Front. Agr. Sci. Eng. 2022, 9(4): 558–576 https://doi.org/10.15302/J-FASE-2022465

RESEARCH ARTICLE

THE SCIENCE AND TECHNOLOGY BACKYARD AS A LOCAL LEVEL INNOVATION INTERMEDIARY IN RURAL CHINA

Jinghan LI[1], Cees LEEUWIS[1], Nico HEERINK[2], Weifeng ZHANG (✉)[3,4]

1 Knowledge, Technology and Innovation Group, Wageningen University & Research, Wageningen 6706KN, the Netherlands.
2 Development Economics Group, Wageningen University & Research, Wageningen 6706KN, the Netherlands.
3 College of Resources and Environmental Science, China Agricultural University, Beijing 100193, China.
4 College of Resources and Environment, Anhui Agricultural University, Hefei 230036, China.

KEYWORDS

agricultural innovation, coevolution, community level, innovation intermediaries, Science and Technology Backyards (STBs)

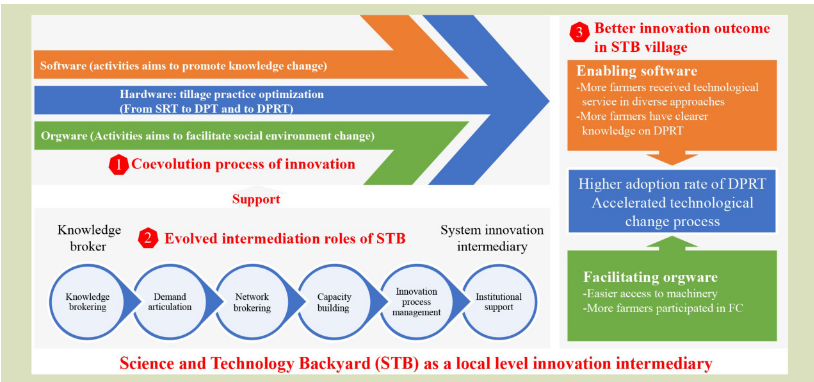
HIGHLIGHTS

- Agricultural innovation is a coevolution process of hardware, software and orgware.
- Innovation intermediaries is important for the coevolution process of agricultural innovation.
- The roles of STBs have evolved from a knowledge broker to a broader innovation intermediary at the village level.
- Facilitating orgware is more effective than enabling software in promoting farmers' adoption of improved tillage practice.
- Collaboration between individual STBs is needed to support the coevolution process of innovation at a larger scale.

Received April 1, 2022;
Accepted June 24, 2022.

Correspondence: wfzhang@cau.edu.cn

GRAPHICAL ABSTRACT



ABSTRACT

Agricultural innovation can be described as a coevolutionary process of technological innovation, symbolic change, and social or institutional innovation, which relies on the interactions and collaboration between multiple stakeholders. This view emphasizes the significance of innovation intermediaries in supporting the coevolution process of innovation. Many studies have provided evidence on how innovation intermediaries play roles in supporting the coevolution innovation process at a broader innovation system level. However, little emphasis has been given to the role of innovation intermediaries in supporting the coevolution process of innovation at the community level in rural China. To address this research gap, this paper offers a case study of a novel type of innovation support intervention designed to promote technical change at the community level, the Science and Technology Backyard (STB). The paper focuses on the efforts of a specific STB in Wangzhuang village to promote innovation in tillage methods in wheat production. The aims was to examine the role of this newly emerging innovation support intervention in supporting the coevolution process of innovation at the community level, and compare the outcome of the coevolution process in the village with an STB to that in villages without an

STB. Innovation journey analysis is applied to understand the evolved intermediation roles in the innovation process, and multivariate regression analysis is employed to assess the outcome of the coevolution process in villages with and without an STB. The findings suggest that the roles of STBs have evolved from knowledge brokers to systemic innovation intermediaries that facilitate the coevolution process of innovation inside an STB village. It has led to a higher adoption rate of improved technology, a better enabling environment for learning, and more effective institutional support in STB villages than in non-STB villages. However, the effect of support provided by a single STB on the coevolution process outside the community was limited. This finding points to a need for collaboration mechanisms and for connecting single STBs to support the coevolution process of innovation at a larger scale.

1 INTRODUCTION

Technological innovation is important for raising agricultural production. For example, improved grain breeding and the introduction of chemical fertilizers contributed to large increases in crop production during the so-called Green Revolution[1]. Scaling up new technology or practice is a challenge that has attracted much attention from researchers[2–4]. Innovation support interventions or learning methods, like training, teaching, and demonstration, are commonly applied to promote new technology or practice adoption[5]. However, many researchers have sharply criticized the top-down and linear views that frequently go along with the use of such methods in innovation support interventions[5,6].

From the perspective of the agricultural innovation system (AIS), innovation is conceptualized as a combination of technological innovation (hardware), symbolic innovation (software), and social or institutional innovation (orgware) within an innovation system[6–9] (note: the terms hardware, software and orgware are used exclusively in these specific senses thought this paper). AIS refers to a “network of organizations, enterprises and individuals focused on bringing new products, new processes, and new forms of organizations into economic use, together with the institutions and policies that affect their behavior and performance”[10]. The nature of innovation is characterized by systemic and coevolutionary features[6,8]. Under the framework of AIS, the diffusion of technology is regarded as both an individual and a collective achievement, beginning at the time of conception and frequently involving redesigning the environment in which an innovation is to be used when scaling up[11,12]. This calls for innovation support interventions to move away from supporting linear technology transfer through training and teaching to supporting dialog and interaction with the help of innovation platforms[5]. Facilitating the innovation process requires creating or strengthening necessary relationships and interactions among heterogeneous stakeholders[13].

Innovation intermediaries are important in embedding relationships within innovation networks to support the coevolution process of innovation. Intermediaries act as bridging organizations that facilitate interactions between different stakeholders[13]. This implies that they evolve from merely contributing as knowledge brokers (focusing on knowledge or technology transfer from researchers to farmers) to innovation intermediaries who have broader roles in supporting the innovation process, such as network brokering, demand articulation, process management, and institutional support[13].

Recent studies have provided evidence of the importance of innovation intermediaries for supporting the coevolution process of innovation, such as the innovation of the smallholder dairy system in sub-Saharan Africa[8], eco-innovation in Sweden and Germany[14], and environmental sustainability transitions in the USA[15]. These studies indicate that coevolution of innovation is a highly dynamic process with various interactional tensions and unexpected effects, which requires intermediaries to meditate in resolving some of these tensions emerging at different actor interfaces. Mechanisms that support feedback, learning and adaptive management in innovation processes were strengthened. These studies typically hold a broader landscape view on how the innovation intermediaries function to support large-scale innovation, and focus, e.g., on an entire sector or market. However, innovation systems typically consist of different levels, like national-level innovation systems, sectoral innovation systems, and community-level innovation systems[12,16]. Little attention has been paid so far to the coevolutionary process of agricultural innovation at the community level, with one study of the role of farmer cooperatives (FCs) as innovation intermediaries in supporting the innovation of smallholder economic crop production at the local level in China[17] as a notable exception.

Science and Technology Backyards (STBs) were introduced by China Agricultural University in 2009[18]. It is a new farming service model designed to reinforce relational embeddedness between education, research, and extension at the community level to provide agricultural extension and advisory services to smallholder farmers. STB can be considered as a hybrid model that combines a top-down approach with bottom-up measures to promote innovation among smallholder farmers[18]. In STBs, technological innovation is supposed to derive from location-specific problem diagnosis and is re-fitted based on local context and farmer demand. A typical STB consists of the following components: a backyard, professionals, a group of leading farmers, training and technical service facilities (e.g., public address systems, computers, projectors, motorized tricycles and brochures), experimental plots, and demonstration plots[19]. Most STB staff are postgraduates or PhD candidates at China Agricultural University or other universities. STBs cooperate with local stakeholders to promote technological change based on the location-specific situation. More than 290 STBs are currently active in different crop systems and regions in China to solve the complex agricultural problems in local communities[20]. Previous studies have provided evidence that STB facilitated the linking of knowledge with farmer action[18], but there is a need to further assess the types of intermediation roles that STB can have in the community level innovation system. A systematic study of the activities of the STB will help to learn how the STB played intermediation roles in promoting innovation in a specific community and thus address the research gap indicated above.

Thus, this study aimed to examine the intermediation roles performed by an STB in supporting the coevolution process of innovation at the community level, and to compare the outcome of the coevolution process in the village with an STB with that of villages without STBs. A case study approach focusing on Wangzhuang (WZ) STB in Hebei Province is used to reach this aim. Innovation journey analysis is applied to understand the evolved intermediation roles in the innovation process, and multivariate regression analysis is employed to assess the outcome of the coevolution process in villages with and without STBs.

The paper is organized in following five sections. Section 2 introduces the theoretical framework and the operationalism of the framework. Section 3 presents the method of data collection and the methods of analysis. The findings are reported in Section 4 and are followed by an analysis and discussion in Section 5. Finally, the conclusions are presented in Section 6.

