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RESEARCH ARTICLE

SMALLHOLDER ADOPTION OF GREEN PRODUCTION TECHNOLOGIES ON THE NORTH CHINA PLAIN: EVIDENCE FROM SCIENCE AND TECHNOLOGY BACKYARDS

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KEYWORDS

agricultural socialized services, green production technologies, green transformation of agriculture, technology adoption, technology trust

HIGHLIGHTS

- A systematical technology diffusion mode that can simultaneously achieve smallholders' technology adoption to different scales was discovered.
- Collaborative, tree-shaped and jump-start modes are the main forms to promote technology diffusion.
- The combination of three modes above facilitates technology diffusion to different scales.
- The STB-based technology diffusion empowered smallholders through technology adoption.
- Trust is the key to promoting technology dependence and adoption among smallholders.

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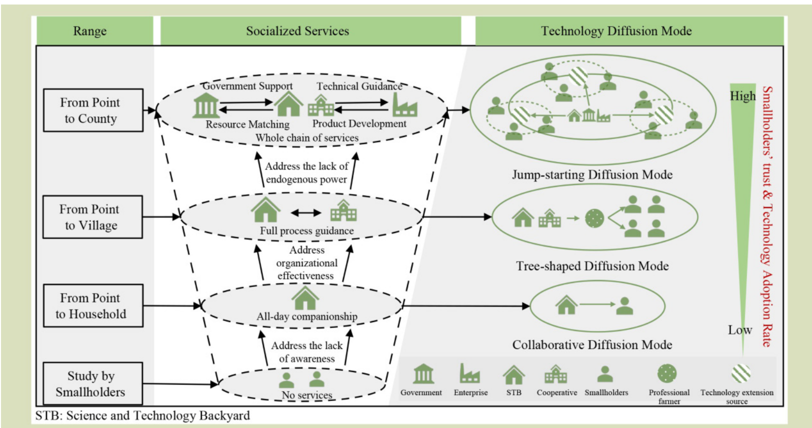
GRAPHICAL ABSTRACT



ABSTRACT

Understanding the impact of agricultural socialized services on smallholder adoption of green production technologies and their mechanisms of action is of great importance for sustainability of farming systems. Currently, there were numerous related studies, but it is still unclear how to gradually achieve the diffusion of technological innovations on pilot sites to a regional level. To answer this question, this paper presents the pathways and mechanisms of green production technologies diffusion by comparing international typical service organizations or modes such as agricultural technology extension service centers (ATESC), farmer field schools (FFS), participatory technology innovation (PTI) and integrated colearning approach (ICLA), while taking Wangzhuang Science and Technology Backyard (WZ STB) in Quzhou, Hebei Province, China as an example. This research had three key outcomes. (1) The combination of collaborative, tree-shaped and jump-start diffusion modes promotes the diffusion of participatory technology innovation to different scales, such as farmers, villages and counties. (2) The three diffusion modes combine and expand the advantages of existing international modes. The collaborative diffusion mode not only provides full scope for the advantages of PTI, but also provides smallholders with service supply for the whole production period. The tree-shaped diffusion mode combines the advantages of FFS from point technology innovation to village diffusion, while achieving a full range of technical service support. The jump-start diffusion mode cannot only achieve large-scale technology diffusion like ATESC and ICLA, but also empower smallholders through adaptive technology innovation. (3) Trust is the key to promoting smallholder reliance on the science and technology provided by STB and to promote their adoption of green production technologies. Accordingly, the following policy recommendations were proposed: strengthen the combination of top-down and bottom-up technology innovation and diffusion models, establish an effective service communication platform and evaluation mechanism, and strengthen the linkage mechanism between socialized services providers and smallholders, which will provide a realistic basis for the national policy of targeted socialized services provision and promote smallholder adoption of green production technologies.

