

REVIEW

Science and Technology Backyard model: implications for sustainable agriculture in Africa

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Abstract Sustainable food production to feed the growing population in Africa remains a major challenge. Africa has 64% of the global arable land but produces less than 10% of its food locally due to its inherently low soil nutrient concentrations. Poor soil fertility and a lack of fertilizer use are the major constraints to increasing crop yields in Africa. On average only about 8.8 kg NPK fertilizer is applied per hectare by African smallholder farmers. There is therefore considerable potential for increasing food production through sustainable intensification of the cropping systems. The low crop yields in Africa are also partly due to limited farmer access to modern agronomic techniques, including improved crop varieties, a lack of financial resources, and the absence of mechanisms for dissemination of information to smallholders. This study analyzed the Science and Technology Backyards (STBs) model and investigated its use for the transformation of agriculture in Africa. Some key lessons for sustainable crop intensification in Africa can be found from analysis of the STB model which is well established in China. These include (1) scientist-farmer engagement to develop adaptive and innovative technology for sustainable crop production, (2) dissemination of technology by empowering smallholders, especially leading farmers, and (3) the development of an open platform for multiple resource involvement rather than relying on a single mechanism. This review evaluates the benefits of the STB model used in China for adoption to increase agricultural productivity in Africa, with a perspective on sustainable crop intensification on the continent.

Keywords sustainable agriculture, Africa, smallholder, Science and Technology Backyards

1 Introduction

Many scholars believe that the name *Africa* originates from words used by the Phoenicians, Greeks and Romans, and means Motherland, a place that is sunny and warm. The African continent is the origin of humanity. It is thus an important historical region for understanding agricultural development. With climatic conditions that are suitable for crop growth, Africa has great potential for increased food production. For example, the arable land area per capita in Africa is about 2 ha, a value eight times higher than on the North China Plain^[1]. The rainfall and temperature in large parts of Africa are very suitable for crop production. As a result, agriculture in Africa is critical for both household livelihoods and economic development. Agriculture provides employment for about two-thirds of the working population in Africa and contributes an average of 30% to 60% of the gross domestic product and about 30% of total exports. That notwithstanding, agricultural productivity is low in Africa, with a great need to increase it using modern technologies.

Low crop yields have resulted in poverty and hunger in Africa. Up to 52% of people in many African countries live in moderate or severe hunger. Ironically, less than 10% of the total world grain production is from Africa, even though the continent harbors about 64% of the global arable land area. In comparison, China with less than 9% of the global arable land area produces 22% of global food (Fig. 1). Africa's demise is historic. The continent failed to benefit from the Green Revolution of the 1960s which advocated the use of agricultural chemicals, especially fertilizers^[2]. On average, grain yield in Africa is very low, about 1 t·ha⁻¹. In China it is about 5 t·ha⁻¹ and in developed countries such as the member states of the European Union it is up to 10 t·ha⁻¹^[3]. The extremely low grain yields in Africa make it difficult for the continent to