2 THEORETICAL FRAMEWORK

This study adopts an innovation systems perspective and uses a theoretical framework developed by Kilelu et al.[8]. This framework highlights the roles of innovation intermediaries in supporting the coevolution of innovation. Innovation was defined as a conducive combination of hardware (technological innovations, e.g., new agronomic practices), software (symbolic innovations, e.g., changing mindset and attitude), and orgware (social or institutional innovation, e.g., a new organizational arrangement)[6–9]. These components of innovation are seen to coevolve in the process of continuous interaction[8].

Innovation platforms have been seen as important interventions to facilitate coevolution processes of innovation by creating a space for multistakeholders to interact and collaborate[5,8,21]. The interaction and collaboration between heterogeneous stakeholders require innovation intermediaries who aim to reinforce relational embeddedness within innovation networks[13]. Innovation intermediaries are bridging organizations that facilitate access to knowledge, skills and services and goods from various organizations[13]. Innovation intermediaries can make diverse innovation intermediation contributions to innovation platforms, including (1) demand articulation, (2) institutional support, (3) network brokering, (4) capacity building, (5) innovation process management, and (6) knowledge brokering[8,13] (Table 1). The innovation processes are characterized as changes from one system to another[8].

We apply the framework to answer the main question: what innovation intermediation functions are provided by STBs to support the coevolution of innovation, and how does this influence the outcome of the coevolution process of innovation.

3 OPERATIONALIZATION AND METHODS

The research reported in this study was split into two parts

Table 1 Innovation intermediation roles and their explanation

Roles	Explanation
Demand articulation	Facilitating the process of identifying innovation challenges and opportunities, including social or technical problem diagnosis, demand assessment, and social environment diagnosis with various stakeholders
Institutional support	Facilitating and advocating informal or formal institutional change (e.g., policy change and stimulating new collaboration relationships)
Network brokering	Identifying and linking different actors
Capacity building	Incubating new organizational forms or strengthening the capacity of existing organizations. The capacity can be performed as more effective work arrangements, broader network etc.
Innovation process management	Coordinating interaction and facilitating negotiation and learning among different actors
Knowledge brokering	Identifying knowledge/technology needs, generating new knowledge or technology, and mobilizing and disseminating the technology and knowledge from different sources

Note: Source from Kilelu et al.[8,13].

based on the research questions. The first part examines the innovation intermediation functions of the STB in the dynamics of the coevolution process of innovation, while the second part focuses on the comparison of the outcome of the innovation processes in communities with and without an STB. Thus, a mixed-method design is applied. Innovation journey analysis was applied to the selected STB in the first part, while multivariate regression analysis was applied to farm survey data in the second part.

3.1 Operationalization and methods for the innovation process

The case study was employed as the main research method in this part. A single case study research design is commonly applied to many studies on agricultural innovation processes[8,13,22]. We choose WZ STB and WZ village as our research case. WZ STB was chosen as a case since it was established in the early stage of STBs development in 2011 and is still in good operation. WZ STB is located in the Quzhou County, Hebei Province, which is a typical smallholder winter wheat and summer maize rotation region of the North China Plain[18]. In 2011, WZ village had a population of 835 and an arable land area of 200 ha. Since 2011, 20 students have worked in WZ STB, and 17 of them graduated and left the WZ STB. These students mainly major in agronomy or agriculture extension. They move their experiments and learning from university to the farmer fields and village. They generally work in the village more than 200 days each year to provide farmers with free technology extension and advisory services. In addition, they interact with communities and stakeholders continuously, which may provide scope for broader intermediation functions. Some necessary subsidies, including in-village life subsidies (40 CNY per day), utility subsidies (500 CNY per month), and transport subsidies from university to STB, are co-funded by the university, local government, and private agricultural related company to support students to work in the village. Technology service is included as one of the criteria for the assessment of student scholarships to reward their technology service works.

Typically, three to four students work in WZ STB simultaneously. The senior student is the head of STB and is responsible for organizing the extension work of the STB. An annual training and communication session between the senior STB students and new STB staff is held in July and August. During this session, new STB staff learn how to conduct research and extension works in the village, and the communication between senior STB students and new STB staff will ensure a continuation of the STB work. The typical service time of each STB staff is 1–3 years for at least 200 days each year. These students make efforts to optimize practices in (1) land preparation/tillage, (2) cultivar selection, (3) seeding date and rate, (4) nutrient management, (5) irrigation and fertilization in spring, and (6) insect, fungus, and weed control[18].

This study held a contextual view on innovation as a change from the specific situation, including changes in farming practices, social environment, and knowledge or attitude. Technological innovation is not limited to technological breakthroughs but extends to technological transformation based on the social environment[22]. To gain insight into the dynamics of the innovation process, we examined tillage practices during the wheat season and related works of STB staff as focal points. The tillage method was chosen as a focal point since it was the first practice WZ STB aimed to change, and it was also important in wheat production. The common tillage practice of farmers was shallow rotary tillage (SRT) in 2011, which led to severe negative effects on wheat production, such as soil compaction, lower water use efficiency, fertilizer use efficiency[23,24], and bad sowing quality after maize straw return[24,25]. Since 2011, STB has conducted many activities to optimize farmer tillage practice during the wheat season.

In this study, an STB is defined as an intermediary at the community level. In our case, stakeholders included an FC in the village, machine operators, village cadres, smallholders, STB staff, and other stakeholders outside the village but had interactions with stakeholders inside the village during the innovation processes. The coevolution process of innovation aimed to promote a transformation from an SRT-dominated production system to an improved tillage practice dominated production system.

STB work diaries were the main materials to understand how the STB delivered intermediation services in supporting the coevolution of innovation processes in tillage practice at the community level. STB work diary is the daily work recording document written by STB staff. STB work diary system started in Dec. 2012. Every STB staff member was required to record their daily work, including their technology service work, research activities, social activities with farmers, and feelings about what they saw in the village. The STB diary has a uniform format to guide the student recording. It included with (1) basic information (date, weather, STB number and name), (2) what, how, and with whom they do their research, extension, or social activities on this day, and (3) photos on this day (not compulsory but highly recommended). These diaries were collected and sorted by managers in charge of STB daily works in China Agricultural University. An STB manager will reward a well-written diary for ensuring the recording quality. After obtaining permission from one of the managers at the end of 2020, we accessed all the WZ STB diaries. To fill in the gaps in information between STB establishment in February 2011 and STB diaries recording (Dec. 2012), we also added some supplementary materials, including the thesis of three students who worked at WZ STB during the period and semi-structured interviews with two STB farmers, and two earlier STB staff (Table 2).

Innovation journey analysis was employed to understand the innovation process. We used Atlas.ti to manage and analyze all the above documents. Atlas.ti is a commonly used software program for coding and analyzing qualitative data. Information extraction and text coding started with identifying the activities and related innovations by text searching keywords related to the tillage method; *tillage* and *plowing* were applied as the keywords for searching. We set 2017 as the final date for text coding, as the diaries no longer contain tillage methods after 2017. Further collation and coding works aimed to identify the intermediation roles in the activities based on the coding results of the last round. STB roles in the above activities were extracted in this round, followed by identifying intermediation roles performed based on the descriptions in Table 1.

3.2 Operationalization and methods for the innovation outcome

Comparison analysis between STB village and non-STB villages were the preliminary method in this part. The comparison of innovation outcomes was presented in the following three aspects: (1) the adoption of improved tillage practice, (2) the enabling software for adoption, and (3) the facilitating orgware for adoption.

The enabling software was assessed using farmer exposure to improved technology or knowledge and their knowledge score on improved practice. We focused on the multiple ways in which farmers access technology or knowledge services and a comprehensive knowledge score on the improved practice. The facilitating orgware was evaluated using access to the machinery and farmer organizations, which provided necessary social conditions for applying the improved tillage practice.

Table 2 Overview of data collection

Methods	Materials	Samples/Objectives	Information gathered
Secondary material collection	WZ STB work diary from Dec. 2012 to Dec. 2017	9 MSc or PhD candidates who worked in WZ STB (1164 pages)	History of tillage method change and efforts of STB staff since Dec. 2012
	Thesis or journal articles of early STB students	2 MSc and 1 PhD who worked in WZ STB from 2011 to 2013	Early activities about tillage method change
Semi-structured interviews	Farmers	2 farmers (1 farmer being an FC member)	Early activities about tillage method change
	STB staff	2 (1 staff who worked in WZ STB from 2011 to 2013; 1 WZ STB manager from 2011 to present)	Early activities about tillage method change

We randomly selected non-STB villages in the 10 townships in Quzhou County. They were selected under the guidance of two extension officers to ensure that (1) all non-STB villages were dominated by smallholder wheat-maize rotational production systems, (2) all non-STB villages have been received a technology extension of the same optimized tillage practice, and (3) all non-STB villages were only exposed to public extension or extension with the same characteristic with public extension. We further designed a random selection standard: three villages from each township, 10 farmers in each village, and recorded the production information of the largest plot of each farmer. We added three more villages to keep the samples during the survey since there were some unfinished questionnaires. If one village has a high percentage of the unfinished questionnaire, we added one more village from the same township by random selection. More farmers (27 in total) were selected in the STB village to enable a comparative analysis (Table 3).

