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SHORT COMMUNICATION

Revitalizing Smallholder Farming in Africa: Insights from China's Science and Technology Backyard Model

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Abstract: Smallholder farmers are crucial to African agriculture, yet low productivity hampers their ability to meet rising food demands from a growing population. Despite numerous support programs, traditional extension approaches and limited access to technology hinder success. The main objective of this article is to discuss how China's Science and Technology Backyard (STB) model can be adopted in African contexts as a viable solution. The STB model, proven successful in China, directly addresses the disconnection between scientists and farmers through direct collaboration in crop fields. The authors first summarize insights from the implementation of the STB model in China and then propose strategies for its adoption in Africa. The subsequent comparative analysis, combined with three case studies, shows that the STB model, which emphasizes farmer-centered innovations, has the potential to bridge knowledge gaps, enhance productivity, and stimulate rural development in Africa despite resource constraints. Finally, the authors note that strategic investments in infrastructure, coordination among stakeholders, and acknowledging associated costs are critical for the successful implementation of the STB model. Simply put, the authors believe the STB model can greatly enhance African smallholders' farming productivity, but before the model can successfully serve its functions, involved stakeholders should ensure all supporting conditions are provided.

Keywords: Smallholders; Farming productivity; Science and technology backyard; Rural revitalization

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1. Introduction

Smallholder farmers constitute the backbone of African agriculture, but their productivity often remains low [1], undermining their capacity to meet the needs of a growing population [2,3]. This deficiency, paradoxically at odds with Africa's excellent agroecological resources [4,5], has attracted various organizations to initiate programs to enhance African smallholders' farming productivity and increase their incomes [6]. Yet, the success of these programs hinges on the effective transformation of agricultural extension approaches and advanced knowledge and technology into farm productivity [7,8]. Without such a transformation, achieving the intended outcomes may prove elusive.

African countries rely heavily on extension services to disseminate innovations from scientists to farmers [9]. While the public extension system remains the most extensive source of information for smallholders in developing countries [10], its effectiveness is often compromised by the scarcity of extension workers. For example, the farmer-to-extension worker ratios are 1000:1 in Kenya and 3000:1 in Nigeria [11–13]. The shortage of well-trained extension agents and the persistent disconnection between farmers and scientists hinder the potential success of African smallholders by generating barriers for the latter to access and adopt the latest agricultural technology [14–18].

Even when African smallholders have access to modern agricultural technology, they often face difficulties understanding its intricacies in practical applications. When it comes to fertilizer choice, for example, many smallholders in Ethiopia struggle to distinguish genuine fertilizers from counterfeit ones [19]. Many also lack knowledge about the precise amount of fertilizer needed to optimize crop yields [20], often leading to the over-application of chemical fertilizers, causing soil and environmental degradation [21]. Others have adhered to blanket fertilizer recommendations, which fail to account for the specific nutrient requirements of their own fields, resulting in stagnant or even declined yields [22,23]. Given these challenges, enhancing smallholders' capabilities to understand and adopt well-established technologies is key to Africa's sustainable agricultural development [24].

One popular approach to addressing these challenges in African contexts is the development of Farmer Field Schools (FFSs) [9]. FFSs represent a participatory learning opportunity that empowers farmers to experiment with new technologies and practices on their own farms, increasing their likelihood of adopting these technologies [25]. Farmers assume a leading role in the learning process, with guidance from trained extension workers [26]. Through FFSs, smallholder farmers gain timely and transparent knowledge about recently developed agricultural technologies and practices, which can substantially contribute to efficient inputs, soil fertility restoration, new food sources, and new marketable products for local communities [27]. As such, FFSs improve not only smallholders' farming skills but also their livelihoods. However, a significant challenge is that extension workers often lack the necessary skills for designing and conducting field experiments [28]. Such experiments are essential for farmers to compare available technologies and practices and choose the most suitable for their own farms [29]. Without this capability, farmers are less likely to adopt new approaches, even when they are aware of the potential benefits of these approaches.

