Exploring Farmers' Participation Mechanisms for Sustainable Farmland Development in the Yellow River Basin, China

Yanshu YIN

COMMUNAUTÉ FRANÇAISE DE BELGIQUE
UNIVERSITÉ DE LIÈGE – GEMBLOUX AGRO-BIO TECH

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Yanshu YIN

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Promoteur(s): Professor Thomas DOGOT
Co-Promoteur(s): Professor Changbin YIN
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Abstract

The food security has always been the focus of global attention. As an important material basis for human survival and development, cultivated land plays an important role in sustainable socio-economic development. About 70% of China's 120 million ha of arable land are mid to low-yield fields. On the one hand, it is the result of the insufficiency in farmland infrastructure and land fragmentation, which leads to inefficient agricultural production and has difficulty in response to natural disasters due to climate change. On the other hand, the application of chemical inputs is significantly higher than the level of developed countries. The excessive input utilization and the random disposal of agricultural waste have caused non-point source pollution, and the negative environmental benefits have become more and more serious. Therefore, China has an increasingly profound awareness of farmland systems to respond to climate change and protect the quality of farmland. In the context of the United Nations Sustainable Development Goals, China has formulated its latest farmland development plan, the integrated of "production - ecology - livelihood" sustainable farmland pilot demonstration is proposed. In other words, under the multiple goals of " ensuring food security, promoting eco-friendly and increasing farmers' income", the improvement of infrastructure and the transformation of production practices can be synergistically promoted.

With these objectives, China is faced with multiple challenges in promoting the process of farmland construction and management. The construction content of high-standard farmland takes insufficient consideration of farmland ecology, and the problems of high-standard farmland which has not matched with standardized and green production practices are highlighted. Moreover, Farmland development activities, which are led by the government entirely, put tremendous pressure on the central treasury, while the lack of participation of other stakeholders results in inefficient farmland development. There are contradictions in the construction of farmland such as the imbalance between governments' supply and farmers' demand, and low construction standards. In order to meet the needs of high-quality and sustainable agricultural, optimizing the mode of farmland development and improving its management mechanism are the major concerns of government management and academia.

The study is based on the perspective of agricultural economics research and aims to optimize the farmland development management system by incorporating farmer participation. three core issues were addressed: a) Chapter 4 quantifies the current three main farmland and farming systems through life cycle assessment, life cycle cost, cost-benefit analysis and net ecosystem economic benefit. The results

demonstrate that sustainable farmland—efficiency-driven farming mode not only reduces resource inputs but also enhances productivity. Moreover, it positively contributes to regulating nitrogen losses, nitrogen and carbon footprint and greenhouse gas (GHG) emission. Furthermore, this mode represents an optimal economic approach, leading to a total decrease in CO_2 emissions of 90 million t, an increase in net ecosystem economic benefits of 101 billion Chinese Yuan, and a rise in grain production of 1,278 t in the North Plain of China (1.22 million ha). This study emphasizes the significance of enhancing precise cropping management practices and advanced farmland infrastructure to promote development of sustainable farming systems. Furthermore, optimization plans for different systems are proposed, providing an objective benefit expectation to encourage farmer participation in sustainable farmland development (SFD). b) Chapter 5 aims to analyze farmers' participation in SFD by employing the extended theory of planned behavior (ETPB). The results demonstrated that farmers' intention was impacted by perceived behavior control (PBC), subjective norms (SN), and attitude (AT) to SFD. Agricultural production conditions (APCs) negatively moderated TPB construct, while policy evaluation (PE) positively moderated. On this basis, a series of policy measures to stimulate farmers' participation enthusiasm are summarized, providing solutions to ensure the stability and effectiveness of farmers' participation. c) Chapter 6 analyzed farmer preferences for participating in SFD through a discrete choice experiment. It also evaluated farmers' willingness to pay for different SFD schemes. The findings indicate that farmers prefer constructing mechanized production roads (MPR), leveling farmland and transforming the contiguous farmland (LF and CF), integrated irrigation and fertilizer facilities (IIFF), and moderate improvement in ecological protection facilities. On the basis of the heterogeneity of the farmer preferences, they can be classified as benefits-driven and ecology-driven. Farmers' willingness to pay for MPR, LF and CF, ED, IIFF, and moderate improvement in ecological facilities has reached 50–80% of construction costs, essentially bridging the investment gap under the SF standards set by the central government. This study establishes a series of policy tools for farmers' participation mechanism in farmland development, offering valuable insights into institutional reforms in land consolidation projects.

In general, the study, titled 'Exploring Farmers' Participation Mechanisms for Sustainable Farmland Development in the Yellow River Basin, China' explores the comprehensive benefits and optimization plans of different standard farmlands and constructs a sustainable farmland participation mechanism of 'government-led, farmer participation.' The research results and conclusions provide effective assurance for improving farmland development efficiency and achieving development goals. The related policy implications offer valuable references and insights for countries and regions at a similar historical development stage in farmland development.

Keywords: sustainable farmland, sustainable farmland development, environment-economic benefits, farmers' participation, farmers' preferences, willingness to payment, optimization pathway

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Résumé

La sécurité alimentaire est depuis toujours un sujet d’intérêt mondial. En tant que base matérielle essentielle pour la survie et le développement humain, les terres cultivées jouent un rôle crucial dans le développement socio-économique durable. Environ 70 % des 120 millions d’hectares de terres arables en Chine sont des terres de rendement moyen à faible. D'une part, cette situation découle de l'insuffisance des infrastructures agricoles et de la fragmentation des terres, ce qui conduit à une production agricole inefficace et limite la résilience face aux catastrophes naturelles liées aux changements climatiques. D'autre part, le niveau d’application des intrants chimiques en Chine est considérablement supérieur à celui des pays développés. La surutilisation des intrants et la gestion inadéquate des déchets agricoles ont engendré une pollution diffuse, aggravant les impacts environnementaux négatifs. Ainsi, la Chine prend de plus en plus conscience de la nécessité de développer des systèmes agricoles durables pour répondre au changement climatique et protéger la qualité des terres agricoles. Dans le cadre des Objectifs de développement durable des Nations Unies, la Chine a formulé son dernier plan de développement agricole, proposant une démonstration pilote d’agriculture durable intégrant « production – écologie – moyens de subsistance ». En d’autres termes, la modernisation des infrastructures agricoles et la transformation des pratiques de production peuvent être promues de manière synergique pour atteindre les objectifs multiples de «sécurité alimentaire, développement écologique, et augmentation des revenus des agriculteurs».

Avec ces objectifs, la Chine fait face à de nombreux défis pour promouvoir le processus de développement et de gestion des terres agricoles. Les projets de développement de terres agricoles à haut standard prennent insuffisamment en compte l’écologie des terres, et des incohérences se manifestent lorsqu'ils ne sont pas associés à des pratiques de production normalisées et respectueuses de l’environnement. De plus, les activités de développement des terres agricoles, entièrement dirigées par le gouvernement, exercent une pression énorme sur le trésor public, tandis que le manque de participation des autres parties prenantes se traduit par un développement agricole inefficace. Des contradictions persistent dans mise en oeuvre du développement des terres agricoles, telles que le déséquilibre entre l’offre des gouvernements et la demande des agriculteurs, et des normes d’améliorations foncières insuffisantes. Afin de répondre aux besoins d’une agriculture de qualité et durable, l'optimisation du développement des terres agricoles et l’amélioration de son mécanisme de gestion sont au cœur des préoccupations des gestionnaires publics et des chercheurs.

Cette étude adopte une perspective de recherche en économie agricole et vise à optimiser le système de gestion du développement des terres agricoles en intégrant la

participation des agriculteurs. Trois enjeux principaux ont été traités. Le premier évalue, dans le chapitre 4,les trois principaux systèmes agricoles actuels selon une triple approche quantitative mobilisant l'analyse du cycle de vie, l'analyse coût-bénéfice et l'analyse des bénéfices économiques nets des écosystèmes. Les résultats montrent que le modèle de gestion durable – axé sur l'efficacité – réduit non seulement les intrants mais augmente aussi la productivité. De plus, il contribue positivement à la réduction des pertes d'azote, de l'empreinte carbone et des émissions de gaz à effet de serre (. Par ailleurs, ce modèle présente une approche économique optimale, aboutissant à une diminution totale des émissions de CO_2 de 90 millions de tonnes, à une augmentation des bénéfices économiques nets de l'écosystème de 101 milliards de yuans et à une hausse de la production céréalière de 1 278 tonnes dans la plaine du Nord de la Chine dont la surface agricole s'étend sur1,22 million d'hectares. Cette étude souligne l'importance que revêtent l'amélioration de la gestion des cultures et les infrastructures agricoles pour favoriser le développement de systèmes agricoles durables. En outre, des plans d'optimisation pour différents systèmes sont proposés afin d'objectiver les perspectives de bénéfices incitant à la participation des agriculteurs au développement durable des terres agricoles. Le chapitre 5 analyse la participation des agriculteurs au développement durable des terres agricoles en appliquant la théorie élargie du comportement planifié. Les résultats relatifs à ce deuxième enjeu ont démontré que l'intention des agriculteurs est influencée par le contrôle comportemental perçu, les normes subjectives et l'attitude envers le développement durable des terres agricoles. Les conditions de production agricole influencent négativement les facteurs explicatifs de la théorie du comportement planifié, tandis que l'évaluation des politiques les influence positivement. Sur cette base, une série de mesures politiques visant à stimuler l'enthousiasme des agriculteurs sont élaborées pour garantir la stabilité et l'efficacité de leur participation. Le troisième enjeu est développé dans le chapitre 6 qui est consacré à l'analyse des préférences des agriculteurs quant à leur participation au au développement foncier agricole à travers une expérience de choix discret et à l'évaluation deleur consentement à payer pour différents projets d'améliorations foncières. Les résultats indiquent que les agriculteurs préfèrent la construction de voiries agricoles, le nivellement et le remembrement des parcelles, ainsi que l'installation d'infrastructures d'irrigation et de fertilisation intégrées et une amélioration modérée des infrastructures de protection écologique. En se basant sur l'hétérogénéité des préférences des agriculteurs, ils peuvent être classés en deux groupes aux comportements distincts, les premiers étant davantage axés sur l'amélioration des bénéfices, les autres sur l'écologie. Le consentement à payer des agriculteurs pour les différents projets d'améliorations foncières cités plus haut atteint 50 à 80 % de leurs coûts de construction; ce qui permettrait de réduire l'effort d'investissement pesant sur les finances publiques.

Enfin, en établissant une série d'outils politiques favorisant les mécanismes de participation des agriculteurs au développement des terres agricoles, cette étude offre des perspectives prometteuses pour des réformes institutionnelles portant sur les projets d'améliorations foncières durables. De manière plus générale, ces implications politiques offrent des références et des perspectives utiles pour les pays et régions à un stade de développement similaire dans le domaine du développement foncier agricole.

Mots-clés: terres agricoles durables, développement durable des terres agricoles, avantages environnementaux et économiques, participation des agriculteurs, préférences des agriculteurs, volonté de payer, voie d'optimisation

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Yanshu YIN

19/09/2024 in Gembloux, Belgium

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List of acronyms

SF: Sustainable farmland
SFD: Sustainable farmland development
HSF: High-standard farmland
HFD: High-standard farmland development
CF: Conventional farmland
CF-SFM: Conventional farmland—smallholder farming mode
HSF-IFM: High-standard farmland—intensive farming mode
SF-ITFM: Sustainable farmland—intelligent farming mode
NABE: New agricultural business entity
LCA: Life cycle assessment
LCC: Life cycle cost
CBA: Cost–benefit analysis
NEEB: Net ecosystem economic benefit
CNY: Chinese Yuan
TPB: Theory of planned behavior
ETPB: Extended theory of planned behavior
SEM: Structural equation model
EFAPP: Environmental-friendly agricultural production practices
AT: Attitude
SN: Subjective norms
PBC: Perceived behavior control
INT: Intention
PE: Policy evaluation
APCs: Agricultural production conditions
CLQ: Cultivated-land-quality
FIC: Farmland infrastructure conditions
NLDCP: National land development and consolidation plan
OSPCHF: Opinions on solidly promoting the construction of high-standard Farmland
NHSCP: The national high-standard farmland development plan
CE: Choice Experiments
LF or CF: Level Farmland or Construct Contiguous Farmland
LF and CF: Level Farmland and Construct Contiguous Farmland
MPR: Mechanized Production Road
ED: Ecological Ditches
IIFF: Integrated Irrigation and Fertilizer Facilities

Chapter 1

Background and key issues

1. The necessity of farmland development in China

1.1Improving the quality of cultivated land is the basis for ensuring national food security

1) The insufficient fertility of farmland hinders grain production capacity and sustainable development of agricultural.

In 2019, the Ministry of Agriculture and Rural Affairs (MARA) conducted a national survey and assessment of farmland quality grades and published a bulletin in accordance with the "Methods for Survey, Monitoring and Evaluation of Farmland Quality" (Ministry of Agriculture Order No. 2, 2016) and the national standard "Classification of Farmland Quality" (GB/T 33469-2016). This standard evaluates the capability of cultivated land to ensure continuous agricultural production and quality safety from the perspective of agricultural production, focusing on soil fertility, soil health, and infrastructure. It categorizes cultivated land quality into ten levels, with Grade 1 being the highest quality and Grade 10 being the lowest. The total area surveyed and assessed for farmland quality grades in the country was 135 million ha, with an average grade of 4.76, an increase of 0.35 grades compared to 2014. The area of farmland graded as Class 1 to 3 was 42 million ha, accounting for 31.24% of the total farmland area. The area graded as Class 4 to 6 was 63 million ha, accounting for 46.81% of the total farmland area. The area graded as Class 7 to 10 was 29.6 million ha, accounting for 21.95% of the total farmland. This part of the farmland has poor basic fertility, prominent production obstacles, and requires continuous farmland infrastructure construction and quality improvement. The main reasons are that improper use and management of farmland, excessive use of agricultural fertilizers and pesticides, and increasing soil acidification have exacerbated farmland degradation. Farmland is facing a situation of quality decline.

2) The poor irrigation and drainage facilities in farmland and the fragmentation of cultivated land severely constrain farmland production capacity.

Currently, due to the scarcity of water resources, nearly half of the cultivated land lacks irrigation conditions or basic drainage facilities. Issues such as low standards and insufficient irrigation facilities, and declining benefits still persist. According to data from the "Overall Plan for High-standard Farmland development," 40% to 50% of the irrigation and drainage facilities nationwide are either low in standard or aged and poorly maintained. Most irrigation and drainage pumping stations operate inefficiently, and the "last mile" problem in farmland water conservancy remains prominent. Severe droughts or heavy rainfall often result in widespread damage to farmland, severely constraining the release of farmland production capacity. At the same time, China's cultivated land is highly fragmented, with 0.106 ha average plot sizes per household[1]. The reason for this situation is the land tenure and property rights system reforms conducted in the late 1980s. land fragmentation finds its origin at the

[1] https://www.stats.gov.cn/sj/tjgb/nypcgb/qgnypcgb/202302/t20230206_1902090.html

end of the 1970s and beginning of the 1980s with the introduction of the household responsibility system. Before the household responsibility system, rural land was owned and managed collectively. Land was only divided into plots to match the soil type, irrigation and drainage condition, and for the convenience of management. Under the household responsibility system, land use rights for arable land were generally assigned to individual households. Three main types of land distribution under the household responsibility system was distinguished (Liu et al., 2000; Kung et al., 2000). The first is that all land was simply assigned to households based upon the family size. A nationwide survey of 300 villages conducted by China's State Council in 1988 confirmed this. Nearly 70% of the villages used this land assignment rule (State Council and People's Republic of China, 1992). The second is that food ration farmland was equally distributed per person, and responsibility farmland was allocated according to the number of labourers in a household[2]. The third is that all land was allocated according to the number of labourers. As a result, land fragmentation became more pronounced. It greatly hinders the process of agricultural mechanization, large-scale operations, and modernization in China.

3) The problem of farmland environmental pollution is prominent.

The rapid development of agricultural production has led to excessive greenhouse gas emissions and increasingly severe non-point source pollution (Yang et al., 2022). According to data from the 2018 National Greenhouse Gas Inventory Report, China's agricultural carbon emissions amounted to 802 million t of CO_2 equivalent, accounting for 6.85% of China's total carbon emissions, such as CH_4 and N_2O, making up 85.67%. The high level of greenhouse gas emissions is closely linked to the significant increase in agricultural production. On the one hand, increasing crop yields is required, which often involves the use of more agricultural chemicals like fertilizers, especially nitrogen fertilizer (Li et al., 2011). As the largest consumers of nitrogen fertilizer, China applied 21.573 million t of nitrogen fertilizer in 2019, three times the global average. Once applied to farmland, approximately 20% nitrogen is lost to the atmosphere through denitrification and nitrogen volatilization, leading to a continual rise in N_2O emissions from farmland (Sun et al., 2019). On the other hand, intensive and monoculture farming systems not only reduce crops' carbon sequestration capacity but also cause a sharp decline in the organic matter and humus content of the soil, leading to soil degradation. In some regions, excessive use of plastic film has led to a "white pollution" in farmland. Therefore, it is imperative to strengthen the comprehensive remediation of polluted farmland and improve soil environment.

1.2Farmland development is the national strategy

Food security is the foundation of economic and social development. The central government has explicitly required ensuring basic self-sufficiency in grain and absolute food security. The 19th National Congress report proposed the

[2] *food ration farmland* means the farmland assigned by the village to a household to pay agricultural tax and state quota. The remaining land assigned to a household is called *responsibility farmland*.

implementation of the rural revitalization strategy, emphasizing the need to ensure national food security. According to the latest population statistics in China, the total population has exceeded 1.4 billion. It is also predicted that the population will continue to grow until 2031. The increase in population and the improvement of people's living standards have led to rigid growth in food consumption. Ensuring national food security is primarily dependent on guaranteeing the productive capacity of farmland, with the construction of high-standard farmland and improvement of farmers' production and management skills being an important strategy to improve such capacity and ensure food security. The construction of high-standard farmland has been highly valued by the Party Central Committee and the State Council. Since its first proposal in the Government Work Report in 2008, the construction of high-standard farmland has been included in the national "Twelfth Five-Year Plan." The Central Document No. 1 in 2009 and 2010 also put forward relevant requirements for the construction of high-standard farmland. In 2012, the "National Farmland Development Plan (2011-2015)" clearly stated the goal of constructing about 26.7 million ha of high-standard farmland for drought and flood resistance during the "Twelfth Five-Year Plan" period. The promulgation and implementation of the "Construction Standards for High-Standard Farmland" (NY/T 2148-2012) and the "Construction Standards for High-Standard Basic Farmland" (TD/T1033-2012) provided scientific basis for the construction of high-standard farmland. In 2014, the "General Principles for High-Standard Farmland Development" (GB/T30600-2014) were approved and published, making the construction of high-standard farmland an important means to stabilize agricultural production and ensure national food security. In 2017, the "National Farmland Development Plan (2016-2020)" proposed the goal of ensuring the completion of 26.7 million ha and striving to build 40 million ha of concentrated, contiguous, drought and flood-resistant, stable and high-yielding, and eco-friendly high-standard farmland during the "Thirteenth Five-Year Plan" period. By 2020, China had completed 53 million ha of high-standard farmland. In 2021, the new round of "National High-Standard Farmland Development Plan (2021-2030)" aimed to enhance the capability of sustainable agricultural development by raising construction standards, strengthening utilization evaluation, and integrating green concepts. Therefore, the large-scale construction of concentrated, contiguous, drought and flood-resistant, water-saving, efficient, and eco-friendly high-standard farmland has become an important strategic initiative in China.

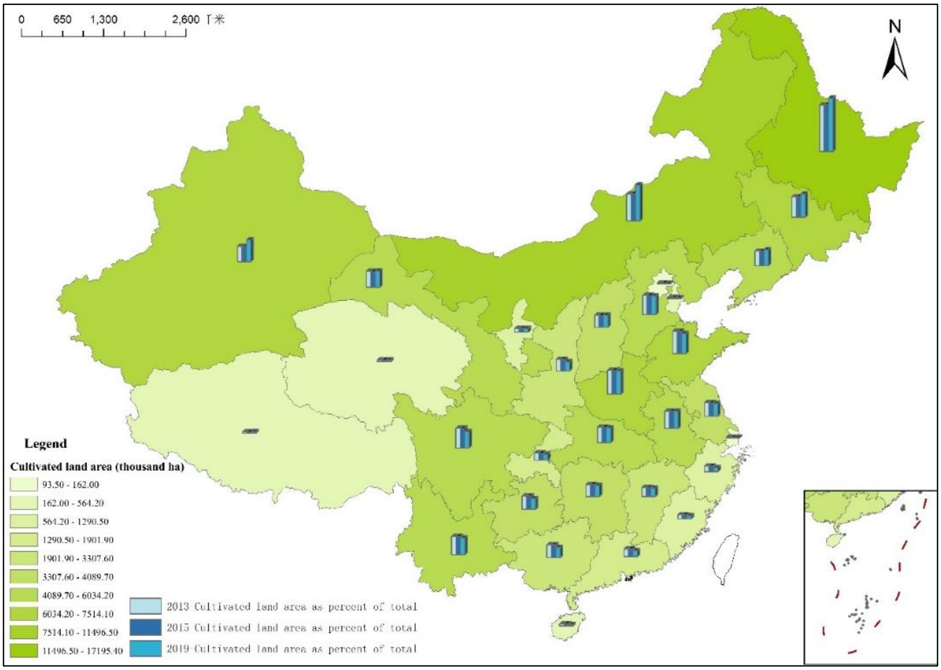

Figure 1- 1 Distribution of cultivated land area in China

2. Demand for farmland development in the Yellow River Basin (YRB)

The Yellow River Basin was selected as the study area is that it is a crucial grain-producing region in China with relatively poor farmland conditions that urgently need improvement. Additionally, it has been designated as one of the initial areas for implementing green farmland development and high-quality agricultural development demonstration projects. The study aims to provide preliminary strategic research for the implementation of the ADB-funded project: Green Farmland Development and High-Quality Agricultural Development in the Yellow River Basin, which will be implemented in the region in 2023.

2.1The current state and problems of farmland

2.1.1 Infrastructure needs to be improved

In some irrigation areas in the YRB, the problems of aging and disrepair, low construction standards, and poor supporting facilities in agricultural water conservancy infrastructure are prominent. The irrigation and drainage facilities in fields are incomplete, the channels are not smooth, and serious issues such as waterlogging, drought, water diversion, and excessive fertilizer runoff are common. Due to insufficient investment, the construction standards of irrigation areas are low, emphasizing quantity over quality, resulting in short service life and inadequate flood control and disaster resistance capabilities, thus affecting the effectiveness of agricultural production. Field surveys show that 44% of farmers believe that the current agricultural infrastructure is aging and in disrepair. 38% of farmers are not satisfied with the current field leveling conditions; 53% of farmers are dissatisfied with the current irrigation and drainage facilities; 43% of farmers are dissatisfied with production roads; and 48% of farmers are dissatisfied with agricultural waste collection pits. According to interviews conducted with agricultural management departments, new agricultural business entities (NABE), and farmers, achieving sustainable farmland standards requires an investment of 67,500-90,000 CNY per ha, which is still a significant funding gap compared to the current government-led investment of 22,500 CNY per ha in farmland development ***(Data source in the text and figures of this section are all from field survey in the YRB, 2022)***.

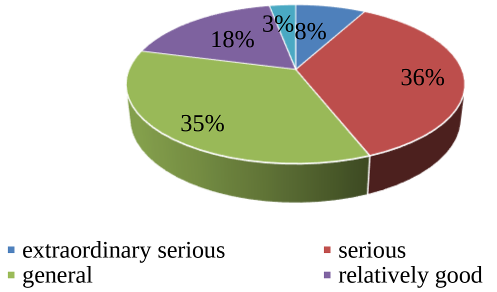

Figure 1- 2 Degree of aging and disrepair of infrastructure

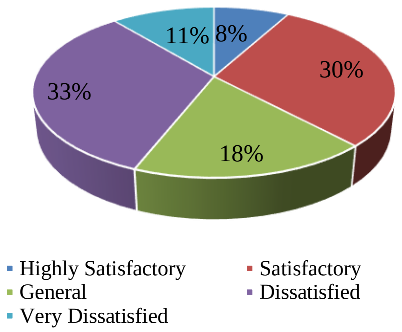

Figure 1- 3 Satisfactory land leveling

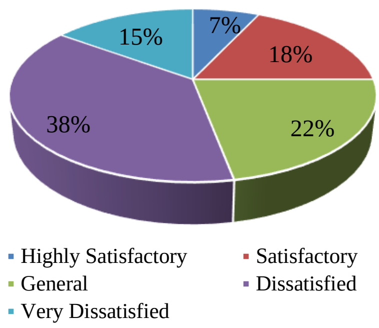

Figure 1- 4 Satisfactory drainage and irrigation facilities

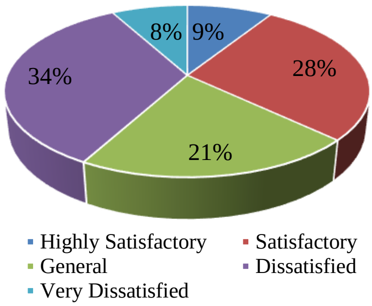

Figure 1- 5 Production road satisfaction

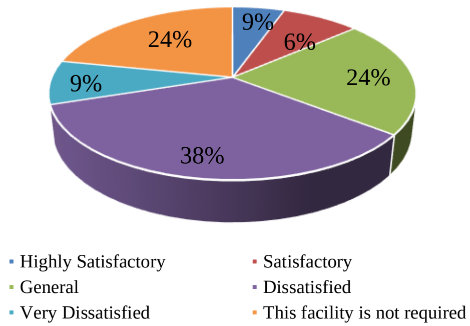

Figure 1- 6 Satisfactory condition of the agricultural waste collection pond

2.1.2 Controlling non-point source pollution is urgent

In recent years, the level of agricultural intensification in the YRB has increased. However, the agricultural planting modes still rely heavily on traditional methods and the use of large amounts of chemical fertilizers. In 2022, the number of chemical fertilizers used in the YRB accounted for about 35% of the national total, placing certain pressure on the soil and water. On the other hand, provinces (autonomous regions) such as Gansu, Qinghai, and Ningxia have a large consumption of polyethylene materials such as plastic film and greenhouse supplies, with low rates of recycling. This has led to "white" pollution in farmland, posing challenges to the prevention and control of agricultural non-point source pollution.

2.1.3 The quality of farmland needs improvement

According to the "2019 National Bulletin on the Quality of Cultivated Land," the main quality grades in the YRB are primarily grades 4 to 6, with a large proportion of medium-quality cultivated land. However, in some areas, the land fertility is declining, with shallow soil, low yields, and relatively poor efficiency, indicating that there is room for improvement in the land productivity. Particularly, in some upstream areas of the YRB, the land conditions are poor, with nutrient-poor soil and mainly medium to low-quality cultivated land. The organic matter in the soil is low, and there are serious problems with salinization and desertification, evident land degradation, poor water and fertilizer retention capabilities, and low water and fertilizer utilization rates. In the middle and lower reaches, the soil degradation and shallow soil layer problems are increasing year by year. Some areas suffer from soil salinization, soil compaction, thickening of the plow layer, increased bulk density, and decreased water and fertilizer retention capabilities.

According to field surveys conducted by research team in 2021, 94% of respondents have implemented measures related to improving the farmland quality and enhancing the farmland ecology. However, the techniques adoption is relatively single-minded, involving the application of farmyard manure, straw returning, and crop rotation, accounting for 48.6%, 44%, and 40.1% respectively. 65% of farmers are dissatisfied with the current cultivated land quality and ecological condition in the

YRB. ***(Data source in the text and figure 1-7 of this paragraph are from field survey in the YRB, 2022)***

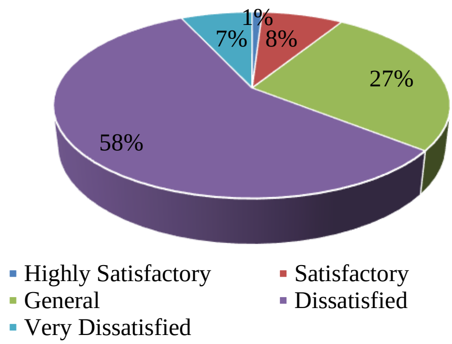

Figure 1- 7 Farmers' satisfaction with cultivated land quality and ecological

2.1.4 Water resource utilization efficiency urgently needs to be improved

The Yellow River's water resources account for only 2% of the nation's total, it supports 12% of the population and irrigates 15% of the cultivated land in the country, with a per capita availability only 27% of the national average (the amount of freshwater resources available to each person). The YRB is categorized as a water-deficient region with abundant resources. In 2018, the water consumption reached 127.1 billion cubic meters, with a high-water development and utilization rate of 80%, far exceeding the internationally recognized warning line of 40%. Agricultural water consumption accounted for 815.9 billion cubic meters, representing 64.19% of the total water consumption, exceeding the national average. Particularly, the effective irrigation water use coefficients in Shanxi, Sichuan, Qinghai, Inner Mongolia, and Ningxia were only 0.543, 0.473, 0.499, 0.543, and 0.535 respectively, lower than the national average of 0.5543 and much lower than the 0.7 level of developed countries. In addition, in the upstream areas of the Yellow River, there are widespread practices of extensive water use and flood irrigation, resulting in large agricultural water consumption and low agricultural water use efficiency.

2.2 Sustainable farmland development (SFD) and its institutional requirements

The Chinese government has conducted a series of farmland development activities. After 1988, China began to explore the path and modes of transforming mid to low yield fields and developing high-standard farmland. Since 2011, the policy of high-standard farmland development has entered the stage of standardized implementation. This is an innovative system which focuses on upgrading agricultural production conditions through engineering measures. The development of high-standard farmland in China as an innovative system has resulted in average cost savings of about CNY 7,500 per ha and increased average grain production by 10-20% compared to ordinary farmland[3]. In the "High-standard Farmland Development Plan (2021-2030)", it is proposed to construct 72 million ha and upgrade 7 million ha of high-standard farmland by 2025, so as to ensure a stable grain production capacity of over 0.55 billion tons. Meanwhile, to develop the integrated of "production - ecology - livelihood" green farmland pilot demonstration is proposed. In other words, under the multiple goals of "ensuring food security, promoting eco-friendly agriculture and increasing farmers' income", the improvement of infrastructure and the transformation of production practices can be synergistically promoted. By 2035, the SFD mode will be popularized, which forms a higher level, more efficient and sustainable guarantee foundation for food security. In particular, the initiation of Green Farmland Development and High-quality Agricultural Development Projects in the YRB, provide new opportunities and challenges for SFD in the region.

With these objectives, multiple challenges are faced with in promoting the farmland development and management. China has built 67 million ha of high-standard farmland by 2022, with a total investment of over 100 billion CNY[4]. Farmland development activities, which are led by the government entirely, put tremendous pressure on the central treasury, while the lack of participation of other stakeholders results in inefficient farmland development. Moreover, the investment of 22.5 thousand CNY/ha is far from meeting the requirement of regional agricultural development. There are dilemmas where the infrastructure contributions by the government are inconsistent with the needs of farmers, and the poor effectiveness of single engineering measures and low construction investment standards. Furthermore, the current construction content takes insufficient consideration of farmland ecology, and the problems of high-standard farmland which has not matched with standardized and green production practices are highlighted. In order to meet the needs of high-quality agricultural development, optimizing the mode of farmland development and improving its management mechanism are the major concerns of government management and academia.

The current farmland system has several modes as the construction objective continues to be optimized, which is reflected in the diversity of infrastructure standards and production practices. SFD modes need to be identified. Farmland system improvement involves various aspects such as resource conservation, environmentally friendly management, and efficiency improvement. So, the evaluation system boundary should include both the input in the construction stage and the utilization stage of farmland, and a multi-indicator system including environmental and economic aspects should be constructed to evaluate the multi-objective effects of different farmlands. Quantitative evaluation of the multi-objective effects of different farmland systems can help to adjust construction activities and framework of SFD. In particular, it is important to evaluate the contribution of farmland systems to achieve the "double carbon" target by 2060 in China **(Research root 1)**. A management institution is a crucial assurance for conducting farmland development, with developed countries adopting modes wherein stakeholders

[3] China High-Standard Farmland Construction Plan (2021-2030) (ndrc.gov.cn)

[4] China Government Network (www.gov.cn)

collaboratively participate in formulating construction schemes and sharing costs (Jiang et al., 2022; Krupowicz et al., 2020). By contrast, China predominantly relies on government leadership, using a "top-down" management mode. Changing the current "high administrative leading, low stakeholders' participation" farmland development mode by guiding stakeholder involvement is a crucial pathway to enhancing the standard and efficiency of farmland development. Agricultural producers, as the practitioners of farmland utilization, should play an important role in farmland development. Currently, smallholder farmers account for over 98% of the main participants in China's farmland development, and 70% of cultivated land is still managed by smallholder farmers. Therefore, understanding farmers' attitudes and revealing their behavioral mechanisms can aid in policy innovation and practical guidance for land use issues, which is significant for ensuring the long-term development of farmland development **(Research Root 2)**. On this basis, establishing a mechanism for farmer participation requires detailing specific plans for their involvement, including the plan design, participation pathways, modes, and standards for construction. This approach aims to protect farmers' rights while creating a construction mode where responsibilities are shared between the government and farmers. It is crucial to avoid mismatches between infrastructure construction and actual needs by recognizing regional and farmer demand differences. By clarifying farmers' preferences, we can understand the current state and needs of farmland development, measure farmers' willingness to pay, and provide precise references for the innovation of SFD management mechanisms and cost-sharing **(Research Root 3).** Overall, focusing on " *Exploring Farmers' Participation Mechanisms for Sustainable Farmland Development in the Yellow River Basin, China*" exploring the comprehensive benefits and development optimization plans of different standards of farmland will help farmers adjust their farmland management methods. This is significant for advancing agricultural modernization. In terms of agricultural management innovation, defining the pathways, plans, and standards for farmer participation in SFD not only helps provide research and practical references for building multi-stakeholder participation mechanisms but also offers a long-term development pathway for the sustainable transformation of agriculture.

3. Literature review

3.1 Related to Farmland Development

The application and interpretation of land consolidation are diverse (Asiama et al., 2019; Jacoby, 1959; Mihara, 1996; Niroula and Thapa, 2005; Ravallion and Dominique, 2006; Xia et al., 2018). People naturally tend to interpret land consolidation in ways that align with their own countries' practices (Hartvigsen, 2015). For instance, Bronstert et al. (1995), drawing from the German experience, describe land consolidation as involving various redevelopment and structural measures: the rearrangement or consolidation of fragmented plots, the removal of terraces and embankments, the construction of rural roads, the restructuring of local streams, and soil improvement. Similarly, the Food and Agriculture Organization of the United Nations (FAO) explains land consolidation based on the European experience (Veršinskas et al., 2020, pp. 3). Land consolidation involves the reorganization and optimization of land resources, serving as a foundation for alleviating conflicts between humans and land and achieving sustainable social, economic, resource, and ecological development. Janus demonstrated the long-lasting effect of farmland merging, which is still evident even 40 years after the completion of a land consolidation project (Janus and Markuszewska, 2019). In Europe, land consolidation has undergone various stages of development. Early efforts focused primarily on improving arable land conditions through activities such as plot merging and ownership adjustments, employing relatively uniform methods. In the 1970s, with the emergence of ecological issues such as land degradation, environmental pollution, and landscape damage, developed countries like the Netherlands and Germany incorporated landscape and ecological protection into their land consolidation goals. They developed more scientific understandings, concepts, and management methods (Vitikainen A, 2014). For instance, the Dutch "Land Consolidation Act" mandates necessary measures to protect land landscapes. German land consolidation places significant emphasis on protecting landscape ecology, including environmental and nature protection projects within land consolidation efforts. It aims to align land consolidation with the natural ecological environment of the area, preventing lasting changes and damage to landscapes. Germany stresses the protection and development of the ecological environment and land culture during land consolidation, ensuring alignment with regional ecological balance and broader national development plans, reflecting the development concepts of ecology, coordination, development, and sharing (Hongling Ye, 2016). Currently, land consolidation is quite advanced, with research primarily focusing on how it promotes regional agricultural development, benefits evaluation, landscape ecology, and case studies from specific areas (Jaroslaw Janus et al., 2017; Reinfried Mansberger et al., 2017). Studies by Lerman et al. show that land consolidation projects effectively increase the arable land area available to farmers, significantly impacting rural economic development and individual farmer incomes. Research on the social, economic, and environmental benefits of land consolidation reveals that it is a powerful measure for sustainable development in rural areas, particularly in remote and impoverished regions. Land consolidation can enlarge plots for easier mechanization and improve the quality of cultivated land. Especially in a situation where there is a serious outflow of young labor (Huang et al., 2023), we cannot ignore the importance of agricultural mechanization.

Since the founding of the people's Republic of China in 1949, farmland development and agricultural development have been in line with economic development. Farmland development has experienced the period of rapidly expanding land (1949-1987), the period of farmland development dominated by the transformation of low and middle-yielding fields (1988-2003), the period of farmland improvement and ecological protection construction jointly developed (2004-2017), and the new period of farmland development integrated with "quantity, quality and ecology" (2018-present). The year of 2004 was the point of "ecological" transformation of farmland development, which divided China farmland development into different features, including land expansion mainly by land reclamation, the improvement of land productivity mainly by low and middle-yielding fields, strict control of land reclamation, and farmland protection of "quantity, quality and ecology". Research on farmland development mostly concentrate on basic theories, technical methods, models, and planning. Currently, research is focusing on the challenges faced by the construction of high-standard farmland and existing work foundation, proposing countermeasures and suggestions on formulating implementation plans, improving work mechanisms, innovating fund management, and perfecting systems (Liu, 2015; Liu et al., 2014; Liu and Zhao, 2017) In addition, the focus of high-standard farmland development are not clear, and there are problems such as fragmented fields, complex farmland ownership, mismatch between capital investment and natural conditions of farmland, and scattered capital investment. The key to solving the problem is to further improve the mechanism and system, increase the overall coordination of agricultural funds at the national level, and combine it with the contract of land transfer (Li et al., 2018; Li et al., 2020). The current situation and achievements of farmland development in China have been elaborated in detail, pointing out various constraining factors in current development (Feng, 2016). Previous studies have suggested that effective implementation of farmland development projects can expand rural employment, drive diverse industries, and provide a foundation for rural development (Kunqiu and Building, 2020; Long et al., 2019). In the study of the timeline of farmland development, factor combination method and ideal solution approach have been applied to construct models, theoretically dividing the timeline and mode of high-standard farmland development in typical hilly areas (Li, L. et al., 2020; Song et al., 2017) By integrating Analytic Hierarchy Process (AHP) with SWOT analysis, an AHP-SWOT mode is established to comprehensively analyze the current development status of high-standard farmland development from four aspects: strengths, weaknesses, opportunities, and threats. Finally, by comparing the weights, the priority development sequence of each aspect is determined, providing theoretical guidance for the construction and development of high-standard farmland and development modes (Xue, 2018).

Focus of research is influenced by the changes of national top-level design. During the "Tenth Five-Year Plan" period, the country had new demands for the quality of farmland development. In the "Eleventh Five-Year Plan" period, most scholars focused on comprehensive evaluation and the integration of multiple industries. During the "Twelfth Five-Year Plan" period, landscape construction became a new aspect of academic research, being considered as the focus of future farmland development (Jiang et al., 2019; Liu et al., 2012; Liu et al., 2016). Many studies have emphasized the discussion on how to protect biodiversity during the farmland development process, considering the protection of ecological diversity as a necessary condition for human-land coordination (Shi et al., 2021; Tang et al., 2019). Besides improving land conditions, scholars have also started various types of land suitability research: using ArcGIS method to study the soil texture of the Sandu Bay Water Economic Zone in Laos, planning reasonable areas suitable for agricultural and forestry land (Fu et al., 2018; Liping et al., 2018).

In summary, aforementioned countries have different phased goals for farmland development, and the heterogeneity of farmland stage issues leads to different focuses on construction content. However, they all evolve from a single goal to a coordinated development of multiple elements, ultimately pursuing the harmonious unity of agricultural development and ecological environment.

3.2Evaluation on farmland construction and utilization

1）International Evaluation Research on Farmland development

Since the 1990s, scholars have begun to study the performance levels of public sectors that conduct land consolidation projects. These mainly reflecting the performance between non-profit organizations and profit organizations' public cooperation. Scholars have studied and discussed the connotation definition of performance evaluation in the public sector, construction of evaluation index system, evaluation methods, evaluation purposes, and effects. With the popularization of the concept of performance evaluation in relevant organizations and stakeholders, the construction of performance evaluation indicators has gradually received attention.

ISia (1998) mainly evaluated the performance level of economic benefits brought by farmland development activities. The specific economic benefits of the project were assessed by comparing indicators such as mechanization and transportation costs before and after the implementation of farmland development activities. As the evaluation system matures and improves, the average transportation cost of farmland production is also included in the scope of economic benefits consideration. The study believes that the distance between plots can reflect the savings in agricultural transportation time brought by the improvement of the project area's road network. The smoothness and straightness of farmland roads are important factors affecting transportation time (Dalba-norris et al., 2012).

When studied the evaluation criteria of farmland development projects, he regarded the size, shape, location advantages, and economic benefits of plots as the factors. Based on the specific situation before and after the project implementation, two sets of different evaluation criteria were designed. On the basis of determining the evaluation criteria and evaluation models, the performance level of farmland development projects was obtained more realistically, providing decision-making basis for how to optimize resource allocation for such farmland development projects (Sklenicka et al., 2002).

2）National Research on Farmland Development Evaluation

Currently, the relevant theories and research methods of high-standard farmland development in China are relatively basic and simple. The theoretical support and method references for high-standard farmland development have been provided. At the same time, the construction standards and evaluation norms issued by various departments of China also provide theoretical guidance for the performance evaluation of high-standard farmland.

In recent years, the post-evaluation of high-standard farmland development in China has focused on comprehensive benefit assessment. Studies have selected farmland development projects as sampling points and constructed an economic and social benefit evaluation index system for high-standard farmland development, including indicators such as the degree of farmer participation in post-project management, village satisfaction, and the scale of land transfer. The entropy weight method has been employed to improve the TOPSIS (technique for order preference by similarity to ideal solution) mode for evaluation (Xin et al., 2017) Additionally, some research has utilized interview data, graphic data, and statistical data to develop a comprehensive performance evaluation index system. This system evaluated the comprehensive effects of high-standard farmland development at the county level, providing differentiated evaluations based on unique regional characteristics (Ma and Chen, 2020; Ma et al., 2018) . Based on the scale of plots and starting from the "General Rules for High-standard Farmland Development," an evaluation index system for the compliance of high-standard farmland development has been constructed. This system comprehensively evaluates the quality and condition of high-standard farmland development and selects suitable plots for construction, evaluating construction effects from different dimensions and perspectives (Li et al., 2018). The C-D production function has been applied to analyze the improvement of grain yield and farmers' income levels through high-standard farmland development. In terms of ecological benefits analysis, research mainly focuses on aspects such as environmental quality, biodiversity, and disaster resistance (Wang, 2014). By fully collecting basic data on high-standard farmland development projects and conducting field surveys, a comprehensive evaluation system and indicators have been constructed, integrating economic, social, and ecological benefits. Hierarchical analysis and fuzzy evaluation methods have been comprehensively applied, and a comprehensive performance evaluation system for high-standard basic farmland has been established (Li, L. et al., 2020; Wang et al., 2019; Xue, 2018; Zhou et al., 2018).