1 INTRODUCTION

Unswerving promotion of the diffusion, application, transformation and upgrading of green production technologies is an important initiative to promote high-quality agricultural development[1,2]. Smallholders are the participants and decision makers in agricultural production. Therefore, empowering smallholders with socialized services is critical to improving agricultural production factor allocation efficiency and promoting green transformation[3]. The 2022 Central Document No.1 promulgated by the Chinese Government and the *14th Five-Year Plan for National Agricultural Green Development* both emphasized that, it is necessary to implement the action of serving smallholders with technology, build a project to improve smallholder capacity, and strengthen the cultivation plan for high-quality smallholders. However, the mismatch between supply and demand for socialized services and the lack of initial endowment of smallholders in China have led to problems such as difficulties in introducing technologies into production and low efficiency in factor allocation[4]. Coupled with the influence of the pattern of difference sequence and organizational trust, of smallholder motivation to adopt green production technologies is insufficient, and the service demand and behavior are inconsistent, which seriously hinders the green transformation and upgrading of agriculture[5,6]. Therefore, determining how to empower smallholders with socialized services, stimulate their endogenous motivation to adopt green production technologies and form a long-term mechanism for sustainable green production is critical to achieving green transformation and upgrading of smallholder production processes.

Two contrasting technology diffusion and service strategies have emerged globally: one is a top-down mode[7,8], which emphasizes scientists innovate technologies in laboratory and instill them into smallholders through organizations such as agricultural technology extension service centers (ATESC). This mode ignores smallholder endogenous motivation, and trust issues arising from the uneven quality of services became a crucial barrier to technology diffusion[9]. The second is a bottom-up mode, which is mainly through socialized services organizations to establish partnerships with smallholders, to form and promote localized technologies through participatory technology innovation[10]. Farmer field schools (FFS), Mother-baby trial and an integrated colearning approach (ICLA) are typical representatives[11]. In these models, multiple organizations, such as universities, governments and enterprises, combined training, technical products and paid services to form a kind of socialized services mode with the participation of multiple subjects, to meet the needs of smallholders[12]. Through interactive learning and repeated games, smallholders have shifted from knowledge-based trust to identification-based trust in service organizations with similar norms, and gradually deepened into special trust or even kinship[13,14]. Concurrently, the shift in trust relationships has facilitated smallholder adoption of intensive and efficient green production technologies, deepening and promoting ecosystem development[15].

All of these socialized services models and different technology extension methods have provided valuable practical experience in encouraging smallholder adoption of green production technologies and promote the sustainability of farming system. Overall, the adoption of green production technologies by smallholders is extremely complex, not only influenced by the supply of socialized services, but also affected by factors such as smallholder cognition, willingness and behavior. Some previous studies have focused only on inculcating technologies to smallholders through technology training and technology supply, while some have discussed only participatory services supply. However, how can participatory socialized services build the ongoing trust of smallholders and motivate them to continuously adopt green production technologies is still unclear.

The Science and Technology Backyard (STB) model, which originated in China, unites different organizations such as the government, enterprises and cooperatives based on the STB, forming a participatory and customized technological innovation system to achieve the adaptive innovation and application of green production technologies. At the same time, the large-scale application of green production technologies was achieved through continuous and supporting socialized service supply[16].

Therefore, we took the Wangzhuang Science and Technology Backyard (WZ STB) in Quzhou, Hebei, China, as a research object, and explored how to build ongoing smallholder trust and stimulate their adoption of green production technologies through participatory socialized services, by sorting out the process of smallholder-centered technology innovation and diffusion. It provides front-line case support and practical experience for correctly guiding the innovation of green production technologies, formulating targeted socialized service supply strategies, and providing case support and practical experience for improving the spillover effects technology innovation and green transformation.

2 TYPICAL INTERNATIONAL SOCIALIZED SERVICES MODELS TO PROMOTE THE ADOPTION OF GREEN PRODUCTION TECHNOLOGIES BY SMALLHOLDERS

The top-down and bottom-up diffusion mode are two contrasting strategies approaches to assist the implementation of green production technologies[17]. The top-down approach primarily emphasizes the technologies that scientists innovate in the laboratory and instill the technology to smallholders through ATESC or other service organizations[18]. Bottom-up refers to the development and diffusion of the most appropriate technologies by taking the actual needs of smallholders as the starting point, and by working with them through iterative discussions and innovations together[19]. Among them, ATESC are the most typical top-down diffusion mode. And organizations such as FFS, modes such as participatory technology innovation (PTI) and an ICLA are the most typical bottom-up dissemination models[11,12,20]. These approaches had provided valuable practical experience in promoting the adoption of green production technologies by smallholders and promoting the sustainability of farming systems.