After sample selection, a 40–60 min questionnaire survey was conducted in September 2020 by one-to-one interviews. We collected information about tillage practice, received technology service and its providers, tillage service status in the village and FCs in the 2019–2020 wheat season. A local specialist designed a knowledge test with 14 questions to evaluate the farmer knowledge level of the tillage method (details are shown in Table S1 in the supplemental material). All the quantitative data analysis was performed by using Stata 15, a commonly used software package for the analysis of quantitative data. Z-tests were used to test the statistical significance of differences between STB villages and non-STB villages.

4 FINDINGS

In this part, we describe the processes of coevolution of hardware, software, and orgware in the use of tillage practices in the STB village (Section 4.1) and assess the intermediation roles that the STB played in the process (Section 4.2). We also assess and compare the recent outcomes of this innovation coevolution between the STB village and the non-STB villages (Section 4.3).

4.1 Processes of coevolution of hardware, software and orgware

This section presents the coevolution process of innovation in STB village in terms of tillage practices during the wheat season (Fig. 1). A dynamic and gradual adjustment toward a coevolution process of hardware, software and orgware with the guidance of STB staff was found. Three phases were distinguished to show the dynamic evolution process.

4.1.1 Phase 1: technological innovation or hardware based on results of location-specific production problem diagnosis

Problem orientation and local specificities were the main working characteristics of STB. After establishing WZ STB in February 2011, STB staff conducted fieldwork in the village. Their fieldwork included observing and recording the production problems in different wheat growth stages and communicating with local farmers about their main concerns. After nearly 1 year of fieldwork, they concluded that the main problem for wheat production in the local area was the low quality of seedling emergence and wheat lodging close to the harvest period. These problems were both closely linked with tillage methods.

Further farmer surveys were conducted to understand the prevalent tillage practices of farmers. The survey results revealed that four low-power deep plowing machines were almost unused to local farmers. The earliest STB staff conducted a random survey with 17 farmers in the village, 82% of farmers continuously adopted SRT (only tilling to a depth less than 20 cm) for more than 10 years, and other farmers adopted SRT continuously for 5–10 years[26]. A large-scale farmers survey in Quzhou county, covering 948 farmers from 2010 to 2013, showed that nearly 94% of farmers adopted SRT

Table 3 Sample description

Sample	Number of observations		
	Total	STB village	Non-STB villages
Township*	10	1	10
Village	34	1	33
Farmers	349	27	322

Note: Source from the authors' survey. * The STB village is in the same township with one of non-STB villages.

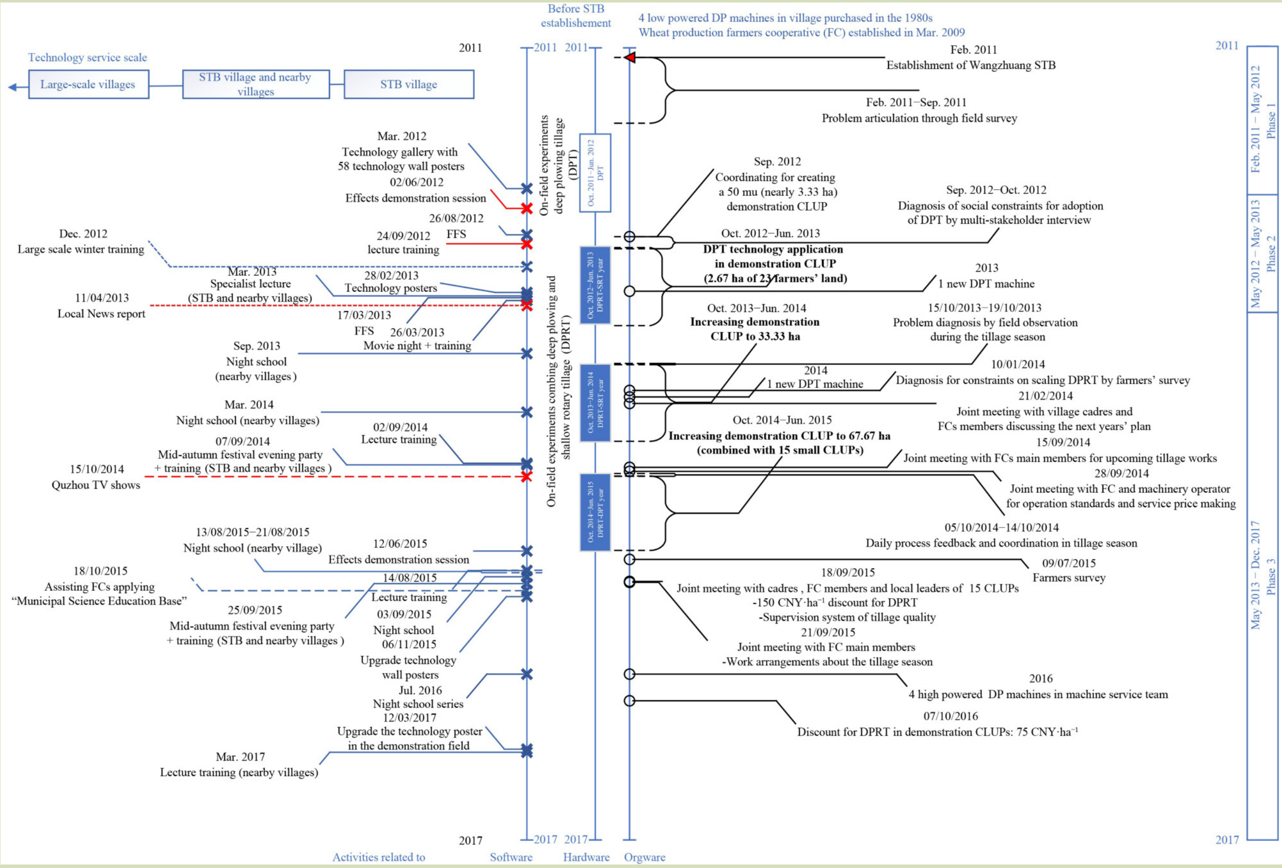


Fig. 1 Timeline of coevolution process of innovation in tillage methods, WZ STB village from 2011 to 2017. X indicates activities related to software (red, specialized in tillage methods; and blue, imprehensive activities included tillage methods); o indicates activities related to orgware. All the ogware activities are specified only for the STB village.

as their tillage method, and only 6% of farmers adopted deep plowing tillage (DPT, tilling to more than 30 cm deep)[27].

Continuous SRT has increased the soil compaction, leading to lower water use efficiency and fertilizer use efficiency[23,24]. The shallow tillage depth also does not work with the straw return technique, resulting in the straw not being fully covered by the soil and thus affecting sowing quality[24,25]. The poor quality of seedling emergence further led to severe wheat lodging in Quzhou County close to the harvest season[26].

After production problem diagnosis, experiments were conducted at a small scale to find technical solutions. In the 2012 wheat growth season (from Oct. 2011 to Jun. 2012), one of the STB staff designed and conducted agronomy field experiments in farmer fields. This experiment evaluated the effects of optimized tillage practice (DPT) on the low quality of seedling emergence and wheat lodging close to the harvest period by comparative experiments with the tillage methods (SRT) commonly used by farmers as a controlled group. This experiment showed that DPT has a better seedling quality in the emergence stage and a better lodging resilience close to the harvest stage than SRT in the 2011–2012 wheat growth season[26]. Although this experiment did not indicate a significant yield difference between DPT and SRT, the significantly better lodging resilience close to the harvest stage helped farmers save their money and time costs. The cost of mechanical harvesting of fallen wheat is twice as high as normal wheat. It also costs farmers more time to find a machine operator who is willing to harvest the lodged wheat.

The effects verification of DPT was conducted simultaneously with the technology demonstration. In Mar. 2012, the STB established a technology gallery using the main local street with eye-catching wall posters aside. DPT was recommended as one of the optimized technologies. Effects demonstration session of DPT was held during the harvest season to convince local farmers to adopt the DPT in the future. However, only 38 farmers participated in this session. From these activities, STB staff introduced the definition of DPT, the potential benefits to the production (improving sowing quality and preventing lodging) and the detailed operation guidelines to farmers.

4.1.2 Phase 2: more social constraints arose beyond the technical solutions

To scale DPT among more farmers in the 2012–2013 wheat season, a relatively large-scale demonstration pilot and training on farmers were both employed by STB staff. Before the 2012–2013 wheat season, STB staff conducted farmer field school training and lecture training to convince more farmers to adopt the DPT. Meanwhile, STB staff began to communicate and coordinate with local farmers. They planned to establish a 50 mu (about 3.3 ha) demonstration field to display the effects of DPT in the local village. Considering the small and fragmented land of local smallholders and no funding for land rental, they tried to establish a demonstration field by combining the land of many farmers for uniform practice (CLUP). Finally, a 2.7 ha CLUP was established after effort-costing coordination with 23 farmers (Fig. 1), although two leading local farmers helped the coordination of the CLUP.