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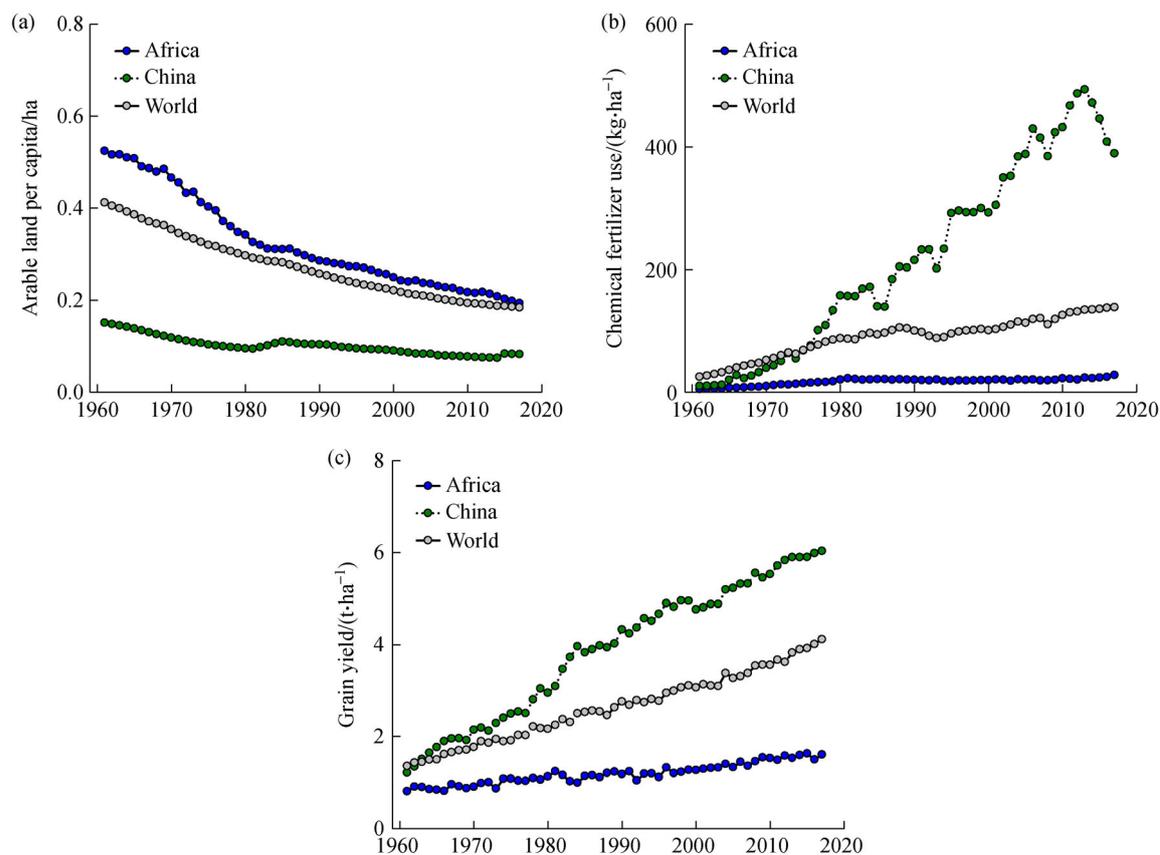


Fig. 1 Percentage of arable land (a), chemical fertilizer use per unit area (b) and grain yield (c) in Africa, China and the world from 1961 to 2018. Data was collected from FAOSTAT^[1].

feed itself, and it has had to rely on importing grains from international markets, which have further eroded its inherently weak economies.

Many factors have contributed to the low agricultural productivity in Africa, including farmer use of unimproved landraces and crop varieties and inadequate use of agricultural inputs, especially chemical fertilizers. It has been estimated that fewer than one-third of smallholders in Africa use chemical fertilizer to increase crop yields^[4]. Furthermore, low application rates of chemical fertilizers in crop production are also common in traditional cropping systems. On average, only about 8.8 kg NPK fertilizer is applied per hectare by smallholders in Africa^[5], and even in emerging countries such as Ethiopia the amount is only 57 kg·ha⁻¹^[6]. In contrast, applied fertilizer can be as high as 589 kg·ha⁻¹ for wheat and maize production in China, which can leave as much as 279 kg·ha⁻¹ fertilizer residues in the soils, a major cause of environmental pollution^[7].

Globally, the requirement for grain production has increased rapidly due to rapid population increase with potential for soil nutrient depletion in the longer term, leading to a vicious cycle of interaction of soil depletion and low crop productivity. If not arrested, African agriculture will be retrogressing compared to east Asia. Factors limiting fertilizer use in Africa include lack of

access to finance by farmers, poor knowledge of markets^[8], risk uncertainty and avoidance, even though it has been shown that yield return is negatively associated with the intensity of chemical fertilizer use in Malawi^[9]. Thus, low profitability emanating from low chemical fertilizer use is common in most parts of sub-Saharan Africa due to extreme lack of chemical inputs. Furthermore, agronomic practices are largely focused on short-term returns and low labor requirements, and these have largely contributed to the low adoption of improved agronomic practices. Poor infrastructure, high transportation costs of chemical fertilizers, machinery and other inputs have also seriously constrained profitability^[10]. For example, the price of chemical fertilizers is up to three times higher in Africa than China, thus smallholders cannot afford this input. It is also not possible for smallholders to use any form of credit to buy seed, chemical fertilizers, and pesticides in emerging countries such as Malawi, Nigeria and Uganda. Agricultural inputs are primarily financed by cash from non-farm activities and crop sales^[11]. It has been estimated that only a third of households in Ethiopia apply at least one of the three key inputs (chemical fertilizers, improved seeds and irrigation), and when two or three inputs were used, the number was reduced to 15% of households^[6]. Farmers in Africa use

these inputs as substitutes rather than complements and they fail to benefit from the synergistic use of these inputs^[12].