2.1 Agricultural technology extension service centers (ATESC)

ATESC belong to government functional departments, which not only has a clear division of national-level institutional departments and job management system, but also has a perfect grassroots service system, such as village and town service centers, technical extension personnel, and demonstration bases. The grassroots extension personnel are responsible for new product demonstration, technical guidance and training, which can help promote agricultural production technologies into villages and households[21]. Data show that in China, as of 2019, a total of 75,000 agricultural technology diffusion institutions have been established in the four industries, including planting, animal husbandry and veterinary medicine, aquaculture, and agricultural machinery, involving a total of 541,000 personnel. Across these the proportion of agricultural technicians at the county and township levels is 92%, effectively solving the problem of the last-kilometer of agricultural technology promotion.

However, the study found that the conversion rate of agricultural technology achievements in China is only 30% to 40%, which is still far away from that of developed countries[22]. This is mainly due to the fact that most researchers tend to conduct technological innovation in laboratory with a single subject demand or interest, but the complexity of the agricultural production environment directly leads to a relatively high demand for technology specialization and customization, and its effective integration with capital and markets[23]. Although ATESC have made a crucial contribution to the diffusion of green production technologies and can better address the diffusion of technologies from the point of innovation to the social level. However, ATESC tend to have an up-down mode of agricultural technology diffusion, and most functional departments provide a relatively single mode of service, with mainly indoctrination-based technology supply, ignoring the needs of farmers and the market. At the same time, as the main body of agricultural technology diffusion, currently exhibit a strong administrative nature, which resulting in a sharp disconnection between actual smallholder technology needs and the technology promoted by the government.

2.2 Farmer field schools (FFS)

FFS were initiated in Indonesia in 1989, were first applied and promoted by local rice smallholders[20]. FFS mainly refers to smallholders training activities during the crop growing season using the field as the main training site, with the aim of training smallholders through informal adult training methods and through heuristic and participatory teaching. The knowledge of the training mainly originates from the field, and through joint learning and discussion between extension workers and smallholders in the field, the practical problems encountered in agricultural production are jointly solved, the ability of smallholders to learn, participate actively, understand and make decisions independently has been improved, and the spirit of human-centeredness has been reflected, while achieving iterative upgrading of the learning process and effects[24]. For more than 30 years, FFS had been widely replicated in 90 countries and have trained more than 12 million smallholders, which was a more typical participatory cultivation method[25]. Trainers in this mode interact frequently with smallholders and join forces with universities, enterprises and other forces to practice in the field with smallholders. This diffusion mode of production technologies at the point, and could better reflects the bottom-up logic of technological innovation and diffusion. However, since most of the teachers in the FFS originate came from ATESC, which is a government department, on one side, the staff had a lot of business to handle and it was difficult for them to stay in the production line for a long time to lead the smallholders to produce together[26]. On the other side, there were professional barriers between different functional departments, and there were limitations in terms of technology and comprehensiveness of the curriculum.

2.3 Participatory technology innovation (PTI)

PTI was first proposed by Brazilian educationalist Paulo Freire (1970), which is a typical bottom-up technology diffusion mode that involves a process of co-participation in technological innovation, empowerment, self-development and improvement. The essence was that, colearning helped researchers understand more intuitively and rapidly the needs of smallholders for production technologies., and providing a realistic basis for formulating localized innovative technologies[27]. Empowering smallholders through a participatory and consultative decision-making process allows for peer-to-peer production technology innovation and diffusion between smallholders and researchers[28].

The concept of bringing smallholders along with production was realized through the joint participation of smallholders and researchers in the process of technological innovation in agricultural production, which effectively improved the awareness, willingness to adopt and behavior of smallholders toward green production technologies[29]. This mode is mainly based on the scientists being located in the front line and making adaptive technological innovations based on agricultural production problems, but it was difficult to achieve large-scale application and diffusion because less consideration was given to subsequent diffusion and other issues.