Difficulty in coordination made STB staff realize that technology application was not only a technical problem but also a social problem. They conducted a multistakeholder interview to diagnose the social constraints for DPT adoption from multistakeholder perspectives[26,28]. First, limited farmers could access DPT machinery. Higher costs hindered updating of outdated DPT machines by individual machine operators. Low-power DPT machines dominated the DPT machinery market. Secondly, for farmers who could access the low-power DPT machine, the higher cost of DPT service also restricted them adopt the DPT. The higher cost of DPT was caused by the fragmented and small land and higher energy cost. Thirdly, low tillage quality achieved by farmers was another concern caused by the outdated machine and lack of training of machine operators. Low-power DPT machines hardly reached the standards of DPT depth, which made farmers lack trust in the DPT. The machine operators in the village rarely received professional training. Most of them were smallholders who owned a machine and provided services to other farmers in the village.

4.1.3 Phase 3: coevolution of innovation to support technical change at a large scale

The social constraints diagnosis has helped STB staff identify the entry point for larger scaling of DPT. They have made efforts to solve the problems of insufficient effective DPT machinery. They communicated with local FCs and convinced them to buy a new DPT machine in 2013 (Fig. 1). A series of technology training activities were held before the 2013–2014 wheat season to raise farmer awareness about the DPT technology. These activities covered STB villages, STB nearby villages, and even border scale (Fig. 1). These training activities highly recommended the DPT as one of the optimized technologies, which aimed to attract farmer interest in applying DPT.

The farmer concerns about higher costs were addressed in two ways. First, STB staff re-fitted the DPT practice to make it adoptable to smallholders. They optimized DPT practice based on the common farmer practice (SRT). A combined tillage method, DPT once after 2 years of SRT (DPRT), was developed by STB staff. According to this DPRT controlled experiment conducted by STB from 2012 to 2015, DPRT can significantly increase yields by 1 $t\cdot ha^{-1}$ and improve the partial factor efficiency of nitrogen fertilizer inputs by 12%[27]. Higher wheat yields compensated for the higher costs caused by the DPT. It also saved two year mechanical cost compared with continuous DPT. The second solution was to develop a relatively large CLUP to increase the work efficiency and decrease the fuel cost of running on the road. STB staff conducted a survey with local machine operators about their minimum acceptable service price of DPT. They found that the minimum price the machine operators could accept decreased as the size of the operating areas increased. The acceptable minimum price of operating an area larger than 7 ha was 150 CNY lower than the acceptable price of operating an area smaller than 0.7 ha[26].

More activities were conducted in the 2013–2014 wheat season to verify the feasibility and potential problems of scaling DPT to more farmers. Technology service activities were also one primary aspect of STB staff work. They also identified the issues in the tillage operation by field observation in the tillage season. Some problems were redetermined, such as “tillage depth cannot reach the standard in some plots (15 Oct. 2013 in WZ STB diary)” and “too small plots were not suitable for adoption of DPT (19 Oct. 2013 in WZ STB diary)”. In addition, a large-scale survey covering all households in the village and FC members was employed to understand their demands and worries about DPT. After the survey, STB staff held a joint meeting with village cadres and key members of local FC in February 2014. They discussed the plan for the coming 2014–2015 wheat season. They decided to increase the CLUP to 68 ha (Fig. 1).

Intensive communication and coordination with village cadres and key members of FC created an enabling environment for scaling DPT in the 2014–2015 wheat season. In mid of September, STB staff discussed with key members of FC about the farmer list who are willing to participate in CLUP and the locations of their plots. They discussed the final size of CLUP, the number of the DPT machine, and machine work efficiency. A large size CLUP of 68 ha was finally decided. Detailed work arrangements were decided in a further meeting held in late September (Fig. 1). In this meeting, STB staff set a quality standard for the DPT and reached a consensus with machine operators. This meeting also discussed smallholder concerns about the higher cost. After the discussion, the machine operators agreed to give a discount of 75 CNY·ha^{-1} on the service price. In addition, 15 small CLUPs were divided according to the location of the plot, and one leader was assigned for each CLUP to effectively manage the process in the limited tillage season. Tillage season in 2014 ran from 5 to 14 Oct. STB staff reported DPRT progresses for the 15 CLUPs daily during this period (Fig. 1). They also coordinated with machinery operators when they found the progress was slower than expected.

The success in in-field experiments of DPRT and conduction of large-scale CLUP gave STB staff confidence in future works. They have held effects demonstration sessions in the harvest period of the 2014–2015 wheat season. A series of intensive technical services were organized to make more farmers aware of the effects of DPRT before the 2014–2015 wheat tillage season. DPRT was highly recommended as a high-yield and high-efficiency farming practice in whole wheat production. In the 2014–2015 wheat season, STB staff copied their successful experience last year. Two additional agreements were reached: a higher discount on DPT service price and a system linking tillage quality, supervision, and discount subsidy. In 2016, 4 large-power DPT machines were active in the village, ensuring sufficient tillage service without much effort coordinating the tillage process. Due to the increasing fuel cost in 2016, the discount on DPT service returned to 75 CNY·ha^{-1} in the 2016–2017 wheat season. DPRT replaced SRT as the prevalent tillage method for the wheat season in WZ STB village after 2017.

4.2 Intermediation roles performed by the STB in the coevolution processes

This section demonstrates that the intermediation roles performed by the STB evolved during the coevolution process. STBs served more as knowledge brokers in the early stage in the community (Table 4). They diagnosed the challenges and opportunities for the local wheat production. After diagnosis, STB staff conducted in-field experiments to verify the effects of technology on solving location-specific problems. These activities mainly helped to link scientific knowledge with local problems. After verifying scientific knowledge, multiple tools were employed to change farmer awareness of DPRT and improve their knowledge of DPRT.

In the second phase, STB staff has begun to contribute beyond that of just knowledge brokers (Table 4). After effort-costing coordination about the establishment of small-scale CLUP, they realized that the knowledge brokering is still far away from promoting technological change at a large scale. So, they took action in demand articulation with more stakeholders to identify the social constraints. They also contributed to network building. Firstly, they embed themselves into the local community, including living in the village for a long time, establishing an interpersonal relationship with farmers, and intensively communicating with farmers, which is likely to increase farmer trust in STB technology service. Secondly, they also engaged more stakeholders inside the community in the innovation process, such as the village cadres, FC leaders, and machine operators. Finally, the connection with stakeholders outside the village, such as the local newspaper and TV station, helped them increase the impact of technology. A new organizational model (CLUP) was applied to create the demonstration field through intensive communication with farmers. Typically, the local extension system establishes a demonstration field by renting land of many farmers. CLUP saves the rental cost of combing small, fragmented farmland.

STBs had wider and more systematic intermediation roles in the final phase to support the coevolution of different innovations. Recommended technical practice was re-fitted based on the farmer demands and the local social environment. STB staff took more effort to create an effective network to facilitate the progress of innovation. Some informal arrangements were developed and strengthened to provide institutional support to the coevolution process. For example, STBs gradually increased the size of CLUPs and fostered an arrangement to link the tillage quality supervision, process coordination and service price discount distribution (Table 4).

4.3 Comparison of the recent outcomes of coevolution of innovation between STB village and non-STB villages

In this section, we first compare the basic characteristics of the surveyed farmers in the STB village and the non-STB villages (Section 4.3.1). After that, we assess and compare the recent outcomes of innovation coevolution in tillage methods between the STB village and the non-STB villages in terms of adoption

Table 4 Summary of innovation activities related to tillage methods and the roles of STB in supporting the process