In light of these challenges, promising solutions should be sought to revitalize African agriculture. The main objective of this article is to analyze how an innovative strategy emerging in China, the Science and Technology Backyard (STB) model, can be adopted in African contexts as a viable solution. Designed to empower smallholder farmers to pursue sustainable agricultural production, the STB model aims to establish a robust connection between the scientific communities and farmers' backyard crop fields—hence the name "Science and Technology Backyard" [30]. It enables scientists to shape their research based on insights gathered from smallholders' feedback; their research outputs can then be tailored to fit the latter's pressing needs. The bridge that channels scientists' talent from the Ivory Tower to farmers' backyards fosters a responsive and effective approach to sustainable agriculture [31].

Our analysis adopts a comparative method with case studies. First, we discuss the nature and key functions of the STB model based on its nearly 15 years of operation in China. Second, we compare the key features of the STB model and the current model in African countries, highlighting what the STB model can bring to African smallholders. After identifying major gaps between the two models, we propose practical strategies that African countries may undertake to successfully adopt the STB model. Initial evidence for such success from a pilot project in Malawi is provided to support our proposal. Finally, we highlight the costs involved and the challenges that may occur when developing STBs in Africa.

2. The STB Model

An STB stands as a dynamic rural hub designed to eliminate barriers that often separate scientists and farmers, effectively closing the gap between scientific knowledge and its real-world applications [31]. Its paramount objective is to promote technological innovation and knowledge exchange, with the immediate goal of boosting the productivity of smallholder farming [32]. This visionary initiative was born in Quzhou County of Hebei Province in the North China Plain from the unwavering dedication of scientists from the China Agricultural University (CAU) [33]. Since the establishment of the first-ever STB in 2009, Quzhou STBs have innovated and introduced 25 key technologies to local farmers, boosting their crop yields by more than 500 kilograms per year, generating an annual increase of 40 million RMB (approximately 6 million U.S. dollars) in total farm income for Quzhou [34].

2.1 Nature and Key Functions

In essence, the STB model directly "fixes" the traditional disconnection between scientists and farmers by stationing scientists (professors, lab scientists, and graduate students) in rural areas where smallholders reside. Unlike traditional agricultural research, which necessitates a two-step process, with scientists conducting research first and extension agents then disseminating the knowledge to farmers [35], the STB model brings scientists directly into crop fields, dramatically reducing the reliance on extension agents for knowledge dissemination. As such, the defining characteristic of the STB model is that it enables scientists to collaborate closely and actively with farmers, identify pressing challenges faced by the latter, and conduct research with them to find practical solutions. The model involves farmers in the entire process, from planning to innovation, technology adoption, and output assessments [32]. Not only do STBs act as a local catalyst for technological and economic advancements, but they also contribute to a global effort to redefine the relationship between scientists, smallholders, governments, non-governmental organizations (NGOs), and private companies, as the model ensures that all these stakeholders work collaboratively in rural settings (Figure 1).