In summary, different researchers approach the evaluation of farmland development project benefits from two main perspectives. The first perspective judges based on the economic benefits in the later stages of the project, namely by assessing the increase in land productivity achieved through farmland development projects, often converting this increase into monetary values for direct comparison. The second perspective adopts a comprehensive evaluation standard that combines economic, ecological, and social benefits. With the increasing experience gained from project implementation, scholars have seen a shift in the evaluation of farmland development benefits from qualitative to quantitative methods, making evaluation results more accurate. Quantitative evaluation methods commonly used include fuzzy mathematics comprehensive judgment and Analytic Hierarchy Process. Through comparing the research of international and national evaluations of farmland development benefits, it is found that there are differences in the depth and results of research in defining the connotations and evaluation methods of farmland development benefits. National studies mainly conduct comprehensive analyses based on factors such as project planning schemes and overall project implementation benefits. Additionally, they incorporate factors related to national policy guidelines. The main aspects of project evaluation are economic, ecological, and social benefits.

3.3Public participation in farmland development

3.3.1 International Research on Public Participation in Farmland Development

The study suggests that the key to success in farmland development projects in the Netherlands lies in a high degree of attention to the interests of landowners and the ability to fully coordinate the important relationship between social public interests and landowner interests. Full participation of all landowners, each performing their role, is crucial for achieving good results in farmland development in Japan (Stańczuk-Gałwiaczek et al., 2018). Firstly, government departments organize committees comprising individuals from all social strata to participate in farmland development, broadening financial, material, and manpower sources. To ensure the smooth implementation of land improvement plans, a series of contracts are usually established before. In Japan, through the organization of committees comprising individuals from all social strata and mobilizing people from the entire society to participate in farmland development, issues related to funding and labor are addressed, and the smooth progress of implementation is guaranteed through pre-established contracts (Nagamine H et al., 1986). The satisfaction of landowners determines the success or failure of projects. Lisec A (2014) conducts in-depth research on land improvement in Slovenia, pointing out that the key factor affecting the progress of farmland development projects is the degree of participation of landowners, which depends on their satisfaction with the project. Therefore, it is necessary to improve the satisfaction of landowners and stimulate their enthusiasm for participation by fully understanding their needs before farmland development. Tan et al. (2009), after comparing and analyzing the effectiveness of farmland development in China with Germany and the Netherlands etc., indicated that the lack of effective public participation mode is the key issue in China's farmland development, and there is no reasonable method for determining the participating subjects. Referring to the composition of the public in farmland development in the Netherlands may produce positive effects.

In the research on the impact of public participation on the benefits of farmland development projects, the study suggested that the key factor in measuring the success of farmland development is the degree of participation and satisfaction of farmers in the project area. Different stakeholders, such as farmers, social elites, and government officials, should strengthen communication to coordinate and meet the needs of different groups. Demetriou D (2012) concluded that the reason for the low project benefits is the contradiction between the high project implementation costs and the low contribution of stakeholders. If stakeholders at all levels are encouraged to participate in land consolidation, the problem will be effectively solved. After studying traditional implementation modes of land improvement, Haldrup (2015) proposed a new governance mode, namely the agreement governance mode. This mode is based on social governance, allowing farmers to contribute their own experience and capabilities voluntarily to complement the limited capacity of the government, enhance the scientific and democratic nature of projects, and thereby improve project benefits. Different countries have different national conditions and systems.

3.3.2 The global cases for other stakeholders' participation modes

Globally, land consolidation projects, guided by relevant academic research and farmland development objectives, have provided several cases of stakeholder participation in project development.

- Japan: Government-led investment mechanism for agricultural land construction, with a shared management mechanism for stakeholders to jointly bear the costs and responsibilities (Case source: Institute of Agricultural Resources and Agricultural Regionalization, CAAS, relevant reports from the visit to Japan in October 2019).

Farmland development funding comes from three main sources: government subsidies, policy-based financing, and contributions from farmers themselves. Government subsidies constitute the majority, increasing from 66% to 86% of the total from 1965 to 1998. The rest mainly consists of policy-based financing, while farmers' contributions are nearly negligible. The allocation of funds for farmland development shows different characteristics in different development stages. In the first stage, it was scale-oriented. From 1965 to 2003, Japan implemented four rounds of land consolidation plans nationwide. Central government expenditure increased from $280 million to $9 billion, with an average annual growth rate of 9.8%. Subsidies for agricultural and rural infrastructure construction, focused on farmland development, became the largest component of Japan's agricultural financial subsidies in 1990, accounting for 39.4% (compared to 20.5% in 1970), and further increased to 46.9% in 1999. The second stage was outcome-oriented. After 2003, Japan changed its farmland development planning period from ten years to five years. The focus of land consolidation shifted towards major grain-producing areas and professional farmers, aiming to increase food self-sufficiency and stabilize farmer incomes. By 2009, the fixed assets of agricultural infrastructure formed through farmland development in Japan amounted to approximately $320 billion, with an investment of about $100,000 per hectare. The third stage was focused on stability and maintenance. After 2010, the Japanese government has been investing approximately $3 billion annually, mainly for the operation and maintenance of related facilities and equipment.

Encouraging diverse investment is essential. Depending on the importance of the project, the central government bears two-thirds of the investment for key facilities, while for non-key facilities, the central and local governments share 80% of the burden jointly. Additionally, for projects with a large area of farmland development, the central government shoulders 66.6%, the local government 29.4%, and farmers 4% of the investment. For projects with a small area of farmland development, the central government covers 50%, the local government 37.5%, and farmers 12.5% of the investment. In the construction of agricultural water conservancy infrastructure, the central government also provides around 30% of the project investment to local governments and farmers in the form of loans.

Implementing farmer self-management as the primary approach. The maintenance costs for farmland are primarily borne by the benefiting farmers, with appropriate subsidies from the central and local governments. The collection of maintenance costs only considers major repair and normal operating expenses, without extracting depreciation costs. If renovation and reconstruction are required after the expiration of the project's service life, the investment will be shared by the central government, local government, and farmers according to the original channels and sharing ratios. Most farmers pay for the maintenance costs for facilities. Farmers must have a payment to the farmland development institution (the farmland development area office), and those who do not pay will be forcibly collected.

Overall, the sustained high investment in farmland development has achieved significant economic and social benefits. Crop yield and quality, agricultural production efficiency, and rural living conditions have been greatly improved. According to calculations by the Japanese Ministry of Agriculture, Forestry and Fisheries, the economic and social benefits generated by farmland development amount to as much as $13.2 billion annually, far exceeding the investment in land improvement.

Typical Case: Farmland development in Ibaraki Prefecture, Japan (Kanto Region)

Ibaraki Prefecture is located in the central part of Honshu Island, Japan. It is one of the three major metropolitan areas in Japan, forming part of the Greater Tokyo Area. It belongs to the Kanto region of Japan, situated 40 kilometers northeast of Tokyo. It faces the Pacific Ocean to the east, borders Fukushima Prefecture to the north, Tochigi Prefecture to the west, and Chiba Prefecture and Saitama Prefecture to the south, with an area of 6,096 square kilometers and a population of 2.881 million. The northern part of the prefecture is mountainous, while the central to southern parts are part of the Kanto Plain. Both agriculture and fisheries are well developed, ranking second in agricultural production. It has the second largest cultivated area in Japan, mainly cultivating rice, wheat, soybeans, citrus fruits, and green onions. Fisheries include nearshore, offshore, and freshwater fishing.

Located in Ibaraki Prefecture's Mito City, Ibaraki Town's farmland development project covers 13 districts totaling 675 hectares, with a total investment of 13.3 billion yen. The central government covers 66.6%, the prefecture covers 20%, the municipalities cover 8.4%, and farmers cover 5%. In recent years, the number of farmers in Mito City and Ibaraki Town in Ibaraki Prefecture has decreased, and the aging population issue has become prominent. Over the past decade, the number of farmers has decreased by 17%, with those aged 65 and above accounting for 40% of the total agricultural population. Before the farmland development project, about 80% of the paddy fields in the area were undeveloped, leading to poor drainage and narrow farm roads, which severely affected mechanized operations and reduced farmers' enthusiasm for cultivation. Considering the reality of a large population and limited land, increasing the scale of farming for individual farmers has significant limitations. Therefore, the key and urgent need lies in land consolidation and improving farmland infrastructure.

The farmland development project is implemented in two steps. The first step, from 2012 to 2015, involves the adjustment of farmers' land to achieve land consolidation. The main process includes collecting information on farmland, surveying farmers' preferences, measuring farmland, conducting land evaluation, formulating land exchange plans, ensuring that more than two-thirds of the relevant farmers attend to decide on the land exchange plan, announcing the land exchange plan, handling objections, and acquiring and paying compensation for unequal land exchanges. During the land exchange period, stability in production is ensured, and new land information is registered after the land exchange. The second step, from 2016 to 2025, involves the construction of roads, farmland water conservancy facilities, etc., aiming to achieve large-scale farming operations through farmland development. This facilitates large-scale machinery operations, reduces agricultural production costs, and improves crop yield and quality.

- South Korea: The "Multilevel Fiscal Investment - Multiform Farmer Participation" Financing Mechanism (Han et al., 2022)

In the 1960s, South Korea's farmland development mainly focused on small-scale irrigation projects, with the central government bearing 40% of the total investment, and the remainder borne by local governments and farmers. In the 1970s, the proportion of central government investment was adjusted to 50%, with local governments contributing 30%, and farmers 20%. In the early 1980s, the central government's investment ratio was adjusted to 60%, with local governments contributing 20%, while farmers still bore 20%. In the late 1980s, the central government's investment ratio increased to 70%, with local governments maintaining 20%, and farmers' contribution decreased to 10%. Since the 1990s, the investment ratio has been determined based on the classification of farmland development. In small-scale farmland development projects, the central government's investment ratio is 80%, with local governments contributing 20%, and farmers not required to invest. For large-scale farmland development projects, the central government bears all the investment. Although farmers do not contribute financially, they need to obtain consent from two-thirds of the households in the project area before applying to the government for farmland development projects. After the farmland development is completed, farmers also need to participate in the operation and maintenance of farmlands.

Encouraging farmers to demonstrate the spirit of "diligence, self-help, and cooperation" to contribute to environmental improvement. For example, villagers are involved in selecting the most urgently needed projects such as farmland irrigation facilities and road construction, thereby mobilizing their enthusiasm in project and increasing the funds utilization rate. In specific terms, the "New Village Movement" agricultural infrastructure construction is supported by the government through the supply and distribution of materials, which are provided charge free or at low cost to villages encouraging farmers to make independent decisions on construction. In 1970, the South Korean local governments distributed materials such as cement, steel bars, and pipes to nearly 30,000 villages nationwide for construction purposes. The government identified projects including field road construction, agricultural power system construction, and farmland irrigation facilities, and villages discussed and selected the projects that needed to be built, which were then submitted for evaluation and material distribution. Subsequently, the utilization and results of the materials provided to each village in the first year were assessed, and villages receiving aid were classified into self-reliant villages, self-help villages, and basic villages based on their performance. Different levels of assistance plans were then formulated for the following year based on the village's classification, creating a competitive mechanism among villages.

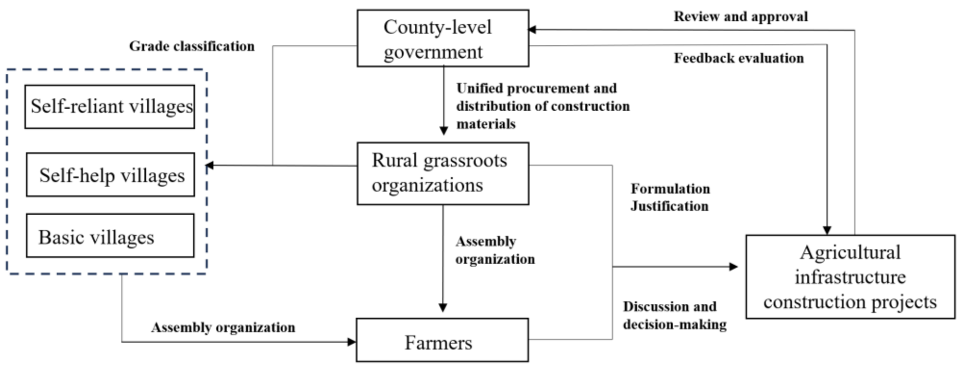

Figure 1- 8 Agricultural Infrastructure Construction Project Financing Mechanism

- Germany: Green Ecological-oriented Investment and Financing Mechanism (Han et al., 2022)

Germany has developed a well-established "ecological" funding mechanism for farmland development. Since the 1990s, Germany has established a comprehensive financing mechanism for farmland development, with funding provided by the federal government, state governments, and landowners. Larger farmland development projects are financed through bond issuance, with preferential policies provided to construction entities. In terms of funding for farmland development, the proportion of government subsidies varies depending on the project's requirements and the nature of the land. For collective facilities with strong public benefits, the government generally subsidizes 80% of the total costs. For the restoration and improvement of new plots and the renewal of village facilities, typically only 30% is subsidized. Projects related to nature conservation and landscape maintenance are fully funded by the government. For the construction of resort and recreation facilities, the government subsidizes 65% to 75%.

Germany initiated agricultural ecological compensation policies in the 1990s, with compensation funds mainly coming from three levels: the European Union, the federal government, and state governments. From 2014 to 2020, a total of 1.6 billion euros was obtained from these three sources for agricultural ecological compensation to expand the area of ecological farms. In terms of fund allocation, support is mainly provided to farmers engaged in sustainable production to promote the transformation of agricultural production modes and protect the ecological. For example, if farmers want to pave field roads, they must allocate a certain proportion of arable land for ecological use. The government plans to increase the proportion of ecological agricultural land to 20% by 2030. Under the CAP framework, Germany's ecological compensation mechanism has promoted the development of ecological agriculture.

- The United States utilizes a "government-market" cost-sharing financing mechanism for agricultural projects (Han et al., 2022)

Through the establishment of a comprehensive agricultural policy credit system and the development of financial institutions such as land banks and production credit banks, the U.S. determines the investment sharing ratio between the market and the government based on the principle of "beneficiary pays". This creates a diversified financing mechanism. For example, financing channels for water infrastructure projects in the United States include preferential loans provided by the federal government, financial appropriations from various levels of government, project bonds, government-related funds for water projects, taxation in beneficiary areas, self-financing by project owners, as well as donations from social groups or individuals. The financing methods include both direct and indirect financing, with government fiscal funds occupying the majority, most of which are provided on a reimbursable basis through market-oriented means, offering non-public utility water projects loans at lower interest rates. Moreover, the structure of water infrastructure project financing in the United States varies depending on the construction period and the nature of the project. Projects with strong public attributes, such as flood control projects, mostly rely on government appropriations, while water facility construction projects are primarily financed through bond issuances.

In terms of farmland development, they should adopt public participation modes that suit their own conditions. China and Europe have different national conditions and systems, which determine the choice of farmland development modes. Simply replicating the practices of Western European countries may lead to many problems. Therefore, modes that are in line with the national conditions and systems should be developed. But past development experiences should be summarized and learned.

3.3.3 Research on public participation in farmland development in China

research on public participation in farmland development mainly includes studies on the necessity of farmer participation, the current situation of farmer participation in farmland development, satisfaction and benefit evaluation, and willingness of farmers to participate in funding for individual farmland facilities.

In terms of the necessity of farmer participation in farmland development, it is considered that farmers' participation is a crucial factor, which reflects the actual needs of the project area. It can facilitate the rational planning of farmland development and promote the efficient and sustainable use of land (Zhang et al., 2019; Zhou et al., 2020). Farmers' participation is seen as a means to safeguard their own interests and regulate the operation of farmland development (Duan et al., 2021). Encouraging farmer participation can ensure the smooth implementation and reasonable of farmland development projects (Zhang et al., 2018). The involvement of village grassroots organizations and farmers can supervise the quality of engineering projects and improve the effectiveness of later maintenance while safeguarding the legitimate rights of farmers (Yang et al., 2017). Farmers' participation is crucial for the successful implementation of projects. Without farmer participation in planning, it will be difficult for them to participate actively in the implementation stage. Only by combining farmers' practical experiences can plans be feasible and achieve the expected results (Yin et al., 2022).

In the research on farmers' willingness and participation in farmland development, their involvement is greatly influenced by various factors such as policy mechanisms and individual circumstances. On one hand, farmers may have limited understanding of and enthusiasm for farmland development due to inadequate awareness. On the other hand, existing mechanisms for farmers' participation and management of farmland development in China remain imperfect, with insufficient legal constraints and regulations (Tang et al., 2019; Zhou et al., 2020a). Previous studies have examined the level of farmers' participation in high-standard farmland development from following perspectives: farmers' awareness of the projects, and their satisfaction with participation. Findings suggested that farmers generally have low awareness of high-standard farmland development projects and limited understanding of related policies. This phenomenon is attributed to factors such as farmers' educational levels, inadequate village-level organization and government publicity efforts. However, most farmers perceive the implementation of such projects as relatively important and beneficial, and they express various needs. Despite strong willingness to participate, the overall level of participation among respondents is low, with most not actively involved in high-standard farmland development. Survey results reflected the local residents' strong desire to participate, hoping to express their opinions by attending project-related meetings and being involved in the process(Sun, 2017; Xu, 2020) . The "feasible capability" theory has been applied to analyze factors influencing farmers' willingness to participate from the perspectives of capability conversion drivers and functional perception. Results indicated that farmers' willingness to participate is positively correlated with agricultural income. The better farmers understand farmland development-related policies, the stronger their willingness to participate. Moreover, the more sound the public participation mechanisms are, the higher the villagers' enthusiasm for participation. Well-implemented field roads, irrigation and drainage layouts can effectively improve farmland production conditions, significantly meeting farmers' production needs and encouraging their participation (Xiang et al., 2017). Research on the mechanism of farmers' effective participation and its impact on the performance of farmland development projects suggests that the higher the level of farmers' effective participation, the higher their satisfaction with the project's performance. However, due to the lack of relevant laws and regulatory mechanisms, as well as farmers' limited awareness and capacity for participation, and weak awareness among relevant departments regarding project management and decision-making behaviors, farmers' participation often remains superficial, resulting in low effective participation rates and low satisfaction with the performance of farmland development projects. Therefore, exploring effective ways and mechanisms for farmer participation is of great significance for improving the performance of farmland development projects (Meng, 2023; Wang and Guo, 2022).

There were intrinsic and extrinsic factors for influencing farmers' participation. Specifically, these factors include legal regulations, project management systems, pathways and modes of farmer participation, and farmer willingness. Externally, the incomplete project management system is the main reason limiting farmers' participation in farmland development. This is reflected in farmers' familiarity with the renovation situation, participation pathways, the completeness of relevant laws and regulations, and the nature of participation. Internally, factors such as farmers' householder situations, individual psychology, and individual cultural levels influence farmers' willingness to participate, leading to differences in participation intentions

(Li and Liu, 2018; Wang, W. et al., 2019; Zhang and Han, 2018). In farmland development projects, the involvement of village committees plays the most significant role in post-construction maintenance efficiency, followed by individual farmer participation, with other organizations and government departments having a relatively minor impact on participation. Theoretically, factors that significantly affect farmland development include farmers' awareness of the project, the support attitude of village cadres, and farmers' market expectations (Wang, 2018; Yu, 2021).

In China, farmland development projects are essentially public service products provided by the government to promote rural development. However, the providers of this public service—the government—and the consumers—farmers, are often separated. Interveners such as project contractors may withhold some information, leading to deviations during project implementation that reduce the quality of public services and undermine the rights of farmers. Furthermore, the entire process of implementing farmland development projects is mostly a government action, with decision-making processes often lacking consideration for the actual desires and needs of farmers. As direct users and ultimate beneficiaries of farmland development projects, farmers need to actively participate in these projects based on their existing knowledge and practices (Yin, 2016). In other words, the assessment criteria for the performance of farmland development projects are based on whether the actual results meet the needs of farmers. The degree and willingness of farmer participation in farmland development projects are directly influenced by the outcomes of this assessment (Sun, 2017a).

Research on farmland development investment and farmer willingness mainly focuses on three aspects: Firstly, research on the main parties of investment in small-scale farmland water conservancy construction (Du, 2015; Shen et al., 2017). By analyzing the different attitudes of stakeholders toward investment in farmland water conservancy construction under market economy to proposed that the main parties of investment in farmland water conservancy construction should be the government and farmers (Hou, 2021). Secondly, research on the investment mechanism of farmland water conservancy construction. For example, based on the dilemma of rural farmland water conservancy construction and the behavioral logic of investment subjects, it is argued that the construction of investment mechanisms is more important than the engineering construction itself (He and Guo, 2010). Considering the public welfare nature of small-scale farmland water conservancy projects, private capital is deemed necessary to supplement the funds for small-scale farmland water conservancy project construction (Wen et al., 2023). Thirdly, in the study of farmers' investment and willingness to participate in farmland water conservancy construction, the influence of relationship networks on farmers' participation in village collective actions was explored. The results show that farmers' willingness to participate in village collective actions is relatively low (Cai and Zhu, 2015, 2017). Based on the theory of planned behavior, the influencing factors of farmers' willingness to participate in the construction of small-scale farmland water conservancy facilities are systematically analyzed. The results indicate that farmers' participation attitudes have the greatest impact on their willingness to participate, followed by subjective norms and perceived behavioral control. Farmers' willingness to participate is mainly stimulated by economic benefits, neighboring participation intentions, external support, and personal capability constraints (Jia, 2018).

Overall, existing research primarily focuses on qualitative analyses of the relationship between grain production and farmland water conservancy, as well as the subjects, mechanisms, investment efficiency, and governance modes of farmland water conservancy construction. Quantitative empirical analyses have also been conducted on the factors influencing farmers' investment in and willingness to participate in farmland water conservancy construction. However, there is limited research on farmers' investment willingness in other aspects of farmland development from the perspective of farmers, and there is a lack of guidance mechanisms. Therefore, this study systematically, comprehensively, and thoroughly studies farmers' participation in farmland development. It explores farmers' cognition, willingness, pathways, influencing factors, and their preferences for project planning, design choices, and participation standards. The aim is to find scientifically sound and practical pathways for farmer participation, providing valuable insights and references for the implementation of farmland development projects.

3.3.4 The pilot case of diversified participation on farmland development in China

In response to the strategic call to encourage rural collective economic organizations and farmers to participate in farmland development through the approach of "substituting subsidies for investments and promoting construction with subsidies," provinces have undertaken explorations to innovate land consolidation modes tailored to their regional characteristics.

- "Four Self" Mode in Hunan Province (Lei et al., 2022)

The "Four Self" Mode in Hunan Province involves farmland development, with "Four Self" referring to "Self-determination, Self-financing, Self-construction, and Self-management". Based on the principle of "construction first, supplemented by subsidies" and the administrative village as the unit, the "Four Self" Mode fully respects the farmers' willingness and guides them to participation. After each stage of the project is completed and passes the acceptance inspection, funds are disbursed by the government according to the budget. Different from the traditional farmland development mode, the "Four Self" Mode involves the entire process from the project preliminary work to its organization and implementation, and then to post-project maintenance. From fundraising to investment and supervision, everything is jointly negotiated and determined by village committee members to requirements. The specific operation of the project is shown in Figure 3-1 below:

i. Organization Method

The organization method of the project is as follows: the village committee, as the owner unit, is mainly responsible for project planning, coordination, and management. Specifically, it is responsible for promoting the farmland development project, mobilizing villagers to actively participate, soliciting collective opinions from villagers, determining the layout and content of engineering construction, hiring qualified units to demonstrate the feasibility of the project and prepare design budgets, raising funds for project construction, organizing and managing project implementation, solving problems that arise during project implementation, strictly managing engineering quality and fund utilization, and managing the post-project maintenance of the project. The villagers elect members to establish the Project Board of Directors and the Supervisory Board, in addition to the village head and the village party secretary. The Board of Directors should consist of no fewer than 5 members, responsible for the project's daily affairs such as material procurement and equipment rental, and should promptly disclose the use of funds within a certain scope to the villagers. Ideally, the Supervisory Board should also consist of no fewer than 5 members, mainly responsible for monitoring the project's quality, progress, and funds during implementation, and supervising the work of the Board of Directors. There is a system of checks and balances among the village head, the village party secretary, the Board of Directors, and the Supervisory Board, each with its own responsibilities. Meanwhile, the project village needs to hire specialized engineering technicians, usually 1-2 individuals with national construction qualifications of level three or above, to provide technical guidance for project implementation and organize post-project documentation.

The functional division of government departments is as follows: provincial land departments, in conjunction with provincial finance departments, are responsible for allocating project funds to county-level finance departments, as well as for formulating relevant policies and providing guidance. They also research and solve common problems that arise during the pilot process. City (state) level land departments and finance departments are responsible for organizing project proposals, design and budget reviews, project implementation supervision, design change approvals, and project acceptance. County (city, district) level land resources departments and finance departments are responsible for organizing project proposals, initial design, budget review, project implementation supervision, individual project acceptance and preliminary inspection, design change review and approval, fund application and disbursement, and overall guidance on project pre-implementation and implementation work. The local township (town) government where the project is located is responsible for supervising and coordinating work, urging village collective economic organizations to organize project implementation according to design standards, maintaining the construction site environment, and helping to coordinate and resolve disputes and conflicts that arise during project implementation.

ii. Project funding and operation

The source and operation of funds are as follows: In the pre-construction, the project initiates funding is obtained by the village committee in the name of the village collective through bank loans. During the project construction, funds are attracted from industrial and commercial capital, in-kind contributions, labor contributions from farmers, village collective economic organizations. It is proposed to expand the source of funds through village collective fundraising, loans, etc., with villagers deciding on the amount of investment in the project. The loan interest rate is based on the current bank rate. After the project is completed and fully inspected and accepted, the village committee uniformly returns the principal and interest. The funds operation is that project construction funds are first raised by village collective economic organizations. After completion of each stage and passing the inspection, the county-level land department applies for funds from the same-level finance department, which is then disbursed after review. This portion of funds can also provide financial support for the next stage of project construction. After the completion of the project, 10%-15% of the project construction surplus funds are used for post-construction maintenance.

- Hubei Province piloted the "award-for-substitute" mode (Wang, 2018)

Hubei Province piloted the "award-for-substitute" mode, which is an innovation in the implementation subject of farmland development projects. It aims to improve the implementation mode, including management procedures and fund-raising, by involving agricultural beneficiaries in farmland development. The implementing party of this pilot project is the township government. Land consolidation projects are conducted at the administrative village level. The implementation area, construction content, and funding for the project are determined through village committee meetings. village collective economic organizations are the recipients of awards and subsidies and serve as the main construction entities. This makes the implementation entity of farmland development projects more diversified. Unlike the traditional farmland development mode, the pilot projects in Hubei Province have explored and reformed the implementation entity, fund-raising and subsidy methods, management procedures. This has significantly promoted the diversified participation of farmland development.

For pilot projects initiated by cooperatives and leading enterprises, they must follow the principle of "land transfer first, then construction implementation". This means that the land contract rights within the project area must be transferred before construction can begin, and the area of land transferred should account for over 70% of the total project area, achieving centralized land management. Government departments responsible for the project conduct qualification assessments, review and approve supporting funds, and file for approval. After the project is approved, intermediary agencies are selected to plan and design the project and provide engineering supervision. During the implementation, the project implementation party organizes construction units to conduct construction according to the planned design. Upon completion, the project is submitted to relevant government departments for inspection and acceptance.

i. Organization Method

The organization mode of the project is as follows: Pilot projects initiated by leading enterprises and cooperatives operate under the mechanism of "government leadership, departmental cooperation, enterprise self-construction, and public participation". This allows leading enterprises and cooperatives, as the implementers and beneficiaries of farmland development, to participate in the independent investment and construction of farmland development projects. In pilot projects where farmers self-build with incentives, the township government acts as the implementing party of the farmland development. It forms a technical working group to provide engineering construction guidance and technical services throughout the village where the project is located. The village collective economic organizations are the beneficiaries of the incentives and are responsible for construction. Farmland development projects are conduct on an administrative village basis, with village collective economic organizations independently determining the project implementation area, construction content, and funding arrangements, thereby having greater autonomy.

ii. Project funding and operation

The source and operation of the funds are as follows: In the pilot projects initiated by leading enterprises and cooperatives, before project implementation, agricultural cooperatives and leading enterprises need to provide a commitment to self-investment, undertaking a proportion of investment exceeding 15% of the project funds. The government uses farmland development projects as platforms to integrate investments in transportation, water conservancy, agriculture, and others, supplemented by special funds for farmland development, and manages project funds according to specific regulations at the national and provincial levels. County-level and above government finance departments are responsible for reviewing and approving the budgets and final accounts of farmland development projects, disbursing project funds, and supervising and inspecting the use of project funds and budget implementation. County-level and above land and resources administrative departments are responsible for compiling investment plans and budget proposals for farmland development and supervising and inspecting the use of project funds and budget implementation. County-level and above audit departments conduct audits on the use of funds for farmland development in accordance with the law.

- Zhejiang piloted the self-financing land reclamation mode (Shen, 2022)

As a pilot project for self-financed land reclamation, Lin'an City encourages various agricultural entities to participate or undertake farmland development projects. The self-financed land reclamation project operates on a "construction first, acceptance later, then allocation of funds" mode. During project implementation, various agricultural entities, social groups, and enterprises can participate. The specific operational process of the project is as follows: the "construction first, acceptance later, then allocation of funds" mode means that various agricultural entities, village collective economic organizations, social groups, or enterprises can raise funds for land reclamation projects and organize construction in advance. After the project is completed and accepted by relevant government departments, funds are allocated back for repurchase to achieve balance. In the later maintenance stage, the land contract holders are responsible for the subsequent management of the reclaimed land. For those who improve the soil fertility of the cultivated land, they can receive rewards according to relevant regulations.

i. Organization Method

Zhejiang Province issued a notice on implementing the relevant matters of the Provincial Government Office's "Notice on Further Strengthening the Management of Land Reclamation and Compensation Balance," delegating the approval, implementation, and acceptance authority of land reclamation projects. In self-financed land reclamation projects, county-level (city, district) governments are responsible for the approval, organization, and completion acceptance of land reclamation projects. The county-level land department is responsible for the management of the entire process, ensuring strict supervision of project approval, implementation, and acceptance. In the later stages of management, the township (street) government is the main party responsible for the subsequent management of reclaimed land. They are responsible for establishing a sound system for later-stage management, dividing and assigning the tasks of later-stage management to villages and households. They arrange professional agricultural technicians to guide landowners in later-stage cultivation and conduct soil fertility testing. Village collective economic organizations are responsible for verifying and accepting the reclaimed land after boundary demarcation and issuing land rights, and guiding landowners. They organize to contract with professional cooperatives or large-scale farmers conducting large-scale land management. For land without demarcation and contracting, specialized personnel should also be arranged for later-stage management. The holders of the land contract rights are responsible for the later maintenance and continuous improvement of infrastructure, adopting appropriate cultivation practices based on local conditions, integrating cultivation with breeding, crop rotation, soil improvement, promoting water-saving and facility agriculture, and improving the overall agricultural technological level.

ii. Project funding and operation

Before the implementation of land reclamation projects, village collective economic organizations, various agricultural operating entities, enterprises, social organizations, and other project implementers first raise funds for construction. After the project is completed and passes inspection, the government repurchases the land and allocates funds. In the later stages of management, the government extracts special funds from the land reclamation budget for daily management, soil fertility testing, and quality improvement. Various agricultural operating entities can participate or undertake land reclamation projects by raising funds, thereby integrating social funds into agricultural construction and expanding the sources of funds for agricultural construction. The "build first, inspect later, allocate funds" mode not only ensures the construction quality but also effectively reduces the financial risks and improves the efficiency of financial funds utilization. In the later stages of management, establishing a mechanism for rewarding subsequent management funds stimulates landowners or leaseholders to actively maintain the cultivated land, ensuring the long-term protection of reclaimed land.

Comparing the case experiences of stakeholder participation in farmland development in sections 3.3.2 and 3.3.3, it is evident that developed countries have relatively well-established investment mechanisms for farmland development projects. In terms of financing, they have developed a cooperative model led by the government, with farmer participation and market operation. The government provides varying proportions of investment depending on the type of construction project. In contrast, the Chinese government bears a significantly higher responsibility for farmland development investments compared to other developed countries. Since the implementation of high-standard farmland development, project investment has been entirely government-led, without involving farmers or other social entities in project development and management. However, small-scale agricultural operations, low profitability, and weak financial capacity of farmers are fundamental aspects of China's national conditions, making it necessary for the government to assume primary responsibility and investment in farmland development. Therefore, at the current stage, there is an urgent need to establish a reasonable stakeholder participation mechanism to overcome barriers to farmland development. Additionally, it is essential to clarify the key benefits for farmers in farmland development to reasonably determine the responsibilities of both the government and farmers.

3.4Limitations of previous studies and original contributions of this study

In summary, the concepts and practices related to farmland development have a long history. Globally, farmland development has continuously improved to meet the specific needs and developmental goals of different countries at various stages. International research on farmland development started relatively early, accumulating a wealth of beneficial theories and methods. Comparatively, this remains a relatively new and hot topic within the Chinese academic community, requiring further in-depth exploration in terms of research perspectives, methods, and theories. Currently, scholars have made valuable explorations in areas such as farmland development evaluation, construction model zoning and timing arrangements, public participation issues, and funding mechanisms, providing a theoretical foundation for this study. However, much of this research tends to examine above issues of farmland development from a single perspective, rather than a systematic and comprehensive viewpoint. This study posits that farmland development is a complex technical and social governance project involving multiple stakeholders and numerous stages. Issues such as funding shortages, single-channel fundraising, supply-demand conflicts due to lack of public participation, and low comprehensive benefits are merely surface problems. Essentially, they are all related to the existing farmland development management mode. To address these issues effectively, it is crucial to identify their root causes and explore solutions based on the current farmland development mode.

Farmland development evaluation is fundamental for adjusting and improving construction goals and content. It also serves as an important basis for stakeholders to determine investment standards, which is crucial for the long-term development of farmland development. Currently, researchers mainly adopt two perspectives when evaluating the benefits of farmland development projects. The first perspective evaluates based on the economic benefits achieved post-project. This involves assessing the increase in land productivity as a result of the project and converting these productivity gains into monetary terms for direct comparison. The second perspective conducts a comprehensive evaluation of economic, ecological, and social benefits of projects. Comparing China and international research on farmland development benefit evaluation reveals certain differences in the depth of research and results concerning the definition and evaluation methods of farmland improvement benefits. In China, evaluations typically focus on a comprehensive analysis of project planning schemes and the overall effects of project implementation. Internationally, evaluations generally assess the economic, social, and ecological benefits following project implementation. Economic benefits are primarily measured by the increased land area, higher grain yields, and economic income generated for residents' post-project. Social benefits are evaluated by examining the project's impact on land ownership, local agricultural production modes and scales, government land management systems, and changes in local farmers' production and living conditions.

Ecological benefits are mainly reflected in environmental impact assessments, selecting specific environmental indicators aligned with different research perspectives to evaluate the project's impact on the environment post-implementation. This study posits that, within the current framework of sustainable development goals, a comprehensive evaluation of both the economic and environmental benefits of farmland development can more accurately reflect the progress towards sustainable transformation of farmland systems. This requires integrating current theories and methods, drawing on existing research experiences, and expanding the boundaries and perspectives of evaluation. Specifically, the research should summarize various types of farmlands and their utilization modes that have emerged due to evolving agricultural development goals. It should systematically consider the benefits in both the construction and post-construction utilization stages of farmland, selecting relevant indicators that align with the multiple objectives of output efficiency, resource conservation, environmental friendliness, and income improvement. Meanwhile, the study should develop evaluation methods that quantify the contribution of different farmland and utilization modes towards achieving planning goals. Based on current national policies and plans, the study aims to propose long-term optimization strategies for various types of farmland development. **(original contribution 1)**

Most scholars recognize farmer participation as a key measure to address farmland development issues. Drawing on studies and case experiences of public participation, this study presents the following points: First, historical experiences and practices show that developed countries did not wait until they were financially abundant to undertake land consolidation, nor did they adjust land consolidation standards based on financial capacity. Instead, large-scale farmland development and the continuous enhancement of construction goals and standards have driven sustainable agricultural development. Second, the issue with farmland development is not a lack of funding sources but rather the absence of an effective management mechanism to aggregate and utilize these funds efficiently. Third, the current top-down, government-led mode of farmland development has several drawbacks. Previous research has mainly focused on emphasizing the importance of farmer participation and the positive impacts of farmland development benefits. This study argues that farmland development is closely tied to the immediate interests of farmers, who are the ultimate beneficiaries of post-construction improvements. Without farmer participation throughout the construction process, both the standards and efficiency of farmland development are diminished, and post-construction comprehensive benefits are significantly reduced. Therefore, farmland development should gradually shift to a new mode of "government-led implementation with farmer participation in planning and investment." The fundamental goal of optimizing and innovating farmland development modes is to promote public participation mechanisms, ensure construction standards, broaden funding sources, improve project execution effectiveness, and advance the governance system and capacity for farmland development. In terms of existing research approaches and methods, international studies predominantly focus on legislation and policy, public participation modes, and the benefits of public participation in land consolidation, often analyzing from the perspective of macro policies. In terms of research in China, it tends to examine farmers' satisfaction with the outcomes of farmland development, the stages, content, and methods of farmer participation, and the necessity of farmer involvement in farmland development. However, there has yet to be a comprehensive set of participation content, pathways, and schemes tailored to the role of farmers, with a lack of specific mechanisms for facilitating farmer participation in farmland development. This study aims to address this gap by adopting a farmer-centric perspective, integrating psychological theories and models to deeply investigate farmers' cognition, willingness, and influencing factors in participating in SFD project. The goal is to establish a pathway that can stabilize and promote farmer participation, aligning farmland development objectives with farmers' desires and ensuring the smooth progress of SFD **(original contribution 2)**. Furthermore, by considering regional farmland conditions and differences in farmer needs, this study seeks to understand farmers' preferences and payment levels for sustainable farmland development schemes, providing precise references for the establishment of farmer participation mechanisms. This can also offer practical insights for optimizing land consolidation systems in other countries and regions at similar stages of development **(original contribution 3)**.

4. key issues

This study aims to address the following scientific questions:

i. How to understand and quantitatively evaluate the comprehensive benefits of SF?

ii. What are farmers' attitudes towards participating in SFD, and how to enhance their enthusiasm for participation?

iii. In what ways should farmers participate in SFD, what are their preferences for SFD schemes, and what payment standard farmers play in cost-sharing for SFD?

iv. Which aspects should policy optimizations be proposed to incorporate farmers' participation in SFD?

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Chapter 2

Concept definition and theoretical basis

1. Types of farmland development and its activities

1.1 Conventional farmland

Between the 1950s and 1970s, China initiated its first large-scale farmland infrastructure construction. However, in the decades that followed, these structures were left without any significant repair or maintenance, resulting in widespread issues of aging, deterioration, low standards, and declining effectiveness in the infrastructure. This is the type of conventional farmland targeted by this study. Its main characteristics include severe fragmentation, dispersed management by smallholder farmers, and a generally low level of infrastructure. For irrigation facilities, some have deteriorated to the point of being unusable, resulting in reliance on flood irrigation. Additionally, some of these farmlands, referred to as “rainfed fields,” lack adequate drainage and irrigation facilities, depending solely on rainfall and offering minimal resilience against natural disasters. Field roads, after decades of use, suffer from unstable roadbeds, worsening conditions, and poorly planned layouts, which lead to ecosystem fragmentation, disruption, and degradation (Jiang et al., 2015; Forman, 2000; Carl, 2006).

1.2 High-standard farmland (HSF)

In 2012, the MARA issued the "Standard for High-Standard Farmland Development" (NY/T 2148-2012), defining high-standard farmland as land that is leveled, contiguous, with deep plow layers, fertile soil without significant obstacles, well-equipped irrigation and drainage facilities, and supporting facilities such as roads, forests, and electricity, capable of meeting the modern production requirements, energy and water conservation, and mechanized operations for crops, achieving sustained high yield, stability, high quality, efficiency, and safety.

Meanwhile, according to the Ministry of Land and Resources, the "Standard for High-Standard Farmland Development" (TD/T 1033-2012) defines high-standard farmland as contiguous, well-equipped, high-yielding, stable, disaster-resistant, and adaptable to modern agricultural production and management within a certain period through farmland development. This includes existing basic farmland that meets the standards after rectification and newly designated basic farmland.

Due to differences in definitions of high-standard basic farmland and high-standard farmland between the Ministry of Land and Resources and the MARA, high-standard farmland development projects could not be implemented. Therefore, under the coordination of the State Council, the MARA and the Ministry of Land and Resources jointly issued the "General Principles for High-Standard Farmland Development" (GB/T 30600-2014). This document redefined the concept of high-standard farmland: high-standard farmland refers to land that is leveled, fertile, contiguous, well-equipped, with supporting infrastructure for agriculture and electricity, high-yielding, stable, and disaster-resistant, and is compatible with modern agricultural production and management methods. It is designated as basic farmland according to regulations.

In 2017, the "Evaluation Norms for High-Standard Farmland Development" (GB/T 33130-2016) were implemented, further refining the definition of high-standard farmland. High-standard farmland is land that is leveled, contiguous, well-equipped, with supporting infrastructure for agriculture and electricity, fertile soil, ecologically friendly, and disaster-resistant. It is capable of achieving high yields and stability in both drought and flood conditions, and is compatible with modern agricultural production and management. It is designated as basic farmland and subject to permanent protection. From the above definition, the basic connotation of high-standard farmland can be summarized as:

1) Farmland with high natural endowment or that can reach the standard of high-standard farmland through remediation;
2) Farmland with large plot size, contiguous and centralized, conducive to realizing economies of scale;
3) Farmland with complete infrastructure and protective forest network, capable of ensuring sustained and stable production capacity and resistance to natural disasters such as droughts and floods;
4) Farmland with favorable location conditions, possessing good spatial stability and less susceptible to land occupation for construction purposes;
5) Farmland with a good ecological condition;
6) Farmland compatible with modern agricultural production and management.

- **High-standard farmland development**

China's land resources are not highly endowed, and the construction of agricultural infrastructure is relatively lagging behind. Currently, apart from some farmland meeting the requirements of high-standard farmland, most farmland has limiting factors that need to be addressed through engineering measures to promote high-standard farmland development. The "General Principles for High-Standard Farmland Development" (GB/T30600-2022) states[5] that high-standard farmland development involves land leveling, soil improvement and fertilization, irrigation and drainage construction, field production roads construction, farmland protection and ecological conservation, farmland power distribution, and other engineering constructions aimed at transforming or comprehensively improving the main limiting factors of farmland, ensuring their efficient utilization. Based on the actual conditions of each region, in accordance with regional characteristics and existing issues with cultivated land quality, this general provides regionally differentiated implementation regulations and standards for various types of projects (see footnote 4).