Innovation type	Activities	Innovation intermediation roles
Phase1		
Software	Field survey before the 2011–2012 wheat season	F1, diagnosing the challenges for the local production and defining the technology demands
	A series of technology extension activities inside the STB village	F6, transfer the improved technology to the local farmers in different approaches
Hardware	In-field DPT experiments in the 2011–2012 wheat season	F6, linking scientific knowledge with local practice: defining the technology demands, making technical solutions and verifying its effects
Orgware	None	None
Phase2		
Software	Multistakeholder interview	F1 & F3, identifying the relevant stakeholders (F3), and diagnosing the social constraints to their adoption of the improved tillage practice (F1)
	A series of technology extension activities inside and outside the STB village, some of them accompanied by social activities	F6 & F3, transfer the improved technology to local farmers in different approaches and develop interpersonal relations with local farmers (F3)
Hardware	None	None
Orgware	Creating a small-scale demonstration CLUP	F2, F3, F5 & F6, coordinating with local farmers with the help of two leading farmers (F3 & F5); creating a demonstration land through a new approach (F2), and this demonstration field was applied to convince farmers to adopt improved practice (F6)
Phase3		
Software	A series of technology extension activities inside the STB village, some of them accompanied by social activities	F6 & F3, transferring technology to farmers (F6) and developing interpersonal relations with local farmers (F3)
	Assisting FC in applying the municipal science base	F4, strengthening the capacity of local FC and increasing FC impacts on a larger scale
	Farmer questionnaire survey and in-field survey or observation	F1, continuous problem diagnosis through different ways
Hardware	Refitting the technical practice through in-field DPRT experiments	F6, connecting technological innovation with local farmer demands and social environment
	Introducing a new DPT machine	F1 & F4, defining the demands for the DPT service (F1), convincing FC to buy new machines to increase their DPT service capacity (F4)
Orgware	Gradually increasing the size of CLUP	F2–F5, facilitating the CLUP model (F2 & F4) through cooperating and coordinating with local smallholders, FC, and cadres (F3 & F5)
	Intensive meeting with local farmers, FC, machine operators, and cadres	F1–F6, helping smallholders to articulate their demand for lower service price and higher tillage quality (F1), and training local machine operators on the tillage standards (F6); facilitating informal arrangements about tillage quality supervision, process coordination, and service price discount (F2) through linking smallholders, FC, machine operators, and cadres (F3); developing and strengthening a clear work arrangement for the tillage season to help the tillage process run effectively (F2 & F5); strengthening the work efficiency of FC and farmer trust on the FC tillage quality by convincing FC to introduce new machine and setting operation standards (F2 & F4)

Note: Source from author collation based on the WZ STB work diary. F1, demand articulation; F2, institutional support; F3, networking brokering; F4, capacity building; F5, innovation processes management; and F6, knowledge brokering.

of improved DPRT (Section 4.3.2), enabling software (Section 4.3.3) and facilitating orgware (Section 4.3.4) for the adoption of DPRT. We further evaluate the effects of the enabling software and facilitating orgware on the adoption of DPRT (Section 4.3.5) by using multivariate logit regression analysis.

4.3.1 Basic characteristics of the surveyed farmers

The basic characteristics of the surveyed farmers in the STB village and the non-STB villages are compared in Table 5. In the year of the survey (2020), there was no significant difference between STB farmers and non-STB farmers in terms of gender and off-farm occupation of householders. But the STB farmers were on average 3.9 years younger and had on average 0.6 years more education than non-STB farmers. The total operated farm size of STB farmers was on average almost 50% larger than the size operated by non-STB farmers. However, the size of the largest plot, which is closely linked to

Table 5 Basic information of farmers in the STB village and the non-STB villages

Basic information	non-STB (n = 322)	STB (n = 27)
Gender of householder (1 = male; 0 = female)	0.96	0.89
Age of householder (years)	58.9	55.0***
Education of householder (years)	7.92	8.52***
Off-farm occupation (1 = yes; 0 = no)	0.27	0.33
Operated total farm size (ha)	0.82	1.40***
Size of the largest plot (ha)	0.18	0.28
Flatness of the largest plot (1 = very uneven; 2 = uneven; 3 = fair; 4 = flat; 5 = very flat)	3.79	3.96

Note: Source calculated based on author survey held in 2020. Significance of differences in mean values between the two groups was examined using z-tests. *** indicate statistical significance at the 1% level.

the mechanical tillage operation, shows no significant difference between STB farmers and non-STB farmers. There was no significant difference in the flatness of the largest plot between STB farmers and non-STB farmers.

4.3.2 Adoption of DPRT

As shown in Table 6, DPRT technology was almost universally used in the WZ STB village in the 2019 wheat growing season whereas most non-STB farmers used SRT. Slightly more than half of the farmers in the STB village who changed the tillage technology did so between 2011 and 2015 whereas more than three-quarters of the farmers changing tillage technology in the non-STB villages changed it during the past 5 years. The yield per hectare of STB farmers was about 1 t higher than the yield of non-STB farmers. There was no significant yield difference between farmers who adopted DPRT or did not adopt DPRT within non-STB villages. According to the previous STB study, tillage practice has a small contribution to production[18]. Although optimized tillage practice does not lead to a significant yield difference, it has assisted other practices, like improving sowing quality and preventing the wheat lodging close to the harvest season[26].

4.3.3 Enabling software

Enabling software in this study aims to promote DPRT adoption by providing an enabling environment and improving farmer knowledge of the technology. It is assessed by measuring farmer exposure to knowledge and level of knowledge of DPRT. Farmers in WZ village have been exposed to DPRT technology through multiple approaches. Since 2011, the WZ STB has shared knowledge with farmers through farmer field schools, technology posters on the street wall, technology display boards in the field, technology broadcasts, technology night schools, and in other ways.

Table 7 shows the difference in technology exposure between

Table 6 DPRT adoption and technology transition in STB village and non-STB villages, 2019–2020 wheat season

	Non-STB villages (n = 322)	STB village (n = 27)
Adoption rate of DPRT (%)	6.52	96.3***
Yield ($t \cdot ha^{-1}$)	7.97	8.94***
Yield for farmers who did not adopt the DPRT ($t \cdot ha^{-1}$)	7.97	9.00@
Yield for farmers who adopted the DPRT ($t \cdot ha^{-1}$)	8.06	8.97***
Farmers changing from SRT to DPRT in the past 10 years (%)	4.04	90.7**
Period when farmers changed technology (%)		
2011–2015	23.1	54.5
2016–2020	76.9	45.5

Note: Source calculated based on author survey held in 2020. Significance of differences in mean values between the two groups was examined using z-tests. ** and *** indicate statistical significance at the 5% and 1% level, respectively. @ One observation only. There were no significant yield differences between farmers who adopted DPRT or did not adopt DPRT within non-STB villages.

farmers in the STB village and farmers in non-STB villages. STB farmers had a better environment to access knowledge and new technology. More STB farmers have received DPRT training and specific DPRT than non-STB farmers. More than 10 years of in-village technology service and multiple types of technology publicity exposed STB farmers to knowledge for a longer period. Compared to non-STB villages, more farmers participated in the experiments of researchers.

Differences between the two groups of farmers in exposure and knowledge of DPRT technology are shown in Table 8. Farmers in the STB village scored significantly higher on long-term exposure and in-field experiments exposure. There was no significant difference in technology training and recommendation exposure between STB farmers and non-STB farmers. The better knowledge exposure environment has enabled more farmers in the STB village to be aware of the existence of DPRT, and its detailed definition, compared to farmers in non-STB villages. However, there was no significant difference between non-STB and STB farmers in the knowledge of the impact of DPRT on production, suitable application scenarios, perceived constraints to adoption, and

Table 7 Comparison of non-STB villages and STB village in technology extension exposure

	Non-STB villages	STB village
Characteristic	Top-down One-off	Bottom-up and top-down Long-term exposure
Tools	Single • Lecture/in-field guidance	Multiple • In-field experiments • Farmer field school • Technology poster on the street wall • Technology display boards in the field • Technology broadcast • Technology night school With social activities, like square dancing, movie night
Timing	Non-agricultural working period	7–10 days before every key agricultural management period during the whole growth season
Content	General	Specific suggestions

Note: Source based on Zhang et al. [18], Jia et al.[25] and Jiao et al.[29].

Table 8 Exposure, knowledge and score on DPRT in STB and non-STB villages in 2020

	Non-STB villages (*n* = 322)	STB village (*n* = 27)
Exposure		
Technology training on DPRT (1 = yes; 0 = no)	0.08	0.30
Technology recommendation on DPRT (1 = yes; 0 = no)	0.32	0.48
Long-term exposure to knowledge (1 = yes; 0 = no)	0.0	1.0***
In-field experiments (1 = yes; 0 = no)	0.25	0.70**
Knowledge		
Awareness of the existence of DPRT (1 = yes; 0 = no)	0.57	1.00**
For those who adopt DPRT, knowledge score on		
Detailed definition of DPRT (1 = very unclear; 2 = unclear; 3 = fair; 4 = clear; 5 = very clear)	3.73	4.55***
Impact of DPRT on production (score 0–5)	3.93	4.13
Suitable application scenarios (score 0–3)	2.71	2.75
Perceived constraints to adoption (score 0–3)	0.83	0.58
Standards for assessing operation quality (score 0–4)	1.05	1.12

Note: Source calculated based on author survey held in 2020. Significance of differences in mean values between the two groups was examined using z-tests. ** and *** indicate statistical significance at the 5% and 1% level, respectively. Detailed information about how the knowledge was evaluated is shown in Table S1.

standards for assessing the operation quality.

4.3.4 Facilitating orgware

Facilitating orgware refers in this study to farmer access to DPRT machinery and to FCs, which facilitate social environment change by supporting the adoption of improved tillage technology. Table 9 shows the differences between farmers in the STB village and in non-STB villages in access to DPRT machinery, and Table 10 shows the differences between the two groups in FC participation and in the services provided by FCs.