2.4 Integrated colearning approach (ICLA)

ICLA was proposed by Marinus et al. with the goal of achieving effective technological innovation and diffusion by addressing and balancing the resource constraints between smallholders and researchers[12]. In general, smallholders often lack the latest agricultural production technologies, while researchers often lack practical experience originating from the production line, and ICLA addresses this problem effectively. On one side, this mode provides opportunities and time for smallholders to efficiently recognize and understand agricultural production technologies by providing them with technical training, and through continuous training, it enabled iterative upgrading of smallholder technical knowledge. On the other side, it also provides a practical venue for researchers to understand the current situation of agricultural production and the actual needs of smallholders. It effectively alleviating the resource constraints of smallholders and researchers, and provides a foundation for achieving sustainable agricultural production at the farm level. The main operational steps are: (1) issue vouchers used to stimulate the interest of smallholders and increased their enthusiasm for participation, (2) determine the time and theme, selecting five consecutive quarters to conduct multiple-cycle technical training and study seminars for smallholders, and research themes optimization and adjustment based on the themes of the previous quarters, feedback from smallholders and field observations, and

(3) ongoing research for each quarterly training, smallholder production behavior monitoring, interviews, yield monitoring and effect evaluation conducted.

ICLA was pilot tested in western Kenya, which demonstrated that this mode could help smallholders and scientists to better understand agricultural production systems, jointly develop more applicable agricultural production technologies, strengthen the dissemination of knowledge and technology from point to point among smallholders, and promote the sustainability of farming production[30]. It applies to the concept of participatory learning and is expected to continuously strengthens the smallholder technical knowledge system through continuous and systematic training. However, in practice, it is more likely to be implemented in the form of simple training at key nodes and farmer research, which could potentially evolve into long-term fixed intervention trials, thus making it more expensive to monitor and more difficult to disseminate production technologies.

The above modes provide valuable experience for agricultural technological innovation and application from the perspectives of top-down and bottom-up respectively, based on technological innovation at the point or technology diffusion to the village and county areas. However, there are certain limitations. For example, ATESC, which use a typical top-down mode, can promote the large-scale application of technology, but it is difficult to solve the problem of mismatch between the technological innovation of scientists and actual demand. Although the PTI mode can effectively solve the problem of adaptive technology innovation at the point, it has the difficulty of large-scale diffusion, and although the ICLA mode can apparently achieve participatory technology innovation and diffusion application, it is less controllable and has the risk of becoming formalistic because of the high requirements on the time and place for joint learning between scientists and farmers. Therefore, Chinese scientists have explored an STB mode with long-term roots in scientific research and practice, which has developed a bottom-up approach to technological innovation through long-term interaction, learning and co-innovation with smallholders. It promotes the application of green production technologies in a small area and effectively solves the problem of adaptive technology innovation and application at the point. Through the whole process of socialized service supply with the participation of multiple subjects, the top-down technology diffusion idea is formed, which effectively solves the problem of technology innovation from the point to the regional technology application, and is a technology innovation and diffusion mode with strong applicability and good practice. The specific development history will be elaborated in the next section.

3 SMALLHOLDER-CENTERED GREEN PRODUCTION TECHNOLOGIES EXTENSION MODEL—A TYPICAL EXAMPLE OF WZ STB

Quzhou County is a typical traditional grain-producing area, but around the 1950s, there were serious production obstacles such as soil salinization and flood disasters. And WZ village, which belongs to this area, used to be the core village for the second generation of soil improvement and alkalinity treatment. It was only after the completion of soil improvement and alkalinity treatment in 1973, that the problem of agricultural production difficulties and food shortage in WZ village was effectively alleviated[31]. The research object selected for this paper, WZ STB, located in WZ village in the north-eastern part of Quzhou County, Hebei Province, China, which was established in March 2011, and is mainly based on technological innovation in winter wheat-summer maize production. Through high-yield and high-efficiency technology innovation, integration, demonstration and application, it has formed a new type of scientific and technological innovation and agricultural technology promotion organization rooted in the front line of production, and integrating technological innovation, talent training and socialized services.

Before the establishment of the WZ STB, the smallholders here were mainly in the free planting mode of one family, with a low degree of organization, relatively traditional production methods and insufficient investment of advanced green production technologies. Through long-term fieldwork, scientists found that although the soil constraints have been largely eliminated, the problems of low agricultural production inefficiency and high environmental costs have become increasingly prominent, which were the key constraints to the sustainable development of agriculture in WZ village[32]. Therefore, to solve this problem, after the establishment of the WZ STB, scientists conduct targeted technological innovation in green production to address the problems of high input and low output in production, and promoted the technology through the following three-dimensional service model (Fig. 1).

