experienced substantial buy-in to its technologies as their potency becomes more widely recognized with the strongest interest expressed by loan projects for rice, wheat, maize, and cassava in numerous countries, and through the emergent agendas within key regional projects addressing climate change adaptation.

### 7.2 Private sector engagement

The Program experienced difficulties to date in the adoption of technologies by the private sector through expansion of their product lines, in large part because companies move cautiously into the manufacture and distribution of new products. At the same time, Regional Public Goods offered for free do not guarantee that competitors cannot quickly move into a new commercial opportunity paved through others' initial investment. This situation is particularly true for improved crops bred by research organizations and later released by national authorities but must then be offered without licensing cost to seed companies as an original donor condition. Alternatively, many seed companies prefer to breed, produce, and market their own proprietary lines. Mechanisms to overcome this reluctance are being explored, including the right to give different branded product names to the same varieties. The manufacture of accompanying input product technologies such as fertilizer blends, biotechnologies, or small-scale equipment is less subject to this constraint, in large part because investors have the latitude of developing trade secrets around their adapted manufacturing process. TAAT is in the process of organizing a technology investor's forum to promote commercial opportunities among its proven technologies in order to overcome these constraints.

### 7.3 Youth-led technology dissemination

TAAT established an Enabler activity devoted to the role of youth as technology adopters, the so-called ENABLE-TAAT Compact. This inclusion responds to concerns of the aging farmer population across Africa and expectations that youth-led entrepreneurship drives future economic growth [26]. This Compact builds upon IITA's Youth Agripreneur Movement and the operations of its experiential learning and enterprise incubation approaches [27]. The Compact serves to reinforce the priority commodities of TAAT (**Table 1**) and test the youth appeal of its technology toolkits. ENABLE -TAAT operates under the understanding that entrepreneurial youth are especially attracted to higher-value, readily marketed and value-added commodities. Youth seek to avoid the drudgery associated with small-scale production through greater reliance upon equipment and automation. They also hold greater access to and expertise in handheld communication devices and are better positioned to rely upon them. In this regard, youth are particularly attracted to the cereal seed industry, biofortified crops especially orange-fleshed sweet potato, cassava processing, flour blending, and raising poultry and fish [28]. In some cases, they served not only as technology adopters but also contributed to the refinement of those technologies, as illustrated by the development of more efficient vegetative propagation, intercropping and animal feed systems. In all, ENABLE-TAAT guided 71,562 youth toward TAAT commodities and technologies and assisted in establishing 166 new youth-led agribusinesses. During its activities, this Compact also registered 5,582 youth as local champions in six countries, trained 2,829 youth in TAAT technologies and reached 197,360 persons through social media outreach. Youth were also quick to recognize and apply the COVID-safe agricultural practices described in Section 6. Another important indicator of success by the ENABLE-TAAT Compact is the magnitude of interest it attracted from local authorities and the buy-in to its expanded activities by additional donors such as the International Fund for Agricultural Development and the Mastercard Foundation.

### 7.4 Livestock and animal enterprise as technology targets

Both animal enterprise and inland aquaculture are priority commodities within TAAT, and they have their own technology toolkits. These commodities and toolkits are not described in detail in this Chapter but warrant a brief description because of their importance as farm enterprises. The technology bundles of the Small Animal Compact consist of strategies that combine improved animal breeds, nutritious feeding regimes, and better veterinary care [3]. TAAT's original design grouped poultry and small livestock (goats and sheep) into a single Compact, but different technology toolkits were subsequently developed for each. Program design also excluded dairy and beef, in large part because of their lengthy production cycles. Commercial poultry is separated between broiler and layer production with different breeds, feeds, and housing requirements associated with each. A contrasting technology is the rearing of dual-purpose, free-ranging breeds that produce both meat and eggs for small-scale farmers. Entrepreneurial youth are strongly attracted to commercial poultry production, particularly eggs, because of its longevity and even cash flow. However, producers experience difficulties regarding the disproportionately high costs of feed and the risks of disease. Aquaculture focuses upon distributing improved varieties of tilapia and catfish through localized hatchery operations and then raising them in various containment systems under improved feed regimes. In short, improved animal and fish production technologies are key to Africa's agricultural transformation, and this opportunity is incompletely addressed within this Chapter as it is focused primarily upon specific field crops.

## 8. Conclusions and next steps

The TAAT Program is a novel and successful means to popularize and deliver agricultural technologies needed by small-scale African farmers. The deployment strategy in Section 4 and the immediate impacts from that deployment presented in Section 5 support this claim. TAAT achieves increased agricultural productivity and diversification, leading to improved food and nutrition security; job creation through expanded commercialization and industrialization; and improved soil, land, and water management practices due to Good Agricultural Practices; among other benefits (Section 4). The validity of its technology bundling and deployment approaches is reinforced by an across-the-board 58% increase in crop productivity resulting in 0.75 MT (dry weight) increased household food supply among over 10 million adopting farmers. The Program and the technologies it advances were expected to strongly interface with national partners, sovereign country loans, donor organizations and development banks, and this too has occurred. TAAT continued to operate throughout 2020 despite the disruption of the COVID-19 pandemic, in large part because the germplasm-led technologies it advocates were already distributed to numerous countries before the onset of the pandemic. Their increased productive capacity strategically contributed to food systems into the contagion [3, 12, 21]. Gains in agricultural production across crop commodities were linked to corresponding increases in system carbon stocks, suggesting a future connection between technology scaling and climate action. These factors signal considerable success of a project initially designed around the need to deploy a suite of proven, modernizing agricultural technologies to small-scale African farmers.

The growth of TAAT will also influence its role as a longer-term deployment mechanism of technologies and an improved approach to delivery partnership. In its first three-year Phase initiated through IITA and the African Development Bank, TAAT did not receive the buy-ins as anticipated from other development banks, and this reluctance limited the scope of its direct activities. One result was the failure to establish additional commodity Compacts as initially intended, particularly one's focusing upon grain legumes, vegetables, and the restoration of tree plantations. TAAT recognizes the need for these additional Compact alliances but could not support them given its available resources. One very positive signal of success, however, is the considered adoption and expansion of its approach within the Consultative Group on International Agricultural Research (CGIAR), a global partnership that unites international organizations engaged in agricultural research. Nine of its 15 Centers currently collaborate within TAAT, and the ongoing "One CGIAR" reform process [29] examines TAAT as a lead regional mechanism for technology delivery in Africa and as a model for delivery alliances elsewhere. This success was further reinforced by the recent "High-level Dialogue on Feeding Africa: Leadership to Scale-up Successful Innovations" (29 & 30 April 2021) conducted as a global virtual event organized by AfDB, The International Fund for Agricultural Development and others. During this event, 17 African heads of state and numerous other dignitaries recognized the need for Africa's agricultural transformation and they pledged support to it (see https://www.afdb.org/en/events/

high-level-virtual-dialogue-feeding-africa-leadership-scale-successful-innovations). In this respect, technology refinement, characterization, bundling and delivery to small-scale farmers of the tropics will remain an essential ongoing effort involving many researchers, development specialists, extensionists, and stakeholders into the future.

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## Author details

Paul L. Woomer*, Welissa M. Mulei and Rachel M. Zozo
International Institute of Tropical Agriculture, Nairobi, Kenya

*Address all correspondence to: plwoomer@gmail.com

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