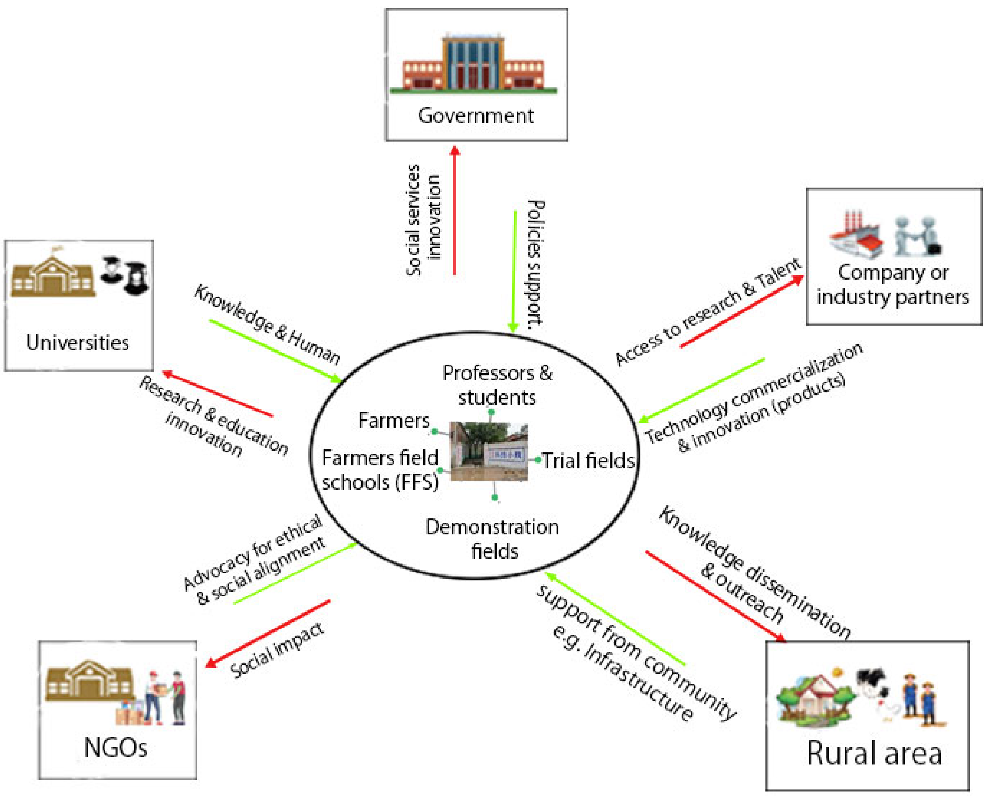

Figure 1. Key elements and functions of a typical STB.

Source: Author's creation incroporting insgiths of Jiao et al.[32].

Today, China boasts an impressive network of over 300 STBs operating across 29 provinces and autonomous regions (out of 31) in its mainland [33]. These STBs are deeply committed to tackling intricate agricultural challenges within local communities, demonstrating a remarkable fusion of knowledge with practical, farmer-centered solutions, as illustrated by the following two case studies.

2.2 Insights from China's STB-driven Agricultural Advancement

A. Basic model: Wangzhuang STB. The first compelling case is the Wangzhuang STB, established in 2011 in Quzhou's Wangzhuang village [33]. In this typical STB model, graduate students (including overseas students) spend a minimum of 120 days annually residing alongside farmers as part of their graduate program. They engage closely with rural communities, partnering with both local farmers and scientists from the CAU's Quzhou Experimental Station. Together, they pinpoint agronomic challenges such as soil fertility, crop cultivation, crop diseases, etc., conducting research in experimental fields to find solutions (Figure 2). During more than twelve years of operation, the Wang Zhuang STB has witnessed the participation of over 100 graduate students (under the guidance of CAU professors), whose partnership with local farmers enables practical applications of scientific knowledge to tackle agricultural challenges specific to the local community.

Figure 2. Graduate students conducting agronomic assessments in Wangzhuang farmers' fields.

Source: Picture taken by author.

The Wangzhuang case demonstrates the STB model's defining feature and core function: fostering scientist-farmer collaborations to find solutions tailored to specific local problems. Nationwide, more than 1,500 graduate students have actively engaged in setting up and running STBs thus far, developing over 1,500 graduate theses addressing diverse agricultural challenges in China. This collective effort has also led to the creation of at least 284 innovative technologies and the training of over 200,000 farmers who have emerged as adept leaders in implementing these advancements [36].

B. High-value-added model: Sichuan Advanced Agricultural & Industrial Institute. Another case that stands out in the STB landscape is the Sichuan Advanced Agricultural & Industrial Institute, an affiliate of the CAU established in 2020. Aiming to create high-value-added products, this institute actively collaborates with food-manufacturing entities, including farmers' cooperatives and local food companies in rural areas of Sichuan, a province well-known for its diverse natural conditions for agricultural production [37]. Dedicated laboratories associated with this institute have developed high-value-added products sourced from local agricultural products, such as figs, peanuts, wheat, and a wide range of other farm produce. Remarkably, more than 300 distinct products have emerged from figs alone since 2020 (Figure 3). Moreover, over 300 business contracts (six with more than 10 million RMB and 32 with more than one million RMB) for the commercialization of scientific and research findings have been signed with local enterprises, showcasing the diversity and potential of agricultural innovations in the areas of new breeds, vaccines, biological engineering, and food processing [38]. No doubt, these proactive measures not only benefit the local farming communities but also bolster the country's food security and overall prosperity.