3.1 From point to household: collaborative diffusion mode for green production technologies

The collaborative diffusion mode, also known as the linear diffusion mode. It mainly refers to the technology diffusion by

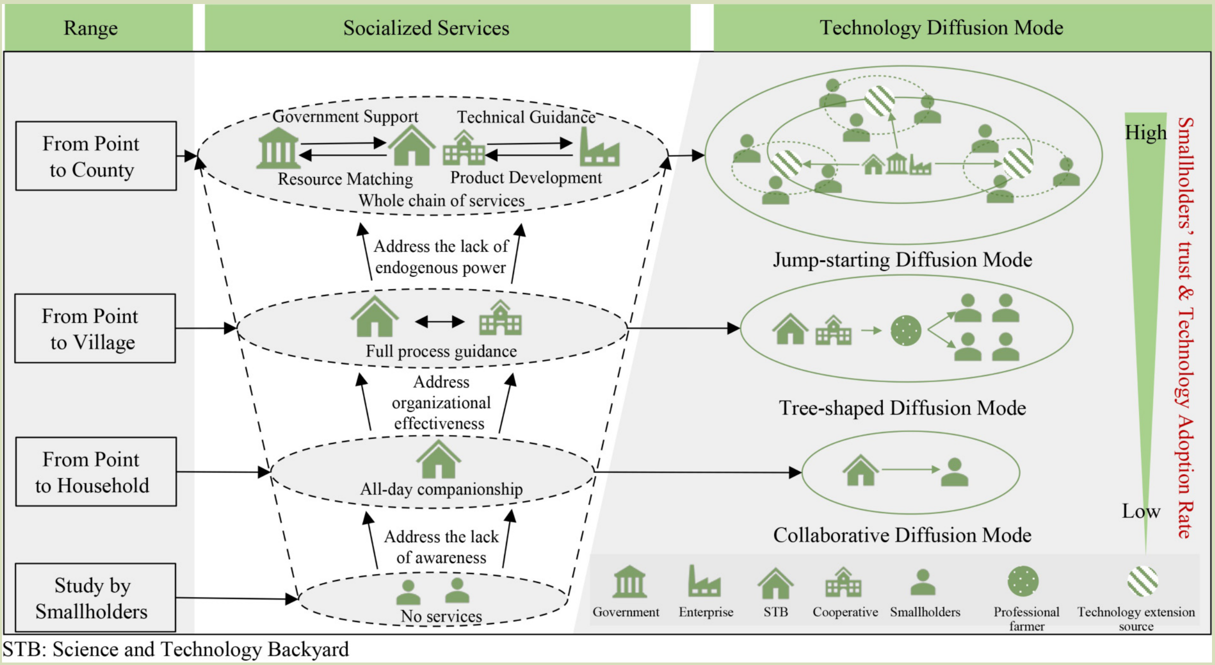


Fig. 1 Diffusion mode of green production technology at different ranges.

green production technologies innovation agents through a one-to-one format[33]. In the early stage of conducting research, the scientific and technical staff of WZ STB innovated a water and nitrogen backward transfer technology applicable to local maize production based on the problems of low yield, low production efficiency and high environmental costs in local agricultural production. This technology mainly postpones irrigation water and fertilizer application to the April 4 or April 5 in every year after the wheat turns green, which can achieve the effects of increasing wheat yield, improving wheat seed quality, and reducing nitrogen fertilizer loss[34].

In this mode, STBs mainly enhance smallholder cognition and initial trust in green production technologies through experimental demonstrations, participatory innovations and one-to-one services to improve the rate of water and nitrogen backward transfer technology in place. The first key aim was to improve smallholder technology awareness through trials and demonstrations. With the help of an advanced smallholders in WZ village, the researchers integrated a 5-ha test field in a flat area near the highway and set up a field trial of water and nitrogen backward transfer technology in it. By demonstrating the effectiveness of the technology to smallholders, to let more smallholders see, understand and know the green production technologies and promote the application of the technology. However, compared with local smallholders and traditional agricultural production, the scientists and their innovative technologies were not readily trusted by smallholders being regarded as outsiders and unfamiliar, which made it difficult to spread green production technologies. The second key aim to improve smallholder trust and technology adoption rate through participatory technology innovation and socialized services provision. Demonstration parties are used to increase the trust of smallholders and motivate them to adopt green production technologies. The scientists take the initiative to join forces with local demonstration smallholders that are highly motivated in production and receptive to new things and work with them to learn, discuss and optimize the techniques that the scientists had innovated in the laboratory. Green production technologies adapted to the local area are formed with participatory technological innovation. Concurrently, hands-on technical socialized services is provided to smallholders through one-on-one technical training and field guidance. Through no distance, no time difference, no threshold, no cost service supply, STBs and their innovative technology gain the initial trust of smallholders who participated in the innovation work, and realized the promotion and application of green production technologies. According to the interview data[35], the average yield of the land that adopted the water and nitrogen backward transfer technology also increased to 10.2 $t{\cdot}ha^{-1}$, which exceeded the highest level of maize production in China in that year, since that group of smallholders put full trust in the STBs.