The cost of crop production, including land preparation, seed and chemical fertilizer use, pesticides and knowledge-based technologies, is highly dependent on the infusion of financial resources. The high cost of agricultural inputs and high risk of investments faced by smallholders hinders sustainable crop production in Africa. Thus, wider use of chemical inputs by smallholders in Africa may not be an effective approach to increase grain yields due to limited financial resources. Under resource-poor conditions, Chinese farmers have a strong sense and awareness of the value of building up soil fertility through organic amendments^[13]. For example, the mud from fishing ponds, lakes or seasonal rivers has high concentrations of soil organic matter and is often seen as one of the best organic fertilizers^[14]. Therefore, developing adaptive technologies rather than coming with an inflexible package, could have a high chance of finding suitable alternatives for sustainable African agriculture.

In addition to developing adaptive technologies, empowering smallholders to change their old ways is a key step to sustainable food sufficiency in Africa, especially in a system where agricultural research and extension systems are often disconnected from the people they aim to serve, with low operating costs and poor means of knowledge transfer^[15]. However, pilot activities have been conducted to transfer knowledge to smallholders. For example, farmer field schools (FFS) were advocated to be an effective approach to disseminate knowledge to smallholders in rural areas with a bottom-up approach, as they provide useful evidence on how to empower smallholders^[16]. However, due to limitations in innovation and staff knowledge, the effects of FFS on grain yield increase in smallholder fields has not been as high as expected in Africa. Therefore, innovation in African agriculture, understood here as a process of technological innovation and knowledge transfer, is urgently needed.

In China an innovative model called Science and Technology Backyards (STBs) was established in 2010 to conduct technological innovation and knowledge transfer for the empowerment of smallholders in rural areas^[17]. The net outcome was that it effectively linked the science community with the farmer community, thus making it a successful model to develop adaptive technology and improve technology adoption by smallholders in China^[18]. The question is, what can STBs provide for African agricultural development and how can it be transferred to Africa? In this study, we investigate the operation of STB in China, adapt a pilot for the transformation of African development, analyze the implications of transferring the STB model to Africa, and finally address potential pathways for sustainable intensification in African agriculture in the future.

2 Operating mode of Science and Technology Backyards in China

STBs in China represent a novel model that links the farming community and the science community for mutual benefit in technology development and knowledge dissemination^[17]. With this approach, technology innovation and information exchange are facilitated for sustainable crop production. In STBs, agronomy experts such as professors, graduate students and extension workers, live and work together with smallholders. The concept of sustainable crop production using STBs was envisaged as the engagement of smallholders and scientists from a top-down approach. In this arrangement, when farmers encounter any agronomic problems in the field they can turn to the experts for help without delay, extra cost, or long-distance travel. The co-operatively decided solutions for sustainable crop production are implemented by scientists and smallholders working together. Then technologies are developed to suit local circumstances are disseminated on a larger scale. With this approach, large numbers of smallholders have been empowered with new knowledge and novel technologies for sustainable crop production. The success of the STB model in transforming traditional agronomy practices into sustainable crop production became apparent in a local county on the North China Plain.

Many factors have contributed to the success of STBs in China. One is the development of adaptive technologies with the full engagement of scientists and farmers in crop production. For example, the excessive use of chemical fertilizer in crop production on the North China Plain was a major factor leading to low N use efficiency and high environmental risks. Technologies for high N use efficiency in crop production needed to be developed. However, from the perspective of smallholders, high inputs were closely associated with high outputs. Therefore, to persuade smallholders to optimize chemical N use in crop production required setting up field trials to demonstrate enhanced N-use efficiency to the farmers. In a pilot study the scientists measured N flow in the root-zone and crop demand dynamically during crop production and developed knowledge of sustainable N use technologies from the principles of plant–soil interactions. For wider use by smallholders, the formulas of compound chemical fertilizers were modified to suit the N availability in the root zone. With this approach, technologies for high N use efficiency were widely adopted by smallholders as these were well adapted to local conditions. This was seen as a result of a collective learning process by all actors (including researchers and smallholders) in the process of knowledge exchange.

Knowledge transfer to smallholders is another important factor that has contributed to the success of STBs in China. A key point for knowledge transfer to smallholders is to

use the leading farmers or community leaders in a promoter-adopter approach. In the STB model the chief farmers are actively involved in scientific research and are thus exposed to intensive knowledge-based technologies including field trials, field demonstrations and technical information available from extension services. Strong participation in the development of adaptive technologies by leading farmers can enhance the relevance of this innovation to specific farmers^[19] who are more likely to adopt advanced technologies and disseminate them to other farmers. With this approach, a network of leading farmers, their followers and scientists is developed.