Figure 3. Award-winning fig wine from manufacturing companies in Sichuan.

Source: Picture taken by author.

Note the pivotal role the local government plays in this model. The Sichuan government reduces the costs of essential inputs for agricultural production, such as water (priced at only 0.144 RMB/m^3 [39]), electricity, and transportation. Additionally, the government subsidizes produce-processing machines for farmers' cooperatives, helping to build factories that purchase crops from farmers for local processing. This collaboration creates unique value-added products from farm outputs, both distributed within China and exported internationally by rural Sichuan-rooted companies. Recognizing the significance of such enterprises, the local government actively acknowledges and rewards them for their innovations in agricultural product development. In 2023 alone, the Sichuan government awarded 1000 manufacturing companies working within rural settings the title of "Provincial Key Industry-Leading Enterprises for Agricultural Industrialization" [40]. This recognition acts as a potent catalyst, inspiring other businesses and farmer cooperatives to operate in rural Sichuan and help create high-value-added products and job opportunities.

2.3 Comparison of the STB Model and the Current Model in Africa

Despite the shared aim of raising agricultural productivity and smallholder livelihoods, as well as the similar role smallholders play in the rural economy of China and most African countries [4,5], there are notable differences between the STB model and prevailing approaches in Africa. Table 1 provides a comparative analysis, emphasizing differences in three fundamental dimensions of technology extension exposure: approaches taken, intervention periods, and the specificity of issues tackled. First, the STB model employs both bottom-up and top-down approaches, fostering collaboration between scientists and farmers [32,33]. In contrast, the African model primarily relies on a top-down approach through extension workers [9,41], often overlooking the pressing needs of smallholder farmers. Second, the STB model emphasizes long-term engagement throughout agricultural cycles [32,33], whereas existing African models often offer one-off interventions during active farming seasons [9]. Third, given the approaches adopted and intervention periods involved, a diverse

Table 1. Comparison between the STB model and the current model in Africa.

Features	STB model	Current model in Africa
Approach	Bottom-up and top-down approaches • Collaboration between scientists and farmers in rural settings.	Top-down approach • Knowledge dissemination through extension workers
Intervention periods	Long-time exposure • During both active and non-active farming seasons	One-off intervention • During active farming seasons
Content/solution	Solutions to specific problems	General solution
	• Targets specific problems in particular areas	• General solution (e.g., national blanket fertilizer application rate)
Tools utilized	Multiple tools	Limited tools (adopting countries, selected)
	• Farmers field school	• Farmers field school (Angola, Benin, Burkina Faso, Ethiopia, Ghana, Malawi, Mali, Mozambique, Nigeria, Rwanda, Senegal, Tanzania, Uganda, Kenya, Zambia, Swaziland, Côte d'Ivoire)
	• In-field experiments	• Pluralistic extension service (Ghana, Kenya, Malawi, Mozambique, Nigeria, Rwanda, Senegal, Lesotho)
	• Technology night school	• Paticipatory extension service (Benin, Mali, Zambia, Swaziland)
	• Yield competition among smallholders	• Government-lead/ministry-based approach (Angola, Cameroon, Uganda, South Africa, Madagascar, Namibia, Zimbabwe, Mauritius)
	• Field days	
	• Technology display boards in the fields and STB centers	
	• Technology broadcast	
	• Technology poster on the street wall	

Source: Adapted from Oladele et al. [9,19,32,33,41,42].

array of tools, such as in-field experiments, FFSs, and technology broadcasts, are utilized in STBs to find solutions to specific local problems [32,33]. In contrast, the one-off interventions of the African model usually have a narrower focus on general issues (e.g., national blanket fertilizer application rate) rather than addressing specific localized challenges [19]. As such, limited tools are adopted in the extension system [9]. For example, as shown in Table 1, most of the sub-Saharan African countries adopted FFSs. A few countries have begun to adopt participatory and pluralistic extension programs involving multiple stakeholders, but most of these programs are still government-led or ministry-based in nature [9,42].