Farmers in the STB village had better access to DPRT machinery. All surveyed farmers in the STB village have access to rotary tillage machinery as well as deep plowing machinery. In the non-STB villages, 97% of the farmers had access to rotary tillage machinery whereas only 23% of the farmers could use deep plowing machinery. More farmers in STB village could access deep plowing machinery from their village than non-STB farmers (Table 9).

More than two-thirds of the farmers in the STB village participated in FCs whereas only 7% of farmers participated in FCs in non-STB villages (Table 10). Agriculture input product purchasing was the most important service provided by FCs in the non-STB villages whereas technology service was the most important service type provided to farmers in the STB village.

4.3.5 Effects of enabling software and facilitating orgware on farmer adoption

A multivariate regression analysis was conducted to obtain empirical estimates of the effects of enabling software and facilitating orgware on farmer adoption of DPRT. Since the dependent variable (*Adoption*) is dichotomous, the logit regression model was applied for estimation.

Table 9 Access to tillage machinery in STB village and non-STB villages (%)

	Non-STB villages (n = 322)	STB village (n = 27)
Access to rotary tillage machinery	96.9	100.0
For those who can access rotary tillage machinery, the source they access		
self-owned	5.13	11.1
machinery services provided inside the village	90.7	88.9
machinery services from other villages	4.17	0.00
Access to deep plowing machinery	22.6	100.0***
For those who can access deep plowing machinery, the source they access		
self-owned	2.74	7.41
machinery services provided inside the village	65.8	88.9***
machinery services from other villages	31.4	3.70

Source: Calculated based on author survey held in 2020. Significance of differences in mean values between the two groups was examined using z-tests. *** indicate statistical significance at the 1% level.

Table 10 Participation in farmer cooperatives (FCs) and services received from the FC (percentages)

	Non-STB villages (n = 322)	STB village (n = 27)
Participating in (FCs)	7.1	66.7***
For those who participate in FCs, service received from the FC		
Technology service	29.2	44.4
Agriculture input products purchase	33.3	16.7
Mechanical service	16.7	5.56
Combination of 2 or 3 of these services	20.8	33.3

Note: Source calculated based on author survey held in 2020. The significance of differences in mean values between the two groups was examined using z-tests. *** indicate statistical significance at 1% level.

The estimation model is specified as:

$$\text{Adoption}_i = \ln(p_i/1-p_i) = \beta_0 + \beta_1 \text{ES}_i + \beta_2 \text{FO}_i + \beta_3 \text{FCH}_i + \beta_4 \text{PC}_i + \varepsilon_i \quad (1)$$

where, Adoption_i is a dichotomous variable representing the farmer adoption of DPRT, ES is the variables related to enabling software, FO is the variables related to facilitating orgware, FCH is the farmer characteristics, PC is the plot characteristics. i denotes the i th farmer, β_{0-4} is the regression coefficients, and ε_i is the random disturbance term. Table 11 shows the definitions and descriptive statistics of the variables in the model.

The results are presented in Table 12. They show that participation in FCs and access to deep plowing machinery had a significant positive impact on farmer adoption of DPRT. But there was no significant relationship between variables related to the enabling software and the adoption of DPRT. The plot size also significantly and positively affects the farmer adoption of DPRT.

The coefficient estimates indicate that the odds of adopting DPRT are ~35% higher for farmers who are a member of an FC as compared to non-members and ~17% higher for farmers with access to deep plowing machinery as compared to farmers who do not have access. As regards plot size, the odds of adopting DPRT are ~2% greater for farmers having 0.1 ha larger plots.

5 ANALYSIS AND DISCUSSION

Our findings demonstrate that the intermediation services performed by STBs evolved from a knowledge broker role to broader innovation intermediation roles as described in Section 4.2. This evolution of functions is consistent with the evolution of the academic focus on innovation support, that is, from knowledge broker to innovation broker to perform a

Table 11 Variables used in the regression analysis (*n* = 349)

Variable name and definition	Mean	Std. Dev.	Min	Max
Dependent variables				
Adoption of DPRT (1 = yes; 0 = no)	0.13	0.34	0	1
Independent variables				
Enabling software				
One-off training on general tillage methods (1, if farmer received one-off training on general tillage methods; 0, if farmer did not receive one-off training on general tillage methods)	0.09	0.29	0	1
Specific technical practice recommendations on DPRT (1, if farmer received specific DPRT recommendation; 0, if farmer did not receive specific DPRT recommendation)	0.34	0.47	0	1
In-field experiments (1, if there was an experiment in farmer land; 0, if there was no experiment in farmer land)	0.29	0.45	0	1
Facilitating orgware				
Participation in farmer cooperatives (1 = yes; 0 = no)	0.12	0.32	0	1
Access to rotary machinery (1, if farmer can access to rotary machinery from any source; 0, if farmer cannot access to rotary machinery)	0.97	0.17	0	1
Access to deep plowing machinery (1, if farmer can access to deep plowing machinery from any source; 0, if farmer cannot access to deep plowing machinery)	0.29	0.37	0	1
Farmer characteristics (of the household head)				
Gender (1 = male; 0 = female)	0.95	0.22	0	1
Age (year)	58.6	10.2	30	87
Education (year)	7.97	3.53	0	18
Off-farm occupation (1, if farmer with off-farming jobs even in the harvest season or farmer with farming job only in the harvest season; 0, if farmer without off-farm job or only occasional off-farm job)	0.28	0.45	0	1
Plot characteristics (of the largest plot)				
Plot size (ha)	0.19	0.15	0.01	1.07
Plot flatness (1 = very uneven; 2 = uneven; 3 = fair; 4 = flat; 5 = very flat)	3.80	0.92	1	5

Note: Source calculated based on author survey held in 2020.

Table 12 Factors affecting farmer adoption of DPRT in the 2019–2020 wheat season (logit model)

Factors	Adoption of DPRT (1 = yes; 0 = no)	
	(Model 1)	(Model 2)
Enabling software		
One-off training on general tillage methods	−0.00	0.00
	(0.044)	(0.047)
Specific technical practice recommendations on DPRT	0.05	0.04
	(0.034)	(0.033)
In-field experiments	0.05	0.05
	(0.043)	(0.037)
Facilitating orgware		
Participation in farmer cooperatives	0.31**	0.29**
	(0.122)	(0.128)
Access to rotary tillage machinery	−0.05	−0.01
	(0.043)	(0.038)
Access to deep plowing machinery	0.16*	0.15*
	(0.086)	(0.079)
Farmer characteristics (of the household head)		
Gender	–	−0.09
		(0.092)
Age	–	0.00
		(0.001)
Education	–	−0.00
		(0.003)
Off-farm occupation	–	−0.01
		(0.022)
Plot characteristics (of the largest plot)		
Plot size	–	0.19**
		(0.085)
Plot flatness	–	−0.01
		(0.009)
Pseudo R2	0.2770	0.3040
Observations	349	349

Source: based on data collected through the author survey in 2020. Note: Robust standard errors in parentheses. Clustered errors were applied at the village level. * and ** indicate statistical significance at the 10% and 5% level, respectively. Definition of the variables is shown in Table 10.

broader innovation support and management function[13]. As a university-driven intermediary, STB began by helping linking scientific knowledge to the specific social environment and then transferred improved practice and relevant knowledge more interactively through diverse approaches. This confirms earlier research on STB[18,30,31]. Beyond knowledge brokering, STB gradually evolved toward performing broader intermediation roles, such as network brokering, innovation process management and capacity building to support the coevolution process of innovation. STBs have emphasized networking with different stakeholders and formatting the new institutional arrangements on the tillage working process management and unified land farming. Intensive communication and collaboration with local FCs also enhanced FC capacity to provide mechanical service. The institutional support facilitated by STB is usually informal and relies on a close relationship with local stakeholders. However, in our case, STB evolution in the intermediation roles performed was also limited to within the community. Beyond the village, the STB still served as knowledge brokers.

The innovation intermediation function evolution of STB has facilitated innovation processes to solve complex and emerging agricultural problems, which performed as an accelerating transformation of wheat tillage practice, enabling a learning environment and facilitating institutional support in an STB village. The strengths of STBs as a community-based innovation intermediary were the rapid and sustained identification of problems and the facilitating innovation from different dimensions. This contrasts with some previous studies, which aim to provide solutions to agriculture problems from innovation in one dimension, including enhancing knowledge[32–35] and optimizing technology[36,37]. We confirmed that system innovation is necessary to solve complex agricultural problems[8,38,39]. In our case, the STB staff practice combined hardware, software and orgware in line with the roles proposed in innovation system thinking (Fig. 2). Thus, STBs have served to connect institutional change (orgware) with the software and hardware dimensions of innovation. This connection was performed to develop and enhance a new pattern of collaboration and work by intensive communication and interaction in the tillage period.