Through working with smallholders, talking to smallholders and leading smallholders in new ways, a farmer-centered primary technology promotion mode—the collaborative diffusion mode—had been formed, which effectively stimulated smallholder motivation, improved the technical awareness and trust of smallholders, and realized the promotion and application of green production technologies. This level of technological innovation combines the advantages of PTI and ICLA to better achieve one-to-one technological innovation and guidance. However, due to the relatively targeted nature of one-on-one training, smallholders in the periphery had relatively few opportunities to engage with scientists and learn technologies. As a result, the problems of small radiation range and low organization make it difficult to achieve effective diffusion of green production technologies at the village level.

3.2 From point to village: a tree-shaped diffusion mode for green production technologies

The tree-shaped diffusion mode refers to the diffusion of green production technologies to many smallholders through the intermediary role of one or more professional famers, with the innovative body (STB) of green production technologies as the source. The mode is characterized by slow development in the early stage and rapid expansion in the later stage[36]. To leverage the power of the professional farmers cultivated in the collaborative diffusion mode, the acquaintance network and trust relationship between them and the surrounding smallholders are fully utilized for the spread and disseminate of the water and nitrogen backward transfer technology through them. The details are as follows.

3.2.1 Selection of professional farmers

The S cooperative (S stands for the name of the cooperative) was the only cooperative in WZ village, and M (M stands for the chairman's name in S cooperative) is the chairman of the S cooperative, who took the responsibilities of finding resources for its cooperative members and increasing their income through multiple channels, and he was highly motivated in agricultural production. After the establishment of the WZ STB, S, who lived next door to the STB, had maintained a relatively close relationship with the researchers in the backyard.

M often took the initiative to go to the STB, communicated with the scientists, and learned about the latest agricultural production technologies, and much more. Through frequent interaction and learning, M developed a strong knowledge and understanding of the water and nitrogen backward transfer technology. With the guidance and help of the scientists, M, who had a stronger sense of responsibility and technical needs, became the first professional farmer trained by an STB, and was able to better apply the water and nitrogen backward transfer technology. Meanwhile, with the help of M, with a leadership role in the circle of acquaintances, the remaining 15 cooperative and community members in this village with higher production motivation joined the cultivation process of technology farmers one after another. In this way, the scientist established a better association with that part of the technology farmers.

3.2.2 Collaboration with professional farmers

Firstly, to gain the trust of professional farmers, the helped the cooperative service functions, the scientists helped the cooperative to apply for the innovation station project in Hebei Province before conducting basic technical training and communication, and introducing a considerable amount of government investment. This action not only increased the operating capital reserve of the cooperative and expanded its service function and radiation range, but also increased the emotional dependence and degree of trust of professional farmers in STBs, effectively promoting the cooperation between scientists and professional farmers. Secondly, through experimental demonstration, technical training and onsite guidance, the whole process and all-round service supply of technology, information and resources has been realized. In this process, it developed and deepened smallholder knowledge, their willingness to adopt and adoption behavior of water and nitrogen setback technology. Finally, yield verification was conducted during the harvest season. It was found that the maize yield achieved by professional farmers reached 9.9 $t\cdot ha^{-1}$ for those who adopted the water and nitrogen backward transfer technology, compared to 6.0–7.5 $t\cdot ha^{-1}$ before adoption of this technology. This significantly increased yield increase built smallholder trust in STBs and water and nitrogen backward transfer technology, and gradually transform into an identity-based trust. At the same time, the reputation of STBs was further enhanced as a result, and the deepening intensity of smallholder trust motivated them to adopt other new technologies on their own, and the diffusion of new technologies became progressively less difficult.