High-standard farmland development is a powerful means to achieve the dual emphasis on quantity and quality management of cultivated land, optimize land use modes, and improve land utilization efficiency. It is also an important approach to establishing a modern agricultural production and management system, as well as a key platform for the construction of new rural areas and the coordinated development of urban and rural areas. This research defines high-standard farmland development based on the connotation of high-standard farmland, as the implementation of engineering, biological, economic, policy, and other measures to eliminate crop growth limiting factors, promote efficient and sustainable resource utilization

[5]https://www.ja.gov.cn/group2/M00/25/03/wKgSGmMzmkGAPodmAB_hklv5FJ4220.pdf

activities, and meet the needs of high-yield and stable production and modern production and management of main crops in the region.

In terms of the content of high-standard farmland development, it mainly includes engineering of land leveling, irrigation and drainage, field road, farmland and ecological conservation. Among them, land leveling engineering refers to measures such as land contiguous transformation conduct to meet the needs of farmland cultivation and irrigation. Irrigation and drainage engineering refer to engineering measures taken to prevent and control disasters such as drought, flooding, waterlogging, and salinization in farmland, including engineering of water source, water conveyance, irrigation, drainage, canal construction, pump stations, and power transmission and distribution. Field road engineering refers to engineering measures taken to meet the needs of agricultural material transportation, cultivation, and other agricultural production activities. Farmland and ecological conservation engineering refer to various measures taken to ensure the safety of land use activities, maintain and improve ecological conditions, and prevent or reduce pollution and natural disasters, including construction of farmland forest network, channel governance, and slope protection. The main contents of engineering construction are shown in Table 2- 1.

Table 2- 1 The major activities and targets of high-standard farmland development[6]

Activities	Targets
Irrigation Engineering	Improving the efficiency of agricultural irrigation water utilization and enhancing the drought-resistant capacity of farmland.
Drainage Engineering	Conversion of saline land and enhancement of farmland resistance to flooding.
Farmland consolidation engineering	Realization of land consolidation and management to reduce the degree of fragmentation of cultivated land.
Field road paving and hardening	To meet the requirements of agricultural machinery to operate and transport of agricultural products.
Agricultural forestry network construction	Regulate microclimate and maintain eco-balance of farmland.

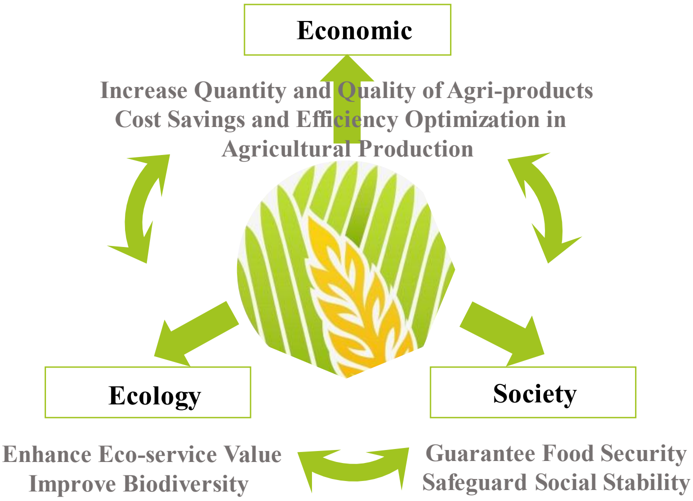
1.2Sustainable farmland (SF)

Based on the content of high-standard farmland development, its construction mode focuses on achieving the goal of centralized farmland and supporting infrastructure through engineering measures to achieve efficient resource utilization, but it neglects the promotion of agronomic measures and ecological construction. Extensive agricultural production modes, excessive use of inputs, and indiscriminate disposal of

[6] China High-Standard Farmland Construction Plan (2021-2030) (ndrc.gov.cn)

agricultural waste are the root causes of land degradation and ecological problems. Related studies show that the number of chemical fertilizer inputs has significantly exceeded the optimal interval for economic and environmental efficiency in agriculture in China, which not only decreased the international competitiveness of agricultural products but also aggravated the problems of resource consumption and environmental pollution, which is not conducive to the development of sustainable agriculture(Gu et al., 2015; Jingjing et al., 2019). The latest general rules of high-standard farmland development put forward the concept of sustainable development throughout farmland development. It aims to strengthen the intensive and economical utilization of water and soil resources' ecological and environmental protection by optimizing the construction of farmland infrastructure and reasonably setting up soil quality improvement activities[7].

SFD aims to improve soil fertility, prevent and control agricultural non-point source pollution, restore ecological conservation, and enhance farmland biodiversity through two main measures: constructing ecologically farmland infrastructure and promoting agricultural production practices with superior environmental and economic benefits. Compared to high-standard farmland, SFD adheres to the concept of sustainable development, placing emphasis on agricultural production, sustainable resource utilization, and ecological construction. It represents an exploration in the new farmland. The "economic-environmental-social" benefits of SF will far exceed those of general farmland (Figure 2-1), with main construction activities outlined in Table 2-2.



[7] General Rules for the Construction of High-standard Farmland (GB/T30600-2022) (jsgg.com.cn)

Figure 2- 1 The Benefits of Sustainable Farmland Development (SFD)

Table 2- 2 The major activities and targets of SFD

Developing Sustainable Farmland	Engineering and production management indicators	Facilities and technical specifications
Farmland ecological infrastructure construction project	Land consolidation	**Land integration** **cultivated land building**
	Farmland ecological circulation water network	**Integrated water and fertilizer facilities** **Ecological drainage and irrigation ditches** Ecological weir Irrigation water pretreatment system Water quality online monitoring station
	Farmland ecological corridor	**Mechanized farming road** **Ecological field ridge** Alley cropping zone
	Farmland ecological landscape	lounge bridge Plank road pergola
	Restoration of farmland biodiversity	Habitat of pollinators Natural enemy conservation area Field ecological forest island
	Farmland quality control and inspection	Location monitoring of cultivated land quality On-line monitoring of farmland drainage and irrigation
Environmental-friendly agricultural production practices	Chemical input reduction control	**Fertilizer reduction, organic fertilizer replacement technology** **Soil testing and formula fertilization technology**

		Physical and biological prevention and control
		Water-saving irrigation technique
	Disposal of waste resources	**Straw-return**
		Recycling of agricultural waste plastics

Note: The study focuses on farmer participation, so in the pre-survey we identified some construction items that are not closely related to farmers. The content in bold font is the construction items involved in the questionnaire.

To summarize the application of the above policy documents, the publication of the "General Rules for High-Standard Farmland Development " (GB/T30600-2022) aims to accurately align with the "High-Standard Farmland Development Plan (2021-2030)". This plan not only outlines the framework for China's farmland development over the next decade but also introduces the core concept of sustainable farmland development. By adopting a strategy of pilot projects and demonstration leadership, the plan aims to transform this innovative concept into actions for farmland renovation and upgrading, leading high-standard farmland development to new heights. Currently, high-standard farmland development remains a central task in advancing China's agricultural modernization. In mature regions, sustainable farmland development pathways and schemes are being actively explored and implemented. Simultaneously, the establishment and optimization of evaluation systems are being carried out to determine the best long-term development strategies for sustainable farmland, ensuring they align closely with and mutually promote modern agricultural development strategies.

The "Evaluation Standards for High-Standard Farmland Development " (GB/T33130-2016) serve as a benchmark for assessing the effectiveness of farmland development and project acceptance. This standard provides a scientific and unified evaluation criterion for the entire process of high-standard farmland development, ensuring the effectiveness of the construction outcomes. It is the most direct and comprehensive guide for directing farmland development work both now and in the foreseeable future.

2. Theoretical bases

2.1Public Goods Theory

Public goods is a modern economic theory that studies public affairs and is a fundamental theory of new political economy. As early as 1739, philosopher David Hume first proposed the concept and preliminary classification of "public goods" in his "Treatise of Human Nature." In 1939, economist Paul Samuelson published the paper "The Pure Theory of Public Expenditure." Later, Samuelson transformed his empirical research results into normative theory and published "The Pure Theory of Public Expenditure" in 1954, initiating modern economic research on the theory of public goods. He proposed a strict definition of public goods, arguing that public goods are products whose consumption by one individual does not reduce the consumption of the same product by others. Compared to private goods, public goods have three basic characteristics: non-rivalry in consumption, non-excludability, and non-competitive consumption. Since the 1970s, research on public goods has focused on how to design mechanisms for decision-makers to ensure the effectiveness of public goods supply. Due to the inherent inefficiency of private sector provision of public goods, competitive markets cannot achieve the Pareto optimality of public goods. Therefore, public goods are often provided directly by government agencies through non-market means to achieve efficient resource allocation.

In real economic life, purely public goods and private goods are not universally present. Farmland and its infrastructure possess the characteristics of public goods and belong to the quasi-public goods (Jin et al., 2021; Mogues et al., 2015). Firstly, they exhibit non-rivalry in consumption. For example, roads, ditches, or other infrastructure built have non-competitive features. Before reaching a congested state, the use by any individual does not affect others' use. Secondly, they have non-excludability in consumption. For instance, farmland protection forests, and flood prevention measures, are non-excludable. These facilities are not exclusively enjoyed by certain individuals, excluding consumption by others. Thirdly, they have indivisibility in effective use. Farmland development can lead to ecological improvements and comprehensive agricultural benefits increasement, which are shared by members within a certain region and cannot be divided into separate parts. Therefore, agricultural construction policies and systems must be guided by the theory of public goods. While the government has the capacity and necessity to provide public goods, it does not necessarily mean that the alone bear the responsibility for supplying public goods. For a long time, there has been a shortage of public goods supply in China, and the existing supply of public goods has been inefficient in service and operation. To address this situation, it is necessary for the government to introduce market mechanisms into the process of providing public goods. Regarding the current supply of public goods in farmland development in China, the system arrangement should gradually shift from being solely provided by the government to a mechanism where the government is the main supplier and diversified production entities are involved, aiming to achieve the optimal institutional mode and arrangement (Xia Shi, 2015; Jiansheng Liu, 2016; Yang Xiang, 2015).

2.2 Farmer Behavior Theory

Traditional Western economic theories regarding farmer behavior can generally be summarized into three viewpoints. Firstly, there is the hypothesis of the "rational economic man" based on neoclassical economics, which suggests that all agricultural production and management activities undertaken by farmers are rational, with the ultimate goal of maximizing profits. Secondly, there is the hypothesis of "bounded rationality," which suggests that farmers' behaviors are influenced by external factors, leading to deviations from their ideal profit goals. Thirdly, there is the rapidly developing field of behavioral economics, which incorporates psychological factors into the analysis framework of farmer behavior, improving the accuracy of predicting farmer behavior and advancing the development and evolution of farmer behavior theory.

- **Rational farmers and farmers with bounded rationality (Popkin**

Samuel, 1979)

Farmers always aim to maximize profit when making production decisions, and all their production activities are "rational", leading to the perfect allocation of production factors. This viewpoint is in line with the analytical logic of classical economics and is known as the "rational economic man" hypothesis. "Maximizing economic benefits" is the basic assumption of rational farmer analysis in classical economics. Within this analytical framework, farmers are considered to be emotionless, completely rational independent economic agents. The essence of their behavior lies in the fact that farmers have sufficient information and rely entirely on the information they possess to allocate inputs and outputs. They weigh the benefits under different input-output scenarios and choose the Pareto optimal solution that maximizes their economic benefits. In fact, farmers' production decisions are faced with risks and uncertainties, which the rational farmer assumption fails to consider, thus unable to accurately reveal relevant information. In response, the theory of bounded rationality has made some adjustments to the classical economic analysis framework in the paper "Bounded Rationality Theory," proposing that under conditions of risk, uncertainty, and incomplete information, individual decisions are not aimed at maximizing profit but rather selecting satisfactory solutions from alternative options. It can be seen that "bounded rationality" relaxes certain conditions related to the assumption of the "rational economic man" based on classical economics to some extent, but fundamentally does not negate the assumption of the "rational economic man". Nevertheless, in reality, farmers' production decision objectives are not solely profit-driven. Therefore, compared to the "rational economic man" assumption, the "bounded rationality" assumption is closer to reality.

- **Behavioral Economics**

Under traditional analytical logic, both the rational farmer behavior assumption and the assumption of bounded rationality exclude psychological factors from the systematic analysis framework, resulting in many farmer behaviors being difficult to explain effectively (CHETTY et al., 2015). In contrast, behavioral economics recognizes the important role of psychology in individual decision-making and is more aligned with the actual decision-making process of farmers. This is also the reason for the rapid development of behavioral economics in recent years. Behavioral economics does not completely overturn classical economics but rather incorporates psychological factors into the traditional economic analysis framework, serving as a complement and improvement to traditional economics. According to the viewpoint of classical economics, when the costs of engaging in certain agricultural production activities exceed the benefits, farmers will inevitably make "no-action" decisions. However, in reality, even when the benefits are low or even non-existent, farmers are still willing to take action under specific circumstances, which traditional economic theory cannot reasonably explain. RABIN (1998) believes that individuals' behavior not only pursues economic interests but also considers other goals. This perspective deviates from the assumption of the "economic man" and requires appropriate adjustments to the utility assumptions of classical economics, which is the context in which behavioral economics has developed.

2.3 System Engineering Theory

System theory was first proposed by the Austrian biologist L.V. Bertalanffy in 1932, and the principles of general systems theory were put forward in 1937. The publication of the monograph "General System Theory: Foundations, Development, and Applications" in 1968 formally established the academic status of this science. Bertalanffy believed that a system is a comprehensive entity composed of multiple elements that are interconnected and interact with each other, each with specific functions. The integrity of a system is not simply the sum of its individual elements; rather, it involves new qualities that the individual elements do not have in isolation. It not only possesses the functions of its individual elements but also new functions produced by the interaction of these elements, which is known as "the whole is greater than the sum of its parts." System theory is a scientific study of the characteristics, laws, functions, structure, and inherent interactions of systems. The task of system theory is to treat the research object as a system, starting from the whole, analyzing the relationships between the system and its elements, between the internal elements of the system, and between the system and its environment. By utilizing the characteristics and laws of systems, it aims to control, manage, and transform systems to achieve optimization and meet human needs.

Farmland development is a complex technical and social governance project involving multiple entities, multiple stages, and multiple disciplines. It encompasses various aspects including implementing entities, organizational methods, fund-raising, operation modes, and supervision management. In the process of farmland development, it is necessary to utilize the viewpoints and methods of systems theory to analyze from a holistic perspective. In the early stages of farmland development, the land to be rectified should be viewed as a land ecological-economic system to ensure the comprehensiveness of all elements on collected, enabling overall analysis and coordinated planning, and then determining the best rectification plan. Evaluation of farmland benefits should be comprehensive, considering social, economic, ecological, and other aspects, rather than focusing solely on one aspect. Throughout the entire process of farmland development, emphasis should be placed on the overall perspective, not only on innovative and applied engineering technologies but also on the optimization and improvement of social governance, to ensure the efficient and smooth progress of farmland development.

2.4 Sustainable development Theory

The theory of sustainable development originates from human reflection on and struggle against the environmental problems brought about by economic development. In 1962, "Silent Spring" pointed out the serious phenomenon of environmental pollution, which raised human concern about environmental issues and awakened environmental awareness. Since then, "environmental protection" has become a focal point of government public policies. In 1972, the United Nations held the first "Conference on the Human Environment," initiating discussions on environmental and developmental issues, establishing global environmental protection strategies for the first time, and adopting the "Declaration on the Human Environment." In 1980, the United Nations Environment Programme and the International Union for

Conservation of Nature jointly released the "World Conservation Strategy," which systematically elaborated that the core of protection lies in the coordinated development of population, resources, and environment, and sustainable development is an important foundation for the sustainable utilization of land resources and a key guarantee for the coordination of human-land relationships. In 1987, the World Commission on Environment and Development, in its report titled "Our Common Future," consistently advocated the concept of sustainable development throughout. In 1989, the United Nations Environment Programme passed the "Declaration on Sustainable Development," which defined sustainable development as the coordinated development of the economy, resources, and environment. In 1992, the United Nations Conference on Environment and Development first proposed the Agenda 21 for Sustainable Development, calling on countries worldwide to translate the concept of sustainable development into concrete action plans, marking the maturity of the idea of sustainable development. In 2002, the United Nations Sustainable Development Summit clarified that sustainable development is a common theme for humanity, aiming to promote comprehensive social development through a healthy ecological, sustainable use of natural resources, and sustainable economic growth.

The implementation of sustainable development strategy in China stems from the proposal of the Agenda 21 for Sustainable Development in 1992. The central government subsequently issued the "Ten Key Strategies for China's Environment and Development," emphasizing the need to change traditional development strategies and pursue the pathway of sustainable development. Subsequently, the central government successively introduced the "China Agenda 21" and the "National Outline for Ecological Protection," placing sustainable development strategy in an important position and emphasizing the need to strengthen ecological protection efforts. In 2007, the 17th National Congress of the Communist Party of China made a scientific summary of the basic requirements for sustainable development, emphasizing both strengthening ecological protection and focusing on resource conservation. In 2012, the 18th National Congress of the Communist Party of China further proposed the concept of green development and the vision of building a beautiful China, and for the first time put forward the idea of ecological civilization. The 19th National Congress of the Communist Party of China in 2017 proposed to accelerate the reform of the ecological civilization system, and the Fourth Plenary Session of the 19th Central Committee of the CPC in 2019 proposed to improve the system of ecological civilization and implement the strictest system of ecological protection. Therefore, the concept of sustainable development is gradually deepening in the process of promoting environmental protection, green development, building a beautiful China, and constructing ecological civilization, in response to the requirements of the times by the Party and the country. The basic principles of sustainable development theory are: fairness, sustainability, and coordination. Fairness is the fundamental principle of sustainable development, and development should follow the fairness between human and nature, and between human and society, while also considering intergenerational and intragenerational equity, and emphasizing the fairness of natural resource allocation. Sustainability is the core of sustainable development, and development must not exceed the carrying capacity of natural resources and the environment, thus ensuring the sustainable development of human society. Coordination is the fundamental aspect of sustainable development, as development must involve the balanced development of the economy, environment, and society, ultimately achieving harmony and unity between human, society, and nature. The core of sustainable development is to promote economic growth while protecting natural resources and the productivity of ecosystems. It is not only about achieving economic sustainability but also social and ecological sustainability. The goal of economic sustainability is not just about capital accumulation but also about achieving high-quality economic development. Therefore, it is necessary to move away from the previous high-input, high-pollution production modes and promote greener production modes, while strengthening the transformation of economic development concepts. Social sustainability aims to achieve harmony between humans and nature. Improving the social environment should reflect the principle of fairness, including optimizing population structure, improving population quality, and enhancing social security. Ecological sustainability involves reshaping the relationship between humans and nature, positioning humans as part of nature. It requires the rational use of natural resources and the protection of ecosystems, with a key focus on environmental carrying capacity. Only by balancing resource and environmental carrying capacity while achieving economic and social development can the ultimate goal of sustainable development be realized.

In today's era, agricultural land construction should be guided by the theory of sustainable development, ensuring that the constructed farmland can achieve permanent protection and sustainable utilize. It is not only about leaving enough land for future generations but also about preserving high-quality and high-yield arable land, laying a solid foundation for the sustainable and stable growth of food production in our country.

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Chapter 3

Research objectives and thesis outline

1. Research objectives

The research aims of thesis are twofold: first, to explore the demand for regional farmland development and the paths for institutional optimization in the context of sustainable agricultural development. Second, to study the specific institutional arrangements for farmers' participation in sustainable farmland development from a farmland development management perspective.

To address the first aim, the thesis presents the necessity and urgency of sustainable farmland development in the Yellow River Basin based on the current policies and development status of regional farmland development in China. By reviewing current research on farmland development and global experiences in the development of farmland development, the study summarizes and draws lessons from successful experiences, identifies research and development limitations, and clarifies the key issues that this study aims to address. These issues should be tackled by involving stakeholders to overcome institutional inefficiencies in farmland development. The study is based on theories of sustainable development, systems engineering, public goods, and farmer behavior to identify and break down the barriers to farmers' participation in sustainable farmland development, thus demonstrating the rationality of farmers' participation.

To address the second aim, the research constructs a logical framework of "farmland development benefits - farmers' participation attitudes - farmers' participation schemes" to create a mechanism for farmers' participation in SFD. It is worth noting that the research theme is tightly centered on sustainable farmland development. Therefore, both the benefit evaluation and the content of farmers' participation in construction will involve environmental factors. However, this study takes an agricultural economics perspective to address institutional optimization issues, which defines the boundaries of the environmental factors considered. For instance, pollution emissions are a key focus in evaluating farmland benefits because they are directly related to agricultural non-point source pollution. However, biodiversity issues are not specifically addressed, as they are not directly related to farmers' interests in farmland development. Below is a detailed introduction to the core research objectives:

1.1Muti-objective effect evaluation on different farmland systems

The evaluation study aims to clarify the integrated benefit performance of SF, on the one hand, to provide the optimization strategy of different farmland systems in this new era of SFD, providing a theoretical basis for further improving the management of farmland systems. On the other hand, it demonstrates the clear benefits of SF, which gives the stakeholders a quantified and more concrete benefit data, and stimulates their enthusiasm to participate in SFD.

Using the farmland development and production management as boundaries, the study conducts a comprehensive evaluation of the benefits of different levels of farmland development and operation. In this study, to better understand the specific contribution and development dilemma from different farming systems, multiple assessment indicators such as LCA, LCC, CBA, net ecosystem economic benefit (NEEB) and scenario simulation were applied into assessment system. In general, the assessment includes economic and environmental benefits. For economic benefits, the study focusses on crop yield, net ecological economic benefits, costs, and outputs (Colomb et al., 2013; Craheix et al., 2016; Loyce et al., 2012). Environmental benefits are assessed using the LCA method to measure changes in environmental factors during the construction and utilization of farmlands, such as greenhouse gas emissions. Finally, a comparative analysis of multiple evaluation factors reveals the diverse benefits of different farmland systems. Based on this, and according to the medium- and long-term planning goals of farmland development, we simulate staged farmland development benefits within the region to derive optimized schemes for different farmland systems and provide policy guidance.

1.2 Analysis of farmers' willingness to participate in SFD and its influences

Guiding the stakeholder participation is a key solution to crack the inefficiency of farmland development. Farmers have stable contractual rights to farmland (30 years per tenure)[8], and they are also the most direct subjects of farmland utilization. Consequently, the second objective of this study aims to examine farmers' attitudes towards participation in SF, and to understand the factors influencing their willingness to participate from a psychological perspective.

Based on the Theory of Planned Behavior, to develop an improved framework, ETPB, to provide a comprehensive understanding of the causal relationships with concerning farmers' behavior intention to contribute to SFD. In particular, this study examines farmers' willingness to participate in SF development by focusing on three psychological factors: perceived value of SF, social norms, and perceived behavioral control. Using Structural Equation Modeling (SEM), the study analyzes these factors and further introduces two external factors—current agricultural production conditions and policy evaluation—to explore their regulatory effects on the formation of farmers' willingness. Through a social psychology model, the study clarifies the pathways influencing farmers' intentions to contribute to SF. Ultimately, this research not only identifies SF development content that aligns with farmer participation based on theoretical analysis but also delves into institutional arrangements that can guide and enhance the enthusiasm of stakeholders to participate in farmland development activities.

1.3 Research on Farmers' Participation Preferences and Their Payment Level in SFD

For the discussion of farmers' participation, from the formation of farmers' willingness to the expression of participation behavior, a reasonable participation scheme is still needed at the institutional level. Objective 3 of this study aims to construct a scenario based on sustainable farmland development financing activities, to comprehensively understand the current situation of regional farmland and the

[8] https://www.gov.cn/zhengce/2019-11/26/content_5455882.htm

actual needs of farmers for improving the farmland system, to clarify farmers' preferences for participation and their payment level. Achieving this objective can provide an accurate reference for constructing a farmer participation scheme.

This study aims to analyze farmers' preferences for ecological infrastructure by investigating their demand, construction levels, and marginal willingness to pay for infrastructure. First, the Random Parameters Logit (RPL) model is used to understand farmers' preferences for participating in sustainable farmland development. Second, by considering factors such as farmers' livelihood endowments, risk preferences, land tenure, and farmland conditions, a Latent Class Model (LCM) is constructed to identify the factors influencing farmers' preference choices. Finally, based on these results, the study explores how to optimize the farmland infrastructure construction system by combining farmers' endowments, production needs, and farmland characteristics, and provides a theoretical basis for developing diversified ecological infrastructure participation standards for farmers.

2. Thesis outline

Thesis focuses on farmers' participation in SFD, guided by theories of public goods, systems engineering, and planned behavior. It aims to construct an analysis framework for the participation mechanism and post-construction evaluation of SF development. The specific idea is as follows:

First, starting from the significant role of SFD in ensuring food security, it addresses the practical issue that needs to be resolved—how to promote the improvement of farmland development standards to achieve efficient and long-term operation? By reviewing relevant domestic and international literature, the paper elucidates the main focus of existing studies and summarizes their shortcomings. Consequently, it proposes the research theme: " Exploring Farmers’ Participation Mechanisms for Sustainable Farmland Development in the Yellow River Basin, China." **(Chapter 1)**

Second, thesis defines relevant concepts, reviews the theoretical foundations, and clarifies the framework for SFD. On one hand, it establishes the system boundaries for evaluating SFD and management, forming the structural support for the entire text. On the other hand, it clarifies the main construction activities involving farmer participation and analyzes the modes and pathways of farmer participation. **(Chapter 2)**

Next, it introduces the current situation of arable land and farmland development in China, explains the selection of the study area and the data collection process, and identifies the obstacles to farmland development and agricultural production in different regions. Based on the farmland system's "production-livelihood-ecology" needs, it identifies the elements of SF and their construction components, providing support for the rational planning of SFD. **(Chapter 3)**

Subsequently, using the construction and utilization stages of farmland as the system boundaries, the study conducts a comprehensive benefits evaluation of different grades of farmland and their management modes. It establishes that understanding the comprehensive benefits of SF is fundamental to adjusting construction activities and improving the institutional framework. Quantifying benefits is more conducive to guiding the participation of diverse stakeholders in SFD. **(Chapter 4)**

Thesis explores the objective and subjective constraints on farmers' willingness to participate in SFD based on SEM (Structural Equation Modeling) and TPB (Theory of Planned Behavior). It addresses the issue of farmers' "lack of willingness," which poses challenges to farmland development, and aims to motivate their participation. **(Chapter 5)** Using Choice Experiments (CEs), the paper analyzes and determines farmers' preferences and marginal willingness to pay for infrastructure improvement projects in SF systems. This helps to adjust farmland management with farmer participation and alleviate the overwhelming budget burden of high investments in China. **(Chapter 6)**

Finally, the paper summarizes the research findings and constructs an institutional framework for farmer participation in SFD. It outlines the main conclusions of the study, highlights its limitations, and suggests directions for future research. **(Chapter 7)**

Based on the theoretical logic and approach of the study, the technical roadmap is illustrated as shown in the Figure 3-1.

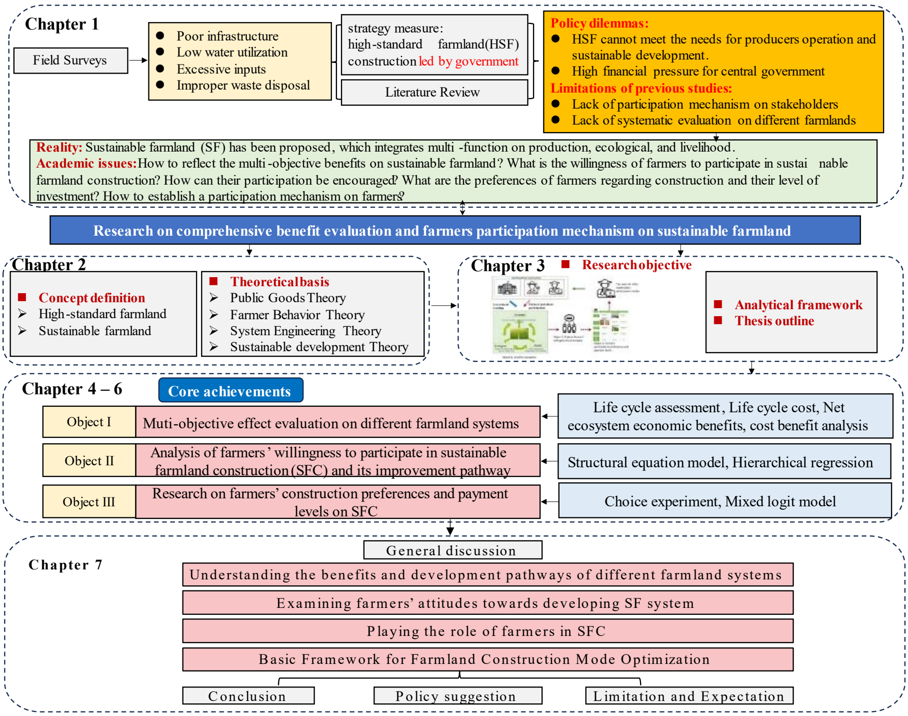

Figure 3- 1 Thesis Framework

3. Methodology

1）Literature Analysis: By integrating existing research findings from national and international scholars, this method aims to grasp the latest research trends in farmland development. It involves drawing on valuable perspectives and methodologies from existing studies. Based on economic theories, particularly those from resource and environmental economics, circular economics, and behavioral economics, this method defines the concept of sustainable farmland, identifies its attributes, thoroughly analyzes its current development status, and diagnoses the challenges in farmland development and management.

2）Questionnaire surveys and interview investigations: Farmland development is a systematic project that must cater to the actual needs of relevant stakeholders and agricultural production. It involves various types of construction activities, and existing statistical data and literature cannot fully meet the needs of this study. Therefore, data must be obtained through surveys. This method aims to collect data on different farmland conditions, current usage, and needs from multiple perspectives and channels to ensure comprehensive information acquisition. Simultaneously, it involves gathering relevant technical data, socioeconomic data, energy consumption data, pollution emission data, stakeholder demands, and institutional arrangements in different regions to prepare for subsequent analysis.

3）Case study: In this study, sustainable farmland, high-standard farmland, and ordinary farmland will be selected as typical cases for data collection and comparative analysis. Using the analytical paradigm of life cycle assessment (LCA), combined with life cycle cost (LCC), cost-benefit analysis (CBA), net ecosystem economic benefit (NEEB), and multi-objective comparative analysis, the study will compare the performance of different types of farmlands in terms of resource conservation, environmental friendliness, and economic efficiency. The advancements in assessment methods significantly enhance academic understanding of the relationship between agricultural activities and their environmental–economic impacts, providing a more robust framework for evaluating sustainable development in agriculture. The specific application and detailed calculation process of these methods are related to Chapter 4.

4）A combination of quantitative and qualitative analysis methods: The qualitative analysis method involves using induction and deduction, analysis and synthesis, and abstraction and generalization to process various materials obtained from literature reviews and actual questionnaire surveys. This allows information relevant to the research to be systematically and coherently presented. The quantitative methods mainly include a series of econometric models, with Ordinary Least Squares (OLS) and Structural Equation Modeling (SEM) applied in Chapter 5, and Mixed Logit Model (XLM) and Latent Class Model (LCM) in Choice Experiments (CEs) applied in Chapter 6. Among them, the extended theory of planned behavior (ETPB) framework was employed in Chapter 5 to illuminate the drivers of farmers' participation in SFD by introducing policy evaluation (PE) and agricultural production conditions (APCs) to enrich the literature. In chapter 6, CEs can more accurately examine farmers’ preferences and quantify the willingness. The specific application of these models and their calculation processes are detailed in the research methods sections of the respective chapters.

4. Study area and data collection

4.1 Study area

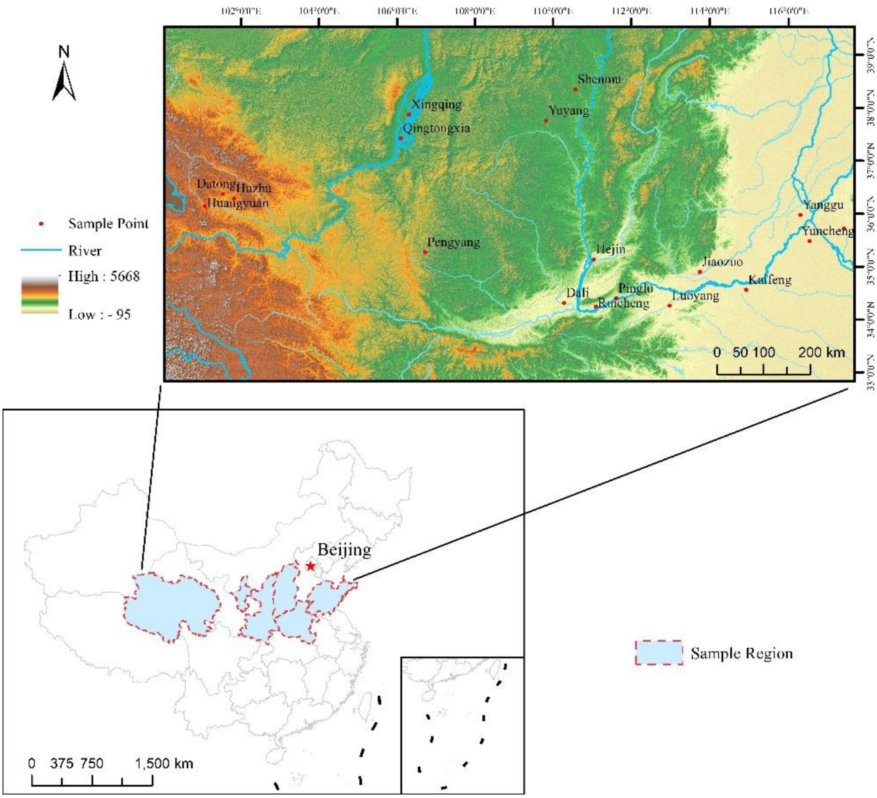

Figure 3- 2 Study area

Six provinces (autonomous region) in the Yellow River Basin, including Qinghai, Ningxia, Shaanxi, Shanxi, Henan, and Shandong, were selected as the study areas. The Yellow River Basin is a crucial ecological barrier and an important economic zone in China, spanning the Qinghai-Tibet Plateau, Inner Mongolia Plateau, Loess Plateau, and Huang-Huai-Hai Plain. The basin covers an area of 795 thousand square kilometers, with 47 million ha of cultivated land. In 2023, the total population of these six provinces (regions) was 288.49 million, with a rural population of 109.96 million. This area had a GDP of CNY 21,587.5 billion, a total agricultural output of CNY 1,787.8 billion, and a total grain production of 155.78 million t, accounting for about one-fifth of China's total. It holds a significant position in regional economic and social development.

In recent years, agricultural and rural development in the Yellow River Basin has shown a positive trend, with comprehensive agricultural production capacity continuously improving. However, some deep-seated contradictions and issues in agricultural and rural development and ecological construction have gradually emerged. These are mainly manifested in the overall shortage of water resources, severe soil erosion, and the daunting challenge of controlling agricultural non-point source pollution. Additionally, there are issues of fragmented farmland, highly dispersed operations, low standards for infrastructure such as irrigation, drainage, and production roads, weak supporting capabilities, and relatively outdated technologies. In 2021, the Green Farmland Development and High-Quality Agricultural Development Project for the Yellow River Basin was officially proposed. This project provides an excellent opportunity to improve the standards of farmland infrastructure and enhance farmland systems in the region. This study is based on preliminary strategic research for the project, using sustainable farmland development as a breakthrough point. It aims to identify specific tasks for the sustainable transformation of farmland infrastructure construction and agricultural production practices according to the differentiated needs of ecological construction and agricultural industry development in the upper, middle, and lower reaches of the Yellow River. Moreover, in response to the new round of farmland development planning and related policies that encourage farmers' participation in farmland development, this study will focus on innovating and improving SFD mode by involving farmers as primary participants. It is intended to safeguarded the efficient implementation of the project and provide a reference for institutional innovation in other related projects.

4.2 Survey and the Plan of Field Sampling

4.2.1 Respondent

The respondents in this study were from six typical provinces (autonomous region) in the Yellow River Basin, including Qinghai (Datong, Huzhu, and Huangyuan), Ningxia Autonomous Region (Qingtongxia, Xingqing, and Pengyang), Shaanxi (Dali, Yuyang, and Shenmu), Shanxi (Hejin, Pinglu, and Ruicheng), Henan (Kaifeng, Jiaozuo, and Luoyang), and Shandong (Ningyang, Yuncheng, and Yanggu), covering a total of 18 counties. The subjects included farmland operators and village committee members from 54 villages. Given the varying socio-economic conditions (population, income, education, etc.), natural resource conditions (cultivated land, water, climate, etc.), and levels of agricultural production and farmland development across the provinces (autonomous region), the sample was diverse. Since Chinese agricultural production is still predominantly composed of smallholder farmers, with the number of new agricultural business entities (NABE) (family farms, agricultural professional cooperatives and agricultural business) continuously increasing, our respondents were mainly farmland operators, including smallholder farmers and NABE. Moreover, as village collective are the owner of farmland property rights and are knowledgeable about the farmland development and agricultural industry structure in their villages, village committee members were also included in the interviews. Furthermore, the study involved interviews with local government officials and market service providers who contribute to farmland development.

4.2.2 Questionnaire Sample

The sampling adopts a combination of "typical sampling, expert guidance, stratified sampling, and random sampling."

First, based on the land types in the Yellow River Basin, the upstream areas of Qinghai Province and Ningxia Autonomous Region, the midstream areas of Shaanxi and Shanxi Provinces, and the downstream areas of Henan and Shandong Provinces will be selected as key regions.

Second, considering the socio-economic conditions, resource endowments, and agricultural industry structures of each province, as well as the cost of survey processing, a stratified random sampling method will be employed. Three counties (cities or districts) will be selected from each province. In each county, three administrative villages will be stratified and selected.

Third, in each village, 12-15 farmland operators and 1-2 village committee members will be randomly selected. Additionally, based on the development of new agricultural business entities in each county (city, or district), approximately 5-10 samples will be randomly selected for interviews.

4.2.3 Survey Tool

This survey will be conducted using the Questionnaire Star software on iPads. The questionnaire will be pre-entered into the software with relevant question thresholds set to check for errors or deviations from the actual data. The electronic questionnaire will be completed using iPads, and interviewers will conduct face-to-face interviews with respondents to enhance the efficiency and quality of the survey.

4.2.4 Survey Design

The questionnaire is divided into three levels: village level, household level, and farmland development providers. The village level mainly covers basic farmland information such as cultivated area, infrastructure, agricultural production structure, and agricultural input-output situation. The household level includes basic information on smallholder farmers, family farms, and professional cooperatives, as well as farmland management inputs and construction needs. The farmland development providers' level includes construction area, engineering input materials and estimates, and contracts.

4.3 Implementation Plan

4.3.1 Pre-survey

The study selects 2-3 villages to conduct a pre-survey and revise the questionnaire based on the pre-survey feedback.

4.3.2 Investigation and Sampling Training

To effectively control implementation costs and ensure the quality of the questionnaire, the survey team consists of PhD and master's students from laboratory of agricultural resource utilization and zoning innovation (IARRP, CAAS), as well as graduate students from agricultural universities in the sampled provinces. Before conducting the survey, I provided training on questionnaire administration and sampling techniques to the recruited graduate students, ensuring that the interviewers fully understand the survey objectives and plan.

4.3.3 Organization and Coordination

Before conducting the survey, I contacted the relevant departments and officials of the selected provinces, counties, and cities to explain the survey's purpose and intent. The CAAS will provide organizational coordination and technical support for the field survey to ensure its smooth implementation.

4.4 Data Processing and Analyzing

4.4.1Quality Control of the Data

Using survey software reduces the likelihood of systematic bias during data collection and editing. Throughout the survey, methods such as on-site checks, questionnaire supervision, and record inspections will be employed to ensure data quality. Additionally, statistical methods will be used to regularly check all variables in each questionnaire.

4.4.2Data Entry and Cleaning

The data collected from the survey will be exported and cleaned. In the first stage, the basic cleaning phase will focus on correcting errors that occurred during implementation, such as handling incorrect information entered by interviewers and invalid questionnaires, and correcting errors in household sample codes. In the second stage, a database will be established. Incorrect variable names, labels, and values will be corrected. Missing data or abnormal values will be verified and corrected through recordings or telephone interviews.

4.4.3Data Analysis Method

Firstly, based on the collected data, descriptive statistical methods will be used to present personal information of the respondents, farmland conditions, agricultural production status, and the current state and needs analysis of farmland development. Secondly, relevant econometric models will be introduced according to the research content to verify the effectiveness of the collected data in addressing the research questions. Thirdly, interview records, data materials, and other information from new agricultural business entities and farmland development departments will be organized to form typical cases as supplements to the research.

Chapter 4

Evaluation on the integrated benefits of different farmland systems

1. Introduction

To advance the United Nations Sustainable Development Goals (SDGs), proactive measures are being implemented to improve the global agricultural system. The total grain production has consistently exceeded 650 million tons for 8 consecutive years in China, with a 0.5% increase in 2022[9], making a significant contribution to achieving "Zero Hunger" of the SDGs. However, it is assessed that adverse ecological environment continues to pose challenges to achieving the 2030 strategic target in China[10]. In particular, the extensive management practices reliant on resource consumption bring about negative environmental impacts, the decreased marginal effect of increased grain yields in agriculture production (Han and Zhang, 2020; Jingjing et al., 2019; Liu et al., 2018; Wanger et al., 2020) .

In recent years, Chinese government has implemented a series of green development initiatives aimed at promoting sustainable agricultural transformation, establishing an environment conducive to efficient output, resource conservation, and eco-friendliness. Transforming the traditional cropping management mode has been a key focus, achieved through technological innovation, mechanization promotion, and appropriate scaled farming(Gou et al., 2015; Liao et al., 2022; Yang et al., 2021). Consequently, industrial agricultural organizations, often referred to as New Agricultural Business Entities (NABE), have been developed, comprising 3.9 million family farms and 2.2 million farmer cooperation units to date[11]. Simultaneously, the construction of high-standard farmland (HSF) has emerged as a priority strategy, integrating land consolidation, improving machine road, irrigation ditch, and other infrastructural enhancements. By 2020, a total of 53 million ha of HSF had been constructed(Yin et al., 2022).