In addition, some effective approaches have been employed to disseminate technology at the village level. For example, a field trial with two treatments, 30 farmer families, 50 farmer field plots and a 7-ha demonstration field was used. With this approach, major factors limiting crop production were identified by farmer survey and some adaptive technologies were developed with the engagement of scientists and farmers, and visible benefits of these agronomic practices were presented in field demonstration trials, with the leading farmers being directly involved in the whole process, and hence, exposed to these advanced technologies. Through intensive communication between smallholders, STB staff and researchers, highly-relevant farm-specific solutions have been developed through a combination of farmer experience and scientific knowledge. The adaptive nature of this approach was a key element for co-operative learning and the generation of promising novel solutions. The role of leading farmers is essential for the creation of technological innovation and knowledge transfer on a larger scale.

Furthermore, this approach has been shown to result in much greater cost-effectiveness when compared to the previous extension practices which were top-down. The new STB model has tended to encourage and facilitate learning by smallholders, researchers and extension workers, and offers a more effective alternative to the current linear and unidirectional knowledge transfer process. In addition, the role of researchers and extension workers in the STBs model has changed from knowledge transfer to problem solving. To develop adaptive technologies and promote adoption at a larger scale, researchers must continually acquire new knowledge in order to improve their interdisciplinary skills. Under the STB model the fragmented knowledge transfer systems have been integrated into a combined force to achieve technological

innovation and knowledge transfer through the involvement of government, enterprises and knowledge hubs.

3 Pilot efforts for transformation of African agricultural development

Empowering smallholders is an interdisciplinary step which can be used on a large scale to transform African agriculture via sustainable intensification. Moving from top-down agricultural extension toward a more participatory approach is an effective means to empower smallholders as it creates space for farmer self-learning and sharing while allowing the extension agents and agricultural researchers to learn from the farmers. Globally, various models have been developed and tested using a bottom-up approach. These include the FFS, the Alliance for Green Revolution in Africa (AGRA), mother-baby trials and digital tools (Table 1). All of these have provided us with valuable evidence of the potential of this approach to transform African agriculture via sustainable intensification.

3.1 Farmer field schools

FFS are a bottom-up participatory approach that aims to empower farmers and increase agricultural productivity. These schools communicate complex concepts such as integrated crop and pest management while also empowering farmers by strengthening their technical skills, problem-solving ability and self-confidence^[16,20,21]. Normally, a group of 20–25 farmers work together to complete a crop season or livestock production cycle^[22]. Developed to enable farmer capacity to observe, analyze and draw conclusions in a production system, these schools have helped farmers to make informed decisions with the assistance of a facilitator^[1]. Interestingly, farmers are able to determine the connection between the agroecosystem and their practical observations. In so doing, they then solve problems by using their technical expertise, lifelong experience and the new technologies that fit their local conditions^[22,23].

The FFS system was started in 1989 with Indonesian rice farmers. So far, about 90 countries worldwide have employed FFS to increase crop productivity in addition to producing over 12 million graduates. Around 60% of beneficiaries including rice and cotton farmers are found in

Table 1 Comparison of several pilot activities conducted by international experts in Africa for agricultural transformation

Component/activity	Farmer field schools	Village-based advisor	Mother-baby trials	Digital Green
Key staff	Local extension workers	Village retailers	Farmers and scientists	Extension workers
Out-reach tools	Training	Training and products	Field trials and demonstration	Videos and some training
Resource integration	Extension system	Small company, retailers	Scientists	Extension system
Service-orientation	Government policy	Farmer and retailer demand	Farmer and scientist demand	Government policy

Asia. Globally, more than half of all FFS projects have been located in Africa, covering staple crops, vegetables and tree crops such as cocoa and tea. However, the effectiveness of the FFS approach has been a subject of debate. For example, although in Indonesia farmers were trained in agronomic practices such as pest control, their knowledge of the technology was inadequate especially when they tried explaining it to their neighbors. In India, non-participants did not have the confidence to implement the new practices they had heard about from their neighboring FFS graduates^[16].

Many factors can explain the low effectiveness of FFS on empowerment of smallholders^[21,23]. For example, although the FFS facilitators played an important role in knowledge dissemination, most were from the local extension services and had very limited ability to balance facilitation, leadership and research^[23]. Due to a lack of a solid research base, the local extension agents had limited ability to explain and interpret new technologies to farmers. Furthermore, the complexity of the FFS curriculum made it difficult for some farmers to implement all agronomic practices in their crops. Also, participating farmers either perceived some of the analytical tools as taking too much time, energy and resources, or these tools were not communicated in a way that farmers understood. Lastly, the FFS system failed to generate sufficient results to convince farmers of the benefits of a recommended practice.