3. Prospects of Fostering Africa's Agricultural Development through the STB Model

3.1 Barriers to Knowledge Communication in African Agriculture

While smallholder farmers play a pivotal role in food security and rural development in Africa [43], they face a significant knowledge barrier to adopting modern agricultural technologies [44]. As noted above, the lack of direct scientist-farmer interactions creates a barrier, as the heavy reliance on (often limited) extension workers for knowledge dissemination blocks effective communication [11–13,45,46]. In the existing model (Figure 4), extension workers are the intermediaries of knowledge dissemination rather than knowledge creators, which seriously limits the possibility of identifying specific local problems and working out tailored solutions. Moreover, the connection between farmers and private companies remains feeble, often leading to price inequalities and profit uncertainty issues for smallholders [47]. While numerous NGOs operate alongside African smallholders [9], the former's impact is constrained by the tendency to introduce pre-packaged solutions without a deep understanding of the specific challenges faced by the latter [48]. Even if farmers temporarily adopt new technologies during NGO interventions, they often revert to traditional practices afterward [49].

3.2 STBs as the Way out?

China's STB model provides a practical solution to these barriers. The STB model thrives on collaborations involving diverse stakeholders, including governmental bodies, research institutions, private enterprises, NGOs, and, most importantly, local smallholders [19], often leading to the formulation of effective policies, innovative solutions, and improved practices. The STB model directly addresses the shortage of extension workers, improving farmers' access to information and technologies. In particular, it actively involves farmers in the research and development process, a crucial element in a region where agriculture is a primary source of livelihood. Moreover, the STB model contributes to rural revitalization by creating employment opportunities and access to markets for (high-value-added) agricultural products. Adopting the STB model in African countries has great potential to invigorate their rural economies by constructing a laboratory for various stakeholders to jointly find solutions to specific local issues. In this laboratory, hypotheses such as the following can be tested:

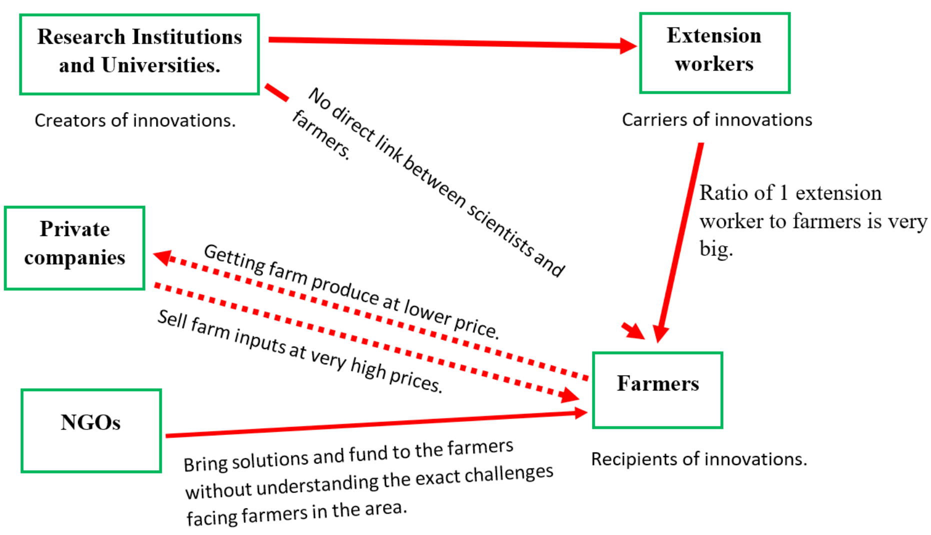

Figure 4. Communication links among various actors in African agriculture.