With the promotion of constructing HSF, the Chinese government issued the "no.1 document", stabilizing the area of grain production and focusing on crop yield in 2023, which requires that agriculture production should fulfill the commitment reducing carbon dioxide emissions and ensuring carbon neutrality to maintain low-carbon and high-quality development[12]. Therefore, integrating "production, ecology and livelihood" has become an important measure in constructing sustainable farmland (SF) to meet the aforementioned requirements[13]. In the SF proposal, a novel system boundary of farmland development was proposed, primarily consisting of farmland infrastructure construction and cropping management activity. In detail,

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[9] http://www.gov.cn/xinwen/2022-12/14/content_5731827.htm
[10] https://www.fao.org/3/cb6872en/cb6872en.pdf
[11] https://m.gmw.cn/baijia/2022-12/26/36256469.html
[12] http://www.moa.gov.cn/ztzl/2023yhwj/zxgz_29323/202302/t20230214_6420463.htm
[13] http://www.moa.gov.cn/hd/zbft_news/qggbzntjsgh/xgxw_28866/202109/P020210916554589968975.pdf

under the guidance of "guaranteeing food security, promoting eco-friendly farmland and increasing farmers' income", "new round of enhancement action aiming to increase grain production capacity by 50 million tons" should be coordinated by improving infrastructure facilities and transforming cropping management. However, 70% of cultivated land is still managed by smallholders, while the remainder is under the management of NABE[14], resulting in a difference in cropping management and farmland infrastructure condition because of various operation modes among different agricultural producers. Therefore, determining how to align infrastructure conditions with cropping management practices become a key step in identifying farming system types. Moreover, conducting quantitative assessments on the multi-benefits in different farming systems also play a crucial role in establishing effective farming systems and provides valuable insights for maintaining sustainable agriculture development.

The current assessment on farmland development effectiveness is inadequate, primarily focusing on a single performance aspect within the progress of certain projects. For example, assessment boundary for cropping management typically revolve around singular cropping technologies (Harun et al., 2021; Paolotti et al., 2016; Jirapornvaree et al., 2021; Wang et al., 2014; Wang, 2022), production efficiency across farms of different scales (Borghino et al., 2021; Pradeleix et al., 2022; Zhang et al., 2022; Zhu et al., 2018), and cropping processes based on different grades or product types (Del Borghi et al., 2014; Tricase et al., 2018). These studies lack a comprehensive understanding on farming system, and these assessment scopes are relatively limited, thus neglecting the martials inputs during the farmland construction stage and the long-term benefits on cropping management. Furthermore, detailed reports on the multi-objective effects and regional contribution rates in different farming systems, particularly concerning improvement pathways, are still lacking. It is worth noting that assessment methodology has been widely applied at present. Notably, life cycle assessment (LCA) was adopted to investigate the changes in environmental impactors, using greenhouse gas (GHG) emission, carbon and nitrogen footprint, reactive nitrogen loss as assessment indicators (Câmara-Salim et al., 2021; Wang et al., 2021). Additionally, both cost–benefit analysis (CBA) and life cycle costing (LCC) have been commonly used to estimate economic benefits in agricultural activity (Pena et al., 2022; Saber et al., 2020; Li et al., 2020a). The advancements in assessment methods significantly enhance academic understanding of the relationship between agricultural activities and their environmental–economic impacts, providing a more robust framework for evaluating sustainable development in agriculture.

Wheat–maize rotation is a crucial cropping system that has been effectively utilized as a tillage practice to improve soil quality and increase farmers' income in China (Li et al., 2020; Wang et al., 2014). Previous reports indicate that the North China Plain is the largest cropping region employing wheat–maize system, contributing approximately 60% of the country's wheat and 30% of its maize. However, diverse farmland infrastructure and cropping management practices in this region have driven

[14] http://www.gov.cn/xinwen/2019-03/02/content_5369853.htm

the implementation of numerous agricultural demonstration projects, resulting in the proliferation of diverse farming systems. In this study, to better understand the specific contribution and development dilemma from different farming systems, multiple assessment indicators such as LCA, LCC, CBA, net ecosystem economic benefit (NEEB) and scenario simulation were applied into assessment system. In particular, the farming systems are summarized by exploring the infrastructure requirements for matching the cropping management modes, analyzing environmental–economic benefits from infrastructure construction and cropping management practices, and clarifying the multi-objective effects under wheat-maize cropping. The study's underlying hypotheses are that sustainable farmland and its corresponding farming mode can demonstrate optimal environmental and economic benefits. Additionally, promoting the optimal farming system in major grain regions could effectively mitigate environmental pollution and enhance grain yield.

2. Materials and methods

2.1 Study area and system description

he study was conducted in Yanggu, Ningyang, and Yuncheng counties, Shandong province of China, which is a major grain-producing region located in the North China Plain, and demonstrates apparent differences in farmland production conditions, such as infrastructure facilities and cultivated land quality, thus triggering different cropping management practices. Specially, smallholder farming is still a major mode, although NABE (e.g., large growers, family farms, cooperative organizations, and agricultural enterprises) has developed recently. More intensive and intelligent modes have been introduced into the cropping management measures in the region. Consequently, the region reveals diverse farming systems, which epitomizes the development of farmland infrastructure conditions and cropping management modes in China.

A typical cropping system in this region is wheat-maize rotation, and wheat is sown in mid-October and harvested at the end of May next year. Conversely, maize is sown in early June and harvested in late September. Major agronomic activities in the wheat-maize rotation include tillage, sowing, fertilization, irrigation, plant protection, harvesting, and straw returning. This investigation study was performed during the entire growing season under the wheat–maize crop rotation in 2021. The average temperature is 14.7°C, and precipitation is 608.6 mm from 2020 to 2021 (Fig S1in Appendix A).

2.2 Field survey and data collection

The data collection was conducted by randomly visiting households and face-to-face interviewing from September to December 2021 to ensure the accuracy of the collected information. Specifically, 88 smallholder farmers and 38 NABE consisting of 24 farming system II, 14 farming system III were selected, the allocated detail of NABE provided by Table S1. All data on both input and output including economic parameters of the cropping management were recorded in detail, and some data reflecting the martial input of farmland construction, such as design plan, feasibility report and engineering project, estimation, were supplied by the local agricultural administration departments.

2.3 Description of the farmland systems under assessment

A total of three farming systems were summarized by profiling the farmland infrastructure condition and cropping management practices. Applied fertilizers include inorganic fertilizer and crop straw, and all parameter differences in different systems are shown in Table S1 in Appendix A.

2.3.1 Farmland system Ⅰ: Conventional farmland – smallholder farming mode (CF-SFM)

The average area of smallholdings is 0.47 ha, and each land plot is only 0.35 ha. The farmland condition is relatively poor, and most of the infrastructure facilities have exceeded or approached their lifespan. Major characteristics of conventional farmland (CF) are uneven land, a lack of machine roads, and outdated irrigation facilities (earth canals). Smallholder management is still dominated by manual labor, while the plowing, harvesting, and straw returning were mainly finished by specific machines, such as the hand tractors used for plowing and tilling as well as special machines used for harvesting and straw returning.

2.3.2 Farmland system Ⅱ: High-standard farmland - intensive farming mode (HSF-IFM)

Intensive farming mode is usually demonstrated in the cultivated lands that are owned by larger growers, and family farms, and the average area of adopting this mode is 8.56 ha, and the average area per plot is 3.81 ha. Farmlands suitable for intensive management have been incorporated into the first round of HSF construction, and these lands are relatively flat and contiguous, and simultaneously matched with well–developed machine roads, irrigation facilities, and a protective forest network. In the farming process, only fertilization was performed by manual labor, the other planting management measures were completely finished by mechanization operations. All laborers participating in cropping management are often trained and have experience in precision agriculture planting practices.

2.3.3 Farmland system Ⅲ: Sustainable Farmland - efficiency-driven farming mode (SF-EDFM)

Intelligent management is mainly demonstrated in the NABE, especially in those agricultural enterprises and the scaled cooperative organizations, which cultivated 78.67 ha of the land with an area of 30.56 ha per plot. These farmlands were recently constructed to HSF requirements and therefore have better basic conditions. On this basis, the business entity not only improved the facilities used for efficient water-saving irrigation, but also upgraded the standards of machine roads, including widening the roads, using bio-coagulation technology, and implementing permeable surfaces and other eco-friendly designs. Therefore, the farmland infrastructure facilities were well equipped, thus significantly meeting the demands of modern and intelligent agricultural production. Whole cropping activities were operated by mechanization, and drip irrigation was adopted to efficiently reduce water waste. Meanwhile, professional agricultural scientists performed quantitatively precise fertilization and plant protection practices in accordance with the specific requirements of crop growth (Concept map of SF-ITFM as shown in Figure 4-1, and the other systems map as presented in Fig. S2 in Appendix A).

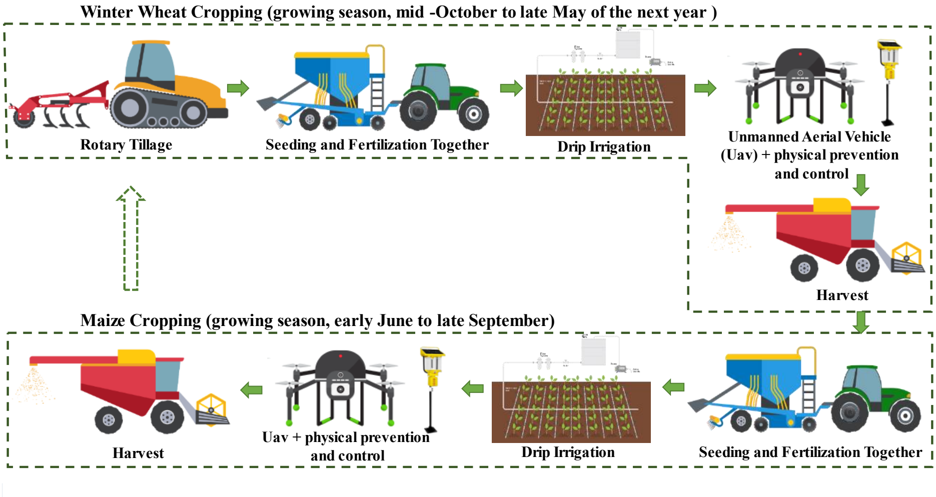

Figure 4- 1 Farmland system III: Efficiency-driven farming mode under the sustainable farmland

2.3.4 Research hypothesis

Agricultural systems should align with the comprehensive development goals of 'resource conservation, efficient output, and eco-friendliness.' Research indicates that transitioning from traditional smallholder farming practices, driven by experience, can mitigate non-point source pollution resulting from excessive chemical inputs (Bruulsema, 2018; Adegbeye et al., 2020; Ren et al., 2023). The adoption of new technologies and advanced production facilities, including integrated water and fertilizer management, physical and biological pest control, and agricultural mechanization, is considered essential for enhancing agricultural resource utilization efficiency (Arunrat et al., 2021; Wang et al., 2014b). Moreover, large-scale farming operations, capitalizing on economies of scale, have the potential to enhance agricultural output and boost farmers' income (Arunrat et al., 2021; Wang et al., 2014b). In summary, achieving sustainability goals in agricultural systems requires standardized and precise management of production, as well as expanding operational scale. Whether through technological innovation or large-scale farming operation, the key lies in excellent farmland infrastructure. Comprehensive and advanced infrastructure is crucial for promoting cropping modes transformation. The characteristics of SF-ITFM in terms of farmland infrastructures and cropping management better align with sustainable requirements. Based on these premises, the following hypothesis is proposed:

Hypothesis 1: Compared to HSF-IFM and CF-SFM, SF- EDFM demonstrates optimal environmental and economic benefits, aligning with the integrated goals of "production-ecology-livelihood" and thus is considered an efficiency-driven farming system.

The most effective approach to promoting a farming system is by highlighting its advantages. In agriculture, establishing demonstration zone is the predominant method for illustrating the benefits of new agricultural products, practices, and modes (Leta et al., 2017; Wang and Cui, 2023; Zhang et al., 2024). Selecting demonstration zone typically requires meeting the fundamental criteria for implementing products, practices, or modes, ideally in areas conducive to maximizing their effectiveness (Adamsone-Fiskovica et al., 2021). Favorable farmland conditions are paramount for demonstrating a farming system, as flat terrain can mitigate the challenges and costs associated with land consolation and infrastructure construction (Qian et al., 2015). Moreover, grain-producing regions play a crucial role in safeguarding national food security, underscoring the importance of establishing demonstration zones in these areas to bolster grain productivity. Recent agricultural policy documents prioritize the development of SF in plain terrain with irrigation capabilities [15]. Therefore, the following hypothesis is formulated:

Hypothesis 2: Promoting the optimal farming system in the North China Plain could effectively mitigate environmental pollution and enhance grain yield, thereby ensuring food security and promoting sustainable agricultural development.

2.3.5 System boundary for assessment

System boundaries, along with relevant inputs and outputs of farming systems, were characterized as depicted in Figure 4-2. Currently, the farmland development is government-mediated, while cropping management is performed by agricultural producers, thereby causing inconsistent investment partners at the two stages. Consequently, economic analyses of farming systems, including LCC, CBA, and NEEB, primarily focus on farmland utilization, while construction costs are examined through comparisons of different farmlands. In this study, an assessment framework was developed to evaluate the multi-objective effects of farming systems on production, ecology, and livelihood, aiming to comprehensively understand their integrative impacts.

[15] https://www.gov.cn/yaowen/liebiao/202402/content_6929930.htm

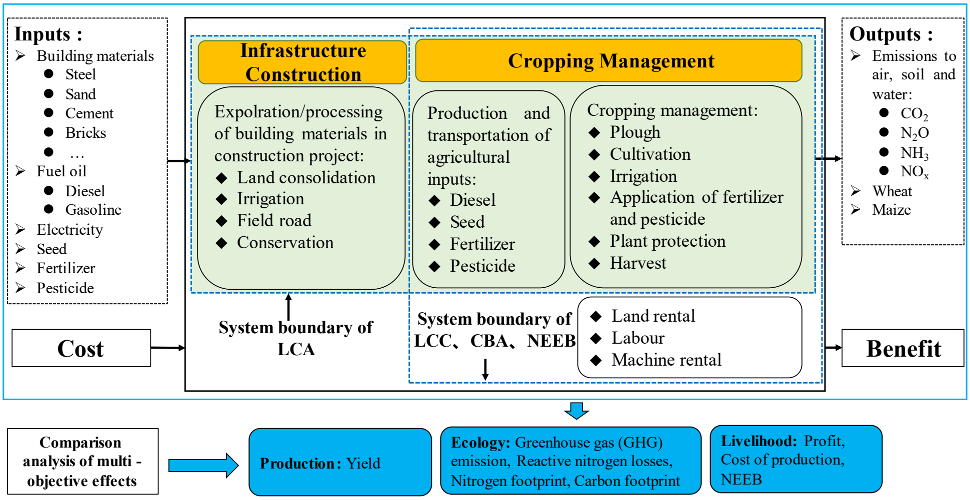

Figure 4- 2 Framework and system boundary for assessment

2.4 Environmental impacts assessment

The environmental evaluation includes two stages representing the infrastructure construction of farmland and cropping management.

2.4.1 Infrastructure construction

Material inputs in the farmland construction stage usually significantly affect the environmental changes, mainly leading to changes in the carbon emission (Shan et al., 2020). Here, the carbon effect on the farmland construction is calculated by the equation (1).

$$C_{CP} = \sum_{i=1}^{N} E_i * EF_{CMi} \qquad (1)$$

Where C_{CP} indicates the total carbon emission during construction period, E_i means the amount of material and energy input, EF_{CMi} represents the carbon emission coefficient of materials and energy sources (Table 4-2).

2.4.2 Cropping management

All inputs used for cropping management are listed in Table 4-1. The environmental changes in three farmland systems quantitatively were compared by LCA, and the system boundary was defined as whole cropping rotation period of the wheat-maize, including agricultural material acquisition, material application, and mechanical mode in the field. The reactive nitrogen losses include N_2O emission, NH_3 volatilization, and NO_3-leaching which were caused by nitrogen fertilizer application. For accurately assessing the environmental impacts, region-specific empirical factors such as N_2O emission, NH_3 volatilization, and nitrogen leaching were adopted (Zhang et al., 2019), thus revealing the environmental impacts such as reactive nitrogen (Nr) losses, GHG emissions, and energy consumption. The above environmental impacts were expressed by unit area of per ha and unit grains mass of per ton, respectively.

Greenhouse gas (GHG) emission from agricultural activities is calculated by the equation (2):

$$GHG_{emission} = \sum_{i=1}^{n}(Input_i * EF_i) \quad (2)$$

i: Input sources; $GHG_{emission}$: GHG emission from agricultural production and transportation, energy and electricity (kg CO_2-eq·hm^{-2}); $Input$: Agricultural materials input; EF_i: Emission factors for agricultural and energy inputs are shown in Table S2 in Appendix A.

The reactive nitrogen losses are calculated by the equation (3):

$$\text{Nr losses} = N_2O_{direct} + N_{leaching} + NH_3volatilization \quad (3)$$

For investigating direct and indirect N_2O emissions of fertilization-triggering, the equation (4) is used for estimating direct N_2O emission, and indirect N_2O emission from the deposition of fertilizers usually exists in the form of NH_3 and NO_x, and is calculated by the equation (5), while the nitrogen emission from leaching and runoff is calculated by the equation (6), and N_2O emission from fertilizer application is calculated by the equation (7).

$$N_2O_{direct} = [(F_{SN} + F_{CR}) * EF_1] * 44/28 \quad (4)$$

$$N_2O_{(ATD)} = (F_{SN} * FRAC_{CASF} * EF_{2SN}) * 44/28 \quad (5)$$

$$N_2O_{leaching} = (F_{SN} + F_{CR}) * FRAC_{LEACH} * EF_3 * 44/28 \quad (6)$$

$$GHG_{N_2O} = \left(N_2O_{direct} + N_2O_{(ATD)} + N_2O_{leaching}\right) * 298 \quad (7)$$

N_2O_{direct}: Direct N_2O emissions from soil fertilization (kg N_2O -N • ha^{-1}); F_{SN}: Fertilizer input at each growing season (kg N • ha^{-1} • growing season^{-1}); F_{CR}: Straw return of per growing season (straw and underground roots)(kg N • ha^{-1} • growing season^{-1}); EF_1: N_2O direct emission factor [kg N_2O -N • (kg N_{input})$^{-1}$]; $N_2O_{(ATD)}$: N_2O emission from fertilizer volatilization in the form of NH_3 and NO_x-N because of deposition (kg N_2O-N·ha^{-1}); $FRAC_{CASF}$: The ratio of the volatilized NH_3 versus NO_x-N. $FRAC_{CASF}$=0.1 kg N • kg^{-1} N (NDRC (National Development and Reform Commission, 2011); EF_{2SN}: Emission factor of the deposited N_2O [kg N_2O • (kg N)$^{-1}$]; $N_2O_{leaching}$: Indirect emission of N_2O from nitrogen fertilizer leaching and runoff (kg N_2O-N • ha^{-1}); $FRAC_{LEACH}$: Ratio of nitrogen losses by leaching and runoff, $FRAC_{LEACH}$=0.2 kg N • kg^{-1} N (NDRC, 2011); EF_3: Indirect emission factor of N_2O by leaching and runoff [kg N_2O • (kg N)$^{-1}$]; 44/28: Conversion coefficient of N_2O-N to N_2O; GHG_{N_2O} : N_2O emission from fertilizer application (kg CO_2 • ha^{-1}); number 298 represents the greenhouse effect equivalent coefficient of N_2O comparing with CO_2 (Change, 2014).

A total of GHG emission from wheat-maize rotation period is calculated by the equation (8):

$$GHG_{all} = GHG_{input} + GHG_{N_2O} \quad (8)$$

2.5 Economic impacts assessment

2.5.1 Life Cycle Cost and profitability

Generally, LCC could better reflect the costs associated with product or service, and is directly decided by the manual action (Hunkeler, 2008). Here, LCC was employed to analyze the costs used for grain cropping such as fixed costs including land rent and physical labour payment, purchase of agricultural inputs, irrigation cost, and machinery rental). It should be noticed that the LCC is only used for assessing the costs in the cropping management, correspondingly demonstrating the total cash flow from the producers, but not including the infrastructure depreciation in the calculation. Combined with an economic analysis, the financial performance of the wheat-maize rotation system was determined by using the LCC and the farmland of per ha. The cost-benefit ratio is calculated to evaluate the profit of per unit cost in three systems as shown in the calculation (9).

$$Cost_{benefit\ ratio_i} = \frac{Profit_i}{LCC_i} = \frac{Income_i - LCC_i}{LCC_i} \quad (9)$$

$Cost_{benefit\ ratio_i}$ is the cost benefit ratio of agriculture producer i; $Profit_i$ is the difference between general income and LCC from agriculture producer i. $Income_i$ is the general income of agriculture producer i from selling wheat and maize, and LCC_i is the life cost of crops.

2.5.2 Net ecosystem economic benefits (NEEB)

Generally, effectively assessing the economic feasibility and environmental costs in farmland system is necessary (Bi et al., 2020; Lin et al., 2023). In this study, the costs from both the agricultural activities and the environmental damage were integrated by NEEB to compare the systematic sustainability in the different farmland systems as shown in the following equation:

$$Yield\ gain = Grain\ yield * grain\ price \quad (10)$$

$$Agriculture\ cost = \sum_{i-1}^{n} AM_i * P_i \quad (11)$$

$$EC_{GHG} = \sum_{i=1}^{n} ED_i * P_C \quad (12)$$

where $Yield\ gain$ expresses the gross plantation income of per ha; $Grain\ yield$ is the wheat and maize yield of per ha, and $grain\ price$ is the locally commercial price of grain; $Agriculture\ cost$ includes agricultural material purchase and field management costs. AM_i is the quantity of the ith agricultural input of per ha, and P_i denotes the unit price of input. ED_i reflects the environmental damage of costs-caused by Nr losses, global warming, and etc. P_C means the conversion coefficient of the environmental damage into currency price, and represents the unit environmental cost of 0.029 USD kg^{-1} CO_2 from GHG emissions (Li et al., 2015; Xia et al., 2016).

2.6 Assessment of economic and ecological potential

In the current study, four typical wheat–maize cropping regions in the North China Plain, Hebei, Shanxi, Shandong, and Henan, were selected to profile the economic and ecological potential assessment. A total of these four cropping regions covers 12.2 million ha of farmland, with 70% of it being irrigable farmland[16], and the HSF amount accounts for more than 50% of the cultivated land[17]. Therefore, the staged study on farmland development in the irrigable farmland was performed by the farmland development plans and the related policy target requirements. The scenario simulation including three development stages (Stage 1: 22% CF–52% HSF–26% SF; Stage 2: 22% CF–39% HSF–39% SF; Stage 3: 0% CF–50% HSF–50% SF) was characterized.

[16] http://www.stats.gov.cn/tjsj/ndsj/2022/indexch.htm
[17] https://www.idpi.cn/gongzuoxindetihui/2169470.html

Specifically, the construction financial needs were estimated in three stages, and the incremental benefits at each stage were analyzed by the assessment system.

3. Results

3.1 Inputs and system productivity

The resource inputs of CF-SFM, HSF-IFM, and SF- EDFM systems are illustrated, revealing notable differences. In summary, SF- EDFM exhibits the lowest resource input among the three systems under wheat-maize cropping, while CF-SFM demonstrates the highest resource input (Table 4-1). The application rate of N-fertilizer was reduced by 32.4% in the SF- EDFM and 32.1% in the HSF-IFM compared to the CF-SFM. Moreover, pesticide application in the SF-EDFM was performed by unmanned aerial vehicles (UAV), resulting in extra 30 kwh per ha in electricity consumption. Additionally, drip irrigation in the SF-EDFM consumed a total of 262.5 kg/ha of drip irrigation belt per year, while irrigation in the HSF-IFM was dominated by pipe irrigation. drip irrigation saving about 30% of water and pipe irrigation saving about 20% of water compared to the flood irrigation, respectively. In terms of electricity consumption, the SF-EDFM and HSF-IFM systems saved 20% and 50% compared to the CF-SFM, respectively, resulting in the SF-EDFM consuming the lowest energy. Furthermore, both the SF-EDFM and HSF-IFM demonstrated a significantly lower labor input compared to the CF-SFM.

Statistics show that the HSF-IFM achieved the highest average grain yields of 7.6 Mg ha-1 of wheat and 10.5 Mg ha-1 of maize, followed by 7.5 Mg ha-1 of wheat and 10.2 Mg ha-1 of maize in the SF-EDFM, while the CF-SFM yielded the lowest grain yields of 6.5 Mg ha-1 of wheat and 8.2 Mg ha-1 of maize.

Table 4- 1 Resource input and output

Item	Wheat cropping			Maize cropping		
	CF-SFM	HSF-IFM	SF-EDFM	CF-SFM	HSF-IFM	SF-EDFM
			Inputs			
Seeds (kg/ha)	187.50	225.00	273.75	33.00	39.00	45.00
N (kg/ha)	324.00	191.25	180.90	315.00	243.75	252.00
P (kg/ha)	216.00	236.25	180.90	52.50	48.75	54.00
K (kg/ha)	67.50	56.25	50.25	52.50	97.50	54.00
Pesticide (kg/ha)	8.43	5.50	5.00	15.72	10.86	10.00
Plant protection for electricity (kwh/ha)	——	——	30.00	——	——	30.00

Drip irrigation belt (PE pipe) (kg/ha)	——	——	262.50	——	——	——
Irrigation water (m^3/ha)	1950.00	1575.00	1275.00	1350.00	1080.00	900.00
Irrigation for electricity (kwh/ha)	900.00	720.00	450.00	675.00	540.00	360.00
Diesel (kg/ha)	210.38	204.13	173.40	153.00	143.18	105.06
Labour (h/ha)	204.26	86.06	45.00	178.72	64.50	38.00
			Output			
Crop yield (kg/ha)	6501.75	7582.50	7500.00	8167.62	10504.88	10231.73

3.2Environmental benefits

3.2.1 carbon effect in farmland construction

GHG emissions during the construction stage in the SF amounted to 7.7 t CE/ha, representing a 1.5 t CE/ha increase compared to the HSF (Table 4-3). This increase can be attributed to relatively higher material inputs in the SF, reflecting efforts to enhance farmland productivity. Consequently, without integrating the analysis with cropping practices, the HSF appears to be more conducive to achieving carbon reduction goals. Since both land reclamation and ditch digging in the CF were mainly finished by manual labor in 1970s, with relatively limited material inputs used for construction, therefore, the GHG emissions from the CF were not estimated in the study.

Table 4- 2 Material input and its carbon emission in construction stage (CS)

Material	Emissions factors	Unit	References	Emission (kg CE)	
				HSF	SF
Diesel	0.862	kg CE/kg	Intergovernmental Panel on Climate Change (IPCC)	469.469	460.856
Gasoline	0.814	kg CE/kg	IPCC	0.004	0.003
Steel	2200	kg CE/t	China Institute of Atomic Energy (CIAE)	98.781	65.781
Sand	1.890	kg CE/m3	IPCC	13.634	16.489
Cement	843.250	kg CE/t	IPCC	5387.398	6396.599
Bricks	1452.300	kg CE/1000 blocks	IPCC	695.432	1300.288
Gravel	2.250	kg CE/m3	IPCC	44.483	46.234

Asphalt	238.520	kg CE/t	IPCC	1.916	2.457
Electricity	0.714	kg CE/kg	Guidelines for provincial greenhouse gas inventories (pilot)	1.124	2.761
Quicklime	0.687	kg CE/kg	IPCC	0.303	0.312
PVC pipe	0.860	kg CE/kg	IPCC	0	5.282
Shelter-belts	-23.660	kg CE/per	(Xiangguo, 2010)	-520.520	-567.84

Table 4- 3 Investment standard and carbon emission in CS

Farmland type	Investment (CNY/ha)	Total carbon emission in CS (kg CE)
Sustainable farmland (SF)	42600	7729.224
High-standard farmland (HSF)	34200	6192.026

3.2.2 Reactive nitrogen losses, nitrogen and carbon footprint, GHG emissions of cropping management

The analysis results indicate that environmental indicators of the CF-SFM are significantly higher than those of other systems. Both SF-EDFM and HSF-IFM exhibit similar levels of active nitrogen loss and nitrogen footprint, whereas SF-EDFM demonstrates lower GHG emissions and carbon footprint compared to HSF-IFM. Therefore, SF-EDFM demonstrates the best environmental performance, followed by HSF-IFM, while CF-SFM exhibits poorer outcomes (Figure 4-3). Besides, NO3-leaching was found to be a critical factor affecting nitrogen losses and nitrogen footprint. The components of GHG emissions, such as chemical input in cropping, transportation, and field application, greatly contributed to nitrogen emission increases, followed by electricity and fuel consumption. Although the contribution ratio from various components was relatively consistent in different systems, the contribution magnitude significantly varied. It is observed that all components in both the SF-EDFM and HSF-IFM almost had no significant negative effects, only the CF-SFM showed the strongest negative effect. Furthermore, the data confirmed that the different systems demonstrated obvious differences in the quantity and type of resource input.

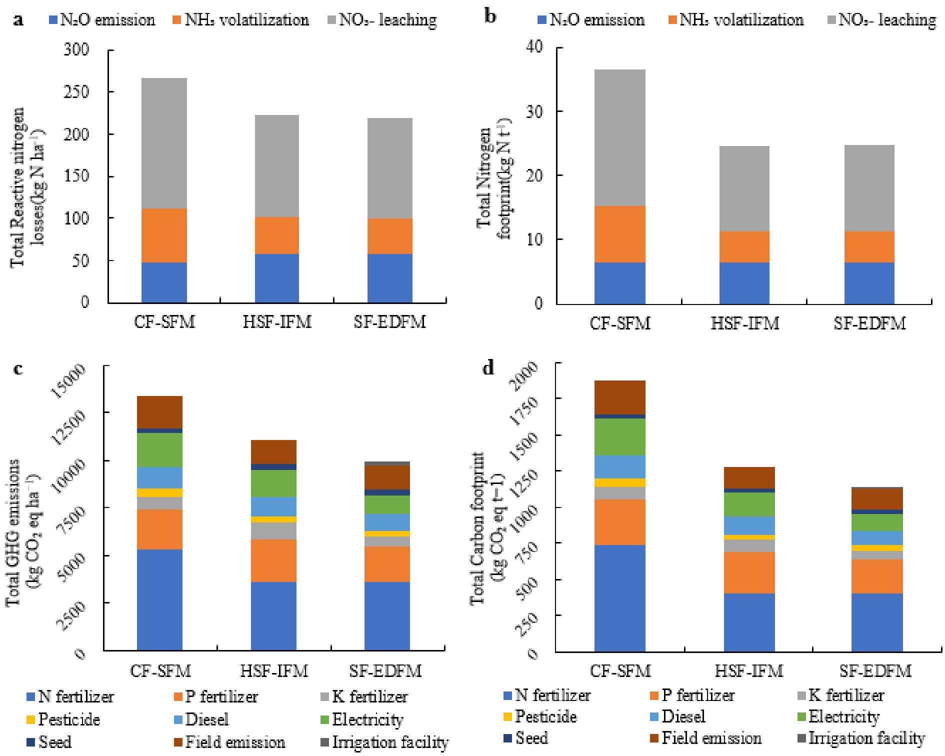

Figure 4- 3 Reactive nitrogen losses (a), nitrogen footprint (b), greenhouse gas emissions (c), and carbon footprint (d) under wheat-maize rotation in three systems

3.3 Economic benefit by LCC, CBA and NEEB

HSF-IFM had the highest cropping costs of 18,691 CNY/ha, followed by the SF-EDFM with 18,287 CNY/ha, while CF-SFM had the lowest costs of 14,012 CNY/ha (Figure 4-4 (a)). Data indicates that agricultural materials, such as seeds, fertilizers and pesticides, accounted for the highest portion of the input costs. Besides, costs associated with mechanical application also occupied a significant portion. Unlike agricultural materials, costs related to labor employment and land rent in both SF-EDFM and HSF-IFM were largely determined by farming scale. Surveys found that land rent in SF-EDFM or HSF-IFM reached 4,500 CNY/ha, maintaining a moderate level in the Yellow River Basin due to local agricultural policy reasons. Additionally, SF-EDFM controlled pests by physical measure, leading to increased energy expense, such as utilization of pest control lights.

The cost-benefit analysis shows that SF-EDFM revealed the highest profits of 25,741 CNY/ha, followed by HSF-IFM with profits of 24,425 CNY/ha, while CF-SFM had the lowest profits of 20,478 CNY/ha (Table 4-4). However, the cost-benefit ratio CF-SFM at 1.461 was higher than that of HSF-IFM at 1.31 and SF-EDFM at 1.41. SF-EDFM exhibited the highest NEEB of 23,792 CNY/ha, followed by the

HSF-IFM with 22,136 CNY/ha, while the CF-SFM showed the lowest NEEB of 17,711 CNY/ha (Figure 4-4(b)).

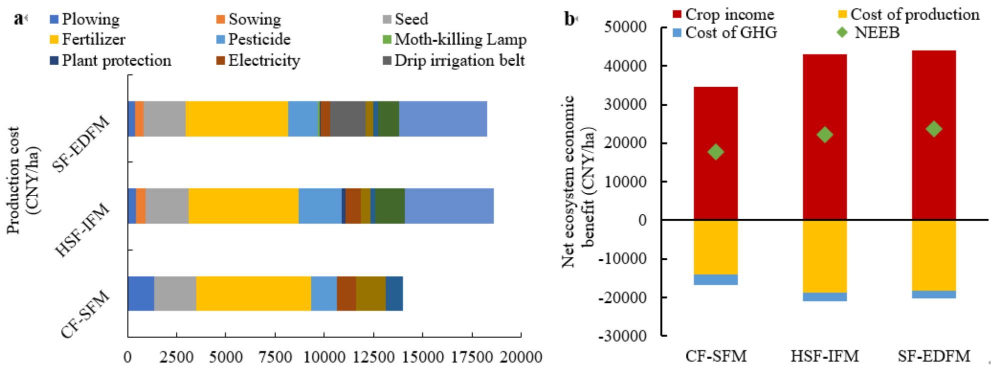

Figure 4- 4 Cost of wheat-maize cropping under three systems (a); NEEB of three systems (b)

Table 4- 4 Cost-benefit ratio

	CF-SFM	HSF-IFM	SF-EDFM
Total cost（CNY/ha）	14012.30±4.50a	18691.89±7.69c	18287.94±5.88b
Profit（CNY/ha）	20477.58±5.71a	24424.86±7.46b	25741.36±8.31c
Cost-benefit ratio（CNY/ha）	1.46c	1.31a	1.41b

Note: Different letters within the same row indicate significant ($p < 0.05$) differences among three farming modes.

3.4 Prospects of SF-EDFM

Integrating the environmental and economic analyses showed that SF-EDFM was more aligned with the target of sustainable agricultural development. This assertion is supported by several factors: 1) SF-EDFM achieves relatively high yields with minimal resource input and retains the potential for further output increases under current resource input standards. This aligns perfectly with the profound connotations of sustainability, namely resource conservation and efficient output. 2) SF-EDFM exhibits the most prominent environmental and economic advantages, showing the integration of eco-friendly development principles into the farming system and enhancing its sustainability. 3) large growers, family farms, cooperatives, and agricultural enterprises are identified as the most suitable operational entities for adopting SF-EDFM, aligning with current strategies aimed at accelerating the cultivation of NABE to promote large-scale agricultural operations. It has emerged as a crucial pathway for transforming the landscape of smallholder farming[18,19]. Based on these considerations, the anticipated hypothesis is confirmed, and SF-EDFM is

[18] https://www.gov.cn/zhengce/zhengceku/2022-03/29/content_5682254.htm
[19] https://www.gov.cn/zhengce/2016-05/25/content_5076559.htm

regarded as an efficiency-driven farming system. Considering the realities of farmland and agricultural development in China, achieving a 1:1 ratio of HSF to SF through three stages is targeted[20]. The total estimated construction costs amount to CNY 8.84 billion (Table 4-5), enabling the realization of goals such as reducing emissions by 9.01E+07 (t CO_2 eq) and increasing profits by CNY 110 billion along with a NEEB of CNY 101 billion. Importantly, these regions could potentially increase grain production by 1,278 t, as depicted in the benefit potentials presented in Figure 4-5.

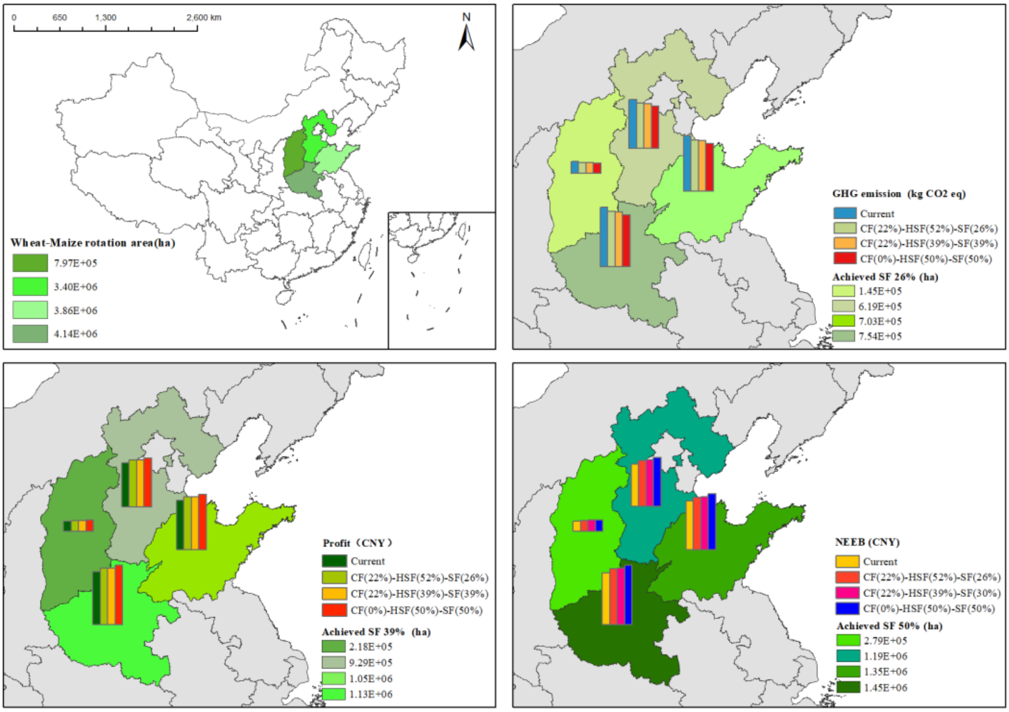

Figure 4- 5 Benefits potential promoting the SF-ITFM in the North China Plain

Table 4- 5 Financial need and environmental-economic effects promoting the SF-ITFM in the North China Plain

	Construction Financial need (CNY)	GHG emissions (t CO_2 eq)	Profit (CNY)	NEEB (CNY)	Total grain production (t)

[20] http://www.moa.gov.cn/hd/zbft_news/qggbzntjsgh/xgxw_28866/202109/P020210916554589968975.pdf

CF(22%)-HSF(52%)-SF(26%)	4.87 E+10	9.67 E+07	5.72 E+10	5.27 E+10	1.47E+04
CF(22%)-HSF(39%)-SF(39%)	4.76 E+09	9.55 E+07	8.58 E+10	7.91 E+10	1.47E+04
CF(0%)-HSF(50%)-SF(50%)	3.55 E+10	9.01 E+07	1.10 E+11	1.01 E+11	1.53E+04

4. Discussions and implications

4.1 The role of SF-EDFM in optimizing inputs and improving its productivity

Analysis demonstrates that SF-EDFM had the lowest resource input. Several factors contribute to this observation. Firstly, SF benefits from well-developed infrastructure and relatively flat land, making it more conducive to mechanized and facilitated agricultural activities. Secondly, large-scale farming is a major characteristic of SF-EDFM. Research has shown that small and scattered land plots decrease machinery efficiency, leading to increased fuel consumption and machinery loss (Valtiala et al., 2023; Bradfield et al., 2021; Zhang et al., 2021). Finally, the specialization degree of farmland managers plays a crucial role in adjusting and executing production practices (Mc Fadden and Gorman, 2016; Yang et al., 2022). Interviews revealed that smallholder farming traditionally relies on experiential knowledge but lacks the specialized technical training. Consequently, smallholders tend to apply excessive amounts of seeds, fertilizers, pesticides, and other materials, leading to higher input costs compared to standard requirements (Nziguheba et al., 2016; Mengistie et al., 2017; Ren et al., 2021). Moreover, smallholders often struggle to innovate agricultural technology, materials, and facilities (Rada and Fuglie, 2019), and face challenges in accessing introduction channels and adopting new production practices (Li et al., 2021; Zhao et al., 2022). Therefore, expanding the scale of cropping on farmland and developing adequate infrastructures are very important task that require guidance for agricultural producers and the establishment of standard farmland infrastructure construction policies. To achieve this target, land transfer action has been conducted to support large-scale farms in China [21-22]. Meanwhile, improving and innovating the technical skills of agricultural producers through training programs is essential. Strengthening farmers' professional knowledge can enhance their willingness to engage in large-scale farming (Sutherland et al., 2017; Taylor and Bhasme, 2018; Xia et al., 2017).

Investigation found that the productivity in SF-EDFM was lower than that in HSF-IFM due to greater losses in seeds, fertilizers and crop grains from mechanical work in the former (Qu et al., 2021). Additionally, SF-EDFM is usually managed by

[21] http://www.gov.cn/gongbao/content/2014/content_2786719.htm
[22] http://www.gov.cn/gongbao/content/2021/content_5600084.htm

agricultural enterprises or cooperative organizations, which often overlook cropping management practices. Although the professional agronomists are employed, the increases in grains yields are still limited because of lacking accountability. In contrast, HSF-IFM is basically managed by the larger growers, cropping cooperative units, and family farms, where agricultural production is the primary source of income. This family-oriented mode of production focuses on intensive farming, resulting in higher crop yields. As for CF-SFM, obsolete farmland endowment and non-standardized farming practices seriously limited productivity relative to the other systems, indicating the urgent need to improve infrastructure and develop the standardized production specification. Agricultural administration should deploy specialized agronomists to provide guidance on applying innovative technology and implementing scientific cropping management practices for smallholders. Furthermore, local agricultural administration departments can motivate NABE participation by organizing grain productivity competition and supervising cropping practices. The governmental agency should also positively develop the publicity education activities to enhance the agronomist's sense of responsibility.

4.2 The contribution on SF-EDFM in response to the environment-friendly agriculture

Obviously, HSF showed lower carbon emissions than SF during the farmland construction stage, primarily because SF required advanced farmland infrastructure and relatively more construction materials. Interviews indicated that the service life of SF's infrastructure could be extended by 5-8 years, with maintenance cost was reduced by 10%. Although these data require further verification, SF provided more convenient conditions for agricultural production, facilitating the increased application of innovative technologies and yielding positive environmental benefits. At present, all industries are implementing stricter environmental standards to achieve the goal of "carbon peaking and carbon neutrality" (Albrizio et al., 2017; Lieder and Rashid, 2016; Zhang et al., 2022c), necessitating the minimization of material inputs during farmland construction. Additionally, the use of new environmentally friendly materials presents a promising pathway for optimizing building materials (Sangmesh et al., 2023; Xu et al., 2022), thus offering valuable support for improving the SF system.