3.2 The village-based advisor system of the Alliance for Green Revolution in Africa

One of the successful approaches that AGRA is using to solve challenges for farmers is the village-based advisor (VBA) approach which involves training and empowering farmers in small-scale farmer engagement as well as monitoring and evaluation programs^[24]. The VBA approach was developed by Dr. Paul Seward, the former Head of Extension and Capacity Building of AGRA and the founder of Farm Inputs Promotion Africa Ltd (FIPS). The system involves the selection and training of young hard-working farmers with low education levels to work as self-employed personnel with fellow farmers within their communities on behalf of AGRA and agrochemical dealers^[25,26]. The VBA system is applicable in both crop and livestock husbandry (e.g., for chicken vaccination)^[27,28].

The VBAs are not paid for their work but act as intermediaries between farmers and agro-dealers. Farmers buy small packets of seed and/or fertilizers from them (VBAs) then they collect a small margin as a monetary incentive^[27,29]. Seed and fertilizer companies supply inputs to VBAs for demonstration and selling to farmers at village level. As estimated by Priest^[27], each VBA gets an average of 125 USD per growing season but this can vary with the technology being promoted or implemented.

After the selection process, VBAs undergo training on innovations by agro-dealers and/or other extension agents, after which they are given the opportunity to sell agrochemicals and to establish demonstrations to train other farmers. As a result, VBAs facilitate convenient transportation, marketing and distribution of seed, fertilizers and produce, hence it becomes cost-effective for small-scale farmers as they are proximal to goods and service delivery^[30].

However, volunteer VBAs tend to spend much time working for other farmers, AGRA, agro-dealers, and/or other organizations, thereby abandoning their farms. This generally impacts negatively on their farm productivity and reduces their cash income. So far, the VBA approach has not yet created firm incentive structures for VBAs such as business training, formal linkages with researchers or agro-dealers and access to business loans to widen their income base^[26,31]. Nevertheless, VBAs serve as a useful link between smallholders and companies. However, most of them have limited capacity to clearly convey agronomy practices to smallholders due to their limited knowledge. To ensure the best results and sustainability of this approach there is still a need to incentivize VBAs in a manner that guarantees financial stability and improves VBA capacity building^[31].

3.3 Mother-baby trials

The mother-baby trial system has been designed to develop, introduce, refine and disseminate suitable on-farm applicable technologies in a quantifiable manner to smallholders. This has been achieved through a farmer/researcher co-designed three-level methodology^[19]. The first and entry level for so-called mother trial is an on-farm, farmer-managed trial located in a highly visible and trafficked area to provide both quantifiable treatment performance data and demonstrative application. The system contains multiple replicated co-designed treatments that meet a variety of farmer needs with controls^[32]. Mother trial technologies are a demonstration of alternatives based on theoretical agronomic practices in which farmers are encouraged to adapt or adopt technology appropriate for their particular system. The baby trials allow farmers to see for themselves the performance of treatments at different trial sites and allow for faster and larger-scale testing at different locations under different management conditions^[33]. This design makes it possible to collect quantitative data from mother trials managed by researchers, and to systematically cross-check them with baby trials on a similar theme that are managed by farmers^[19].

Mother-baby trials through participatory cultivar selection can effectively be used to identify farmer-accepted cultivars and thereby overcome the constraints that cause farmers to grow old land races or varieties instead of recently released crop varieties^[19]. Moreover, mother-baby

trials designed as a participatory research approach can increase the job efficiency of scientists enabling farmer knowledge to be retained effectively from year to year^[34]. By using the mother-baby trial design research costs have been markedly reduced and adoption rates increased because farmers are allowed to participate in cultivar testing and selection^[35]. Additionally, production has increased when farmers have adopted new varieties via participatory research^[36].

This mother-baby trial approach has provided concrete evidence on the benefits of scientist-farmer engagement for knowledge transfer with sufficient field demonstration to increase technology adoption by smallholders. The challenge with this system is how to upscale and expand the model for greater farmer adoption of new technologies. This could be achieved if resources from local government, business and NGOs were integrated to disseminate technology at a large scale. Risk aversion of smallholders, which is the most vulnerable point of the whole supply chain, has been largely neglected and should be addressed.