H_1: Implementing the STB model in country/region A will lead to an X% increase in agricultural productivity (e.g., crop yields or technical efficiency) among smallholder farmers within N_1 years post-implementation.

H_2: Implementing the STB model in country/region B will lead to a Y% increase in household income (or farm income) among smallholder farmers within N_2 years post-implementation.

H_3: Implementing the STB model in country/region C will lead to a Z% increase in employment among smallholder farmers within N_3 years post-implementation.

The following pilot project demonstrates the initial success of the STB model in an African context.

3.3. Initial Evidence of Success: Pilot STBs in Malawi

In November 2023, three STBs were established in Malawi, strategically located at the Mzuzu Residential Training Center (RTC) in Nkhatabay district, the Lisasadzi RTC in Kasungu district, and the Nthuchira RTC in Mulanje district. Covering the northern, central, and southern regions, respectively, these STBs mark a crucial step in advancing agricultural practices across Malawi. At Lisasadzi, a successful collaboration among two CAU graduate students, two extension officers, and 30 local smallholder farmers yielded promising results during the 2023/2024 growing season. Through this collaboration, farmers learned how to optimize fertilization techniques to maximize crop yields. Initially targeting an ambitious maize yield of 8000 kg/hectare, joint efforts of the three parties led to the selection and adoption of the SC 653 maize variety, known for its potential yield of 8000 kg/hectare, in the experimental field (Figure 5, left). Graduate students and extension officers then collected and analyzed soil samples alongside farmers to fine-tune fertilization practices. They increased the application of topdressing chemical fertilizer from 50 kg/acre to 78 kg/acre and raised compost manure usage from 100 kg/acre to 245 kg/acre, effectively optimizing nutrient levels essential for maize cultivation. In contrast, non-STB farmers adhered to conventional practices, relying solely on the national blanket fertilizer application rate of 50 kg/acre for chemical fertilizers, with only a few applying compost manure, averaging 100 kg/acre. Unsurprisingly, their crops encountered nutrient deficiencies, particularly in nitrogen. It is evident from Figure 5 that maize plants in STB fields (left) outgrew those in non-STB fields (right).

Figure 5. Comparison of maize growth between STB fields (left) and non-STB fields (right).

4. Challenges to and Strategies for Implementing the STB Model in Africa

4.1 Challenges

Implementing the STB model in Africa is not without challenges, however. The first fundamental challenge is resource constraints. African countries often face binding resource limitations [50], but the STB model necessitates significant investments in infrastructure, training, and capacity building [32]. The second substantial challenge lies in the lack of coordination. The STB model requires close cooperation between government agencies, research institutions, private enterprises, NGOs, and smallholder farmers [33]. In African contexts, effective collaboration is often hindered by communication gaps and a general lack of coordination among stakeholders [39,51]. Third, smallholder farmers in Africa often have limited access to markets [52], which in turn hampers their ability to benefit from the innovative technologies developed through the STB model. The sustainability of agricultural investment projects is often a concern in Africa [5].

4.2 Strategies

What does it take to transplant the STB model successfully in Africa, then? Initially, investing in rural infrastructure is imperative. This involves allocating resources toward developing research facilities, extension centers, and robust communication networks near farmers. These components provide the foundation for collaboration tailored to meet specific local needs. Research facilities enable scientists to conduct experiments and innovate, while extension centers disseminate crucial knowledge to farmers, ensuring that they adopt the latest best-suited practices. Meanwhile, efficient communication networks facilitate seamless information sharing across the agricultural value chain. Effective coordination among diverse stakeholders in the farming sector is also essential. Governments can establish inter-agency committees and task forces to align efforts efficiently, ensuring optimal resource utilization. Additionally, providing financial and technical support to NGOs and other entities dedicated to fostering collaboration and innovation in agriculture is crucial. Simply put, collaborations between governmental, non-governmental, and private sector partners can yield innovative solutions to amplify the impact of the STB model and make it sustainable.