A Previously reported, SF-EDFM is considered as a symbol of environment-friendly agriculture due to its lower resource input and adoption of environment-friendly production practices in cropping, with agricultural material quantities also being subjectively controlled by producers (Zhang et al., 2023). The study shows that various low-efficiency practices in agricultural production easily led to the resources waste and increased the GHG emissions (Gołaś et al., 2020; Hou et al., 2020). Generally, differences in machinery application primarily result in environmental effects due to variations in fuel consumption types across different machines (Houshyar and Grundmann, 2017; Li et al., 2012). In particular, field survey shows that machinery with low fuel consumption requires higher purchase expenses, typically affordable for agricultural businesses or machinery cooperatives, thereby highlighting the importance of promoting energy-efficient machinery to address this dilemma. Moreover, electricity consumption is considered a key factor affecting environmental performance, mainly due to its association with irrigation systems (Huang et al., 2021), with drip irrigation in the SF-EDFM being one of the most water and electricity saving methods (Surendran et al., 2016; Yahyaoui et al., 2017; Li and Xu, 2022). However, drip irrigation technology is not widespread in the cropping, and that requires a better land flatness, and the renovation project is a complicated process and relatively cause higher costs, thus lowering the willingness of investing the agricultural production. Furthermore, even with support from relevant projects, agricultural producers exhibit reluctance to adopt this renovation, indicating a lack of knowledge about technology addressing operational difficulties and maintenance costs (Luo et al., 2021; Xu et al., 2018). In general, agricultural machinery purchase subsidies should be extended and optimized in China [23], considering different machinery types and formulating reasonable subsidy ratios for various agricultural producers. In addition, the government should pay more attention on supporting resource-saving, environmentally friendly facilities and technologies, guiding NABE to share infrastructure construction cost. Administration division should provide detailed training on the application of environment-friendly technology, emphasizing its benefits to promote agricultural operators' willingness to adopt new technology. Furthermore, a reasonable subsidy mechanism would be more conducive to producers' enthusiasm for technology adoption during technology diffusion (Knierim et al., 2019; Li et al. (2022).

4.3 SF-EDFM prevails in economic performance

CF-SFM has demonstrated the lowest production cost, while HSF-IFM has a higher cost than SF-EDFM. This difference arises because CF-SFM largely relies on the labor inputs of smallholder farmers, resulting in reduced expenses related to hiring machinery and labor. Meanwhile, smallholder farming rarely adopts innovation agricultural technology to reduce the costs in technical innovation at present. In contrast, both HSF-IFM and SF-EDFM reveal high levels of mechanization and modernization, along with widespread adoption of water-saving irrigation and environmentally friendly pest control techniques. However, farming scale remains a significant factor contributing to cost disparities (Omotilewa et al., 2021), as supported by the LCC results. These findings suggest that the lowest cost observed in the SF-EDFM could be attributed to a comparison of individual inputs. It is noteworthy that expenses related to agricultural materials comprise the largest proportion of input costs. Therefore, encouragement of large-scale farming and government intervention in the agricultural market is warranted, along with the formulation of relevant agricultural subsidy policies to alleviate the burden on smallholder farmers.

The results confirm that the SF-EDFM not only yielded the highest benefit but also achieved relatively higher yields. Conversely, scaled agribusiness and large cooperative units typically possess ample storage facilities, thereby eliminating limitations on the sale of agricultural products in terms of space and time.

[23] http://journal.crnews.net/nybgb/2021n/dssq/tzjd/935154_20210511102626.html

Consequently, we suggesting that the construction of storage facilities for agricultural products in the form of a village or town should be seriously introduced into the agribusiness system. Meanwhile, a dynamic announcement platform publicizing the prices of agricultural products should be established to better understand the sale market for agricultural producers.

4.4 SF-EDFM is necessary for developing high efficiency

It is suggested that SF-EDFM could significantly contribute to the environmental and economic aspects of the agricultural system in the North China Plain, as demonstrated in scenario analysis. Relevant study has highlighted the importance of various factors in the development of SF, including land consolidation, construction of machine roads, and the implementation of water-saving facilities during the construction stage (Asiama et al., 2021; Asimeh et al., 2020; Wang, 2022b). Moreover, energy-efficient machinery and EFAPP are considered as essential components for the development of the SF ecosystem (Aroonsrimorakot et al., 2021; Yin et al., 2022). Our investigation indicates that SF-EDFM exhibited excellent efficiency in the multi-objective comparative analysis (Fig. 6). The coordinated promotion of SF's infrastructure construction and transformation of cropping management has achieved a synergy effect, surpassing the sum of its individual components, thereby enhancing the efficiency of sustainable agriculture transformation. Furthermore, conducting SF pilot demonstrations aligns with the multi-objective needs in sustainable development. However, the current policy appears to neglect suitable operators for SF-EDFM. Due to factors such as an aging labor force and limited capital endowment, policies aimed at transforming smallholder farming have relatively limited effects (A et al., 2018; Grzelak et al., 2019; Lu and Xie, 2018; Wei et al., 2021). Agribusiness and cooperative units are well-suited for SF-EDFM, suggesting that efforts to cultivate NABE should focus on becoming leaders in developing SF-EDFM.

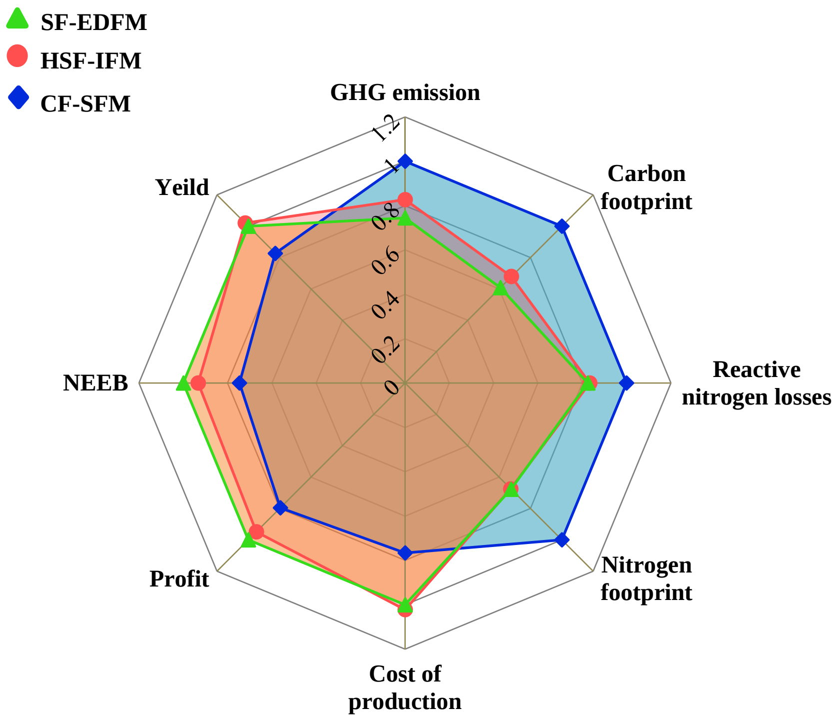

Figure 4- 6 Comprehensive multiple-objective comparison under wheat-maize cropping in three systems

5. Conclusions

Smallholder farming plays a significant role in China's grain production. However, challenges such as poor infrastructure, fragmented land, and limited capacity among smallholder farmers hinder the adoption of innovative technologies. Additionally, unlocking the potential land productivity remains challenging, and outdated techniques in smallholder farming contributes to increased environmental cost. To address these challenges, a series of actions were developed by constructing the HSF and promoting the EFAPP, and the SDGs received increasing attention from the Chinese government to realize the commitment of "carbon peak and carbon neutral" as an urgent task. In response, the development of SF has been proposed, with local agricultural administration departments encouraged to conduct demonstration activities. In this context, assessing multi-objective benefits are beneficial to understanding sustainable agricultural development and identifying optimization pathways. LCA is a better pathway profiling the environment impact from agriculture activities. Combining LCC and CBA reveals the economic contributions of different farming systems. However, there has been less focus on the effect of farmland type on agricultural production and the impact of farmland construction materials. This study apparently contributes to enriching current assessment methods on farming systems. Firstly, three farming systems (CF-SFM, HSF-IFM, and SF-EDFM) are summarized by a matching form of farmland infrastructure condition and cropping management. Subsequently, the resource input, productivity, environmental benefits, and economics of different farming systems were quantified and compared. The multi-objective benefits data shows that the SF-EDFM is an optimal choice by simulating the contribution potentials. Finally, this study deeply explores optimization pathways for improving farming systems and provides a policy-making reference for assessing sustainable agriculture development (Fig. S3 in Appendix A).

It is imperative to acknowledge and account for the constraints inherent in this study. First, the case data only represented the typical modes under the wheat-maize cropping system in the North China Plain and did not reflect the characteristics and performance under the other cropping systems in the other regions, suggesting that expanding study cases with diverse cropping systems is necessary for selection, thus completely improving the systematic evaluation in the future study. Second, based on the IPCC analysis, the environmental impact factors related to the "carbon" should be considered. Although other impact categories can be estimated, experimental and monitoring data should be used to obtain more precise results in future studies. Finally, a wide investigation representing the various farmland and cropping management modes is of great importance, thereby optimally supplementing the other niche modes and accelerating the transformation process of agricultural sustainability.

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Chapter 5

Driving Mechanism for Farmers' Participation in Improving Farmland Ecosystem: Evidence from China

1. Introduction

The sustainable management of the agri-system is imperative for achieving UN-Sustainable Development Goals (SDGs), especially the development of sustainable agriculture to meet Goal 2: zero hunger (FAO[24]). Farmland system provides the largest share of food supply and has an essential contribution to socio-economic development in the world (Stephens et al., 2018). Agriculture is the top priority of the national development strategy, especially for China with a population of 1.4 billion. Since the Reform and Opening-up for creating the agricultural household contract responsibility system from 1978, China has achieved significant progress in agricultural production while it is still limited by fragmented land and imperfect irrigation facilities. Medium to low-yield fields account for over 70% of 120 million ha in Chinese cultivated land[25]. In fact, China has an excellent design for large-scale construction of high-standard farmland (HSF), aiming to enhance national food security[26]. Developing HSF has boosted crop yield by 10-20% compared to conventional farmland, with an expense reduction of CNY 7,500 per ha[27] in production. However, its principal efforts aim to improve farmland infrastructure conditions (FIC) on production, but ignoring the ecological attributes of farmland system.

China utilizes more chemical fertilizers and pesticides than developed countries, at 506.1kg/ha and 10.3kg/ha, respectively[28]. Excessive agri-chemical inputs and haphazard agricultural waste management have resulted in non-point source pollution, with serious environmental problems (Dubey et al., 2016; Gruber, 2017; Gu et al., 2015; Han and Zhang, 2020; Jingjing et al., 2019; Liu et al., 2018; Wanger et al., 2020). The integrated benefits of environmental-friendly agricultural production practices (EFAPP) have been piloted and demonstrated (Cowie et al., 2018; Johnson et al., 2016; Zhang et al., 2022). Its contributions to promote cultivated land quality (CLQ) and ecological conservation, and adapt climate change should not be underestimated (Hu et al., 2020; Li, W. et al., 2021; Lili et al., 2022; Maris et al., 2015; Wang, Ziteng et al., 2020; Wei, C. et al., 2021; Zhang et al., 2019). China has implemented associated policies to encourage the application of EFAPP, but there is no institutional scheme that integrates engineering and agronomic measures with systematically responding to the demand for sustainable agricultural development. SFD is not only upgrading farmland infrastructures, but also promoting EFAPP to

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[24] https://www.fao.org/sustainable-development-goals/indicators/zh/

[25]Report of the State Council on Land Management and Mineral Resources Development and Utilizatio n and Protection (http://www.npc.gov.cn/zgrdw/huiyi/cwh/1130/2013-01/06/content_1750100.htm)

26High-standard farmland can improve food security (https://www.chinadaily.com.cn/a/202109/23/WS614bbba1a310cdd39bc6ad54.html)

27 China High-Standard Farmland Construction Plan (2021-2030) (https://www.ndrc.gov.cn/fggz/fzzlgh/gjjzxgh/202111/P020211102598713060217.pdf)

28 2021 China Statistical Yearbook (http://www.stats.gov.cn/tjsj/ndsj/2021/indexch.htm)

synergistically establish sustainable agricultural production system by farmland construction.

The current management mode of high-standard farmland development (HFC) has led to the dilemmas caused by "high administrative leading-low farmers' participation." Firstly, China has already constructed 53 million ha of HSF. The total investment is CNY 86.7 billion in 2020[29]. The farmland development activity, which is ultimately led and invested by the central government, has brought tremendous pressure on central finance. Secondly, the investment, which is CNY 19,500 per ha, hardly achieve sustainable agricultural yield objectives. The current agricultural production conditions are still insufficient response to natural disasters. Agricultural disaster area reached 20 million ha, resulting in CNY 370 billion loss in 2020[30]. Farmland is also subjected to increasing expectations such as "guaranteeing agricultural product security, providing ecological function, and performing cultural services". In this context, encouraging the participation of stakeholders is the critical pathway to upgrading standards and improving the benefits of farmland. As a practitioner of farmland utilization, agricultural producers deserve to have a primary role in SFD. Smallholder farmers account for more than 98% entities, with approximately 70% of total cultivated land in 2016 in China[31]. To understand farmers' attitude is helpful for policy innovation and practice guidance on land-use concerns (Huang, X. et al., 2017; Vukina et al., 2008). Hence, it is imperative to assess whether farmers are interested in volunteering with SFD and what factors influence their decisions. A comprehensive of the influence mechanism will help the government to formulate more effective policies.

In general, the intention is an individual's psychological preference for a behavior. Furthermore, behavior is an individual's adopted action in the past. Decision-making is the transformation process from intention to behavior, which is dynamic. Farmers' intention is their psychological preference to participate in SFD. Whether farmers have participated in SFD in the past is considered as the behavior. SFD-related policies have just been implemented currently in China. Farmers' participation behavior and decision-making have not been developed. Thus, focusing on farmers' intention at this stage is especially critical. Farmers' intention, behavior, and decision on farmland management were generally influenced by their gender, age, education, family size, income (Liu and Chen, 2012; Liu and Tan, 2006; Luu, 2020; Malawska et al., 2014; Seroa da Motta and Ortiz, 2018; Thinda et al., 2020; Wang, Y.B. et al., 2021; Zhu et al., 2010), and benefit expectations (Hernandez-Espallardo et al., 2013). In terms of variables, the influencing factors were mainly related to farmer or household characteristics. The effect of these indicators was limited. There was still a lack of information to explain the motivation of farmers to participate in sustainable agriculture development.

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[29] https://baijiahao.baidu.com/s?id=1710844140410199335&wfr=spider&for=pc

[30] 2021 China Statistical Yearbook (http://www.stats.gov.cn/tjsj/ndsj/2021/indexch.htm)

[31] The Third National Agricultural Census Bulletin (http://www.stats.gov.cn/tjsj/tjgb/nypcgb/qgnypcgb/)

Socio-psychological analysis methods are widely used to identify human behavior motivation and its influencing factors, improve understanding of farmers' decisions, and guide policy design (Borges et al., 2014; Floress et al., 2017; NDRC, 2011; Wang, Zhengzao et al., 2020; Wauters and Mathijs, 2013; Yazdanpanah et al., 2014). In the resource and environment management studies, Theory of Planned Behavior (TPB) has been employed in assessments of biodiversity enhancement (Spash et al., 2009), agriculture system improvement (Li, F. et al., 2021), and pro-environmental behavior (de Leeuw et al., 2015). Despite the demonstrated benefits of TPB, the current application has certain limitations (Agidew and Singh, 2018). The original framework didn’t consider potential factors including environmental endowments and government incentive program, which could stimulate behavior change (Meijer et al., 2015a; Pratt and Wingenbach, 2016).

An acceptable modification of TPB is an efficient method to address its imperfections and boost theoretical explanatory power (Savari and Gharechaee, 2020; Tama et al., 2021). Recently, the method based on the extended theory of planned behavior (ETPB) has been widely applied in agriculture. For example, the new conceptualizations of knowledge, moral norm, and perceived threats of intensified agriculture were appended to the TPB framework that revealed farmers' attitudes (AT) toward conserving farm biodiversity (Maleksaeidi and Keshavarz, 2019). Tama et al. (2020) introduced knowledge and perceived climatic threats to analyze the influences on farmers' intention to adopt conservation agriculture consistently. The subsidy policy was used as an extension of TPB to discover that it affected farmers' intention to conduct green manure rotation. Environmental literacy was involved in ETPB to fit farmers' attitudes in mitigating non-point source pollution (Li, F. et al., 2021; Wang, Yandong et al., 2018).

The study employed the ETPB framework to illuminate the drivers of farmers' participation in SFD by introducing policy evaluation (PE) and agricultural production conditions (APCs) to enrich the literature. It was widespread that PE affected farmers' cognition and behavior intentions (Huang, X. et al., 2017; Xie et al., 2018; Yu et al., 2018). However, the literatures are still focused on a single activity related to farmland development. It lacks an in-depth investigation of the mechanism that shapes farmers' behavior intention (INT) on integrated farmland development. The expected findings can provide new insights for policymakers and practitioners to design or adjust schemes related to improve farmland ecosystem or formulate more appropriate agricultural strategies.

The ultimate purpose of the study is to develop an improved framework, ETPB, to provide a comprehensive understanding of the causal relationships with concerning farmers' behavior intention to contribute to SFD. In particular, the study aims to achieve improvements in the following three dimensions: 1) to examine the model suitability of ETPB for farmers' intention to contribute to SFD; 2) to identify potential influencing factors of farmers' behavior INT in addressing agricultural development strategies; and 3) to explore the impacts of PE and APCs (e.g., CLQFIC) on TPB construct.

2. Theoretical and hypotheses

2.1 Theoretical Analysis of farmers' participation in SFD activities

The study aims to guide farmers' participation in SFD, which is attributed to the fact that the content and standard of farmland development have changed with the goals and plans of agricultural development in different stages[32, 33](Zhou and Cao, 2020). SFD focuses on the farmland functions of production, livelihood and ecology. Meanwhile, the finance demand is increasing in farmland development. The single financing mode led by the government is not advisable for farmland development. Agricultural producers should play a role in the construction activities as they are the primary actors in farmland utilization. Thus, based on the central finance bearing the basic farmland development, farmers are encouraged to participate in the incremental part of the farmland development. It is conducive to solving the dilemma between capital restriction and the inability of construction standards to meet the needs of modern agricultural production.

Based on the assumption of "homo-economicus" in neoclassical economics, the farmers, as decision-making entity, would select the behavioral practices that maximize their utility under certain constraints. It is necessary to identify the participant activities that align with the farmers' capacity and fundamental interests. On one hand, agricultural infrastructure belongs to public goods (Liu and Ji, 2020). It is generally believed that farmland infrastructure, represented by drainage and irrigation ditches and field roads, is a "quasi-public goods" (Wang and Liu, 2019). Meanwhile, farmland belongs to farmers as "private goods" with exclusivity and competition in terms of use. Therefore, it is reasonable and necessary to consider farmers' decisions, behaviors, and influences on their participation in the construction and renovation of "quasi-public goods" and "private goods" in SF infrastructure (Wang, Z. et al., 2021). On the other hand, as the primary actors in applying EFAPP, it is crucial to guide farmers to in-depth adopt relevant practices (Li, J. et al., 2020; Li, W. et al., 2021; Liu and Zheng, 2021). Based on the above analysis, the study identified the targets boundaries and key activities of farmers' participation in SFD (Figure 5-1). The following is to further focus on farmers' willingness to contribute to SFD according to the framework, reveal the pathways of farmers' decision-making, and deeply explore the influencing factors and acting mechanism of behavior INT.

[32] National land development and consolidation plan (2001-2010) (https://jlps.mnr.gov.cn/global/reward!readResult.do?resultId=eafe035b-4564-41c1-aae5-5f6a202a72a1)

[33] Opinions on solidly promoting the construction of high-standard farmland (http://www.gov.cn/xinwen/2017-02/22/content_5169998.htm)

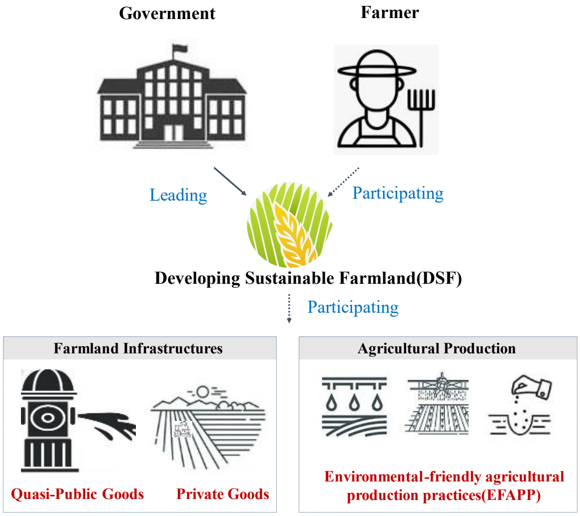

Figure 5- 1 Targets and key activities of farmers' participation in SFD

2.1.1 TPB and its extended framework

Ajzen (1991) proposed that TPB is a derivative of the theory of reasoned action (TRA), which constructs a "cognition → intention → behavior" driving mode that integrates factors from actors, internal management, and the external environment. It is widely applied in the study of decision-making behavior. The core of TPB is based on the psychological perspective to explain the individual decision-making process. In TPB, attitude (AT), subjective norms (SN), and perceived behavioral control (PBC) jointly determine individual INT (Ajzen, 1991; Ajzen and Madden, 1986). In addition, there may be interaction between AT, SN and PBC (Icek and Driver, 1992). Farmers' participation behavior is a joint participation of two activities of SFD, which is still in the exploratory stage for policy development. The TPB construct allows for trade-offs based on the presence of actual behavior (Change, 2014; Daxini et al., 2019; Tama et al., 2021; Tao et al., 2021). Consequently, the examination of the behavioral dimension is not addressed in the framework of the study.

ETPB could better reveal farmers' decisions than TPB (Carrington et al., 2010). The policy support influences the propensity to embrace agricultural green production(AGP)(Chen et al., 2017). The current conditions can impact farmers' willingness to invest in irrigation facilities (Hui and Siyu, 2012), while external knowledge (Ru et al., 2018), value perception (Li, M. et al., 2020c; Zhang et al., 2020), and trust (Ashworth et al., 2012; Midden and Huijts, 2009) can be employed as moderating factors in the TPB framework. The study considers the current system in China, in which the government led the support of FIC and EFAPP in the form of infrastructure investments and production subsidies. As an essential external contextual factor, the institutional background creates a specific incentive structure for practitioners, and the motivational orientation of the institution determines the direction of behavior (Chen et al., 2017). Farmers' evaluation on government actions (i.e., PE) reflected the benefits of the actions, so as to strengthen farmers' cognition. Meanwhile, the demonstrated benefits can stimulate the farmers' responsibility awareness and thus promote their enthusiasm to participate. Moreover, due to different resource endowments, farmers demonstrate different willingness to participate in SFD. The APCs are the crucial indicators for the precise design of regional policies. Generally speaking, it is an exciting experiment to consider the moderating role of PE and APCs on the TPB framework.

2.1.2.1 The influence of AT, SN, and PBC on intention

Institutional change theory suggests that individual cognition determines behavior, directly affecting inter-individual coordination. The differences in farmers' decision to participate in SFD are determined by their cognition. TPB believes that individual intention is the direct psychological factor to affect behavior (Ajzen, 1991), while AT, SN, and PBC influence the INT.

AT represents an individual's positive or negative opinion about any activity based on their beliefs and experiences. Positive behavioral AT, such as the perception that SFD contributes to the efficiency of production, boost farmers' INT. Studies have demonstrated that farmers are more motivated to adopt suitable agricultural measures if they believe that they are beneficial with positive outcomes (Atinkut et al., 2020; Li, M. et al., 2020b, a; Li, M. et al., 2020c; Liu et al., 2021). The following hypothesis is formulated:

H1. A positive AT has a favorable influence on farmers' intention to participate in SFD.

SN describes the social pressure that individuals perceived when making decision on the behavior, and it reflects the influence on other people or groups. If an individual believes its behavior is important to getting supports from others, the more likely that the individual will perform it. Conversely, the less likely the individual will perform the behavior (Adam and Shauki, 2014; Jiang et al., 2018). The external influences on farmers' decision to participate in SFD primarily derive from family members, neighbors and friends, village committee, and local government. The questionnaire is set up with appropriate questions to reflect farmers' SN.

H2. The SN bolsters the farmers' intention to participate in SFD.

PBC describes the degree of difficulty that the individual perceives in conducting the behavior. Even if an individual has positive behavioral AT and SN, one may have a lower INT to behave when one does not control the behavior. According to Jd et al. (2019), the greater one's ability to control these characteristics, the greater one's ability to develop behavioral INT. In agricultural production, the PBC comprises individual condition profiles such as physical and capital contributions (Andow et al., 2017; Li, F. et al., 2021; NDRC, 2011). Based on the analysis, it is expected that the INT of farmers' participation in SFD will improve their control beliefs about performing this behavior. From the above, the following hypothesis is formulated.

H3. PBC has a significant positive influence on farmers' INT participating in SFD.

2.1.2.2 The influence of agriculture production conditions on the TPB construct

Guagnano et al. (1995) proposed that the “Attitude-Context-Behavior” theory integrated external factors into the TPB framework and pointed out that environmentally responsible behavior results from the interaction between internal environmental attitudes and external contextual factors. SFD is based on the current farmland status with its resource endowments. The resource endowments prior to SFD are the external context that influences the actors (Wang, Z. et al., 2021). Moreover, behavior economic theory states that an actor's choice preference and willingness are influenced by their degree of knowledge about the relevant events. Consequently, when farmers consider that the agricultural production conditions can meet their psychological expectations, the enthusiasm for SFD declines.

H4a. CLQ negatively moderates farmers’ INT to participate in SFD.

H4b. FIC negatively moderates farmers’ INT to participate in SFD.

2.1.2.3 The influence of policy conditions on the TPB construct

The farmers’ awareness on government actions is the beginning of the understanding of SFD, including the comprehensive evaluation on local government performance. The farmers’ cognition has been explored on the government-implemented land expropriation (Bao et al., 2017; Cao and Zhang, 2018; Huang, X. et al., 2017). Furthermore, the main aspects of government performance are regulatory conditions, profit distribution, right principles, and information responsiveness (Wang, Y et al., 2018). Favorable evaluations of administration practice can help farmers better understand SFD. Hence, the following hypothesis is proposed:

H5. PE positively moderates farmers’ INT to participate in SFD.

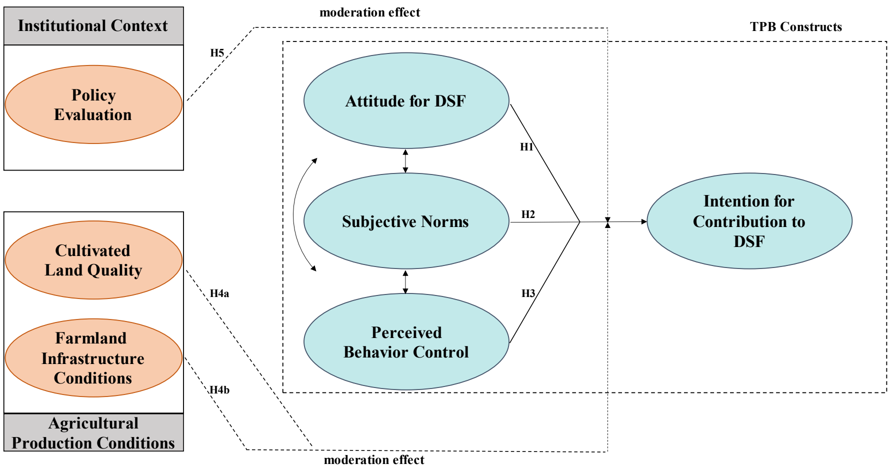

Figure 5- 2 The framework of the ETPB

3. Material and methods

3.1Study area

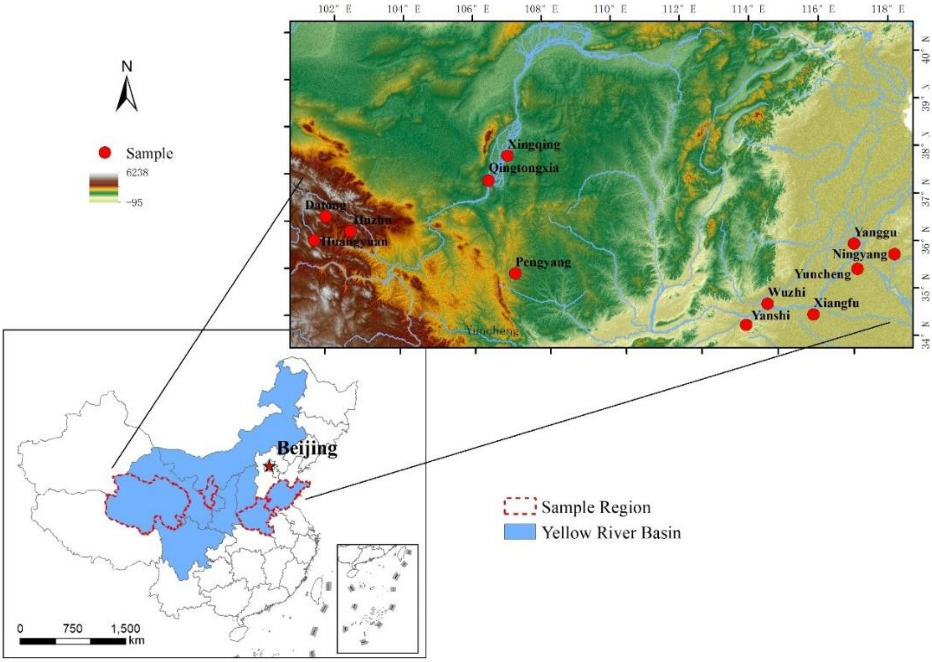

Figure 5- 3 Study area and sample distribution

The four provinces or autonomous region of the YRB are selected as the study area. The population amounts to 214 million, with 86.7 million rural residents, the GDP is CNY13.51 trillion, the agriculture GDP is CNY2.14 trillion, the cultivated land is 15.74 million ha, and the food production is 128 million tons, accounting for about one-fifth of China in 2020[34]. So, the area plays an important role in China's economic and social development. However, the farmland ecosystem is characterized by land surface fragmentation and imperfect infrastructures, such as drainage ditches and field roads. The low CLQ(grades 4-7) significantly limits production capacity. Agricultural practices of "High-input, High-consumption" have long been adopted, which hurts the sustainable agriculture development. How to upgrade production facilities and environment, enhance stability of food system and ecological function of farmland have become the focus of government and academia.

In this context, the Chinese government has conducted a series of farmland development activities, and by 2020, 9.12 million ha of HSF has been completed in these 4 provinces or autonomous region, accounting for 17% in China. It is the typical

[34] China Statistical Yearbook 2021(http://www.stats.gov.cn/tjsj/ndsj/2021/indexch.htm)

region regarding agricultural production characteristics and development potential. It is the crucial implementation region for high-quality agricultural development planning, and that is the principal consideration in which the region is selected for the study.

3.2 Sample Collection

The survey was conducted from Sep-Dec 2021 by random household visits with professionally investigators in agricultural economics. Face-to-face interviews can improve the accuracy of the collected information. Moreover, the survey dates avoided the agricultural production seasons, and farmers had free time and patience to be interviewed. Totally, 1236 questionnaires were collected, including 1133 valid questionnaires, with an effective rate of 91.6%. Furthermore, the sample size in the study fully satisfied the sample reasonableness test(Wang et al., 2019; Wang et al., 2016).

3.3Statistical analysis

3.3.1 Reliability and validity analysis

Reliability, convergent, and discriminant validity are used to assess the theoretical mode. The Cronbach's and composite reliability (CR) values should be N0.7, and reliability represents the internal consistency of the measurement items from a latent variable (Li, F. et al., 2021; Zhang et al., 2020). The convergent validity of each measuring item and the average variance extraction (AVE) of each latent variable should be tested, which can be supported if the values are higher than N0.5 (Fornell and Larcker, 1981). If the square root of each AVE value is greater than the correlation coefficient of each variable, the discriminant validity can be validated (Paulraj et al., 2008).

3.3.2 Structural equation model (SEM)

SEM can simulate and evaluate a wide range of hypotheses on measurement by modeling complicated and obfuscated interactions between variables, both observable and unobserved(Fan et al., 1999; Hayduk et al., 2007; Mcintosh, 2012; Tabri and Elliott, 2012). Observed variables(OVs) are indicators, which are collected to reflect hypothetical constructs that cannot be directly assessed in SEM. Therefore, SEM can be divided into two basic models: the structural model and measurement model. To specify the relationships between the OVs and LVs, factor analysis is performed using the correlation matrix and varimax rotation with measurement models in SEM. Next, the linkage in the LVs is modeled by utilizing confirmatory path analysis employing structural models in SEM.

The study adopted SEM to simulate and estimate the relationships in the model-based depicted in Fig. 3. In SEM, AT, SN, PBC, INT, APCs(CLQ & FIC), and PE function as LVs, which OVs measured through factor analysis.

The structural model is tested for constancy following two methods. The sample was divided into three groups based on education level and analyzed by a multi-group test. It could verify whether the stability of the structural model was disturbed by the education level of the respondents. Next, the sample was randomly grouped to check whether the sample size influenced the path relationship. In general, the $P \geqslant 0.05$, or changes in TFI values less than equal to 0.05, or CFI$\leqslant 0.01$ during model comparison, indicate that the stricter invariance hypothesis should not be rejected(Pousette and Hanse, 2002; Wu and Yao, 2006).

3.3.3 Moderation effect test

In regression analysis, testing the moderating effect of a variable means that the interaction effect of the moderating variable and the independent variable is verified to be significant (Xu et al., 2017). The regression equations for the moderating effect are as follows:

$$y = a + bx + cm + e \qquad (2)$$

$$y = a + bx + cm + c'mx + e \qquad (3)$$

Among the equations, m is the moderating variable, mx is the moderating effect, and the moderation effect means the analysis of whether c' significantly meets the statistically significant critical ratio. The moderating effect relationships were validated by using the hierarchical regression analysis.

Furthermore, this research used an ordinary least squares (OLS) regression analysis to examine the effect of farmers' characteristics on their intention to participate in SFD.

The SPSS 26.0, PROCESS, Stata 16.0, and AMOS 26.0 were applied to conduct the analyses in the study. SPSS 26.0 was used to perform descriptive statistical analysis, PROCESS was used to perform hierarchical regression, Stata 16.0 was used to conduct the OLS regression analysis, and AMOS 26.0 was used to perform SEM.

4. Results

4.1Sample characteristics and OLS results

4.1.1 Socioeconomic characteristics of the sample

As shown in Table S4 (in Appendix B), most respondents were males, representing 62.8% of the overall sample size. Farmers aged 41-60 and over 60 years old occupied 59.4% and 29.3%, respectively, while farmers with only a primary education accounted for 32.7%. The findings showed that approximately 63% of farmers had less than 0.67 ha cultivated land. However, nearly 60% earn more than CNY 50,000 per year, which was incomparable with the small size in cultivated land and reflected the fact that the proportion of non-farm income had increased (Han et al., 2018). Professional farmers declined, with 63.4% combining non-farm income to meet their livelihood needs. Moreover, about 60% of farmers had a negative attitude towards land transfer.

4.1.2 Results of OLS

Table S6 (in Appendix B) presented the OLS results. The results indicated that the farmers' gender and the land transfer situation could significantly affect their participation intention. Compared with female respondents, males were more willing to participate in SFD, and farmers with land transfer were more enthusiastic about participating in SFD.

4.2 Measured item descriptive statistics

In the survey, farmers were interviewed to respond the questions on a 5-point scale(1 to 5). Table 1 summarized the question items of all OVs and their measures. Overall, it was presented that farmers had a medium response to AT, SN, PBC, and INT questions. Fig. 5 shows the distribution of response levels to the observable variables. A relatively large number of farmers provided a high-level response to the AT and SN questions. Due to farmers' various control beliefs, their answers to PBC-related questions showed a relatively low response, with 60% of farmers indicated that their economic and health status had difficulties participating in SFD. 58% of farmers reported that they could not recognize barriers in farmland utilization, and 57% of farmers failed to understand the SFD related policies sufficiently. Behavior INT of farmers was at a high response(4-5scale) with a proportion of 48%. Besides, the study assessed the level of farmers' intention to participate based on the different forms of participation in SFD activities. According to the results (Fig. S in Appendix B), the level of farmers' intention to participate (investment or labor, adoption of EFAPP) was low(mean= 2.19, 2.55, respectively). The expected conclusions of the study could contribute to enhancing farmers' INT.

Table 5-1 showed the APCs in the survey areas, and according to respondents' opinions, CLQ was degenerated and infertile. Concerning FIC, the drainage, irrigation facilities, and field roads were superior in Henan and Shandong's plains, but Qinghai and Ningxia's plateau were seriously lacking (Fig. S3 in Appendix B). The farmers' evaluations of SFD policies, presented a high level of appraisal for government measures(mean=3.88). Figure 5-4 revealed that farmers were satisfied with the government conducting technical training, promoting SF and investment, and establishing the regulatory mechanism. The conclusion of the study can contribute to formulating the action plan and support system framework for SFD.

Table 5- 1 Descriptive statistics of the items used to measure the TPB construct

LVs	***OVs***	**Item descriptions**	**Scale of response (1–5)**	**Mean**	**Std.**
AT	AT1	SFD can provide increased efficiency in agricultural production.	Strongly disagree(1)-Strongly agree(5)	3.166	1.150
	AT2	SFD contributes to the improvement of agricultural production conditions.		3.162	1.144
	AT3	SFD to enhance the eco-services of farmland.		3.306	1.154
	AT4	SFD helps to increase income in agriculture.		3.200	1.173
SN	SN1	My family's support has an impact on my engagement in SFD.	Strongly disagree(1	3.437	1.208

	SN2	The attitudes of my neighbors and friends can drive my participation in SFD.	)-Strongly agree(5)	3.380	1.213
	SN3	The attention given to SFD by the village committee will encourage them to participate in the activity.		3.327	1.170
	SN4	The pressure from government can affect my decision to involvement in SFD.		3.238	1.175
PBC	PBC1	I understand the current obstacles to farmland utilization and have options for solution.	Strongly disagree(1)-Strongly agree(5)	3.246	1.202
	PBC2	I can understand the key activities of SFD and relevant policy.		3.177	1.176
	PBC3	My financial capacity and health condition can permit me to participate in SFD.		3.214	1.198
INT	INT1	I would like to contribute to the development of SF(Form: investment or labor).	Strongly disagree(1)-Strongly agree(5)	3.263	1.164
	INT2	I volunteer to promote joining SFD with other people.		3.173	1.148
	INT3	I will actively respond to village committee on land utilization and agricultural production issues.		3.303	1.162
CLQ	CLQ1	No soil hardening on the farmland.	Strongly disagree(1)-Strongly agree(5)	2.462	1.247
	CLQ2	Soil nutrient composition is adequate.		2.561	1.065
	CLQ3	We never dispose of agricultural waste plastics(Packages for fertilizer and pesticide, agri-film)indiscriminately.		2.794	1.155
FIC	FIC 1	I have no demand for land consolidation.	Strongly disagree(1)-Strongly agree(5)	2.881	1.332
	FIC 2	Existing irrigation and drainage ditches on farmland are adequately configured.		2.852	1.364
	FIC 3	Existing on-field roads meet production demand		2.883	1.324
	FIC 4	Existing fields with sufficient agricultural waste collection facilities.		2.847	1.337
PE	PE1	The government has conducted training on techniques related to SFD.	Strongly disagree(1)-Strongly agree(5)	3.832	0.929
	PE2	There is a high level of government investment in SFD.		4.002	0.883
	PE3	The government has promoted elements related to SFD.		3.817	0.958
	PE4	The government has appropriate regulatory mechanisms in SFD.		3.868	0.952

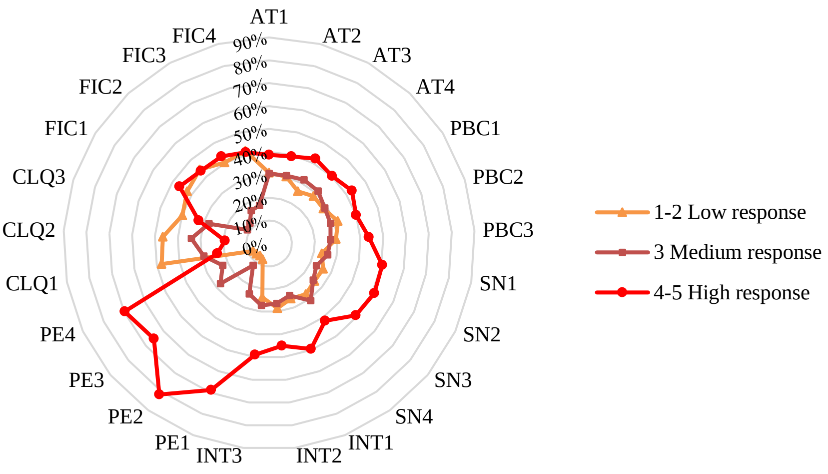

Figure 5- 4 Farmer responses as evaluated by a five-point Likert-type scale.

4.3 Measurement model

The results of exploratory factor tests and reliability validity tests were shown in Table 5-2. Cronbach's α > 0.7 indicated that the *OVs* given an adequate representation of the *LVs* and the model was sufficiently reliable to be used in the analysis. The standard estimate loadings for *OV*s >0.7, The CR>0.7, and AVE>0.5 confirmed the applicability of factor analysis.

Table 5- 2 Reliability and validity test

LVs	***OVs***	**Std. Estimate**	**Cronbach's α**	**CR**	**AVE**
AT	AT1	0.813	0.898	0.898	0.688
	AT2	0.847			
	AT3	0.799			
	AT4	0.858			
SN	SN1	0.788	0.886	0.887	0.665
	SN2	0.887			
	SN3	0.879			
	SN4	0.693			
INT	INT1	0.908	0.880	0.883	0.716
	INT2	0.828			
	INT3	0.799			
CLQ	CLQ1	0.772	0.818	0.818	0.600
	CLQ2	0.766			

	CLQ3	0.785			
FIC	FIC1	0.977	0.985	0.985	0.941
	FIC2	0.969			
	FIC3	0.976			
	FIC4	0.959			
PBC	PBC1	0.802	0.857	0.85	0.66
	PBC2	0.824			
	PBC3	0.822			
PE	PE1	0.879	0.937	0.937	0.789
	PE2	0.895			
	PE3	0.892			
	PE4	0.887			

4.4 Structural model

4.4.1 Goodness of fit

SEM was utilized in two steps, the first was to estimate the goodness of fit of the theoretical model for the *OVs*, and then was to measure the correlationship with the *LVs*(Hair et al., 2010; Kline et al., 2011; Livote and Wyka, 2009; Tabachnick and Fidell, 2007). Eight indices were selected in the study to assess the degree of model fit(Bagheri et al., 2019; Bondori et al., 2018). According to the results (Table 5-3), all indicators were better than the recommended values, which means the investigation data were suitable for SEM.