3.4 Digital Green

Digital Green is an independent nongovernmental global development organization whose aim is to empower smallholders to a life out of poverty through harnessing the collective power of technology and grass-root-level partnerships^[37]. It is a technology-smart platform for agricultural extension on which farmers to make short videos that record their challenges, share solutions and highlight their achievements. The philosophy of Digital Green is based on a participatory process for content development and involves a locally generated digital video database, human-mediated instruction for dissemination and training, and a regimented sequencing to initiate a new community.

Digital Green or video-based extension has been most successful in providing a cost-effective approach to information dissemination which has increased the adoption rate of productivity-enhancing agricultural technologies and practices by smallholders, especially women. Digital Green is regarded as a fascinating intervention that has helped to resolve gender responsive issues and contributed to poverty reduction. That notwithstanding, the benefits have not reached many women due to inadequate transportation and infrastructure, lack of training of extension workers in information and communication technology and poor linkage with other extension providers in addition to the technical challenge in content identification and selection when screening and producing nutritional videos.

Although Digital Green has been piloted in African agriculture, it has not improved food security and the standard of living of farmers in Africa due to the complexity of agricultural production, poor infrastructure facilities, poor government policies, limited resources of

smallholders and low soil fertility of agricultural land. Agricultural production is quite complex as it covers not only the soil, plant science and climate, but also links with economic factors such as profit made by the smallholders and the whole supply chain in Africa. How to support African smallholders to increase agricultural productivity remains a major challenge to scientists, policymakers, business and government.

4 Implications of Science and Technology Backyards for sustainable intensification of agriculture in Africa

We must depend on smallholders to transform African agriculture toward sustainable intensification fundamentally^[38,39]. The lessons from China's experience show that the resource-environment costs of food production are very large with land expansion and overuse of chemical fertilizers^[40]. The effective approach to move agriculture toward sustainable intensification in Africa is to increase grain yield per unit land area rather than expansion of agricultural land^[41]. Empowering smallholders to increase grain yields in Africa is the only way to increase food production and achieve food self-sufficiency on the continent (Fig. 2).

4.1 Scientist-farmer engagement to develop adaptive and innovative technology for sustainable crop production

Placing the empowerment of smallholders as a top priority has proved to be a major factor in the successful implementation of STBs in China^[18]. One effective approach is scientist-farmer engagement in developing potential solutions for sustainable crop production^[17]. From the strong interaction between smallholders and scientists, the partners can more easily identify the agronomic problems in crop production through intensive interview and field observations as a first step for the scientist to come up with a scientific solution (Fig. 2). Potential solutions supported by the principles of sustainable crop production have increased smallholder enthusiasm and engagement in research when presented by scientists. The interaction that has ensued between scientists and smallholders has often stimulated smallholder innovation. That way, the requirements of smallholders and scientists are clearly mapped out with smallholders being mainly interested in simple and labor-saving technology and high economic benefit, while scientists are interested in maximizing crop yields and economic benefits with limited environment impact by increasing nutrient use efficiency. At the end, these potential solutions have been integrated to meet the requirements of smallholders and the co-operatively decided solutions have been developed by compromising