4.3 Costs Involved

Yet, ensuring and expanding the effectiveness of the STB model involves various costs, encompassing initial setup, ongoing operational, and future maintenance expenses. This includes costs related to land acquisition, infrastructure, equipment (e.g., public address systems, computers, projectors, and informational brochures), staff salaries, and accommodation [53]. Ensuring suitable living arrangements for staff, fair compensation, and various payment structures (stipends, wages, and bonuses) are also crucial elements. Attracting and retaining qualified personnel, especially graduate students, requires competitive remuneration packages, conducive work environments, academic growth opportunities, research involvement, and avenues for career advancement. Although the STB model provides valuable solutions in agricultural production, integrating professional sectors such as "food marketing" may encounter initial challenges due to varying focuses and requirements for skill sets, necessitating customized strategies and a period of time for seamless integration.

5. Discussion

5.1 Key Findings and Policy Implications

Our analysis above suggests that the STB model offers a transformative strategy for rejuvenating smallholder farming in Africa. Emphasizing collaboration among scientists, farmers, and stakeholders, STBs bridge scientific knowledge and practical applications, empowering farmers with innovative technologies, addressing agricultural challenges, enhancing food security, and stimulating rural development. Successful implementation of the STB model in Africa necessitates strategic measures such as investing in rural infrastructure, coordinating stakeholders, empowering farmers, and fostering innovation. Given resource constraints, acknowledging associated costs is crucial for scale-up and expansion, covering setup, operational, and maintenance expenses.

Since the key to the STB model's success is to foster close collaboration among different stakeholders to induce farmer-centered innovations, four policy implications can be derived. First, China and African countries shall begin to construct forums for sharing experiences and lessons learned in implementing the STB model. Graduate students trained in STBs in China play a critical role in these forums. Second, NGOs supporting alternative extension services, such as FFSs, may consider incorporating STBs into their intervention packages—in fact, as noted above, FFS is an essential tool utilized in the STB model (Table 1). Third, given the STB model's fundamental strength in resolving specific local issues, pilot projects shall be implemented in areas with different agroecological conditions to generate high-quality data for testing the effectiveness of STBs in African settings. Disseminating knowledge about STBs in Malawi may help induce local demand for pilot STBs from smallholders. Finally, private enterprises shall also be informed about the development of STBs to explore the possibilities of creating markets for high-value-added agricultural products.

5.2 Limitations

Our proposal is not without limitations, however. First, due to the limited number of pilot STBs in Africa thus far, the effectiveness of our proposed strategy is not entirely clear at this point. Reassuringly, Malawi has started constructing pilot STBs, and STBs there have begun to show promising results (section 3.3). Of course, full-range impact evaluations require more time to generate suitable data for empirical testing [54]. In this regard, this article serves as a call for related pilot studies. Second, the STB model involves multiple stakeholders, and we have implicitly assumed that these stakeholders in Africa share the same motivation and capacity as their Chinese counterparts. This assumption remains to be tested. In particular, as noted above, governmental support is a key element of the STB model, but governments in different countries might have different resources and priorities [42,55]. The innovation capacity of scientists could also differ across contexts [4]. Yet, in any case, as the Malawian STBs demonstrate, promising yield growth can be achieved when graduate students, extension workers, and local smallholder farmers work closely together.

5.3 Plan for Future (Evaluation) Studies

In light of these limitations, future research will be fruitful in the following aspects. First, more pilot studies shall be implemented to explore how STBs can be established smoothly in Africa. Ideally, a "phase-out" design shall be adopted to allow for rigorous impact evaluations [54]. Second, after more STBs have been developed, impact evaluations shall be performed to assess the effectiveness of these STBs in terms of productivity gains, income generation, and social impacts based on the following "Results Chain" framework (Figure 6) [56]. Specific hypotheses to be tested include (but are not limited to) H_1–H_3 proposed above. Associated cost-benefit and cost-effectiveness analyses shall also be conducted, and long-run goals (e.g., food security and rural revitalization) shall be assessed [55]. Further assessment is also needed to understand the broader impact and limitations of STBs across different disciplines, such as crop cultivation, soil management, pesticide control, etc.