Table 5- 3 Goodness of fit measures of SEM model

Index	**χ^2/df**	**SRMR**	**RSMEA**	**GFI**	**AGFI**	**IFI**	**CFI**	**TLI**
Estimate value for hypothetical model	2.640	0.020	0.038	0.977	0.966	0.988	0.988	0.984
Recommended level	< 3	< 0.08	< 0.08	> 0.9	> 0.9	> 0.9	> 0.9	> 0.9

4.4.2 Results of SEM

Figure 5-5 depicted the SEM standardized path coefficients (PCs) of the original TPB (Model 1). Tables (S 13-15 in Appendix B) verified the ETPB findings after introducing the moderate factors. The strong positive impacts of AT(F1), SN(F2), and PBC(F3) in predicting INT were provided based on model 1, and H1, H2, and H3 were verified. PBC had the most significant influence on INT with a PC for 0.27($p<0.01$), followed by SN for 0.24($p<0.01$) and AT for 0.23($p<0.01$). AT, SN and PBC were shown to have a favorable interaction. Farmers' AT, SN, and PBC all had a similar belief of "contribution to SFD," hence the three components impact each other. The result fitted perfectly with elements relationships of the TPB and reaffirmed the rationality of applying the theory in this study. Furthermore, Table 5-4 confirmed the discriminant validity.

The relationship between *LVs* and *OVs* variables was also obtained from the path analysis in Figure 5-5. Farmers demonstrated favorable attitudes regarding the advantages of SFD, with the most robust performance in the AT for increasing income. The importance given by the village committee to the farmers' contribution to activity was the most critical factor that reveals SN with PC for 0.86($p < 0.01$). PBC consists of clarity of barriers to farmland utilization, sufficient information about SFD and its related policies, and the ability to contribute to economic and healthy conditions by participating in this activity. In terms of results, all factors were at a higher contribution. Consequently, hypotheses 1-3 were supported (Table 5-5).

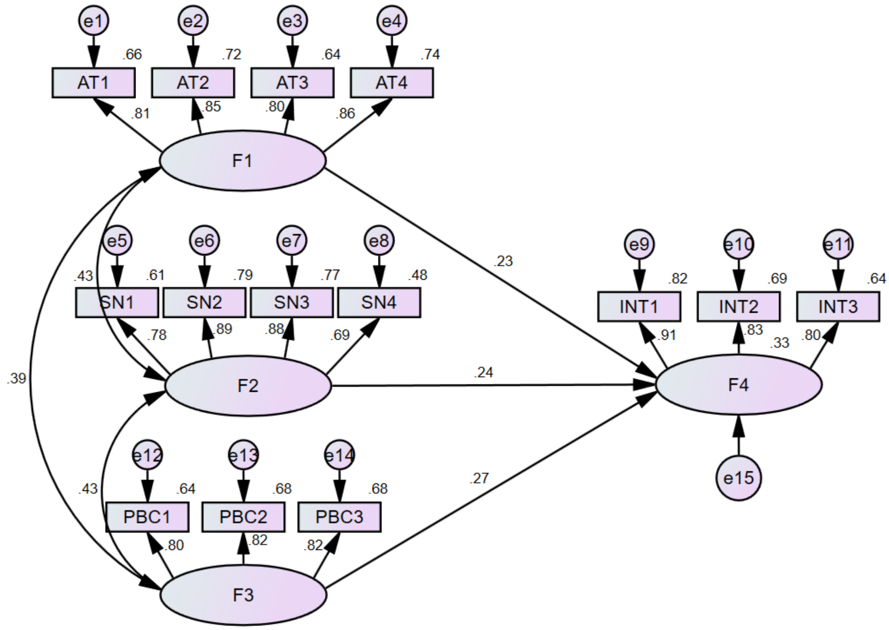

Figure 5- 5 Standardized PCs of the structural model for TPB(Model1)

Table 5- 4 The discriminative validity results

	PE	PBC	FIC	CLQ	INT	SN	AT
PE	**0.888**						
PBC	0.009	**0.816**					
FIC	0.008	0.089	**0.970**				
CLQ	0.130	0.073	0.066	**0.774**			
INT	0.057	0.462	0.046	0.099	**0.846**		
SN	0.036	0.430	0.255	0.095	0.453	**0.816**	

AT	0.055	0.392	0.061	0.087	0.439	0.431	**0.830**

The square root of the AVE for each construct was presented in bold and italic

Table 5- 5 Concrete results of Model1 and hypothesis testing

Path	**Hypothesis**	**Std. Estimate**	**S.E.**	**C.R.**	**P**	**Supported**
AT→INT	H1	0.231	0.038	6.885	***	YES
SN→INT	H2	0.238	0.038	6.941	***	YES
PBC→INT	H3	0.269	0.038	7.740	***	YES

"***", "**", "*" significant at 1%, 5%, 10% level, respectively.

4.4.3 Results of Testing for Multigroup Invariance

Farmers' decisions to participate in agricultural actions were usually influenced by their education level (Jia et al., 2021; Mbaga-Semgalawe and Folmer, 2000). The literature revealed that farmers' education was a factor that reflected their environmental literacy, and enhancing farmers' environmental literacy could help to strengthen their motivation to participate in farmland ecological improvement (Vignola et al., 2010; Yu et al., 2017). Accordingly, the study conducted the multi-group analysis based on the respondents' education. The results show that P＞0.05 for Structural weights and Structural residuals(Table S 4 in Appendix B). The model path coefficients, factor loadings, and variances did not make statistically significant differences in group comparisons. Farmers' education would not change the path assumptions, and the structural model was well stabilized. It is probably attributable to the survey way. Since SF is a new farmland mode, farmers still lack a uniform standard of knowledge about it. Hence, before formal questioning, the investigators intervened for the SF's effect by picture presentation and described the construction activities and related policies in detail. It provided farmers with a sufficient understanding of SFD and subsequently controlled the effect of farmers' different educational literacy on their intention to participate. Similarly, model constancy test results under random grouping proved that the theoretical model was not limited by sample size (Table S 7 in Appendix B).

4.4.4 Results of Moderating effect

Tables S13 and S14 (in Appendix B) showed the CLQ and FIC negative moderating the AT-INT, SN-INT, and PBC-INT pathways. It implied that better APCs could weaken the INT of farmers participating in SFD. In comparison, the moderating effect of CLQ (mean=-0.078) was greater than that of FIC (mean=-0.081). The reason was that CLQ had a more immediate influence on crop yields, while FIC's emerged benefits and efficiency required a long-term process. As a result, the INT of farmers' SFD involvement was more sensitive to CLQ's influence. Table S15 (in Appendix B) verified the role of PE as another regulator that acted positively in moderating the AT-INT, SN-INT, and PBC-INT interactions. Farmers' AT, SN, and PBC were transformed towards INT if they were more satisfied with government actions.

4.5 Scenario Analysis

In part, the benefits of SF were estimated. Furthermore, it examined the regional investment contribution of farmers' involvement in SFD. The payments are 3862 CNY/ha, 2244 CNY/ha, 6624 CNY/ha, and 6160 CNY/ha in Qinghai, Ningxia, Shandong, and Henan, respectively, based on the number of rural family and area of cultivated land in each region. The construction costs of FIC are higher owing to geomorphological peculiarities of the plateau in Qinghai and Ningxia. However, the regions had the lowest rate of farmer investment. If the activities of SFD were conducted entirely by region, the maximum efficiency could not be achieved despite the multiple entities' efforts to broaden the financing source. Therefore, it also revealed that regional cooperation was required to accomplish optimal resource allocation.

How could SFD be used to achieve a "production-ecology" value of win-win? The integrated water-fertilizer technology is the deputy of demonstrating the benefits of SFD activities. It provides the irrigation facilities required for agricultural production while also having excellent ecological attributes. The application of the technology reduced fertilizer inputs and irrigation water by 30-50 %, lowering GHG emissions from 28.69 billion kg CO_2-eq-kg^{-1} to 14.34 -20.08 billion kg CO_2-eq-kg^{-1}. The quantified environmental-economic benefits of SF were shown in Table S16. Assessing the life cycle of SF construction and operation was helpful for agricultural production guidance and carbon management design in agriculture.

5. Discussions and implications

5.1What realities are reflected in the farmers' characteristics

Descriptive findings indicated the aging of population and the generally lower education level of rural labor. Besides, the cultivated land operated by farmers was small and scattered. Finally, the current purely agricultural production was increasingly unable to meet farmers' livelihood needs. In this context, some farmers were still reluctant to transfer their cultivated land. The phenomenon was caused by renting land with lower income than its production (Huang, W. et al., 2017). In land transfer, price depended on the farmland conditions (Chen et al., 2020; Fu et al., 2022; Zhang and Wang, 2021). Current studies showed that the dilemmas in agricultural production were a reality so that SFD is necessary for the globe (Abubakari et al., 2016; Xu and Zhao, 2019; Zhao and Chen, 2018).

The OLS results showed that male farmers were more interested in participating in SFD. It was attributed to the fact that men were the primary labor and more concerned about improving farmland conditions. Furthermore, INT-related questions involved labor and investment. Men were more physically capable and better able to lead decisions in agricultural production. The results also revealed that farmers who had conducted land transfer were more enthusiastic about participating in SFD. It was that farmers who conducted land transfer were more aware of the market needs for farmland quality. SFD can improve farmland infrastructure and land quality. The improved farmland can increase the land rent and agricultural revenue, furnish production convenience, and provide a pleasant environment. SFD is a necessary action to meet the trend of land transfer.

5.2 Why do farmers show a low-willingness to contribute to SFD

The PBC (mean=3.21) results showed medium perceived control of farmers on participating SFD. Jiang et al. (2018) also confirmed them. Furthermore, PBC was identified as the primary factor affecting farmers' INT. It suggested that control beliefs were of significant value in reinforcing INT, with constraints regarding personal financial ability, health, and ability to collaborate with SFD -related policy particularly salient (Hung Anh et al., 2019). Thus, if farmers cannot overcome the difficulties of livelihood endowment, they may lose enthusiasm and eventually fail to make positive decisions (Basanayak et al., 2013; P. et al., 2004) (A et al., 2018; Grzelak et al., 2019; Lu and Xie, 2018; Wei, X. et al., 2021). It illuminated that policy booking should provide differentiated participation modes and criteria. Meanwhile, it is also essential that SFD participation mechanism can address the barriers to farmers' livelihood endowments. Farmers' cooperatives can serve as an intermediary platform to tackle the participation constraints of group capacity. Farmers can join the cooperative by the ways of land equity or product mortgage. According to the contract agreement, the cooperative can participate in SFD standing for the farmers. Current studies have also shown that PBC was a critical determinant (Wilson et al., 2018). In Daxinis' study, PBC-related questions were set in terms of the level of easiness and self-confidence of farmers to follow the nutrient management plan (NMP)(Daxini et al., 2019). EFAPP activities in SFD and NMP are technical management practices requiring specialist knowledge, skill, and attention to detail. Education could enhance farmers' familiarity and skill with the technology, improve their self-confidence to use technical innovations, and avoid relying on intuitive judgement instead of using formalized EFAPP (Burton, 2014; Nuthall and Old, 2018; Zhang et al., 2017). Thus, the findings of similar studies were considered comprehensively. In formulating policies, technical guidance should be provided by advisors in the agricultural production process, and cooperation between farmers and advisors should be promoted (Madden et al., 1992).

SN was identified as another key independent predictor, implying that farmers' INT was sensitive to social pressure. Previous studies have found SN to be an important determinant of farmers' intentions towards adopting, for example, improved agricultural system(Li, F. et al., 2021), multifaceted agricultural production(Senger et al., 2017) and grazing management measures(Schaak and Mußhoff, 2018). In fact, the finding explained that individuals did not make decisions without considering their actions in relation to that of others, nor were individuals independent of social and cultural influences(Hunkeler, 2008).Therefore, it was most likely since they could be perceived as having an unfavorable experience and would be rejected by social relations if they were reluctant to participate in the action(Ru et al., 2019). In terms of the variance contribution of the OVs, the actions of other villagers in SN accounted for the enormous contribution to influencing farmers' decisions, followed by the concern of village committee, and next by the support of families. In contrast, pressure from the government accounted for the most negligible contributions. Most farmers may hold a skeptical attitude about the cost, benefit, and technical difficulty of EFAPP. They consider more about communication and cooperation with others around them and farmers' participation in SFD requires their labor and financial inputs. Supposing that neighbors have a positive attitude and a high level of attention from the village committee toward SFD, it will be able to avoid villagers' "free-riding" behavior in using infrastructure and agricultural elements. It explained why they hoped to reach a consensus with a highly respected village committee as the most direct regulator of collective action. It enlightened that if a platform was provided for villagers to interact, the scope and speed of SFD information dissemination among villagers could be increased by interpersonal networks. Extensive studies recognized the vital role of facilitating or intermediary organizations in “bringing farmers together, providing information, building trust and acting as mediators between farmers and government” (Emery and Franks, 2012; Martinovska Stojcheska et al., 2016).

AT's effect showed that the transformation of farmers' intention was based on increased agricultural benefits, production conditions, productivity, and improved ecological functions by SF. The economic value and psychological satisfaction of providing a conducive environment were relatively more important to farmers, while ecological aspects received little attention. The government probably focused on its economic revenue while neglecting to introduce the ecological functions on promoting farmland development-related activities. It was worth noting that the principal grain-production regions(Shandong and Henan) had been maintaining intense cropping with large quantity of chemical inputs and adopted a single way of managing waste agri-plastics, which led to severe consequences of farmland pollution. Therefore, it was suggested to focus on publicizing and demonstrating the ecological benefits of SFD and guide farmers adopting precision fertilization and green plant protection to restore healthy soil structure and improve soil fertility.

5.3 How to strengthen farmers' willingness to participate

5.3.1 The role of the current state of APCs

APCs were critical variables for influencing farmers’ INT. The most notable CLQ dilemmas were soil hardening and inadequate nutrient supply. Consequently, policymakers should prioritize initiatives to improve CLQ in the region. The findings of CLQ suggested that farmers' INT to participate in SFD was reduced by healthier cultivated land. Among them, CLQ contributed the most to regulating the AT-INT relationship. It was probably attributed to agricultural production dependent on resource factors such as land supply. On one hand, the excellent resource endowments limited the possibility for-economic and ecological improvement, and the supply of current resource elements had already satisfied farmers’ expectations. On the other hand, long-term exposure to excellent resource endowments also delivers better capital and technical capacity for farmers. As a response, the first step for policymakers was to benchmark SF standards and perform SFD activities in a result-led and site-specific way to ensure the efficient utilization of agriculture resource. Besides that, the government should broaden the scope of SFD propaganda. The differences between current farmland and SF should be contrasted, and the various benefits of SFD should be precisely publicized, which would help strengthen farmers' belief in SFD and thus change their behavior.

The negative moderating effect of FIC was confirmed in the pathway relationship test. Infrastructure was regarded as a crucial component in increasing productivity and income. Farmers in the FIC superiority region would consider the current conditions near SF standard. They have little motivation to invest in farmland improvement. For this reason, they pay the slightest attention to the obstacles to farmland utilization, making AT-INT and PBC-INT more sensitive to FIC intervention. Improving farmers' perceptions of farmland barriers contributes to enhance beliefs about INT. Consequently, the government should inform and train farmers about the benefits of updated infrastructure, particularly the ability to mitigate climate change and develop ecological functions, increase farmers' awareness of pro-environmental, and motivate them to participate in SFD.

Farmers' demand for farmland building generally follows the "dynamic growth - dynamic equilibrium" pattern, indicating that farmland development activities' marginal efficiency decreases under farmers' psychological expectations. The findings of the study could well be applied to improve farmers' cognition so as to promote farmland development through publicity, guidance, training, and incentives. However, when the farmland development has evolved to meet farmers' preconceptions sufficiently, the marginal efficiency of farmland development activities approaches 0 for farmers. Then, it is challenging to continue intervening in farmers' efforts on higher standards of farmland development. In particular, there remains a disconnect between the farmers' predicted state of farmland and SF standards. Therefore, it will face challenges how to bridge and allocate the gap in the future study for academia and policymakers.

5.3.2 Impact of the current policy

Current studies had found that institutional variables encourage farmers to engage in collective action and adopt EFAPP(HE L J, et al., 2019; HUANG Y Z et al., 2020). According to the results, PE had a positive moderating effect on the AT-INT, SN-INT, and PBC-INT pathways. Conducting SFD entailed costs and had externality that subsequently affected farmers' motivation. The attitude of the others was related to the cost allocation of SFD while the efficacy of the government as SFD main party was more noticeable. Farmers' sufficient knowledge of SFD policy helps them understand and appreciate the relative benefits. It could motivate them to participate in SFD. Farmland system improvement with ecological benefit and positive externality had slow payoffs and high investments. Farmers, as rational decision-makers, had little incentive to participate in such activities (Dai et al., 2020; Houessionon et al., 2017; Qian and Ying, 2014). The government was expected to provide the reasonable investment in infrastructure development and subsidies for farmers to adopt EFAPP. It helps stimulate farmers' awareness of the responsibility to sustainably apportion the cost of public goods supply and promote technology adoption. It was consistent with present agriculture development policy. For example, the latest plan for HFC was proposed to positively guide the farmers to participate in farmland development, encourage innovative investment patterns, and reasonably increase the proportion of social capital[35]. However, the current policy has not provided detailed plans for the participation of stakeholders in SFD. What are the different stakeholders' participation contents, forms, and standards? How should they be integrated into a satisfactory participation mechanism? All these need to be discussed in depth. However, the paper presents the new insights and viewpoints. Because it clarified the activities of farmers' participation and explored the benchmarks of their contribution based on different forms. Furthermore, it revealed the influence path of farmers' decisions, which helps provide a more precise reference for policymaker.

It was noticeable that the impact of the study extends beyond the specific circumstances under examination. It also had critical implications for academia and policymaker. First, a paucity of literature explored the improvement of farmland system and benefits with farmer participation by utilizing ETPB. Second, the paper's empirical method could be copied and used for other evaluations of farmer decisions. Finally, the findings and policy implications were applied to other areas in China as well as locations with similar agricultural system around the world.

6. Conclusions

The fragmented mode of developing sustainable agriculture has resulted in inefficient resource utilization. The lack of participation from stakeholders has caused an imbalance between the supply and demand of construction actions and the lower utilization of resources. The continuous investment had brought rather financial pressure on the Chinese central government. In order to achieve functional synergy and value enhancement of farmland ecosystem, promoting farmers' participation in SFD is considered the better option. Behavior economic study has mainly focused on elements in farmers' decision-making, such as the desire for environmental public goods, altruism's intrinsic drive, social expectations, and individual and family assets. There were few studies on farmer psychology, so the study contributes to the knowledge. First, it successfully verified the suitability of the TPB framework, which introduces APCs and PE as moderating variables in the analysis of farmers' contribution to SFD. Subsequently, it empirically investigated the drivers of farmer participation in SFD and further tested the moderating effects of QLC, FIC, and PE on TPB construct. Based on the results, farmers' INT to engage in SFD is affected by

[35] China High-Standard Farmland Construction Plan(2021-2030) (http://www.moa.gov.cn/hd/zbft_news/qggbzntjsgh/xgxw_28866/202109/P020210916554589968975.pdf)

PBC, especially the control beliefs regarding capacity restriction. Therefore, relevant departments should organize special training and formulate supporting policies to improve farmers' understanding of relevant policies and technical skills. As for SN, especially those derived from interpersonal relationships emerged as another critical, independent predictor of farmers' participation in SFD. The observation for policymakers implied that strengthening the interpersonal social network could be essential to increase farmers' INT to contribute. APCs were the vital moderator in shaping behavioral INT, so development programs and farmer participation rates should be adequately planned in different region. Institutional variables were also shown to impact intention by moderating farmers' beliefs, which the degree of intention could be significantly enhanced. Therefore, the study identified a policy tool to promote farmers' engagement in SFD.

However, the study's limitations should be recognized. First, the *LVs* in the SEM were determined by the farmer's self-reporting responses, and there was a probability of social pressures or self-presentational bias, which means that respondents may answer questions to please or impress the interviewers, resulting in overstated positive consciousness (Armitage and Conner, 2001; Juan and Royal, 2006; Meijer et al., 2015b). Farmers' evaluation of the APCs was just their subjective perception, and the combination of monitoring data in future research would provide more precise modification of the model and more detailed information for decision-makers. Second, the transformation relationship between intention and behavior had not been examined due to the actual participation behavior had not yet occurred by farmers. As SFD mechanism gradually being improved, the study can follow up on the participants' actual behavior, expand and modify the model to provide more closely supports for policy formulation. Finally, the study was limited by the solidification of the TPB and did not examine the effects of farmers' livelihood endowments on the construct. Future research can be conducted as a multi-group comparative analysis based on farmers' socioeconomic characteristics or directly examine the effects of various factors on farmers' participation decisions.

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Chapter 6

Farmers' role in the SFD: insights from preferences and payments

1. Introduction

To achieve the United Nations Sustainable Development Goals, agricultural production systems face increased demands, including continually enhancing land productivity, promoting environmentally friendly production practices, and improving farmland ecology (FAO, 2022). Farmland development is recognized as a priority strategy to bolster agricultural production efficiency and optimize resource utilization, with initiatives being implemented globally (Hao et al., 2023; Li et al., 2023). HSF represents a distinctive land consolidation system in China. By 2020, 53 million ha of HSF had been constructed, resulting in a 10%–20% grain yield increase and cost-effectiveness of 7.5 thousand Chinese yuan (CNY) per ha. However, during this period, the construction objectives focused on enhancing grain production capacity, with insufficient awareness regarding the sustainability of the production modes and the importance of farmland ecological preservation (MARA, 2021b). The issue is pervasive in land consolidation projects undertaken in developing nations (Do et al., 2023; Nguyen and Warr, 2020). Consequently, the latest farmland development planning advocates for a SF system, aiming for "efficient output, resource conservation, and environmental friendliness" (Yin et al., 2022; Zhou and Cao, 2020). SF requires constructing and renovating ecological infrastructures that align with sustainable production practices. SFD aims to further enhance comprehensive production capacity and quality benefits on grain, promote the transformation of agricultural production modes, improve the service functions of farmland ecosystem, and increase farmers' income (Wang, 2022).

A management institution is a crucial assurance for conducting farmland development, with developed countries adopting modes wherein stakeholders collaboratively participate in formulating construction schemes and sharing costs (Jiang et al., 2022; Krupowicz et al., 2020). By contrast, China predominantly relies on government leadership, using a "top-down" management mode. The mode is limited by the lack of stakeholder participation, resulting in the failure of the construction infrastructures to align with actual needs and the dual challenges of idle and insufficient supply of infrastructures for agricultural production. Moreover, SFD requires an investment of 60-90 thousand CNY per ha, which poses a great financial burden to the government (CPPC, 2021). Hence, there is an urgent need to optimize and innovate management institutions by integrating stakeholders' participation in construction. Farmers inherently benefit from the effectiveness of governance as a direct stakeholder in farmland utilization and management. Farmers should be vital in formulating farmland development schemes and sharing costs. This study addresses the dilemma implemented in farmland development by involving farmers' participation, thus overcoming the obstacles to agricultural sustainability transformation.

Shanxi and Shaanxi have issued the 2021-2030 Farmland Development Plan, which proposes increasing construction standards and per-ha investment, broadening funding channels, and guiding diverse parties to participate in farmland development. Meanwhile, the green farmland development project in the YRB was implemented in 2023. The region, designated as a project area, will establish green and climateresilient agricultural production bases to enhance the agricultural system's sustainability (EPHQD, 2023). Research on farmers' preferences for participating in SFD can clarify the current status and demands of farmland development, and calculating the payment levels for farmers provides precise references for formulating stakeholder investment mechanisms.

Research related to farmland development focuses on the relationship between farmland water conservancy facilities and production (Bhavsar et al., 2023), the entities investing in facility construction (Jie, 2022; Simango et al., 2021), and farmers' participation and investment willingness (Akrofi et al., 2019). Theoretical analysis methods such as Planned Behavior Theory, Symbiosis Theory, and Public Goods Theory are widely used in such studies (Li et al., 2021; Yin et al., 2022). Empirical analysis commonly adopts sampling surveys to establish econometric models, with structural equation models and binary discrete choice models being frequently used. Recently, choice experiments (CE) have been used in farmers' behavioral preferences, focusing on farmers' participation in innovative production technology (Aravindakshan et al., 2021; Schaafsma et al., 2019), ecological compensation (Nong et al., 2021; Ureta et al., 2021), ecosystem improvement (Wang et al., 2021), and policy design (Caputo and Lusk, 2022). Existing research provides essential insights into logical frameworks, theories, and analytical methods for this study. However, farmland development is often project-based, with construction activities integrating multiple categories of facilities. Previous studies focused on a single infrastructure, limiting their practical contributions. Regarding research on farmers' participation in farmland development, the emphasis is on exploring willingness rather than payment levels. This study examines farmers' needs and payment levels for all infrastructures related to SF, providing a more systematic and operationally robust basis for developing a participation mechanism. In terms of research methods, traditional willingness surveys lack a measure of payment levels under specific farmland development standards. By contrast, CE can more accurately examine farmers' preferences and quantify the willingness.

This study aimed to understand the construction preference and the payment level of farmers who participate in SF and the variation of preference in relation to individual characteristics and farmland conditions. In a discrete choice experiment, we elicited farmers' preferences for a program that combines infrastructure and ecology improvement on farmland, supported by a conditional payment to avoid the arbitrary selection of farmers. First, this study discusses farmers' preferences, clarifying the development needs of farmland development to provide a reasonable reference for regional SFD schemes. Second, it explores the heterogeneity of farmers' preferences, elucidating the intrinsic relationship between farmers' endowments and preferences to provide guidance for formulating differentiated participation pathways for farmers. Finally, it accurately measures the payment level of farmers, quantifies the intensity of farmers' willingness, and provides a more targeted basis for a cost-sharing mechanism. Overall, this study is of significant importance in optimizing farmland development management institutions and improving construction efficiency by clarifying how farmers participate in farmland development in terms of pathways, schemes, and standards.

The remainder of this paper is structured as follows. Section 2 presents the material and methods of this paper, including the selection of the study area, the establishment of the research framework based on a literature review, the proposal of the research hypotheses, the design of the choice experiment, and the descriptions of the data collection and econometric models. Section 3 provides the results of this study, and Section 4 discusses the findings and policy implications. The conclusions and limitations are provided in Section 5.

2. Material and methods

This section delineates the rationale behind the selection of the research area, constructs a comprehensive theoretical framework for this study, and proposes corresponding hypotheses. In addition, it explores the experimental design and data collection, presenting the methods utilized, such as the mixed logit model and latent class model.

2.1Study area

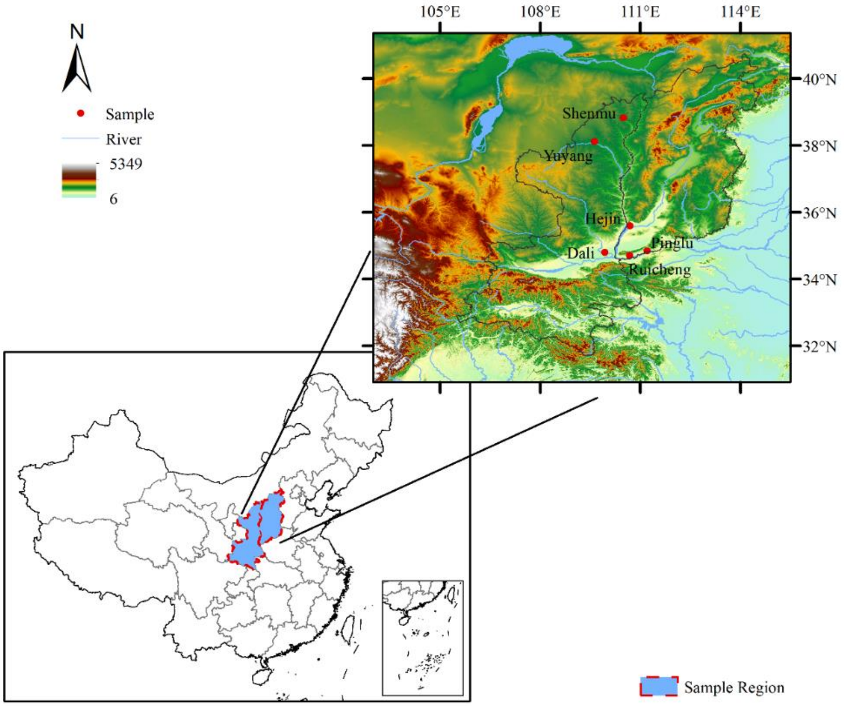


Figure 6- 1 Study area

This study was conducted in a major area of agricultural production at Shanxi and Shaanxi provinces (Figure 6-1), which is in the YRB in China. Shanxi and Shaanxi provinces, representative of the Loess Plateau region, constitute 4% of the national cultivated land and contribute 5% to the national grain production, playing a crucial role in ensuring food security (CNBS, 2023). As of 2020, 2.05 million ha of HSF in the region has been successfully constructed, significantly improving production conditions. However, because of inconsistent construction standards and low investments, the HSF varies. Moreover, the completed HSF only represents approximately 30% of the region's total cultivated land, with most of the farmland still facing issues such as a weak infrastructure, inadequate infrastructure support, declining production efficiency, and severe soil erosion in regions. There needs to be proper protective measures for farmland, and previous construction projects showed insufficient attention to farmland ecology, making them incompatible with sustainable agricultural production modes. To address current challenges in farmland development and bottlenecks in agricultural sustainability, Shanxi and Shaanxi have taken the lead in establishing demonstration zones for SF. Meanwhile, policies pertaining to these demonstration zones propose the exploration of a management system that can ensure the long-term development of SFD. This study's inception effectively responds to practical demands.

2.2 Theoretical framework and hypothesis

The core of SFD lies in enhancing farmland infrastructures and ecology, falling under the category of public goods provision. Public goods are characterized by non-excludability and non-rivalrous consumption. However, most public goods do not fully meet these criteria, existing as "quasi-public goods." Farmland, irrigation facilities, field roads, and ecological facilities, for instance, be classified as quasi-public goods (Wang and Liu, 2019; Wang et al., 2021). The usage of these infrastructures is confined to specific regions and limited to farmers within regions. To maximize benefits, farmers can invest in and construct quasi-public goods. The framework theoretically supports the farmer's participation mechanism for SFD.

On the basis of assumption of rational actors in neoclassical economics, farmers, as decision-makers, choose action schemes that maximize their utility within constraints. In selecting specific farmland development alternatives, farmers exhibit different preferences according to the actual needs of farming, which is a decision made after weighing expected benefits and costs. The direct effect of farmland development on increasing grain yield and its positive impact on changing production modes to enhance resource utilization efficiency have been verified in academia and recognized by farmers (Li et al., 2023; Li et al., 2024). Flat and large-area farmland and field roads provide necessary conditions for mechanized farming, which is an essential measure to improve production efficiency and save labor (Hao et al., 2024). In addition, IIFF can achieve a 20–30% reduction in water and fertilizer. Consequently, the following hypothesis is proposed:

Hypothesis 1: Farmers prefer field production roads, land leveling and contiguous transformation, and IIFF.

Previous studies have found differences in farmers' attitudes toward participating in activities related to ecological improvement. The promotion of farmland's ecological enhancement has significantly affected agriculture. Farmers' awareness of ecological conservation has been heightened. Some farmers believe that improving farmland's ecology can enhance their living and production environment and demonstrate a sense of social responsibility (Maleksaeidi and Keshavarz, 2019; Tama et al., 2021). The long-term benefits of such improvements will positively affect future generations. However, some farmers may not be actively involved in such activities because of the solid positive externalities of farmland ecological improvement, from which they cannot directly benefit economically (Yin et al., 2022). The following hypothesis is proposed:

Hypothesis 2: Farmers exhibit differences in their choices regarding ecological conservation facilities.

Farmers exhibit diverse preferences, primarily influenced by the constraints that they encounter, rather than being attributed to their "irrationality" or "bounded rationality." These constraints depend on various factors. Household income not only determines whether farmers engage in infrastructure construction but also dictates the level and manner of their participation (Khan et al., 2022). Farmers' age reflects their physical condition and farming experience, impacting their decision-making in infrastructure construction (Villamayor-Tomas et al., 2019). The educational level of individuals correlates with their comprehension knowledge of infrastructures in production (Li et al., 2023). Higher educational levels generally enhance farmers' willingness to participate in agricultural activities. However, higher education levels may also lead decision-makers to engage in non-agricultural activities, potentially reducing their inclination toward infrastructure construction. Participation in SFD is an investment behavior influenced by farmers' risk propensity, aversion to risk, and ability to identify risks (Aravindakshan et al., 2021). Land is a crucial input in agricultural production, that affects farmers' decision-making and willingness. According to behavioral economics theory, individuals' preferences and willingness are affected by their awareness of relevant factors (Luu, 2020). Farmers' willingness to participate in farmland development also depends on their cognition of relevant facilities. Thus, a hypothesis is proposed:

Hypothesis 3: The heterogeneity of farmers' preference is influenced by their endowments and perception of farmland conditions.

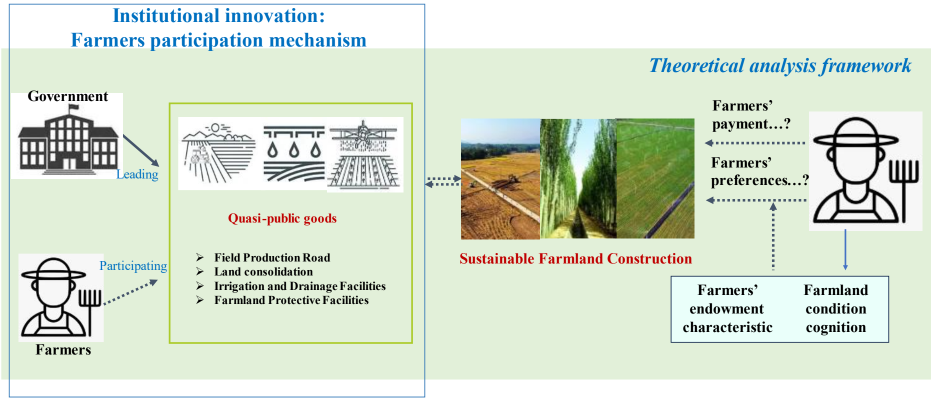


Figure 6- 2 Theoretical Framework

2.3 Choice experimental design and data collection

2.3.1 Attributes and level configuration

The selection and design of assessment attributes and their levels are crucial for the successful implementation of CE. Therefore, this study follows the principles of selecting attributes based on infrastructure construction categories under SF standards. It ensures that the chosen attributes are intuitive and easy for farmers to compare in different choice sets. In addition, it guarantees that the attributes are relevant to SF policies and reflect the attributes of urgently needed construction categories. To design the assessment attributes and level values, the research team conducted preliminary investigations scientifically and rationally before the questionnaire design. In June to July 2021, on-site surveys of the status of farmland development in Shanxi and Shaanxi were conducted, and interviews were conducted with local agricultural management departments, village committees, and farmers to understand the needs for farmland development. From September 2021 to September 2022, team members visited the YRB in batches, conducting field surveys on the current state of farmland and infrastructure construction in multiple project areas and non-project areas on SFD. Building on the preliminary survey, the basic status of farmland development was identified. The research team designed the experimental booklet and CE questionnaire through literature review and focus group interviews. Subsequently, in July 2022, the research team conducted a simulation experiment and in-depth interviews with 44 farmers. Experimental attributes and survey data were adjusted and quantitatively analyzed, ultimately finalizing four construction evaluation attributes and one monetary attribute for SF, as shown in Table 6-1.

A method combining stratified and random sampling was used in the field survey, following the hierarchy of 'county-township-natural village-farmer.' Considering factors such as each county's economic development, population proportion, and transportation conditions, three townships were selected from each county, with three to five natural villages chosen from each township. A random sample of 10–15 households was surveyed in each natural village, totaling 608 farmers. The survey included a dual evaluation by farmers and researchers on the questionnaire understanding and completion attitude of participating households in the experiment. After excluding 35 invalid questionnaires, the final dataset comprised 573 valid questionnaires (308 from Shanxi, 265 from Shaanxi), with 4620 valid observations in Shanxi and 3975 in Shaanxi.

Table 6- 1 Attributes and level descriptions

Attributes	**Attribute levels**			
Field production road	Maintaining status quo	To construct the mechanized production road (MPR)		
Land consolidation	Maintaining status quo	To level the farmland or construct the contiguous farmland (LF or CF)		To level the farmland and construct the contiguous farmland (LF and CF)
Irrigation facility	Maintaining status quo	To construct ecological ditches (ED)		To construct integrated irrigation and fertilization facilities (IIFF)
Ecological facility improvement on Farmland①	Maintaining status quo	Moderately improved		Highly improved
Costs per household (CNY/0.0667ha)	0	400	600	1000

① : **Biological habitat, ecological corridor, protective forest.**

Field production road. Field roads are crucial agricultural, infrastructures that significantly increase the mechanization rate and promote modern agricultural production (Gebresilasse, 2023; Shamdasani, 2021). “Field production road” generally refers to machine plowing roads and production roads. Through on-site investigations, substantial variations were observed in the current configuration of field production roads. Overall, 70% of surveyed farmland in the region requires construction or improvement of field production road. It is noteworthy that farmland engaged in large-scale cultivation has mostly optimized field road, meeting the demands of mechanized operations. In the new round of HSF construction planning, it is proposed to rationally scheme and construct field road networks, prioritizing the transformation and utilization of existing roads. The plan stipulates that field roads in plain areas should be short, straight, and smooth, and those in mountainous and hilly areas should follow the terrain. It also emphasizes the construction of bridges and culverts, meeting the requirements for agricultural production such as machinery operations and transport of agricultural inputs. Given the configuration and construction standards of field production roads, this study sets two levels for this attribute: “Maintaining the status quo” and “MPR.”

Land consolidation. Land consolidation generally involves two types of activities: LF and CF. LF ensures the thickness of the arable layer through measures such as backfilling with topsoil and excavating elevated areas to fill low-lying areas, improving field drainage and cultivation conditions. The core of CF is to reorganize and adjust scattered, fragmented, small plots of farmland to create contiguous, orderly, and large plots, facilitating more efficient and intensive farmland management, enabling large-scale farming, and promoting mechanized production. Land consolidation aims to enhance land utilization and ensure sustainable resource utilization (Hao et al., 2023). Simultaneously, it aims to improve the ecological environment of the farmland, reduce soil erosion, and prevent land degradation. The study area urgently needs land consolidation, considering varied demands across different regions. This study sets three levels for the land consolidation attribute: “Maintaining status quo”, “LF or CF”, “LF and CF.”

Irrigation facility. Water conservancy facilities are a crucial guarantee for agricultural production. Traditional irrigation and drainage facilities, mostly open ditches, result in large water volumes, leading to low irrigation water utilization rates. In addition, high water pressure in open ditches causes uneven irrigation and issues such as fertilizer loss (Zhu et al., 2023). Open ditches neglect their ecological functions, causing damage to the habitat and landscape for channel organisms and a significant decline in biodiversity. Farmland development emphasizes coordinating irrigation zone productivity and the ecological environment in the new era. There is a greater focus on strengthening the construction of on-farm irrigation and drainage facilities, promoting efficient water-saving irrigation, increasing effective irrigated areas, and improving water use efficiency (Xiong et al., 2023). Ecological ditches and IIFF are widely promoted and used. Ecological ditches primarily enhance channel water conveyance efficiency, reduce slope erosion, and create an environment that supports biological survival and growth, fostering biodiversity. IIFF, including drip and spray irrigation, are water-saving irrigation systems that allow precise water and fertilizer application based on crop needs. These facilities are crucial for improving irrigation water use efficiency and fertilizer utilization rates. This study defines the irrigation facility attribute using three levels: “Maintaining status quo”, “ED”, “IIFF”.

Ecological facility improvement on farmland. Biological habitats, ecological corridors, and protective forests enhance farmland ecology. Their functions include improving microclimates, mitigating, and defending against natural agricultural disasters, creating environments conducive to crop and field biological growth, and enhancing farmland ecological services. Farmland ecological improvement projects have strong public benefits, but agricultural producers may not fully recognize these benefits. This study investigates farmers' support level for farmland ecological improvement actions. Simultaneously, it focuses on discussing facility construction needs under SF standards. The attribute is set as “Maintaining status quo” “Moderately improved” “Highly improved.”

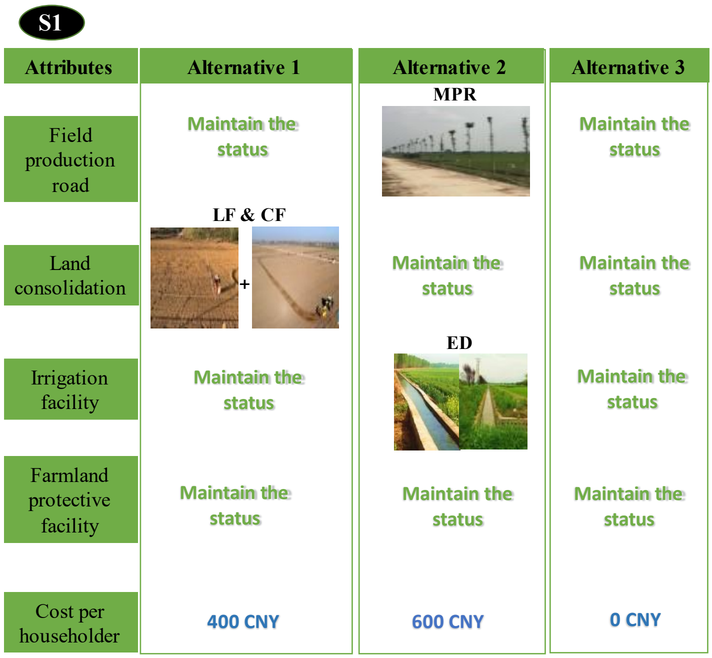
Costs per household. In this study, the term “monetary attribute” refers to the amount that households are willing to pay when selecting a specific attribute combination from the choice sets. To determine the specific amounts for the monetary attribute, the contingent valuation method was primarily used during the presurvey to investigate the respondents' willingness to pay for the SFD. The most frequently occurring amounts of 400, 600, and 1000 CNY per household were selected as the monetary attribute.

2.3.2 Orthogonal experiment and questionnaire design

The questionnaire design involves an orthogonal experiment to create intuitive alternatives with different levels of attribute combinations. These alternatives are then grouped into choice sets, which are further combined to form experimental questionnaires. In this study, each CE questionnaire provides respondents with five choice sets (i.e., each respondent completes five independent CEs) and each choice set includes three alternatives. Figure 6-3 illustrates a choice set, where “alternative 3” represents no intervention, and “alternative 1” and “alternative 2” represent different degrees of intervention.