3.2.3 Village extension of technology

Although the water and nitrogen backward transfer technology has been well promoted and applied among the professional farmers collaborating with STBs, other villagers still had some doubts and hesitations about the adoption of the new technology. Therefore, to achieve a wider range of technology diffusion and application in the second year, with the demonstration role and active promotion of the 16 professional farmers, smallholders perceive usefulness was improved through technical knowledge exchange, and perceived ease of use was improved and the perceived risk was reduced through observation of the planting effectiveness by the professional farmers, with the help of the acquaintance network and trust relationship between the professional farmers and other villagers. Through the one-to-many technology diffusion system, tree-shaped diffusion mode was formed to realize the diffusion and application of water and nitrogen backward transfer technology in the whole village.

In summary, a number (which in the process of diffusion and application of water and nitrogen backward transfer technology is 16) of professional farmers, have been trained through collaborative diffusion mode. To achieve better technology diffusion, tree-shaped diffusion mode has led to the adoption of green production technologies by smallholders in the whole village through shared learning. This level of technological innovation and diffusion better absorbs the advantages of FFS. From the perspective of human capital and organizational capital, this mode effectively solves the problems of insufficient high-quality human capital and low organizational effectiveness within the rural areas. Through higher degree of organization, professional farmers are used as the carrier to promote the establishment of trust among neighboring residents through 1-to-*N* service supply, forming a standardized agricultural production method and revitalizing the original rural basic resources. Although this mode has formed the organizational model of STBs combined with cooperatives and smallholders, it still faces the problem of resource depletion within the countryside and the power bottleneck of sustainability of farming system due to the influence of insufficient initial rural endowment, etc.

3.3 From point to county: a jump-start diffusion mode for green production technologies

The Jump-start diffusion mode introduces the same agricultural production technologies in different regions at the same time, with multiple sources of technology diffusion as the center of the circle, and simultaneous technology diffusion to surrounding farmers. This is the current mainstream agricultural technology diffusion mode. And the diffusion scope and diffusion speed of this mode are better than those of the collaborative and tree-shaped diffusion mode[37]. From the two aforementioned modes, it is clear that, relying solely on smallholder technology training, on-site observation and other forms can solve the problem of technology landing in the village domain, but it is difficult to achieve large-scale diffusion of technology[38]. Therefore, to solve the problem of insufficient initial impetus endogenous power for the development of primitive rural areas and to realize the diffusion of green production technologies in a wider range such as county areas, it is necessary to combine multiple forces to increase the breadth and permanence of technology diffusion[39]. Taking deep tillage technology in Hebei Province as an example, STBs have realized the popularization and application of the deep tillage technology from one demonstration to eight counties in Hebei Province by introducing government policy support on the basis of uniting cooperatives, professional farmers, smallholders and others.

3.3.1 Experimental demonstration and technical training

Theoretically, with the help of agricultural machinery, deep tillage technology can optimize soil structure and porosity, improve the root growth of wheat and maize, and increase the nutrient and water use efficiency[40]. Therefore, through the experimental verification of field trials, positive results of the deep tillage technology had been achieved. Unfortunately, since this technology large machinery to operate and smallholders in WZ village had only about 0.1 ha of land per household[41]. Under the traditional mode of the household contract responsibility system with remuneration linked to output in China, most smallholders had a strong sense of boundaries, and it is unrealistic to break the boundaries of each smallholder's land and conduct large-scale land transfer. The combining land for uniform practice (CLUP) was a solution to this problem, which is based on centralized and unified supply of social services without changing the ownership and management rights of smallholder land. This mode not only broke the bottleneck of smallholders do not understand the technology, reduce the risk of high cost in purchasing their own agricultural equipment, but also overcame the constraint to land transfer. However, the technology diffusion journey of the STB was not smooth absolutely. When they were ready to extend the technology to the neighboring villages, most of the smallholders believed that there were many reasons for the increase in grain production, such as the increase of fertilizer use, seasonal reasons and standardization of management practices, rather than brought about by a single deep tillage technology, which made it difficult to promote the technology. For example, Zhang et al.[16] showed that, integrated soil-crop system management (ISSM) can achieve high yields and efficiency through best crop management practices, and the percentage of smallholders willing to adopt ISSM was as high as 61% in the village where the STB was located, 39% in the temporary radiation village, but in the control village only 6% of smallholders were willing to adopt ISSM. Similarly, the deep tillage technology will result in a wheat yield increase through improved nutrient and water utilization, but still faces similar difficulties in scaling up outside the village area during the extension process.