6. Conclusions

The STB model, proven successful in China, provides a transformative strategy for revitalizing smallholder farming in Africa. By promoting collaboration among scientists, farmers, and stakeholders, the model reduces the gap between scientific knowledge and its real-world applications, equipping farmers with advanced agricultural technologies, mitigating agricultural challenges, enhancing food security, and boosting rural development. Successful development of the STB model in Africa requires strategic measures such as investments in rural infrastructure, coordination among stakeholders, and innovations based on feedback from farmers. Given resource constraints, acknowledging associated costs is crucial for scale-up and expansion. Overall, the STB model signifies a promising path for agricultural advancement in Africa despite challenges. We envision its success in Africa can reshape the agrarian landscape, positively impacting millions of smallholders and paving the way to a resilient and prosperous future.

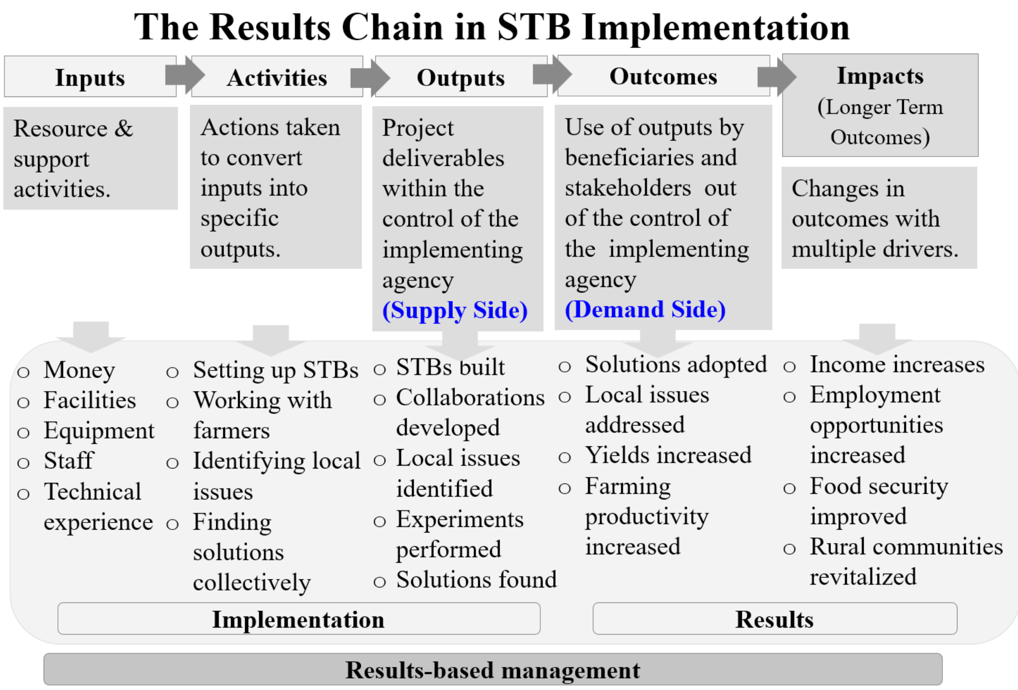

Figure 6. Results framework for STB implementation.

Source: Author's creation, based on the general results chain framework [54].

Author Contributions

Augustine Talababie Phiri (ATP), Xiaohui Zhao (XZ), and Qihui Chen (QC) designed the study. ATP and QC revised the manuscript. ATP, XZ, and QC performed the research. ATP performed case studies. XZ and QC provided advice on case studies and interpretation of findings. ATP, XZ, and QC wrote the manuscript. All authors read and approved the final manuscript.

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Data Availability

Not available.

Conflict of Interest

The authors disclosed no conflict of interest.

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