Our results also show the importance of innovation intermediaries in fostering an effective innovation network through intensive communication and interaction. This result is consistent with the aim of innovation intermediaries to enhance relational embeddedness in innovation networks[13]. Arguably, the strength of STB in sustainably solving complex agricultural problems lies in their continuous embeddedness in the local community. In contrast to traditional public extension services, which involve isolated innovations and one-off, top-down knowledge dissemination[40,41], STB focuses on situating innovation within the specific social environment and building effective innovation networks through enhancing multiactor interaction. It confirms that large-scale technology adoption or technological transformation should be regarded as a collective rather than an individual process[11]. Our findings also show that enabling software alone has no significant relationship with the adoption of DPRT whereas the facilitating orgware has a significant positive relationship with the adoption of DPRT. The focus of innovation support interventions on

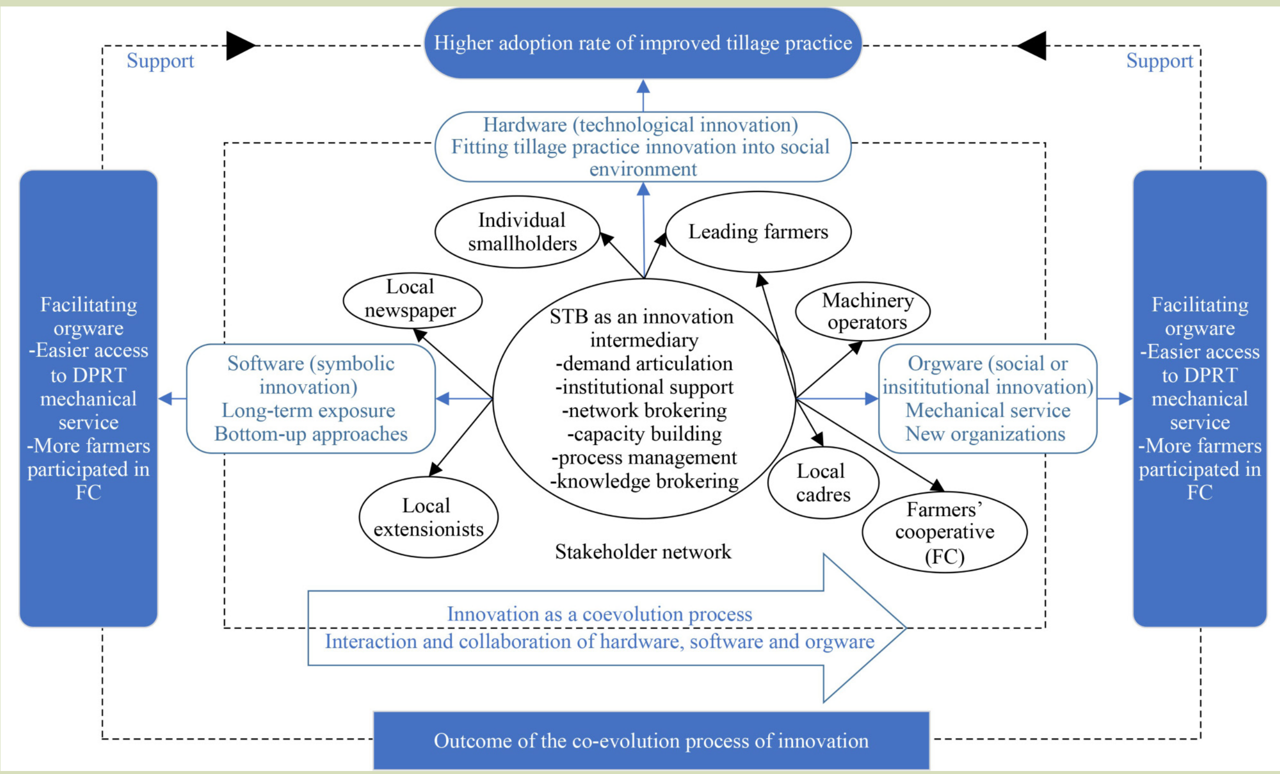


Fig. 2 Schematic representation of STB as an innovation intermediary to support the coevolution of software, orgware, and hardware, and the outcome of the coevolution process.

promoting effective institutional support needs to increase. Effective institutional support requires a collective effort of multistakeholders.

However, a single STB has limited power to facilitate the establishment of a wider network of stakeholders. Unlike some innovation intermediaries, which have a broader scale, such as industry[14] or national level programs[8,13], one single community-level STB does not build a broader innovation network and incorporate more diverse stakeholders. Rather, it aims to engage existing actors in the innovation process, enhance communication and interaction between existing stakeholders inside the community, and build local stakeholder capacity. Community-centered characteristics have also helped to reduce coordination and communication difficulties among a wider range of stakeholders, facilitating their rapid and sustained engagement with emerging problems. Likewise, this characteristic negatively affects its ability to function as an innovation intermediary outside the community. More single STBs were established and connected as STBs networks in recent years to increase STB impacts at a larger scale[19,42].

6 CONCLUSIONS

This paper has demonstrated the potential of community-based innovation intermediaries in facilitating the coevolution of innovation to support technology change in tillage practice in wheat season. We first presented an innovation journey analysis to gain insight into the intermediation roles served by an STB in the coevolution of innovation. This paper presented the coevolution process outcome in terms of adopting an improved tillage method, relevant enabling software and facilitating orgware between villages with and without STB by using multivariate regression analysis.

Our results show that the STB in WZ village has had a dynamic and comprehensive role as a community-level innovation intermediary to support the coevolution of the innovation processes of the tillage method in the wheat season. Compared with non-STB villages, WZ STB village had a much higher adoption rate of optimized technology practice (96% vs 7%), a better knowledge exposure environment, and more effective institutional support. The regression results show that the adoption of DPRT is mainly affected by facilitating orgware. The odds of adopting DPRT are about 35% higher for farmers who are a member of an FC as compared to non-members and about 17% higher for farmers with access to deep plowing machinery as compared to farmers who do not have access. However, the WZ STB has served only to a limited degree in supporting the evolution processes of innovation outside the village.

Our research fills a gap by providing insight into the role that STB may have as a community-level innovation intermediary in supporting the coevolution of innovation in rural China. A key implication for policy is that it is important to support that standard innovation support providers such as agricultural extension organizations develop the capacity to provide broader innovation intermediation than just knowledge brokering. The problem-oriented and community-centered work mechanism of STB has the potential to solve the problem of the division between technological innovation and the social environment in the existing public promotion system. In our case, STB has an in-time problem diagnosis and feedback system, problem-oriented adaptable roles, and long-term relational embeddedness with local stakeholders.

The study also highlighted some areas for future research. The first area is to investigate how to increase the impacts of community-level innovation intermediaries on supporting large-scale innovation processes. The second area is to further verify the intermediation roles that STBs do and/or can usefully have in connection with different farming practices and innovations. This latter theme connects to the limited scope of this study. Only one STB was selected in our study without considering more STBs and the collaboration in STBs networks. Another limitation in this study is that we have explored the intermediation roles in connection to changes in tillage methods as a case study. We have implicitly assumed that changes in other practices are similar in the STB village and non-STB village. We still need to further validate the intermediation role of STB by considering different farming practices.

In conclusion, this study provides evidence that STBs can and do perform broader innovation intermediation roles at the community level than conventional innovation support providers in rural China. In the case of WZ STB, this has facilitated the coevolution process of innovation in tillage practices. In comparison with non-STB villages, the coevolution process facilitated by WZ STB resulted in, a better learning environment and a more enabling social environment, which should eventually lead to higher adoption rates.

Supplementary materials

The online version of this article at https://doi.org/10.15302/J-FASE-2022465 contains supplementary material (Table S1).

Acknowledgements

This study was supported by China Scholarship Council (201913043) and Agricultural Carbon Neutral Account Establishment Program in Quzhou (202127). We are grateful for the support provided by the Agricultural Green Development program (AGD).

Compliance with ethics guidelines

Jinghan Li, Cees Leeuwis, Nico Heerink, and Weifeng Zhang declare that they have no conflicts of interest or financial conflicts to disclose. All applicable institutional and national guidelines for the care and use of animals were followed.