3.3.2 Introduction of resources and technology extension

To solve the above problems of localized technology not being promoted outside the village area, STBs hope to use the power of the government to improve the power of the administration of technology itself, gain smallholder trust to a greater degree. To obtain government help, it is necessary to first gain the trust of the government. Therefore, the scientists gained the trust of government officials through field demonstrations of test results (e.g., changes in soil planning surface after deep tillage) and the comparisons of soil physical and chemical properties before and after technology adoption, explaining to government officials the operating principles of deep tillage technology and its benefits to agricultural production. Secondly, to gain the support of the government and the trust of smallholders. With the power of the Agricultural Bureau and the technicians in each township, STB held a county-wide technical training site meeting to enhance smallholder trust in the technology with the authority of government personnel and government activities. Thirdly, government subsidies are introduced to reduce the production costs of smallholders. Since the initial adoption of deep tillage technology would increase the agricultural production costs of smallholders, government department invested 1.6 million CNY as a special subsidy for the application of deep tillage technology. This measure greatly reduced the perceived risk and production costs of smallholders in adopting deep tillage technology, and increased their trust in and probability adoption of green production technologies. Ultimately, the technology was promoted to a larger area. Through experimental demonstrations, technical training, the proliferation of professional farmers, Quzhou achieved a total of 43 CLUPs in 13 villages in 2010 from the first CLUP in 2009. Over 3 years, all smallholders in eight counties in Hebei Province have adopted deep tillage technology. The original annual deep tillage was also replaced with deep tillage once every 2–3 years, which not only protected the arable land but also made Quzhou County an advanced county in grain production in China for the first time.

In addition, STBs have also actively introduced external resources by establishing small-scale fertilizer plants and joint product materialization with enterprises. Through the six unified production methods of unified purchase of agricultural materials, unified tillage, unified sowing, unified fertilization, unified pest control, and unified harvesting, STBs have realized system-wide and chain-wide technical support for professional farmers and smallholders, increased the trust and adoption of green production technologies by a wider range of smallholders. Through the promotion of agricultural technology extension centers and the marketing departments of the enterprises, the scope of technical services had also been expanded. This approach gives full draws on the advantages of bottom-up technological innovation. With the participation of multiple actors, smallholder trust in green production technologies had been reconstructed and strengthened, which stimulated their continuous adoption of green production technologies, and realized the green transformation and upgrading of food crops. At the same time, it draws on the strengths of ATESC, which drives the internal capital increase of agriculture through external resource input, amplifies the top-down diffusion effect, and realizes the standardization and organization of agricultural production.

4 IMPLICATIONS AND CONCLUSIONS

Socialized services are the bridge and link between green production technologies innovation and adoption by smallholders. We analyzed the role of socialized services in promoting the adoption of green production technologies by smallholders, using the STB model in WZ village, Quzhou County, Hebei Province, as an example. The main findings were: (1) the collaborative diffusion mode, tree-shaped diffusion mode and jump-start diffusion mode, are the main means which promote from the participatory approach technology innovation until to smallholder adoption of regional level; (2) the three diffusion modes combine and expand the advantages of existing internationally typical service organizations or models; and (3) no matter what kind of technology extension mode is used, it will promote the technology adoption behavior of smallholders by changing their trust.

Based on the above conclusions, the following policy recommendations were made: (1) strengthen the combination of top-down and bottom-up technology innovation and diffusion mode, using a bottom-up model to conduct adaptive technological innovation and top-down model to achieve a wider range of applications, the STB program provides a good real-world example; (2) establish an effective service communication platform and evaluation mechanism, so that efficiency of technological innovation and socialized services can be improved through timely communication and evaluation; and (3) strengthen the linkage mechanism between socialized service subjects and smallholders, as with various zero-distance services, such as demonstration and field guidance, the relationship between service organizations and smallholders is strengthened, the level of smallholder awareness and trust in green production technologies is improved, and the endogenous motivation of smallholders to learn and adopt new technologies independently is stimulated.

Compliance with ethics guidelines

Yajuan Li and Qianni Huang declare that they have no conflict of interest or financial conflicts to disclose. All applicable institutional and national guidelines for the care and use of animals were followed.

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