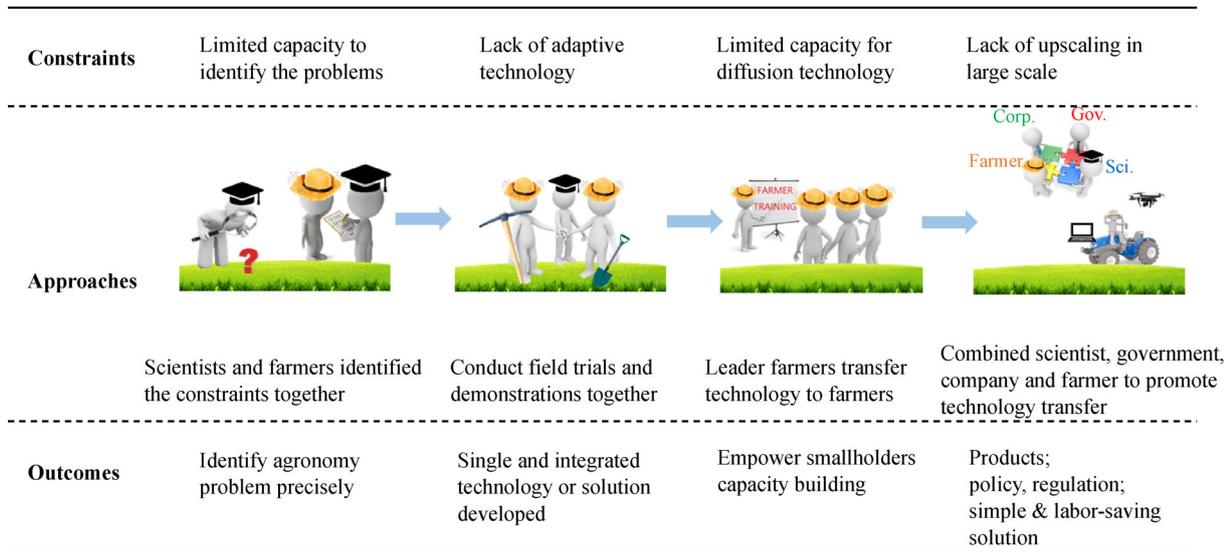


Fig. 2 Implications of Science and Technology Backyards for agriculture sustainable intensification in Africa.

the demands of both scientists and smallholders. Through intensive dialog with smallholders, scientists have built progressive partnerships with smallholders and gained their trust^[42].

With this partnership and trust, scientists have been able to discuss problems or goals with smallholders in a genuine manner^[42], with smallholders also concurrently engaging in scientific research and contributing to the development of adaptive technologies. Field trials on sustainable crop production have been conducted in smallholder fields to improve knowledge contextualization. For example, in order to test the optimum chemical N use for high-yield crop production, two treatments, optimum and farming practice N use have been compared in several STB farmer field plots^[43]. All the field operations have been conducted by smallholders while scientists have provided them with technical support and have trained them on the key crop growth stages. Some systematic field trials have also been conducted by smallholders and scientists using this approach. Based on the results of systematic field trials, a set of field guidelines has been developed^[44]. Through scientist-farmer engagement in setting up the field trials, recognition of the scientific views has been extended beyond the academic community, and with understanding of the views of smallholders participating in scientific research, the knowledge-action boundary has started to break down, leading to an increase in smallholder innovation^[45]. With this approach, technologies and practices have been adapted by smallholders to suite highly localized conditions.

A large number of studies have been conducted on technological innovation for smallholders. For example, crowdsourcing data were used to conduct meta-analysis for

evaluating the impact of single agronomic practices on crop production and proposed the potential of the approach for smallholders^[46], but its routine application was not very effective. The ineffectiveness of this approach was due to lack of participation by smallholders. Crop systems are highly heterogeneous in terms of soil type, planting pattern and resource endowment, which implies the need for adaptive technologies suited to the context of the crop system. Unfortunately, scientists frequently produced the knowledge with formal logic and assumed that smallholders would apply it automatically^[47]. In such cases, they do not know the end use of the knowledge created and who are the specific end-users and how to make it more practical for decision-makers^[48]. Smallholders are mostly concerned about the cost-effectiveness and ease-of-use of agronomic practices^[49]. Furthermore, scientists tend to produce generic recommendations that bypass established decision-making processes, which often results in poor understanding of the science outside the academic community and low interest from smallholders in scientific research^[50]. Knowledge of localized best-practices for farmers with varying resource constraints is one of the primary constraints limiting the adaptation rate of recommended technologies^[51]. Therefore, participatory research and scientist-farmer engagement are effective approaches to generate demand-driven knowledge, and this is a key element for STB implementation^[52]. In STBs the role of scientists in the STB is beyond their normal roles as mere knowledge creators in research and academic institutions, and is extended to mutual learning and understanding and systematic integration^[53]. With this approach, scientists and farmers have co-created knowledge to solve agronomic problems through collaborative actions.

4.2 Dissemination of technology by empowering smallholders, especially leading farmers

Transfer of knowledge to stimulate smallholder action is a key step in empowering smallholders to achieve sustainable intensification on a larger scale. A large number of models have been used to disseminate knowledge to smallholders^[21,27,54]. However, the impact of these pilot works continues to be debated. Knowledge transfer is more complex than technology generation, covering a range of stakeholders such as government, scientists and policy-makers^[55]. Therefore, to empower smallholders would require a close working relationship among all stakeholders. In STBs, outreach tools from the bottom-up approach were employed to disseminate improved technologies. Thus, the starting principle of all the tools is to build smallholder capacity using a farmer-centered approach. For example, field trials and field demonstrations are conducted by scientist and smallholders working together. This can provide a clear demonstration of the technologies and the key operators are trained, especially in recognition of key crop growth stages. In addition, farmer field days are held regularly to share and disseminate these agronomic practices^[56].