REFERENCES

1. Evenson R E, Gollin D. Assessing the impact of the green revolution, 1960 to 2000. *Science*, 2003, **300**(5620): 758–762
2. Rogers E M, Singhal A, Quinlan M. Diffusion of innovations. In: Salwen M B, Stacks D W, eds. An Integrated Approach to Communication Theory and Research. *Routledge*, 1996: 182–186
3. Sartas M, Schut M, Proietti C, Thiele G, Leeuwis C. Scaling readiness: science and practice of an approach to enhance impact of research for development. *Agricultural Systems*, 2020, **183**: 102874
4. Wigboldus S, Klerkx L, Leeuwis C, Schut M, Muilerman S, Jochemsen H. Systemic perspectives on scaling agricultural innovations. A review. *Agronomy for Sustainable Development*, 2016, **36**(3): 46
5. Schut M, Klerkx L, Sartas M, Lamers D, Mc Campbell M, Ogbonna I, Kaushik P, Atta-Krah K, Leeuwis C. Innovation platforms: experience with their institutional embedding in agricultural research for development. *Experimental Agriculture*, 2016, **52**(4): 537–561
6. Leeuwis C, van der Ban A. Communication for Rural Innovation: Rethinking Agricultural Extension. 3 eds. *Wiley-Blackwell*, 2004
7. Smits R. Innovation studies in the 21st century: questions from a user's perspective. *Technological Forecasting and Social Change*, 2002, **69**(9): 861–883
8. Kilelu C W, Klerkx L, Leeuwis C. Unravelling the role of innovation platforms in supporting co-evolution of innovation: contributions and tensions in a smallholder dairy development programme. *Agricultural Systems*, 2013, **118**: 65–77
9. Leeuwis C, Schut M, Waters-Bayer A, Mur R, Atta-Krah K, Douthwaite B. Capacity to Innovate from a System CGIAR Research Program Perspective. Penang, Malaysia: *CGIAR Research Program on Aquatic Agricultural Systems*, 2014
10. World Bank. Enhancing agricultural innovation: how to go beyond the strengthening of research systems? Washington DC: *World Bank*, 2006
11. Leeuwis C, Aarts N. Rethinking adoption and diffusion as a collective social process: towards an interactional perspective. In: Campos H, ed. The Innovation Revolution in Agriculture. *Springer*, 2021: 95–116
12. Hekkert M P, Suurs R A A, Negro S O, Kuhlmann S, Smits R E H M. Functions of innovation systems: a new approach for analysing technological change. *Technological Forecasting and Social Change*, 2007, **74**(4): 413–432
13. Kilelu C W, Klerkx L, Leeuwis C, Hall A. Beyond knowledge brokering: an exploratory study on innovation intermediaries in an evolving smallholder agricultural system in Kenya. *Knowledge Management for Development Journal*, 2011, **7**(1): 84–108
14. Kanda W, Hjelm O, Clausen J, Bienkowska D. Roles of intermediaries in supporting eco-innovation. *Journal of Cleaner Production*, 2018, **205**: 1006–1016
15. Gliedt T, Hoicka C E, Jackson N. Innovation intermediaries accelerating environmental sustainability transitions. *Journal of Cleaner Production*, 2018, **174**: 1247–1261
16. Markard J, Truffer B. Technological innovation systems and the multi-level perspective: towards an integrated framework. *Research Policy*, 2008, **37**(4): 596–615
17. Yang H, Klerkx L, Leeuwis C. Functions and limitations of farmer cooperatives as innovation intermediaries: findings from China. *Agricultural Systems*, 2014, **127**: 115–125
18. Zhang W, Cao G, Li X, Zhang H, Wang C, Liu Q, Chen X, Cui Z, Shen J, Jiang R, Mi G, Miao Y, Zhang F, Dou Z. Closing yield gaps in China by empowering smallholder farmers. *Nature*, 2016, **537**(7622): 671–674
19. Yang P, Jiao X, Feng D, Ramasamy S, Zhang H, Mroczek Z, Zhang W. An innovation in agricultural science and technology extension system: case study on science and technology backyard. Rome: *FAO*, 2021

20. National Academy of Agriculture Green Development (NAAGD). Science and Technology Backyard: a 500-year-old fantasy turned into a global practice. Beijing: *NAAGD*, 2021
21. Klerkx L, Adjei-Nsiah S, Adu-Acheampong R, Saïdou A, Zannou E, Soumano L, Sakyi-Dawson O, van Paassen A, Nederlof S. Looking at Agricultural Innovation Platforms through an Innovation Champion Lens. *Outlook on Agriculture*, 2013, **42**(3): 185–192
22. Klerkx L, Aarts N, Leeuwis C. Adaptive management in agricultural innovation systems: the interactions between innovation networks and their environment. *Agricultural Systems*, 2010, **103**(6): 390–400
23. Wang L, Li J, Li J, Bai W X. Effects of tillage rotation and fertilization on soil aggregates and organic carbon content in corn field in Weibei Highland. *Chinese Journal of Applied Ecology*, 2014, **25**(3): 759–768
24. Tian S, Ning T, Wang Y, Liu Z, Li G, Li Z, Lal R. Crop yield and soil carbon responses to tillage method changes in North China. *Soil & Tillage Research*, 2016, **163**: 207–213
25. Jia C. The Demonstration of High-yield and High-efficiency Technology for Winter Wheat-Summer Maize in Wangzhuang Village, Quzhou Country, Hebei Province. Dissertation for the Master’s Degree. Beijing: *China Agricultural University*, 2013 (in Chinese)
26. Wang F. Application and Demonstration of Soil Deep Plowing and Deep Loosing Technologies. Dissertation for the Master’s Degree. Beijing: *China Agriculture University*, 2013 (in Chinese)
27. Zhao P. Quantifying and Closing Yield Gaps for Winter Wheat and Summer Maize Rotation in Smallholder Farming System. Dissertation for the Doctoral Degree. Beijing: *China Agriculture University*, 2016 (in Chinese)
28. Wang F, Cao G, Liu Q, Zhang H, Shen J. Present situation, problems and countermeasures of production mechanization of wheat-maize rotation system in Huanghuaihai region: taking Quzhou County as an example. *Journal of Hebei Agricultural Sciences*, 2012, 16(6): 58−62 (in Chinese)
29. Jiao X, Wang C, Zhang F. Science and Technology Backyard: a novel model for technology innovation and agriculture transformation towards sustainable intensification. *Journal of Integrative Agriculture*, 2019, **18**(8): 1655–1656
30. Liu X, Zhang Y, Han W, Tang A, Shen J, Cui Z, Vitousek P, Erisman J W, Goulding K, Christie P, Fangmeier A, Zhang F. Enhanced nitrogen deposition over China. *Nature*, 2013, **494**(7438): 459–462
31. Yuan Z, Jiang S, Sheng H, Liu X, Hua H, Liu X, Zhang Y. Human perturbation of the global phosphorus cycle: changes and consequences. *Environmental Science & Technology*, 2018, **52**(5): 2438–2450
32. Huang J, Xiang C, Jia X, Hu R. Impacts of training on farmers’ nitrogen use in maize production in Shandong, China. *Journal of Soil and Water Conservation*, 2012, **67**(4): 321–327
33. Huang J, Huang Z, Jia X, Hu R, Xiang C. Long-term reduction of nitrogen fertilizer use through knowledge training in rice production in China. *Agricultural Systems*, 2015, **135**: 105–111
34. Jia X, Huang J, Xiang C, Powlson D. Reducing excessive nitrogen use in Chinese wheat production through knowledge training: what are the implications for the public extension system. *Agroecology and Sustainable Food Systems*, 2015, **39**(2): 189–208
35. Huang J, Hu R, Cao J, Rozelle S. Training programs and in-the-field guidance to reduce China’s overuse of fertilizer without hurting profitability. *Journal of Soil and Water Conservation*, 2008, **63**(5): 165A–167A
36. Chen X P, Cui Z L, Vitousek P M, Cassman K G, Matson P A, Bai J S, Meng Q F, Hou P, Yue S C, Römheld V, Zhang F S. Integrated soil-crop system management for food security. *Proceedings of the National Academy of Sciences of the United States of America*, 2011, **108**(16): 6399–6404
37. Chen J, Zheng M, Pang D, Yin Y, Han M, Li Y, Luo Y, Xu X, Li R, Wang Z. Straw return and appropriate tillage method improve grain yield and nitrogen efficiency of winter wheat. *Journal of Integrative Agriculture*, 2017, **16**(8): 1708–1719
38. Turner J A, Klerkx L, Rijswijk K, Williams T, Barnard T. Systemic problems affecting co-innovation in the New Zealand Agricultural Innovation System: identification of blocking mechanisms and underlying institutional logics. *NJAS Wageningen Journal of Life Sciences*, 2016, **76**(1): 99–112
39. Rodenburg J, Schut M, Demont M, Klerkx L, Gbèhounou G, Oude Lansink A, Mourits M, Rotteveel T, Kayeke J, van Ast A, Akanvou L, Cissoko M, Kamanda J, Bastiaans L. Systems approaches to innovation in pest management: reflections and lessons learned from an integrated research program on parasitic weeds in rice. *International Journal of Pest Management*, 2015, **61**(4): 329–33940
40. Gao Q, Zhang C. Agricultural technology extension system in China: current situation and reform direction. *Management Science and Engineering*, 2008, **2**(4): 47–58
41. Hu R, Cai Y, Chen K Z, Huang J. Effects of inclusive public agricultural extension service: results from a policy reform experiment in western China. *China Economic Review*, 2012, **23**(4): 962–974
42. Jiao X, Zhang H, Ma W, Wang C, Li X, Zhang F. Science and technology backyards: a novel approach to empower smallholder farmers for sustainable intensification of agriculture in China. *Journal of Integrative Agriculture*, 2019, **18**(8): 1657–1666