Table 6-1 outlines the attributes and levels for SFD. Representative choice sets need to be selected with 216 possible alternatives (2*3*3*3*4=216) and 23,220 potential choice sets (C_{216}^{2}=23220). This study used an orthogonal experimental design and obtained 10 alternatives and 45 choice sets after eliminating unreasonable options. Furthermore, an expert panel was organized to examine the rationality of each choice set. Adjustments were made to the choice sets with dominant strategies, resulting in the final selection of 15 choice sets divided into 3 versions. One version of the questionnaire was randomly selected for questioning.

Figure 6- 3 Choice set example



By assuming that farmers have different choices for SFD schemes to achieve their utility maximization, we adopt a random utility model, specifically the mixed logit model, which is an extension of the standard conditional logit model (McFadden, 1974). This model accommodates unobservable preference heterogeneity among respondents by allowing coefficients to vary across decision-makers. In addition, the model avoids assuming independence of irrelevant alternatives.

On the basis of the random utility model, the utility a farmer i derives from alternative j is given by

$$U_{ij} = V_{ij} + \varepsilon_{ij} \quad (1)$$

where V_{ij} represents the utility of farmers i participating in the experiment, based on observable characteristics, in choosing alternative j and ε_{ij} is a random error term.
Step 1: The mixed logit choice probability of choosing alternative j is given by

$$P_{ij} = \int \frac{exp(X_{ij}\beta_j)}{\sum_{j=1}^{J} exp(X_{ij}\beta_j)} f(\beta_j|\theta) d\beta_j, \quad (2)$$

where X_{ij} is the experimental attribute variable for farmers i choosing alternative j, as shown in Table 1. $\beta_j$is the corresponding estimated coefficient, and $f(\beta_j|\theta)$ is the probability density function for β_j, assumed to follow a certain distribution (Train, 2009), such as normal, uniform, and triangular distributions. In this study, we assume a normal distribution for $f(\beta_j|\theta)$, with θ being the vector of estimated parameters for this density function, such as the mean and variance in the case of a normal distribution. In the mixed logit model, β_j is a random variable, that can be expressed as follows:

$$\beta_j = \beta_k + \overline{\omega}_k, \quad (3)$$

where β_k is the coefficient for the random utility variable, assumed to be a fixed value, and $\overline{\omega}_k$ is the random disturbance term. β_k and $\overline{\omega}_k$ can be considered the mean and variance of this normal distribution. Therefore, the observable utility function V_{ij} can be expressed in a simple linear form:

$$V_{ij} = (\beta_k + \overline{\omega}_k)X_{ij} + \varepsilon_{ij} . \quad (4)$$

Step 2: To examine the impact of heterogeneity among farmers on their choice preferences, this study introduces a latent class model. The respondents' choice preferences are divided into different classes $c(c-1,\dots,C)$ to capture preference heterogeneity, with preference coefficients a_c for class c.Preferences within the same class of farmers are homogeneous, but preferences among farmers from different classes are heterogeneous. This model can uncover some patterns in the heterogeneity of farmers' preferences. By assuming that respondent n belongs to class c , the probability of choosing option $j^*$from choice set t (out of T choice sets) is as follows (Colombo et al., 2009; Greene and Hensher, 2003):

$$prob(i, j^*, t|c) = \prod_{t=1}^{T} \frac{e^{\alpha_c x_{ij^*t}}}{\sum_{j=1}^{J} e^{\alpha_c x_{ijt}}} \quad , \quad (5)$$

The models are estimated by maximum simulated likelihood using 1000 Halton draws (Hole, 2007). We estimate uncorrelated coefficients using dummy coding (Hensher et al., 2005).

Step 3: Willingness to payment (WTP) on SFD by farmers

The WTP estimate, which is the ratio between the coefficient for each attribute and the price coefficient. The marginal WTP for attribute x is as follows:

$$\widehat{wtp} = -\frac{\widehat{\beta_x}}{\widehat{\beta_p}} \ , \tag{6}$$

The standard approach in equation 6, which is also referred to as a WTP in preference space, is obtained from procedures based on the mixed logit model (Train and Weeks, 2005).

3. Results

This section presents the key findings of this study. It begins with the descriptive statistics of the samples, followed by base model results illustrating farmers' preferences for SFD. Moreover, it explores the heterogeneity in farmer preferences using latent class model. Furthermore, the Willingness to Pay (WTP) of farmers' participation in SFD is estimated.

3.1Descriptive statistics

In the empirical analysis of the mixed logit model, two types of variables are included: the CE attribute and socioeconomic information of participating households. The information encompasses individual characteristics, household features, and perceptions of current farmland conditions, as shown in Table 6-2.

In the survey sample, 80% are male, with an average age of 55 years or above and an average education duration of approximately 8.8 years. In studies examining farmers’ decision-making regarding participation in agricultural activities, most participants are male (Fischer and Wollni, 2018; Kragt et al., 2023; Zemo and Termansen, 2018; Zhang and Paudel, 2019). It is attributed to males serving as the primary labor force in households, affording them a more profound understanding on agricultural production and associated tasks. Field surveys corroborated that some female participants faced challenges in assessing infrastructure development needs. By contrast, male participants displayed a more systematic grasp of rational construction schemes and cost considerations, facilitating more comprehensive and logical decision-making. The aging population and lower educational attainment among rural laborers are acknowledged realities in China, consistent with findings from similar research. Approximately 80% of the Shanxi region’s sample comprises professional farmers, while it is around 60% in Shaanxi. By 2022, China’s rural population is approximately 1.05 billion, accounting for 75% of the total population, with roughly 800 million engaged in agricultural cultivation (CNBS, 2023). Therefore, the high proportion of professional farmers observed aligns with the reality in China. There is a significant disparity in participating households’ average annual household income, with Shanxi averaging approximately 60 thousand CNY/a and Shaanxi at 10 thousand CNY/a. In 2022, rural residents’ per capita disposable income was 18 thousand CNY per annum, with an average household size ranging from three to five individuals (CNBS, 2023). Therefore, the average household income level in the surveyed area is generally consistent with the national average. The risk propensity of the respondents indicates a predominantly risk-averse orientation. There is a notable difference in land transfer, with 55% of households in Shaanxi engaging in land transfer compared with approximately 40% in Shanxi. Land transfer policies are actively promoted to expand agricultural operations and increase land productivity through centralized production. It also reflects that the farmers can exercise their land use rights and contracting rights flexibly according to their needs, enabling them to expand or relinquish agricultural operations more dynamically (MARA, 2021a). In addition, the current farmland conditions are similar in the two regions, and respondents perceive land quality and facility adequacy at an average to above-average level.

Table 6- 2 Descriptive statistics

Variable	**Definition**	**Shanxi**				**Shaanxi**			
		Max	**Min**	**Mean**	**SD**	**Max**	**Min**	**Mean**	**SD**
Gender	Male=1, Female=0	1	0	0.838	0.369	1	0	0.868	0.339
Age	Age of Respondents	79	31	58.653	9.929	79	30	57.325	10.960
Educational level	Educational Experience for Respondents (Year)	16	0	9.141	2.527	15	0	8.445	2.761
Occupation	Part-time farmer =1, Professional Farmer =0	1	0	0.201	0.401	1	0	0.362	0.481
Risk proneness	1-6 Risk propensity increases gradually	6	1	2.516	2.006	6	1	2.298	1.855
Number of labors	Average number of labors per household	5	1	3. 41	1.831	6	1	3.84	2.418
Land transfer	Yes=1, No=0	1	0	0.396	0.489	1	0	0.551	0.497
Household Income (CNY/a)	Annual household Net income (10 thousand CNY)	15	1.7	6.091	2.427	10	0.035	0.835	1.250

Cultivated land quality satisfaction	Strongly dissatisfied (1)-Strongly satisfied (5)	5	1	4.052	0.938	5	1	4.011	0.813
Degree of well-equipped on farmland infrastructure ②	Strongly unequipped (1)-Strongly well-equipped (5)	5	1	3.055	1.041	5	1	3.192	0.863

① : **Ditches, roads, water, electricity.**

3.2 Estimations of the basic model

In the mixed logit model, the significance and direction of the coefficient signify farmers' preferences for attributes within the SFD scheme. Positive coefficients denote a preference for such infrastructure construction among farmers, whereas negative coefficients suggest a lack of preference for farmers (Haider, 2007; Jia and Zhao, 2021). The regression results are presented in Table 6-3.

Table 6- 3 Mixed logit results (model 1)

Variable	**Shanxi**				**Shaanxi**			
	Coef. Mean		S.D. Mean		Coef. Mean		S.D. Mean	
	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
MPR	0.978**	0.461	1.852***	0.250	0.568	0.401	2.097***	0.233
LF or CF	-0.114	0.487	2.414***	0.503	0.336	0.389	1.659***	0.409
LF and CF	1.004**	0.453	1.146***	0.358	0.846**	0.411	1.289***	0.282
ED	0.609	0.348	3.226***	0.488	0.516	0.289	2.381***	0.407
IIFF	1.609***	0.463	-3.002***	0.706	1.103***	0.365	2.23***	0.524
Moderately improved	0.742***	0.381	0.848**	0.454	0.504**	0.366	1.816***	0.531
Highly Improved	-0.268*	0.364	2.499***	0.465	-0.525*	0.259	1.438***	0.334
Costs per household	-0.002**	0.001			-0.002***	0.001		
asc	-7.21***	2.127			-6.275***	1.503		
asc_Gender	0.610	0.499			1.592	0.532		
asc_ Age	0.018	0.022			0.051	0.017		
asc_ Educational level	0.231***	0.078			0.186**	0.043		
asc_ Occupation	0.295	0.462			-0.041	0.312		
asc_ Risk proneness	-0.479**	0.212			-0.465**	0.210		
asc_ Number of labors	0.040	0.231			0.36	0.190		

asc_ Income	0.027	0.072	-0.011	0.094
asc_ Land transfer	0.837***	0.199	0.237**	0.181
asc_ Cultivated land quality satisfaction	0.411	0.381	0.329	0.323
asc_ Degree of well-equipped on farmland	-0.365**	0.167	-0.328	0.151
Log likelihood	-680.851		-817.053	
Pseudo R^2	0.22		0.24	
Prob>chi2	0.000		0.000	
chi2（12）	200.060		212.970	

**p*<0.10, ***p*<0.05, ****p*<0.01

Note: *costs per household 0 was used to model the third option (no participation), no improvements were used for the other attributes (maintaining status quo)*

For Shanxi, the result indicates heterogeneity of farmers' preferences for "MPR," "LF and CF," "IIFF," "moderately improved," and "highly improved" variables. In contrast, it suggests that farmers exhibit heterogeneity for "LF and CF," "IIFF," "moderately improved," and "highly improved" variables in Shaanxi.

The results confirm the validity of Hypothesis 1. When the farmers' preferences for each attribute variable are analyzed, the following patterns are evident:

Production road preference: The coefficient for the preference toward MPR in Shanxi is significantly positive. Compared with maintaining the status quo, engaging in MPR enhances the participation utility for farmers.

Land consolidation preference: The coefficient for the preference toward the combination of LF and CF transformation is significantly positive in both regions, and LF or CF alone is insignificant. It implies a pronounced demand among farmers for the combined transformation of LF and CF improvements.

Irrigation facility preference: The coefficient for the preference toward IIFF is significantly positive in both regions. Conversely, the improvement of ED is not significant, indicating a substantial demand among farmers for IIFF. The efficacy of ED primarily lies in environmental optimization and in mitigating non-point source pollution. However, its impact on enhancing resource utilization efficiency and output is less significant than that of IIFF's (Hadizadeh et al., 2018).

Farmland protection facility preference: The coefficient for the moderately improved attribute is significantly positive, and the coefficient for the highly improved attribute is significantly negative in both regions. It suggests that farmers prefer farmland protection facilities in the order of moderately improved, maintaining the status quo, and highly improved.

The estimated results for **costs per household** in both regions are significantly negative. This implies that participating farmers tend to contribute by paying lower expenses for SFD, to achieve improvements in agricultural production conditions.

In addition, the estimated results of the farmer characteristics suggest that individuals with higher levels of education, currently involved in land transfer activities and confronting inadequate infrastructure exhibit enthusiasm for participating in SFD. The influence of educational level has been widely validated in studies on farmer participation in agricultural activities (Wąs et al., 2021; Zulfiqar et al., 2021). Consequently, it is evident that the attributes of SFD significantly influence farmers' preferences and exhibit heterogeneity. Furthermore, attribute variables are crucial factors influencing farmers' participation compared with farmer characteristic variables.

3.3 Estimations of the latent class model

The latent class model can further identify respondents' preference heterogeneity and can categorize households with similar preferences into the same class. On the basis of the mixed logit model results, the findings in the Shanxi and Shaanxi provinces were broadly consistent, allowing a joint modeling approach to analyze farmer preference heterogeneity. The optimal classification structure for the latent class model must be determined in advance, typically based on the AIC and BIC criteria. By calculating, it was found that when farmers were divided into two classes, the AIC and BIC achieved the minimum estimates.

Class 1 farmers account for 57.6% of the total respondents, and Class 2 farmers account for 42.4% (Table 6-4). The average probability of the two classes of farmers has a small gap, with percentages of 49.6% and 41.2%, respectively. The participation rates of both classes of farmers in this study are relatively high, and there are no instances of meager participation rates or resistance to participation compared with similar studies (Permadi et al., 2017; Schulz et al., 2014).

Farmers' preferences for SFD schemes vary by class. MPR, LF, CF, and IIFF significantly positively affect participation for Class 1 farmers, and highly improved and costs per household negatively impact their participation. For Class 2 farmers, ED, IIFF, and moderately improved significantly positively affect participation, and costs per household have a negative effect. It indicates that Class 1 farmers prefer infrastructures that enhance agricultural efficiency and benefits, while Class 2 farmers are more concerned regarding resource-saving facilities and farmland ecological construction. These results confirm the validity of Hypothesis 2.

The latent class model also estimated the impact of the farmer characteristic variables on farmer participation in SFD schemes. The results indicate that compared with Class 2 farmers, older age, lower educational level, risk-averse individuals, engagement in land transfer activities, and better-cultivated land quality make farmers more likely to be classified into Class 1. This result supports Hypothesis 3.

Table 6- 4 latent class model results (model 2)

	Class 1		Class 2	
	Coef.	S.E.	Coef.	S.E.
MPR	0.343^{**}	0.637	0.365	0.315
LF or CF	0.070	0.785	-0.016	0.260
LF and CF	0.481^{**}	0.714	0.230	0.286

ED	-0.497	0.562	0.966*	0.149
IIFF	0.916**	0.401	1.092**	0.390
Moderately improved	-0.724	0.730	0.413**	0.293
Highly improved	-0.802*	0.413	-0.451	0.171
Costs per household	-0.001**	0.001	-0.002***	0.000
asc	-2.524***	0.741	1.491***	0.481
Gender	-0.636	0.334		
Age	0.027**	0.013		
Educational level	0.165**	0.042		
Occupation	0.165	0.272		
Risk proneness	-0.103**	0.157		
Number of labors	-0.085	0.164		
Income	0.004	0.039		
Land transfer	0.231**	0.250		
Cultivated land quality satisfaction	0.393***	0.135		
Degree of well-equipped on farmland	-0.173	0.121		
cons	3.727***	1.119		
Percentage of various categories of farmers	0.576		0.424	
	0.484		0.496	
Log likelihood		-817.053		
AIC		2698.956		
BIC		2888.529		

**p*<0.10, ***p*<0.05, ****p*<0.01

3.4 WTP estimation

This study calculates payment levels based on specific attributes. Farmers' payment levels for MPR, LF and CF, ED, IIFF, and moderately improved are 353, 431, 339, 847, and 99 CNY/ha, respectively (Table 6-5). This result reflects high willingness among farmers to participate in SFD. However, related research has shown a discrepancy between farmers' willingness and behavior in participating in public goods supply and environmental governance (ElHaffar et al., 2020; Li et al., 2021). This requires achieving benefit goals through social networks and long-term trust norms (Le Coent et al., 2021). In other words, farmers' investment mechanisms rely on formal institutional arrangements and informal community institutions to achieve cost-sharing among farmers, encourage cooperative behavior, and constrain opportunistic behavior.

Table 6- 5 WTP results

	WTP	95% confidence interval	
MPR	353.294**	49.420	657.168
LF or CF	201.059	-124.061	526.179
LF and CF	431.198**	121.356	741.040
ED	339.05**	61.852	616.247
IIFF	847.221**	494.776	1199.665
Moderately improved	99.08**	34.912	563.248
Highly improved	-58.36	-307.049	190.329

*p<0.10, **p<0.05, ***p<0.01

4. Discussions and implications

4.1Preference for farmer participation in SF

On the basis of the facility attribute analysis, farmers exhibit a more urgent demand for the MPR in Shanxi. Through the survey, it is evident that agricultural authorities prioritize mechanized operations to enhance productivity, with widespread coverage and a rich variety of machinery provided by agricultural machinery cooperatives. It may contribute to increased awareness among farmers regarding the benefits of MPR. Concerning land consolidation, farmers in both regions show a significant demand for dual treatment involving LF and CF. In reality, most areas in the YRB exhibit fragmented farmland patterns, and the topography of the hills and mountains leads to widespread uneven land, hindering convenience in agricultural production (Liang et al., 2021; Lu et al., 2022; Zhou et al., 2022). Regarding irrigation facility, both regions exhibit a significant preference among farmers for IIFF compared with ED construction. It may be because ED's primary functions focus on ecological benefits such as preventing soil erosion and agricultural non-point source pollution, while providing limited assistance in enhancing production income. IIFFs, known for their water-saving and fertilization effects that lead to increased yield and quality, have gained widespread recognition (Chen et al., 2022; Zhou et al., 2020; Zhuang et al., 2019). Operating entities engaged in large-scale planting have already begun independently adopting such facilities (Cai and Du, 2016; Lang et al., 2021). Farmers face difficulties in independent transformation due to small planting areas, scattered plots, and limited capital endowment. Under the unified management of SFD by the government, farmers have found new opportunities to use IIFF. Farmers' preferences for ecological protection facility are ranked as moderate improvement, maintaining the status quo, and high-level improvement. Such facilities are more public-spirited, benefiting farmers mainly through improved environmental perception and the demonstration of social responsibility (Chen et al., 2022; Xia and Yang, 2022). This indicates that although farmers are ecologically aware, they are unwilling to invest too much. The payment level results indicate that participating farmers tend to engage in SFD by paying lower costs to achieve environmental improvement and increased social welfare, aligning with theoretical expectations.

In summary, LF and CF, IIFF, and MPR urgently need improvement projects. There is still inconsistent awareness of certain facilities in different regions. The promotion of SF-related construction content should be led by local governments, aiming to enhance farmers' awareness from various perspectives such as facility usage methods and cost-benefit. It is also suggested to establish differentiated construction schemes in policy formulation to meet regional needs. Meanwhile, the government should consistently guide farmers to understand the importance of improving farmland ecosystem services. However, intervening to increase farmers' payments for ecological improvement projects is inappropriate. Because stallholder farmers remain financially vulnerable, there is limited space to expand their payment levels, which contradicts social moral standards. The key focus in enhancing farmers' ecological awareness is to enable them to adopt more sustainable production practices, integrating environmental protection consciousness into all their agricultural activities and emphasizing changes in farmland ecology. The government must allocate and use farmers' inputs more reasonably, transforming their contributions into dedicated funds for specific facility construction. Meanwhile, establishing a funding management system involving farmers in cooperative supervision would encourage their active participation, promoting farmland development efficiency.

4.2Whether preference would vary with the external and internal aspects of farmers?

Clearing the heterogeneity of farmers' preferences is beneficial for providing participation schemes that better match their endowment characteristics. In this experimental result, farmers are divided into two classes. The first class of farmers predominantly participates in high-cost, high-return infrastructure construction. Strengthening their environmental responsibility and ecological awareness is needed. It requires the government to learn from international experiences and conduct various activities related to agricultural ecological protection through diverse channels, including case studies and practical initiatives. The second class of farmers prefers resource-saving and environmentally friendly facilities. However, the construction of IIFF must correspond to flat and large-scale farmland. Further investigation into the current farmland situation is needed to avoid insufficient understanding of synergistic effects on various facility construction and application, and results in an unreasonable construction scheme.

This study found from the characteristic variables of the two classes of farmers that those older, those with higher educational level, risk-averse individuals, those engaged in land transfer, and those with better-cultivated land quality are more willing to participate in benefit-driven facility construction. With the aging trend in agricultural production becoming increasingly apparent, they solely rely on agricultural income, prompting a stronger desire to increase production profits and a heightened focus on related facilities (J et al., 2021). It also reflects that older farmers show less enthusiasm for ecological facility improvements, a result supported by related studies(Feyisa, 2020; Gao et al., 2020; Jia and Zhao, 2021; Ruzzante et al., 2021). As the educational level of farmers increases, their comprehension of the significance of SFD also increases (Schaafsma et al., 2019). They gain more advantages in agricultural production and management, fostering a clearer assessment of the benefits and returns of diverse facilities (Aravindakshan et al., 2021). However, it should not be ignored that the relatively low proportion of farmers with high school education or above in this survey might also influence the estimation results. Behavioral economics provides insights into how risk preferences shape individual behavior in uncertain environments. Risk-averse farmers are more inclined to participate in benefit-driven facility construction. This indicates that the acceptance of such facilities has reached a high level, as farmers perceive SFD as a risk-sharing activity related to the long-term government-led farmland development and the beneficial outcomes that farmers recognize. They trust government actions and are more willing to improve farmland conditions under cost-sharing. It also supports the government in establishing a more comprehensive SFD mechanism to further enhance its management role. Farmers engaging in land transfer experience positive utility when participating in benefit-driven facility construction. Farmers in a leasing status typically are more concerned regarding farmland conditions (Zhang and Paudel, 2019). For tenants, the focus is enhancing facility levels to meet agricultural production needs. Landlords also anticipate improving farmland conditions under cost-sharing, aiming for future higher rental prices and longer contract durations while ensuring the sustained efficient use of the land. Land transfer is an effective pathway to promote large-scale operation, necessitating the government to clarify ownership responsibilities and determine participation channels of SFD based on different producers. The participation mechanisms for farmers and industrial organizations (large grower, family farm, cooperative, and agribusiness) should be established according to the nature of their managed land, land transfer area, and contract duration. Cultivated land quality and infrastructure conditions are fundamental aspects for understanding the requirements of farmland improvement. On the basis of the field surveys, farmers with better-quality cultivated land generally believe that the most effective way to increase food yield is by equipping more advanced infrastructures. However, they do not perceive infrastructure construction as helpful in improving cultivated land quality. It emphasizes the importance for the government to focus on promoting and advocating the indirect and long-term benefits of SFD. Overall, the determination of SFD schemes should not only respect regional production demand differences but also prioritize farmers' preferences and intentions. Tailored information interventions should be provided to farmers of different classes based on farmland investigations, aiming to achieve optimal construction scheme formulation.

4.3 How do the payment levels for farmers contribute to SF?

Farmers exhibit a high willingness to pay for various types of facilities. This study referred to the estimated costs of previous farmland development projects in the study area and the budgets of the Green Farmland Development Project in the YRB. Depending on the difficulty of renovation in different regions, the construction costs are as follows: LF and CF: 200–800 CNY/0.067 ha, MPR: 200–500 CNY/0.067 ha, IIFF: 400–1000 CNY/0.067 ha, ED: 100–400 CNY/0.067 ha, moderate improvement of farmland ecology: 50–100 CNY/0.067 ha, and high improvement of farmland ecology: 200–500 CNY/0.067 ha. Farmers' contributions to various facilities have reached 50–80% of the highest costs, reflecting their high enthusiasm for participating in SFD. In recent years, Shaanxi has consistently increased investment in farmland development projects (China Xinhua News, 2023), especially focusing on irrigation facilities through various subsidies, establishing large scale of water-saving facilities, and creating multiple national water-saving irrigation demonstration areas (Shaanxi Government, 2022). The realization of the benefits helps farmers better understand the significance of SFD, promoting their proactive attitude towards participation. Currently, the government' s investment standard for farmland development projects is 22,500 CNY/ha, and the demand for SFD ranges from 67,500 to 90,000 CNY/ha. This study has identified the infrastructures suitable for farmer participation in SF and has further determined the specific payment levels for these infrastructures. However, farmers are one of the stakeholders in farmland development, and cost-sharing in public goods construction should further consider the proportions borne by the government, farmers, and other stakeholders.

For the allocation of fund from farmers, it can be stipulated that government investment in SFD is contingent upon farmers providing matched fund. This mode aims to diversify fund sources while enhancing farmer participation and efficacy. Relying solely on government investment may foster dependency among farmers, potentially leading to instances of free-rider and the tragedy of the commons (Galioto and Musotti, 2023; Githinji et al., 2023). Conversely, expecting farmers to fully finance farmland development could impose financial burdens beyond their means, diminishing their perceived value of the endeavor and reducing their willingness to development SF. Consequently, a single fund mode is not sustainable. The fund framework should incorporate government investment as the primary source and matched contributions from farmers. Implementing a farmer-led "build first, subsidize later" mode may prove effective in the project operation. This mode capitalizes on initial fund raised by various avenues, including rural collective economic organizations, farmer labor, in-kind contributions, and community fundraising. Such a strategy ensures that rural social capital is optimally utilized for agricultural and rural development, enhancing overall fund efficiency. After the successful acceptance of SFD, the government can provide incentives or subsidies as rewards. Policy formulation related to special standards of farmers investment should be based on regional situation, ensuring farmers' contributions are fully allocated to their preferred construction schemes.

4.4 How to recognize and strengthen the role of farmers in farmland development?

Farmland, a fundamental element of agricultural production, plays a crucial role in continuously enhancing production capacity. Since the founding of the People's Republic of China, farmland development has been closely linked to the nation's economic development, reflecting the transformative processes and stage characteristics of agricultural and rural development, and farmland development. Farmland development has yet to yield ideal results despite undergoing various developmental stages compared with developed countries such as Japan, North

America, and Australia (Yang et al., 2022). The main reasons for this discrepancy lie in existing issues in management, primarily manifested in unreasonable schemes that fail to align with the actual demands of agricultural production (Junjie et al., 2022; Zheng et al., 2023). Insufficient investments have led to low construction standards, falling short of the expected quality goals (Bao and Feng, 2021a). The fundamental constraint stems from the government's dominance in farmland development, lacking substantial participation from involved parties. Thus, on the basis of the farmers' perspective, this study conducted an exploratory experiment on their involvement in SFD. The findings provide insights into guiding farmers in understanding the essence of SFD, motivating their active participation, and formulating mechanisms for their involvement in SFD. Relevant policy implications are summarized based on the results (as shown in Figure 6-4).

- Local governments should lead training and awareness campaigns on the use and benefits of new facilities and technologies to enhance farmers' understanding of SFC.
- Farmers' preferences should be respected, and differentiated facility construction plans should be established to meet regional needs.
- Establish specialized funding for farmers' inputs, complete the construction of facilities that farmers are concerned about, and simultaneously create a fund management system for collaborative supervision by farmers to stimulate their active participation.
- Draw from international experiences in promoting farmland ecologically and introducing diverse intervention initiatives to foster farmers' interest in farmland ecological construction.
- Formulate differentiated participation and input standards based on the financial requirements of regional farmland construction and farmer categories.

Figure 6- 4 Policy implications extend

This study innovatively addresses investment limitations in farmland development, explores the genuine needs of producers, and establishes a participatory mechanism for SFD, considering the current state of farmland and farmers' preferences. At the institutional level, it reconciles the substantial financial pressure on the central government with inadequate realization of farmers' inherent responsibilities, balancing between farmers' demands and construction funding requirements. It provides a precise implementation scheme for the new farmland development strategy and offers valuable insights for devising management mechanisms in other countries undergoing farmland consolidation. In addition, it contributes a novel perspective and serves as a reference for related research in the field.

5. Conclusions

SFD is a priority strategy aligned with the integrated goals of output efficiency, resource conservation, and environmental friendliness. To address challenges such as low investment standards and poor construction outcomes resulting from the need for more stakeholders' participation in farmland development, this study focuses on optimizing and innovating farmland development institutions by integrating farmers' participation. First, on the basis of the SFD framework, this study identifies farmers' preferences and clarifies their infrastructure demand. Second, further exploration of farmer preference heterogeneity clarifies the characteristics of heterogeneous farmer classes. Finally, the farmer's willingness to pay is measured based on SFD attributes. Overall, the findings indicate a strong demand from farmers for LF and CF, IIFF, and MPR, and enthusiasm for ecological facility construction remains to be enhanced. Respondents' age, educational level, land transfer status, risk propensity, and current land conditions influence farmers' participation utility and preferences. Farmers' payment levels for MPR, LF and CF, ED, IIFF, and moderately improved in ecological protection facilities have reached 50–80% of construction costs. Therefore, formulating SFD schemes should be tailored to local conditions. It is imperative to ask local governments to take the lead in promoting the benefits of various infrastructures and providing relevant technical training, thereby enhancing farmers' acknowledgment of SFD elements. Moreover, in strengthening actions to enhance farmers' ecological consciousness, introducing diverse intervention initiatives to foster farmers' interest in farmland ecological construction is essential. Furthermore, at the central government level of governance, formulating mechanisms for farmers' investment should thoroughly address their requirements and establish special funds. Overall, this study validates the effectiveness of determining SFD schemes based on farmers' preferences and successfully provides a regional plan for project demonstration areas. The payment level of farmers has been clarified, providing a reliable theoretical basis for cost-sharing on SFD. Notably, the study expands the research ideas and methods for stakeholders' participation in agricultural activities. The conclusions and policy implications can serve as experiential references for promoting the effectiveness of land consolidation and optimizing the management institutions of other agricultural projects in developing countries.

This study establishes a set of policy tools for farmer participation mechanisms in farmland development but has certain limitations. First, this study involves two provinces, and the results demonstrate regional differences. Therefore, the research findings need to adequately represent the reality of farmland and farmers' preferences in other regions. Future studies should broaden the selection of study locations to understand the construction foundations in different areas and refine farmer participation institutions while recognizing variations. Second, the study only investigates farmers' investment levels. Given the numerous stakeholders in farmland development, the construction of investment mechanisms should involve more participants. Exploring standards for the involvement of other stakeholders is a future research direction.

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Chapter 7

General discussion, conclusion and policy implication

1. Conclusion

This paper examines farmland development modes from a systemic and holistic perspective, focusing on the YRB, a critical grain-producing region in China. Through field research and interviews with various stakeholders, the study provides an in-depth understanding of the current state of farmland. Based on this assessment, it diagnoses existing issues and formulates the essence, activities, and institutional requirements for SFD. The lack of involvement from relevant stakeholders is considered the fundamental reason for low standards, poor outcomes, and funding limitations in farmland development. Building on existing research, this study focuses on the selected scientific issues, exploring three specific areas: “comprehensive benefit evaluation and enhancement pathways for different farmland systems”, “mechanisms driving farmer participation in SFD” and “farmers’ preferences for infrastructure construction plans and their payment levels”. Finally, based on international cases of multi-stakeholder participation in farmland development and Chinese pilot cases, combined with the outcomes of this study, an optimized scheme for farmer participation in SFD was developed.

In chapter 4, the system boundary of farmland development is identified, revealing that how different inter-matching forms of farmland infrastructure development and field management practices affect the environmental-economic efficiency. The results demonstrate that HSF-IFM not only lowered resource input, but also improved the productivity, and also plays a positive role in regulating the reactive nitrogen losses, nitrogen and carbon footprint and greenhouse gas emission. Additionally, HSF-IFM is an optimum economic practice, and totally decreases CO_2 emission of 9.01E+07 t, and increases the net ecosystem economic benefit of 101 billion Chinese yuan and the grain yields of 1,278 t in the North Plain of China.

In chapter 5, the attitudes of farmers towards participating in SF development and the mechanisms influencing them are examined. The results demonstrated: a) Farmers' intention was impacted by perceived behavior control (PBC), subjective norms (SN), and attitude (AT) to SFD. b) Agricultural production conditions (APCs) negatively moderated TPB construct, while policy evaluation (PE) positively moderated.

In chapter 6, introducing farmer participation to optimize SF construction institutions can improve farmland development efficiency and address limited construction funding. The paper analyzes farmer preferences for participating in SF construction through a discrete choice experiment survey of farmers in the project area. The research also evaluated farmers' willingness to pay for different SF construction schemes. The findings indicate that farmers exhibit preferences for constructing mechanized production roads (MPR), leveling farmland and transforming the contiguous farmland (LF and CF), integrated irrigation and fertilizer facilities (IIFF), and moderate improvement (MI) in ecological protection facilities.

Based on the heterogeneity of farmer preferences, they can be classified into benefits-driven and ecology-driven. Additionally, factors such as age, education level, risk proneness, land transfer, and cultivated land quality can influence the classification of farmer preferences. Farmers' willingness to pay for MPR, LF and CF, ED, IIFF, and MI has reached 50-80% of construction costs, essentially bridging the investment gap under the SF standards set by the central government.

Chapter 7 summarizes the core objectives of the research, the logical framework, and the main findings in relation to current policies. On this basis, it constructs a basic framework for optimizing the mechanism of farmer participation in farmland development and provides an optimized design for the connotation and composition of farmland development modes. The focus of optimizing these modes is to improve organizations of rural grassroots governance, aiming to stimulate farmers' enthusiasm for participating in farmland development, increase their effective participation, and solve the challenges of fundraising. The key to enhancing rural grassroots governance lies in identifying the appropriate units for farmer self-governance and establishing platforms and mechanisms for effective farmer participation. By forming rural grassroots social organizations that genuinely represent farmers' interests and constructing a comprehensive framework for farmer self-governance, the organizational level of farmers can be improved. This approach aims to effectively align the provision of national public goods with the demand for agricultural public goods. Additionally, by actively exploring efficient integration methods for government financial funds, continually refining and clarifying the responsibilities and authorities of various government departments, and strengthening the supervision and management of both internal and external operational environments for farmland development, the mechanisms for farmer participation can be continuously improved. In the project initiation, the focus is on emphasizing the primary role of farmers. During the project planning and design, the emphasis is on the overall guidance and leadership of the government. In the project organization and implementation, the participation of farmers in terms of investment and labor is reinforced. In the project completion and acceptance, the role and status of farmers in evaluation and acceptance are highlighted. In the post-project maintenance phase, the primary responsibility of farmers for maintenance is emphasized.

The Ministry of Land and Resources and the Ministry of Finance jointly issued a notice (Ministry of Land No. 30 [2018])[36] to adjust the support for major projects and actively guide farmers, rural collective economic organizations, and farmland economic organizations to participate in major project construction. The latest farmland development plan (2021-2030) [37] proposes the principle of government leadership and multi-party participation, requiring respect for farmers' wishes, protection of farmers' rights, and active guidance for farmers, agricultural enterprises, rural collective economic organizations, and various social capital to participate in

[36] https://www.gov.cn/xinwen/2018-03/06/content_5271351.htm

[37] http://www.moa.gov.cn/hd/zbft_news/qggbzntjsgh/xgxw_28866/202109/P020210916554589968975.pdf

farmland development. These policy formulations also confirm the alignment of this study with the government's reform initiatives.

2. General discussion

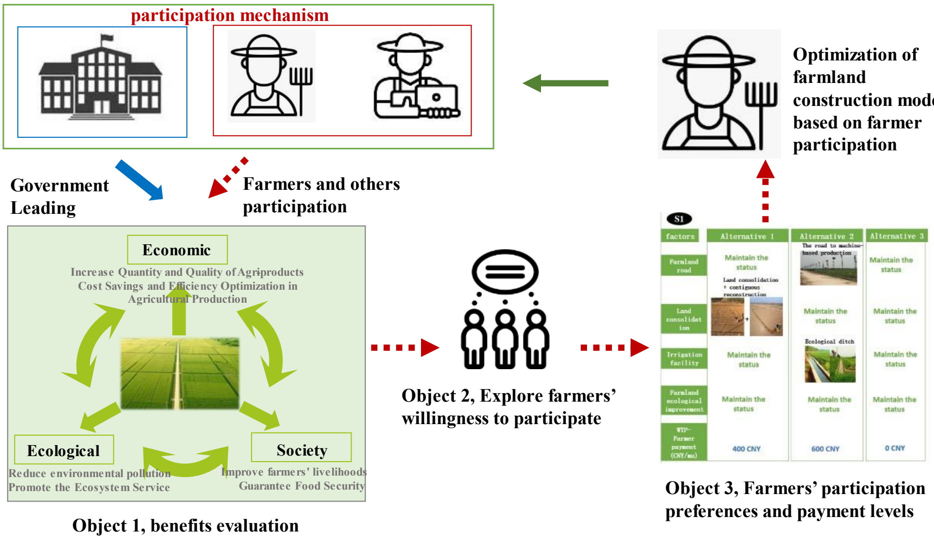

Figure 7- 1 Objectives and logical map of thesis

Historical and international experience shows that farmland development can effectively boost agricultural income, increase farmers' earnings, and promote agricultural development. It facilitates the transition from traditional to modern agriculture. SF development is a strategic necessity to meet the integrated goals of "production-ecology-livelihood" in the current agricultural system. It is also a crucial path for achieving rural revitalization and China's " carbon peak, carbon neutrality" commitments, as well as an innovative measure for realizing the 2030 SDGs.

Farmland development is a complex technical and social governance project that involves multiple stakeholders and various stages. It is a systematic effort that includes implementation entities, organizational methods, fund-raising, operational modes, supervision and management. Current practices show that the top-down, government-led project-based mode to farmland development has many drawbacks. Farmers, who are the direct stakeholders and beneficiaries, have insufficient participation. Farmland development plans often do not align with actual production needs, and limited funding sources lead to substandard construction, affecting both the efficiency of fund usage and project execution. Consequently, the goals of farmland development benefits are difficult to achieve. consequently, to change the traditional "top-down" government-led farmland construction mode characterized by "government investment, government implementation, government supervision," there needs to be a gradual transition towards a new mode of farmland development characterized by "government guidance, stakeholders' participation, cost sharing, and joint supervision." The fundamental purpose of optimizing the farmland development mode is to enhance overall effectiveness through improving stakeholders' participation mechanisms, broadening funding sources, increasing the efficiency of fund usage and project execution, and magnifying the comprehensive effects of farmland development. Farmers cultivate the land and are most familiar with its condition, understand local environmental conditions best, and are well aware of production facility needs. Achieving seamless integration between governments' public goods supply and farmers' demands for farmland necessitates the active involvement of farmers. On the other hand, farmers are the ultimate beneficiaries of farmland development. Improving farmland conditions, farmland ecological functions, and increasing agricultural income through farmland development directly impact farmers' production and living. Therefore, farmland development is closely related to farmers' vital interests. As the ultimate beneficiaries and direct users of farmland development, farmers should participate in farmland development.

Therefore, this paper sets one ultimate goal and three specific objectives around the institutional challenges of SFD. As depicted in Figure 1, Objective 1 serves as the guiding presence in the research. It entails a multi-objective evaluation of existing farmland types and their utilization patterns to clarify the comprehensive performance of SF benefits. This provides motivation for relevant stakeholders to participate in construction while also offering reasonable reference for further improving farmland development. Given that farmers are the most direct beneficiaries of farmland development, Objective 2 focuses on examining farmers' willingness to participate in SF development. From a psychological perspective, it seeks to understand the internal factors influencing their willingness to participate and aims to construct policy-driven mechanisms that can inspire farmers' enthusiasm for participation. However, the transformation from willingness to action requires a reasonable participation plan. Objective 3 involves constructing scenarios based on SFD activities, delving into the actual needs of farmland and farmers, and clarifying farmers' participation preferences and their payment levels. Achieving this objective provides precise references for constructing farmer participation schemes. The establishment of mechanisms for farmer participation in SFD involves innovation and optimization of existing mechanisms. Therefore, the ultimate goal of this study is to optimize farmer participation mechanisms based on farmers' responsibilities, capabilities, tasks, and interests, considering implementation entities, organizational methods, funding sources, operational environments, and supervision and management comprehensively from five aspects. The experiences gained from this study can be applied to the participation of other stakeholders in farmland development or the governance of other public affairs, as well as ecological improvement activities.

2.1 Understanding the benefits and development pathways of different farmland systems

Improving the infrastructure and transformation used for the cropping management are necessary practice developing the SF system. Previous studies confirmed that improving infrastructure is conducive to ensuring the food security, and the adoption of environmental-friendly agricultural production practices (EFAPP) could mitigate the environmental damage of agricultural activities-caused (Yin et al., 2022; Zhang, X. et al., 2022). At present, the CF-SFM, HSF-IFM, and SF-ITFM are main three farmland systems, only the SF-ITFM demonstrated the best environmental-economic effect, followed by the HSF-IFM, but the CF-SFM had remarkable efficiency difference comparing to the other systems. However, the CF occupies 66% of the cultivated land, in which 70% is farmed by smallholders, while the HSF-IFM is in a transitional state between the CF-SFM and SF-ITFM, and reveals more universality in agriculture production. The HSF construction has reached the peak at certain extent, but the support on the EFAPP has made the advanced progresses. Consequently, to further improve the efficiency of agricultural transformation, the SF-ITFM's superiority has been recognized and promoted by the pilot demonstrations (Fang et al., 2021; Wang, 2022), because the promotion of SF-ITFM has not formed an absolute advantage yet. Therefore, how to gradually realize the goals of “food security-farmland ecology health - farmer prosperity” by improving different farmland systems is core element. Our study expounds the reasons for the difference in benefits brought by the different farmland systems, and thereby proposing a specific improvement pathway. Our study expounds the reasons for the difference in benefits brought by the different farmland systems. Based on China's farmland development and agricultural development goals, it simulates the benefit increments required to achieve the final target (HSF: SF=1:1). Building on outcomes, it proposes specific optimization pathways for different farmland systems.

2.2 Examining Farmers' attitudes towards developing SF systems

SF has been identified as the mode that best aligns with current development goals for the farmland system. Precisely measuring its benefits and examining farmers' attitudes towards participation in SFD-specific activities, along with the influencing factors, is a crucial prerequisite for exploring farmers' participation pathways. Currently, the inadequacy of FIC and the degradation of CLQ seriously restricted the potential for food production and the value achievement of ecological function for farmland in China. Current studies showed that agricultural infrastructure was vital to safeguard food security by increasing the capacity to mitigate and respond to natural disasters. Furthermore, encouraging the adoption of EFAPP helps to enhance the product quality and ecological function of farmland substantially. In other words, SFD could achieve a win-win scenario for agri-production and ecology. Farmers showed a medium response to the intention to participate in SFD. However, the results of the integrated participation forms reflected the real idea of their low intention to participate. It is related to the long-term lack of a participatory mechanism for farmers accompanying with farmland development policy evolution. Meanwhile, it revealed farmers' dependence on government-led farmland development. Consequently, the paper explains why farmers were reluctant to participate in SFD, and identifies the critical paths to enhance farmers' willingness to participate in SFD. This provides a reference for developing region-specific SF development plans and guiding future government actions.