Most importantly, farmer-to-farmer knowledge transfer in the STB model has been employed to achieve adoption of technologies on a larger scale. With this approach, leading farmers are given a high profile, and they become key players in knowledge transfer in rural areas. The leading farmers in each village are volunteers with a strong desire to adopt the technologies and are intensively trained in the STBs in order to enhance their knowledge of recommended technologies. They also obtain knowledge through their involvement in field trials and demonstrations. Compared to the FFS, the leading farmers can explain and understand clearly the technology and train their neighbors^[18]. In fact, understanding and adopting the technologies in their own field is very important for leading farmers as it was shown that leading farmers were most likely to recommend their own adoptions and experience of technologies to their other farmers^[6]. With this village-level nexus, a cycle was developed that increased the number of farmers getting involved in the research and promoting technology dissemination at a larger scale. Through the network of leading and other farmers, the clear effects in field demonstration and trials increases the understanding of more farmers.

4.3 Development of an open platform for attracting multiple resources involvement

In addition to a bottom-up approach, a top-down approach was employed by STBs to link grass root initiatives with government extension system and the supply chain. To effectively conduct knowledge transfer, resources from government, and enterprise were integrated into the STB

model^[57]. STBs become an open platform to attract multiple resource involvement. Governments are responsible for releasing policies and regulations that support and promote technological innovation. For example, in order to stimulate smallholder enthusiasm for farming, subsidies covering fertilizer, machinery and other inputs are provided^[58]. They are uniquely positioned to promote farmer education that can help change attitudes and promote the adoption of new technologies. Concurrently, policies to encourage smallholders to adopt sustainable agronomic practices are also developed by governments. However, the governments have limited capacity to develop technological innovation, hence the need for a platform to integrate resources. When resources from government and STB are integrated together, STBs develop adaptive technologies that verify these at a local scale and disseminate on a large scale through the power of government. The dissemination of technologies has been achieved by a systematic process of characterizing, diagnosing, redesigning, implementing, broadening adoption and evaluations, as well as involving governments, enterprises, and knowledge hubs.

The STBs generally provide the fertilizer business with product development opportunities and these companies create improved chemical fertilizers based on formulas evaluated in the STBs, and increase market share and increase sales profits. Thus, new partnerships have been developed which accelerate technology transfer and empower smallholders. By collaboration with business, the recommended new technologies have been rapidly integrated into products and technical manuals. For example, in order to persuade smallholders to avoid overuse of chemical fertilizer in crop production, various chemical fertilizer formulations were developed by collaboration with fertilizer companies. Through this approach, optimum chemical fertilizer use to reduce environmental risk has been expanded to a much larger scale^[59]. Through cooperation with business, both adaptive technologies and products are more readily accepted by smallholders.

In Africa the effective implementation of the STB model needs to integrate resources from local government, business and knowledge hubs. For example, the cost of chemical fertilizers is 3–5 times higher than in China and is beyond the capacity of smallholders to afford^[6]. Repackaged chemical fertilizers in small quantities should be standardized and encouraged by local government^[60]. Subsidies reducing chemical fertilizer costs should be provided to smallholders. Furthermore, soil quality surveys should be conducted throughout the county. Taxes should be imposed on owners of poor soil fertility land due to land degradation^[61]. The combination of command-and-control and an incentive-based policy should be implemented at the same time to increase food production in Africa^[61]. In summary, creating an open platform for adaptive innovation technologies for

dissemination of technology empowering smallholders and attracting more resources from the wider community are the key to the success of STBs in China.

5 Conclusions

Africa produces less than 10% of its food from 64% of the global arable land area while China produces 22% of food with less than 9% of the global arable land area. This indicates great potential for Africa to improve its food security and self-sufficiency and to become a food exporter. From the analysis of some pilot efforts for the transformation of agriculture in Africa (e.g., mother-baby trials) we found that low access to agronomic information by smallholders and the lack of knowledge dissemination mechanisms are major limiting factors. STBs developed in China provide some key opportunities for sustainable agricultural intensification in Africa. These include (1) scientist-farmer engagement to develop adaptive and innovative technology for sustainable crop production; (2) dissemination of technology by effectively empowering smallholders; and (3) development of an open platform for attracting multiple resource involvement, rather than relying on a single mechanism. This paper provides a perspective on sustainable agricultural development in Africa and the potential benefits of transferring the STB model to Africa.

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