2.3 Playing the role of farmers in SFD

Based on the discussions in the above research, the fundamental aim of SFD is to further enhance comprehensive production capacity and quality benefits on grain, promote the transformation of agricultural production modes, improve the ecological service functions of farmland ecosystem, and increase farmers' income. Researches indicate a disconnect between previous farmland development planning and actual needs, with high rates of redundant post-construction modifications limiting the enhancement of diverse benefits in 'production, ecology, and livelihood' (Bao and Feng, 2021; Zheng et al., 2023) . Additionally, effective supply of farmland development has been consistently constrained by difficulties in financing. Even with the latest standards, which have raised the investment to 45 thousand CNY/ha in many areas, it still falls far short of meeting the expectations for SF (Shuai et al., 2023) . Hence, farmers' willingness to participate in farmland development should be prioritized in SF management to maximize the expected efficiency of farmland improvement. Insufficient construction funds and limited facility supply can be better resolved by attracting stakeholders. Utilizing the CE and considering specific scenarios of SFD, the study delves into farmers' preference and the sources of their heterogeneity. In this study, farmers' participation level is quantified based on SF benefit goals and a regional farmer participation scheme is proposed which encompassing 'pre-construction planning' and 'construction investment'. The findings can inform the formulation of policies for other stakeholders participating in farmland development and give a guidance to government for future decision-making.

2.4 Basic Framework for Farmland Development Mode Optimization

This study examines farmland development modes from a systematic and holistic perspective. By deeply comparing different farmland development models, it identifies the benefits of various farmland systems and their optimization paths, providing a theoretical basis for investigating farmers' attitudes towards SFD participation, participation modes, and levels. Key focuses for optimizing farmland development modes include stimulating farmers' enthusiasm, enhancing their effective participation, and solving funding challenges. The study of the driving mechanisms for farmers' participation in SFD opens up a crucial path to enhance farmers' enthusiasm under non-economic constraints, ensuring the long-term success of construction activities. Additionally, measuring farmers' construction preferences and payment levels further clarifies that farmers should deeply engage in SFD through both construction planning and funding efforts. This provides research insights and paradigms for accurately understanding regional farmers' construction needs and participation standards. The analysis of optimizing the farmers' participation in SFD shows that developing differentiated construction plans with farmers at the core, applying tailored incentive measures as intrinsic motivation, creating a favorable policy environment, and leveraging demonstration effects as extrinsic motivation can collectively stimulate farmers' participation enthusiasm.

On this basis, to design a mechanism for farmer participation in SFD, it is necessary to explore the nature and constituent elements of farmland development modes, propose optimization plan, and offer policy recommendations for implementation. By clarifying the role of farmers, increasing the level of farmer organization, and establishing mechanisms to ensure farmer participation, we can optimize grassroots rural governance modes and enhance effective farmers' participation. Additionally, by integrating government agricultural funds and fostering rural social capital, funding challenges can be addressed. Therefore, this section will construct a basic framework for optimizing the farmland development system and conduct an optimized design of the nature and composition of farmland development modes.

The focus of optimizing the farmland development mode lies in stimulating farmers' enthusiasm to participate, enhancing their effective involvement, and addressing the funding challenges. The key is to identify appropriate units for farmer self-governance and establish grassroots rural social organizations that can effectively represent the interests of farmers. By relying on these grassroots social organizations, the organizational level of farmers can be improved. Through the growth and development of collective economic organizations, the collective land ownership in rural areas can be effectively implemented, ensuring the effective alignment between supply and demand for rural public goods.

From the perspective of the connotation and composition of the farmland development mode, further optimization of the implementation entity, organizational methods, funding sources, operational environment, and supervision and management can achieve optimization of the farmland development mode. In terms of the implementation entity, it is important to identify appropriate units for farmer self-governance, stimulate farmers' active participation in farmland development, and enhance the effectiveness of farmer-led construction. Regarding organizational methods, it is crucial to rely on suitable units for farmer self-governance and establish a well-structured framework. Meanwhile, continuous refinement and improvement of the responsibilities and authorities of various government departments should be conducted. In terms of funding collection, active exploration of efficient integration methods for government fiscal funds is needed. Additionally, through the established framework of farmer self-governance, rural idle funds should be aggregated, rural social capital cultivated, and a rational mechanism for benefit sharing formed. It is essential to clarify that both the government and farmers contribute to the post-construction maintenance funds for farmland development, ensuring a fixed source of funds for post-construction maintenance of farmland. In terms of the operational environment, there is a need to enhance the optimization of external factors such as relevant laws, regulations, and policy. Meanwhile, there is a need to strengthen the management capabilities and technical expertise of the entities responsible for farmland development, creating a favorable internal and external operational environment. Regarding supervision and management, vertically, there should be deeper oversight of farmland development projects, with the establishment of mechanisms for public participation in supervision. This will create a positive situation where social supervision and government oversight work together. Horizontally, the scope of supervision for land improvement projects should be expanded, with a focus on monitoring the post-construction maintenance stage. This is to eliminate the downside of projects focusing on construction than on maintenance and to establish a diverse and comprehensive supervision mechanism.

Looking at various stages of farmland development, in the project initiation stage, it's essential to emphasize the role of farmers and enhance their autonomy in decision-making. A rural grassroots social organization structure, distinct from the administrative village committees, should be established to specifically promote farmland development. The construction needs, scope, and content of the project are determined through consultations with the village collective and approved by the village representative assembly. Government departments are responsible for reviewing and confirming the necessity and feasibility of conducting farmland development in the village.

In the project planning and design phase, it's crucial to emphasize the overall guidance and leading role of the government. The grassroots government must integrate the overall land use planning, agricultural development layout, and local economic, social, and ecological conditions. They should establish short-term, medium-term, and long-term goals for farmland development, clarify tasks for each stage, provide overall guidance and professional technical assistance. They should also conduct public announcements and solicit opinions on planning proposals to enhance the scientific and rational nature of the planning process.

During the project implementation stage, it's important to enhance the participation of farmers in labor and investment. For small-scale projects with relatively minor engineering and financial requirements, the village collective can organize local villagers to conduct the work themselves. However, for projects with complex content, large-scale rehabilitation, and significant financial needs, it may be challenging for the village collective to organize implementation. In such cases, the village collective can be authorized to tender the project to qualified enterprises. This allows enterprises with construction qualifications to conduct the engineering work through the bidding process. Additionally, it is required that these enterprises prioritize hiring local villagers to ensure their active participation in the project implementation phase. Government departments are mainly responsible for supervision and providing technical services.

During the project completion and acceptance stage, it's important to emphasize the role and position of farmers in the evaluation and acceptance. For rural collective-led agricultural construction projects, evaluation and acceptance are conducted in a "government-led, expert-led" manner. For projects entrusted to enterprises by the village collective, evaluation and acceptance are carried out in a "government-led, expert-led, and farmer-led" manner to ensure the participation and oversight of farmers in the evaluation and acceptance.

In the later stage of project management, it's crucial to strengthen the responsibility of farmers in maintenance and management. The village collective should establish clear norms to define the responsible parties and their duties, allocate special funds for post-construction maintenance, and establish a follow-up assessment mechanism to ensure the long-term and effective performance of agricultural construction projects.

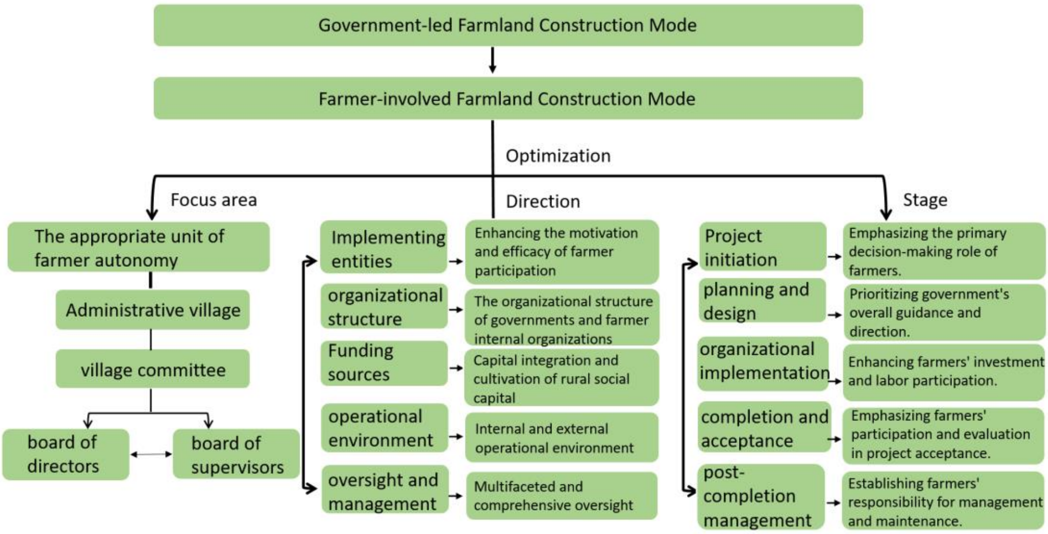

Figure 7- 2 Basic Framework for Farmland Development Mode Optimization

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3. Policy implication

In advancing the process of SFD, it is crucial to establish a scientific and effective benefit evaluation system, emphasize the primary role of farmers, develop differentiated construction plans tailored to local conditions, and reasonably determine the funding proportions between the government and farmers. These measures are key to ensuring the successful implementation of projects. They not only contribute to the sustainable development of farmland development and the rational use of resources but also effectively promote active farmer participation and enhance the efficiency of agricultural production.

3.1 Constructing a Benefits Evaluation System for Farmland Development

The benefit evaluation system for farmland development is a crucial component in ensuring the sustainable development of farmland development projects and the rational use of resources. Establishing this evaluation system helps to understand the development achievements of farmland development, monitor the progress of agricultural development, and guide its direction. The manifestation of benefits can effectively encourage the participation of relevant stakeholders in agricultural development activities. Therefore, the establishment of the benefit evaluation system should consider the following aspects: 1) Multi-dimensional Evaluation Indicators: Establish a multi-dimensional evaluation system that comprehensively considers the economic, social, and environmental benefits of farmland development projects. Economic benefits may include increased yields and reduced costs; social benefits may encompass higher farmer incomes and improved living conditions; and environmental benefits may involve reduced carbon emissions, nitrogen loss, land degradation, and enhanced farmland biodiversity. 2) Data Collection and Monitoring: Develop robust data collection and monitoring mechanisms to gather relevant data throughout the farmland development process and during the long-term use of the farmland. This includes collecting input-output data, social impact data, and soil and environmental monitoring data. 3) Policy Incentives and Constraints: Based on evaluation, implement policy incentives to reward or subsidize projects with significant benefits. Conversely, impose constraints or adjustments on projects with poor performance, guiding resource allocation towards more beneficial directions. 4) Continuous Improvement and Optimization: Continuously improve and optimize the evaluation system by adjusting indicators and methods based on actual conditions and accumulated experience. This ensures the evaluation remains scientific and effective. By constructing a scientific, reasonable, and comprehensive benefit evaluation system, strong support can be provided for the implementation and management of farmland development projects.

3.2 Emphasizing farmers' role and reasonably guiding their participation

To achieve SFD, it is essential to fully consider the "positive externalities" of agricultural infrastructure and guide farmers’ participation in its development. 1) Farmers should be involved in the construction of agricultural infrastructure that falls within the categories of quasi-public goods or private goods. 2) Farmers' willingness and preferences should be fully respected. Diverse participation methods should be provided based on the family endowments of farmers in different regions. Farmers should have the option to participate through financial contributions or labor, depending on their household circumstances. 3) Strengthen the education and training of farmers to increase their awareness of the importance of agricultural infrastructure. Equip them with knowledge of environmentally friendly agricultural practices and technologies. And improve the willingness of farmers in major grain-producing areas to engage in SFD. 4) Strengthen farmers’ ecological awareness, shift away from monotonous guidance methods and innovate diverse intervention activities to make farmers more inclined to focus on farmland ecological construction.

3.3 Adapt measures to local conditions and formulate differentiated farmland development plans

Developing SF construction plans should be tailored to local conditions. Comprehensive surveys and research should be conducted to understand the differing needs of various regions and types of farmers, including the current state of farmland, agricultural production and management plans, and regional agricultural industry structures. This information provides a basis for creating differentiated plans. Based on the survey results, targeted and SFD plans should be developed. Local governments should lead the promotion of the benefits of various facilities and provide relevant technical training to enhance farmers' understanding of SF construction elements. During the implementation of SF construction projects, it is important to flexibly respond to the changing needs of different farmers and promptly adjust project plans and management measures. Farmers should be allowed to make adjustments and personalized settings according to their actual situations to improve the project's adaptability and sustainability. Establishing robust communication channels and feedback mechanisms to maintain close contact with farmers is crucial to understanding their needs and opinions, and adjusting plans and measures accordingly. Demonstration bases should be set up to showcase successful farmland development cases, encouraging farmers to learn from them. Additionally, promoting experience exchange and sharing among farmers will improve the overall level of farmland development.

3.4 Reasonably determining the funding proportions between the government and farmers

The government should establish different funding ratios based on the specific circumstances of each project and the characteristics of the region, allowing for flexible adjustments within a certain range. By setting up subsidy or reward mechanisms, the government can encourage farmers to participate in farmland development. For projects with a higher proportion of farmer investment or substantial contributions, a certain percentage of financial subsidies or rewards can be provided to increase their motivation and participation. The government can also provide technical training, preferential loans, and tax reductions to guide farmers in increasing their self-financing efforts. These measures not only reduce the financial burden on farmers but also enhance their willingness and capacity to participate. Promoting the formation of cooperatives or farmer professional cooperatives can facilitate collective investment in farmland development. Cooperatives can integrate resources, share risks, improve the efficiency of fund use, and achieve economies of scale. When designing the farmer contribution mechanism, it is essential to fully consider their construction needs and establish sound regulatory mechanisms to ensure the rationality and effectiveness of fund usage. Encouraging multiple parties to participate in farmland development projects, including agricultural enterprises and social investors, can diversify funding sources, alleviate the financial burden on both the government and farmers, and improve the efficiency of fund utilization.

3.5 Designing a plan for farmers' participation in SFD

3.5.1 Subject of Implementation Optimization

The optimization of the subjects implementing farmland development should shift from being led by a single government department to being led by farmers. On the one hand, it is necessary to comprehensively consider the technical and governance characteristics of farmland development, continuously stimulate the enthusiasm of farmers to actively participate in farmland development, and fully leverage the role of farmers. On the other hand, it is important to identify appropriate units for farmer self-governance, establish a complete framework for farmer self-governance organizations, and enhance the effectiveness of farmland development led by farmers.

- **Improving Farmers' Participation Initiative**

Compared to the traditional "top-down" farmland development mode, the "bottom-up" farmland development mode emphasizes the primary status of farmers as stakeholders throughout the entire process of farmland development, relying more heavily on farmers' participation. However, it can be observed from practice that farmers' spontaneous participation in farmland development projects is still weak. How to increase farmers' attention to farmland development work on a wider scale and stimulate their competitive engagement in farmland improvement projects is crucial for further optimizing the "bottom-up" farmland development mode. Through analyzing farmers' motivation, decision-making, and behavior choices in participating in farmland development activities, it can be concluded that it is necessary to fully leverage the role of leaders and active members within village organizations, develop differentiated incentive measures, and identify common interests among different households to stimulate farmers' spontaneous participation in farmland development projects. Moreover, efforts should be made to create a favorable policy environment, demonstrate leadership effects, and strengthen the construction of village regulations and agreements to incentivize and promote farmers' active participation in farmland development.

- **Enhancing the Effectiveness of Farmers' Participation**

The effectiveness of farmers' participation directly determines the quality and outcome of farmland development projects. To improve the effectiveness of farmers' participation, it is necessary to break through the limitations of the rural grassroots governance mode, strengthen village organizations, and establish a organizational structure based on this foundation. Relying on villages as the basic units, rural grassroots social organizations should be established as the main implementing part for farmland development. This involves adopting a diversified implementation mode for farmland development that involves the active participation of other agricultural entities and the land department.

In farmland development projects, it is crucial to identify appropriate units for rural self-governance and implement a "bottom-up" with farmers as the main drivers. This allows farmers to play a leading role in farmland development, with the implementation part having the authority in various stages such as project initiation, planning and design, organization and implementation, completion and acceptance, and post-project maintenance. Farmers should have the right to speak, make decisions, participate, and supervise. For projects with low technical complexity and difficulty, village committee can organize farmers to implement them independently. For projects with high technical complexity and difficulty, village committee can commission qualified enterprises with engineering qualifications to implement them. The government should guide and encourage the participation of farmers and social organizations in basic public services in villages, forming a virtuous mechanism of "mutual consultation, joint construction, joint management, and shared benefits" among farmers.

3.5.2 Organizational optimization

Further optimization of the organization mode for farmland development should be based on the transformation of government functions and the introduction of implementation by rural committee. It should continuously refine and improve the responsibilities and authority of government departments at all levels, emphasizing the construction of rural grassroots social organizations and internal organizational structures within projects.

- **Clarifying the responsibilities of government departments**

For government departments, it is important to strike a balance between delegation and supervision, clarify the responsibilities and priorities of each level of government, appropriately delegate administrative approval authority, and focus on providing overall guidance and services. At the central level, the focus is on top-level design, regional coordination, monitoring and supervision, and institutional development, including the formulation and oversight of macro-policy measures. Provincial governments are responsible for overall supervision of farmland development projects, primarily defining the key areas and directions of regional farmland development based on regional development strategies and characteristics of land use, as well as formulating relevant institutional policies and providing guidance. They also research and develop solutions to major common problems encountered in pilot projects. County-level governments are the main responsible entities for farmland development projects. The governments are primarily responsible for approval-related tasks such as project initiation, design, budget review, approval of design changes, project supervision, and acceptance, as well as the formulation of funding integration plans for farmland development projects. They are also responsible for integrating and disbursing funds, providing guidance for project implementation, and overseeing early-stage implementation work. Township (or town) governments are primarily responsible for supervising workers, ensuring that village collective economic organizations maintain construction environments as required, supervising project implementation, coordinating and resolving disputes and conflicts that arise during project implementation, providing engineering construction guidance and technical services to villages, and ensuring the overall implementation of the project.

- **Enhancing the internal organizational structure of the project**

It involves establishing rural grassroots social organizations based on village groups within administrative villages, which represent the interests of farmers and are mainly responsible for the specific organization and implementation of farmland development projects. These grassroots social organizations are distinct from government administrative systems and village committee organizations. Unlike village committee, grassroots social organizations are composed of members elected by farmers from outside the village committee members. They are mainly responsible for organizing, implementing, supervising, and managing village public affairs and public welfare projects, including farmland development projects. They do not handle administrative affairs, and their required funds are raised through village self-governance mechanisms, such as collective accumulation, fundraising within the collective, and donations. The organizational structure of rural grassroots social organizations mainly consists of the Village Council and the Supervisory Board. The Village Council is responsible for proposing, deliberating, and executing tasks. Proposing tasks involves mobilizing villagers and soliciting opinions on matters such as whether to undertake farmland development projects. Deliberating tasks involve convening village representative assemblies to collectively discuss and determine construction content, layout, project implementation plans, and fundraising methods. Executing tasks involve hiring qualified units to conduct project feasibility studies and budget preparation, submitting design change requests to relevant departments (if necessary), organizing project construction and daily management affairs, resolving implementation issues, ensuring strict quality control, managing fund utilization, and subsequent routine maintenance. This includes activities such as material procurement, equipment leasing, hiring technical personnel to provide on-site technical guidance, organizing technical personnel to organize and archive project data, and timely publicizing village affairs to villagers. The Supervisory Board is mainly responsible for overseeing major decisions, village affairs transparency, and village collective financial management, such as monitoring and publicizing the funds, quality, and progress of farmland development projects, as well as supervising the work of the Village Council. Both the Village Council and the Supervisory Board are subject to supervision by the administrative village committee and all villagers.

Overall, the government is gradually transitioning from a leading role to a guiding, directing, and servicing role. This is achieved through continuously strengthening cooperation among various departments, leveraging their coordination roles, forming synergy, increasing financial investment, and policy support. At the same time, it emphasizes the status and role of farmers, focusing on constructing and improving rural grassroots social organizations as effective carriers and platforms for farmers' participation in farmland development. Following the principle of "government guidance, farmer-led, and multi-party participation," it ensures rational division of labor among government departments and implementing entities, thereby ensuring the efficient operation of all stages of farmland development.

3.5.3 Funding Source Optimization

The optimization of funding for farmland development should actively explore efficient methods of integrating government fiscal funds. Under the guidance of government fiscal funds, the main direction is to introduce social capital by purchasing public services from society. At the same time, efforts should be made to strengthen the construction of rural collective economic organizations, aggregate idle funds in rural areas, cultivate rural social capital, and transform the way funds are invested. Funds should be allocated before construction begins to improve the overall efficiency of fund operation. It is essential to clarify that funding for farmland development comes from both the government and farmers, determine the investment ratio reasonably, and establish a mechanism for sharing benefits to ensure the long-term effective implementation of farmland development projects.

- **National Fiscal Funds Allocation**

Regarding the allocation of national fiscal funds, on one hand, using farmland development projects as a platform, integrating existing agricultural funds through top-level design, internal and external integration, and the establishment of integration guarantee mechanisms to achieve centralized fund allocation and improve the efficiency of fund utilization. On the other hand, it is possible to raise funds for farmland development through the issuance of government bonds by the central or local government, thereby improving the financing efficiency of farmland development. Additionally, the characteristics of policy financial institutions, such as long loan terms, large scale, and low profitability, can be fully utilized to provide long-term, low-interest or interest-free loans to local governments or farmers for investment in farmland development. Government fiscal funds are disbursed in the form of subsidies after the completion and acceptance of the project. For farmland development projects with large investment amounts and engineering volumes, part of the government fiscal funds can also be invested as initial startup capital to drive other fund investments.

- **Farmers' Self-financing Part**

It is necessary to strengthen the construction of a relatively complete rural grassroots governance system and service structure and enhance the construction of rural collective economic organizations to provide organizational guarantee for the coordinated use of rural social capital. At the same time, it is important to regulate and guide the cultivation of rural social capital from the legal and institutional level, relying on the internal systems and norms of rural grassroots non-governmental organizations to incentivize or restrain individual behaviors of members, and use this as a platform to integrate village collective funds, government fiscal inclusive funds, and rural idle funds for village public welfare activities, maximizing the scale benefits of funds. On the other hand, according to the government's investment in farmland development funds, it should be conditional on farmers providing matching funds. This approach not only expands the sources of funds but also enhances the enthusiasm and effectiveness of farmers' participation in farmland development. Relying solely on government investment in farmland development may lead to farmers' dependency on the government's investment, resulting in phenomena such as free riding and the tragedy of the commons. Conversely, if farmers are solely responsible for financing farmland development, the cost may exceed their reference price, reducing their perceived utility from the transaction and diminishing their willingness to invest, thus increasing the difficulty of raising funds. Therefore, a single funding mode is unsustainable. Farmland development funding should include farmers' self-financing to form a joint investment mode, with government investment as the mainstay and farmers' self-financing as a supplementary component. During the operation stage of farmland development projects, implementing a farmer-led "build first, reward later" mode leverages initial funds raised by project implementers through bank loans, funds from rural collective economic organizations, commercial capital, farmers' labor contributions, in-kind contributions, village fundraising, etc. This mode enables better utilization of rural social capital for agricultural and rural development, improving the fund utilization efficiency. After the successful acceptance of farmland development, the government then provides rewards or subsidies. In the later stages of farmland management, it is important to determine the proportion of farmers' investment appropriately. Farmland development aims to transform traditional agriculture, promote modern agriculture, enhance the comprehensive benefits of farmland development, and establish a reasonable mechanism for sharing benefits, enabling farmers to perceive the utility of transactions and be willing to contribute to the construction and subsequent management of farmland improvement projects.

- **Enterprise investment**

For the portion of investment from enterprises, it can leverage more social funds to participate in farmland development. However, the investment of enterprise funds in farmland development should be actively and prudently promoted according to local conditions. From the policy and legal perspectives, attention should be paid to safeguarding the long-term interests of farmers, preventing industrial and commercial capital from occupying land for "non-agricultural" construction, and mitigating the risks associated with the use of government financial funds. Gradually, this will lead to the formation of a new pattern of investment in farmland development, with joint contributions from government finances, enterprise funds, and rural social capital.

3.5.4 Operation Environment Optimization

The optimization of China's farmland development operational environment should be approached from both internal and external perspectives. This involves improving the external environment through relevant laws, regulations, and policy documents related to land consolidation, as well as enhancing the management capabilities and technical levels of responsible entities within farmland development. Gradually, this will refine the internal and external operational environment of farmland development.

- **External Operation Environment Optimization**

From the perspective of the external operational environment of farmland development, on the one hand, it is necessary to expedite the legislative process for farmland development. Addressing issues such as unclear legal entities and functions, non-standard legal procedures, incomplete legal content, enforcement, and maintenance mechanisms in China's farmland development requires legislation and regulation at the national level. It includes establishing regulations and standards for farmland development procedures, organizational implementation methods, division of responsibilities, fund allocation and management, evaluation, and ensuring alignment with relevant laws and regulations. Furthermore, public participation should be incorporated into the entire process of farmland development through legislation and regulations. It is essential to clearly define the principles, entities, content, methods, procedures, safeguards, incentives, and accountability mechanisms of public participation in farmland development. This involves continuously strengthening the construction of platforms for public participation, solidifying the stages of public participation, and refining the methods of public involvement. By providing a legal framework and clear regulations for public participation in farmland development, we can guide the public to actively engage in the process, effectively safeguarding their rights to information, participation, expression, and oversight. This will ensure institutional support for enhancing the effectiveness of public participation in farmland development.

On the other hand, it is necessary to continuously improve the technical standards system for farmland development. Advanced land consolidation concepts and technical methods should be integrated into the technical standards developed during the planning and preparation stages to prevent farmland development projects from focusing solely on short-term benefits and single objectives, while neglecting ecological environmental protection and sustainable development. Based on a comprehensive analysis of regional characteristics and development directions, regional development plans should be formulated in conjunction with planning standards to promote coordinated development across various aspects. Planning should play a guiding role, coordinating implementation through planning. By establishing construction standards for demonstration projects, it provides a reference for farmers to conduct farmland development projects on their own in various regions, addressing issues such as low construction quality and difficulty in standardizing technical standards in farmer-led farmland development projects. Through assessment and acceptance standards, the government not only focuses on reviewing the quality indicators of cultivated land but also emphasizes monitoring and evaluating the quality of cultivated land and quantitatively assessing the improvement of the ecological environment. Subsidies are withheld for those who fail to meet the specified standards, thereby urging farmers or NABE to strengthen their focus on the quality of cultivated land and the ecological environment during the farmland development process. Through categorizing and refining subsidy standards, we aim to improve the traditional method of direct budgetary subsidies and gradually transition to a cost-based subsidy approach. This shift ensures that project funds are allocated according to actual construction needs, enriching the content and types of subsidies and enhancing their adaptability. It also guides rural collective economic organizations or NABE to engage in ecological and high-tech farmland development.

- **Internal Operating Environment Optimization**

Regarding the internal operating environment of farmland development, on one hand, it is necessary to strengthen the construction of grassroots social organizations in rural areas and continuously improve the system of villagers' self-governance, enhancing their ability for self-governance. This involves enriching the membership of rural grassroots social organizations, clarifying the responsibilities, establishment procedures, terms and qualifications of members, operation, and rules of procedure. Activities such as consultations and discussions within these organizations, as well as the use of collective funds, should be subject to regular public disclosure and oversight by villagers. Specific matters related to the distribution of collective economic benefits and the establishment of long-term mechanisms for post-construction land management, which affect the vital interests of the masses, should be clearly defined. Gradually, standardized mechanisms for adjusting and distributing benefits should be improved to mobilize the enthusiasm of various sectors of society to participate in farmland development. The work of grassroots social organizations should be guided by the needs of the masses. By improving the democratic management system at the village level and the system of village affairs transparency, the rights of farmers to information, decision-making, participation, and supervision should be guaranteed. This will ensure the sharing of value-added benefits after land development and enhance the management capacity of the responsible parties.

On the other hand, it is important to provide farmers with specialized training, professional guidance, and technical services to promote the application of advanced concepts and technical in farmland development. Through centralized training, experience exchange, and visits, villagers conducting their own farmland development projects should receive specialized training and guidance, enabling the application of advanced technologies and concepts in the construction process. For projects undertaken by farmers themselves, government departments should provide on-site technical guidance by engineering technicians with national construction qualifications of a certain level or above to the project villages. For projects that are complex and have high implementation difficulty, policies should be improved to allow rural collective organizations or NABE to commission qualified companies with engineering construction qualifications to conduct the construction, ensuring the professional level.

3.5.5 Supervision and management optimization

The optimization of supervision and management of farmland development should be approached from two aspects. Firstly, it is necessary to strengthen vertical supervision of projects by introducing social supervision and establishing mechanisms for public participation in supervision. This will further standardize social supervision and create a situation where social and government coexist harmoniously. Secondly, it is important to expand the horizontal scope of supervision for farmland development projects. Supervision should not be limited to the initial stages, organization, implementation, and completion acceptance phases; it should extend to the later stages of farmland development and maintenance after acceptance, ensuring that supervision is conducted throughout the entire process of projects, thus eliminating the drawback of heavy emphasis on construction and light supervision in farmland development projects.

- **Building a public participation supervision mechanism**

The supervision and management of farmland development should be diversified, relying on social organizations to exercise social oversight rights more effectively and constructing a supervision mechanism of multi-party participation.

In terms of government supervision, it is necessary to clarify the responsibilities of various departments and levels of supervision subjects. Different levels of government departments have different focuses on supervision of farmland development projects. Provincial-level and above government departments mainly focus on formulating macro policies, systems, and technical standards, as well as conducting spot checks on projects. Government departments below the provincial level are responsible for the specific implementation of supervision for projects, focusing on supervising the entire process of project operation.

Regarding social supervision, it is necessary to establish platforms for public participation in supervision and improve the long-term mechanism. By optimizing rural grassroots governance modes, the organizational level and autonomy of farmers can be improved. For example, setting up dedicated boards of directors and supervisory boards responsible for supervising and managing public affairs in villages can enhance the effectiveness of public participation in supervision. On this basis, continuous improvement should be made in the procedures, methods, principles, content, safeguard measures, and incentive mechanisms for public participation in supervision. Solidifying the public participation process and refining the methods of public participation will establish a complete feedback mechanism and institutional system for public participation in project supervision.

- **Establishing a long-term supervision mechanism**

Supervision and management of farmland development should be integrated into every stage of the project, ensuring comprehensive supervision throughout the entire process.

During the project's initial planning and design, government departments should focus on reviewing the qualifications of design firms and whether the project planning and design schemes meet the norms and standards. Meanwhile, it is important to respect the public's right to supervise and make decisions.

During the project implementation, strict supervision of project construction must be ensured. For projects organized and implemented by villagers themselves, government departments should pay attention to supervising the farmland development by village committees or grassroots social organizations. This includes establishing regular disclosure and financial transparency mechanisms and measures, facilitating supervision channels, establishing feedback mechanisms, and standardizing contract management and engineering supervision. This ensures that farmers in the project area fulfill their responsibilities and obligations as supervisors effectively. For projects entrusted to construction units, government departments should focus on reviewing the qualifications of construction enterprises and units, and participate in the entire construction process for full supervision.

During the project completion and acceptance, government departments should organize experts and technical teams to conduct rigorous reviews, gradually improving the "self-inspection – initial inspection – re-inspection – random inspection" system. Regarding fund allocation, strict auditing of project settlements is necessary, and the subsidy funds should only be disbursed after government departments have approved the audit. Village committees and rural grassroots social organizations should publicize the subsidy situation, accept supervision from villagers and the public. After the subsidy fund allocation plan has been publicized without objection, the government department will disburse the subsidy funds to the village committees, rural grassroots social organizations, or the commissioned project implementers.

During the later stage management and maintenance, the source of funds for management and maintenance should be clearly defined, and a supervision mechanism for the use of funds should be established. On one hand, a supply mode jointly funded by the government and rural collectives should be established. By calculating the costs of management and maintenance, the government and rural collectives' funding proportions should be determined, and specific plans for the source and use of management funds should be formulated, establishing a special fund with earmarked use. On the other hand, a mechanism should be established with farmers as the main managers, jointly supervised by the government and rural collectives.

4. Limitation and expectation

The study developed a set of policy tools for farmer participation in farmland development, but it has certain limitations.

The case data only represented the typical modes under the wheat-maize cropping system in the North China Plain and did not reflect the characteristics and performance under the other cropping systems in the other regions, suggesting that expanding study cases with diverse cropping systems is necessary for selection, thus completely improving the systematic evaluation in the future study. Additionally, based on the IPCC analysis, the environmental impact factors related to the "carbon" should be considered. Although other impact categories can be estimated, experimental and monitoring data should be used to obtain more precise results in future studies. Moreover, the case studies and empirical research discussed in this paper focus on key regions currently advancing farmland development. However, factors such as farmland conditions, agricultural production and management status, industrial structure, and farmers' endowments significantly influence the formulation of farmland development plans and the level of farmers' participation. This highlights the necessity of designing farmer participation mechanisms for SFD tailored to local conditions. Future research should expand the discussion to a broader range of regions to better align with regional construction needs and continuously improve the farmer participation mechanism. Furthermore, this study emphasizes the introduction of farmer investments. Given the numerous stakeholders involved in farmland development, the investment mechanism should attract a wider range of participants. Exploring participation criteria for other stakeholders is a direction for future research.

Although farmer participation in SFD is a vital pathway for promoting rural sustainable development, examining the post-construction management and maintenance of facilities by farmers is also crucial. In many cases, the management and maintenance of facilities after project completion become a key issue, directly affecting the project's long-term benefits and sustainability. Future research should focus on farmers' management and maintenance of post-construction facilities to comprehensively evaluate the sustainability and effectiveness of the projects. This can be explored through the following aspects: 1) Exploring Management Mechanisms and Modes: Researching the facility management mechanisms and modes in different regions and types of projects, including farmer self-management, cooperative management, government, or third-party management, to explore effective management approaches. 2) Analyzing Influencing Factors and Issues: Analyzing the factors affecting farmers' facility management, including economic, social, and institutional aspects, and proposing solutions to potential issues such as funding, technology, information, and awareness. 3) Formulating Policies and Measures: Developing corresponding policies and measures based on research findings to promote farmers' participation in the effective management and sustainable utilization of post-construction facilities. This may include providing technical training, establishing reward and punishment mechanisms, and creating financial support systems.

Appendix

Chapter 4: A

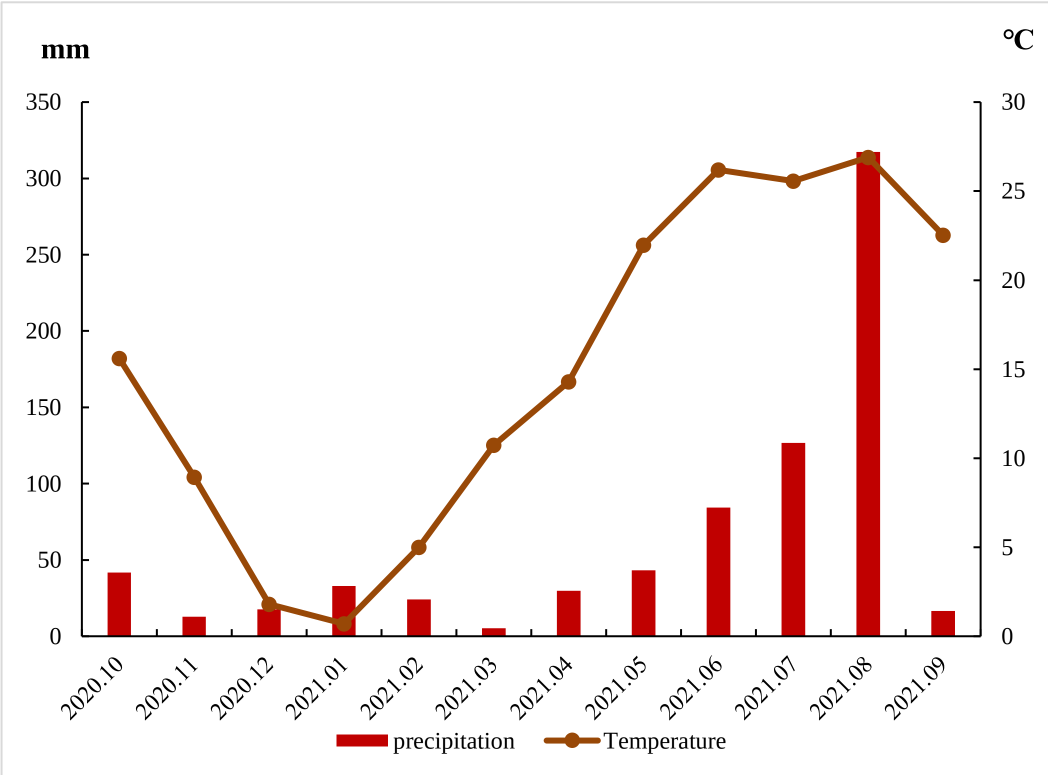
Chapter 5: B

Chapter 6: C

3.6 Additional description of chapter 4

1.1Study area and system description

Fig. S 1 precipitation and temperature during the wheat-maize growth season

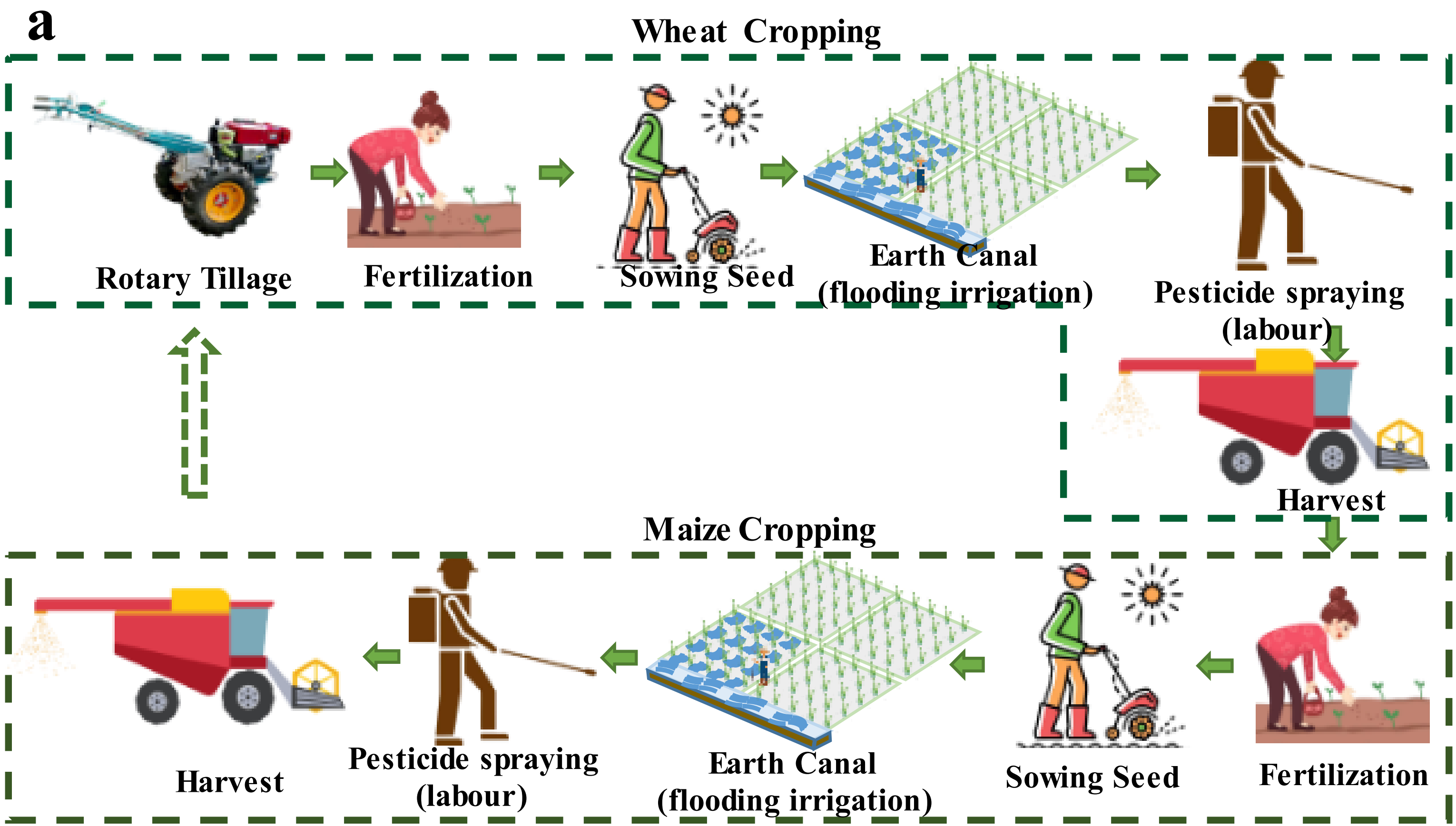


1.2 Description of the modes under assessment

Table S 1 Deference in three modes

Assessment scope	Objectives	Mode 1: CF-SPM	Mode 2: HSF-IFM	Mode 3: SF-EDFM
Farmland management situation	Cropping erea	0.47	8.56	78.67
	Average area per land plot (ha)	0.35	2.44	30.56
Infrastructure	Farmland consolidation	×	HSF project (2014-2016)	HSF project (2019）
	Farmland machine road	×	HSF project (2014-2016)	HSF project (2019）
	Irrigation project	Earth Canal	HSF project (Pipeline irrigation)	HSF project + High-efficiency water-saving project（2019）
	Shelter forest for farmland	×	√	√
Wheat production	Land preparation	rotary tillage	rotary tillage*2	rotary tillage*2
	Sowing Seed	labour	seeding and Fertilization Together	seeding and Fertilization Together (drip irrigation belt laying)
	Base fertilization	labour		
	Top dressing	labour	labour	drip fertilization
	Plant protection	labour	machinery	Uav + physical prevention and control
	Irrigation mode	flooding irrigation	pipeline irrigation	drip irrigation
	Harvest	harvester (for hire)	harvesting and straw crushing are integrated	harvesting and straw crushing are integrated
	Straw treatment	straw Crusher (for hire)		

Maize production	Land preparation	rotary tillage	seeding and Fertilization Together (no-tillage)	Seeding and Fertilization Together (no-tillage, drip irrigation belt laying)
	Sowing Seed	labour		
	Base fertilization	labour		
	Top dressing	labour	labour	drip fertilization
	Plant protection	labour	machinery	Uav + physical prevention and control
	Irrigation mode	flooding irrigation	pipeline irrigation	drip irrigation
	Harvest	harvester (for hire)	harvesting and straw crushing are integrated	harvesting and straw crushing are integrated
	Straw treatment	straw Crusher (for hire)		
Sample situation	—	smallhorder farmers: 88	large grower: 16+planting coorperative: 4+farmily farm: 4	agricultural cooperative: 2+ agribusinesses: 2


a
Wheat Cropping
Rotary Tillage
Fertilization
Sowing Seed
Earth Canal
(flooding irrigation)
Pesticide spraying
(labour)
Harvest
Maize Cropping
Harvest
Pesticide spraying
(labour)
Earth Canal
(flooding irrigation)
Sowing Seed
Fertilization

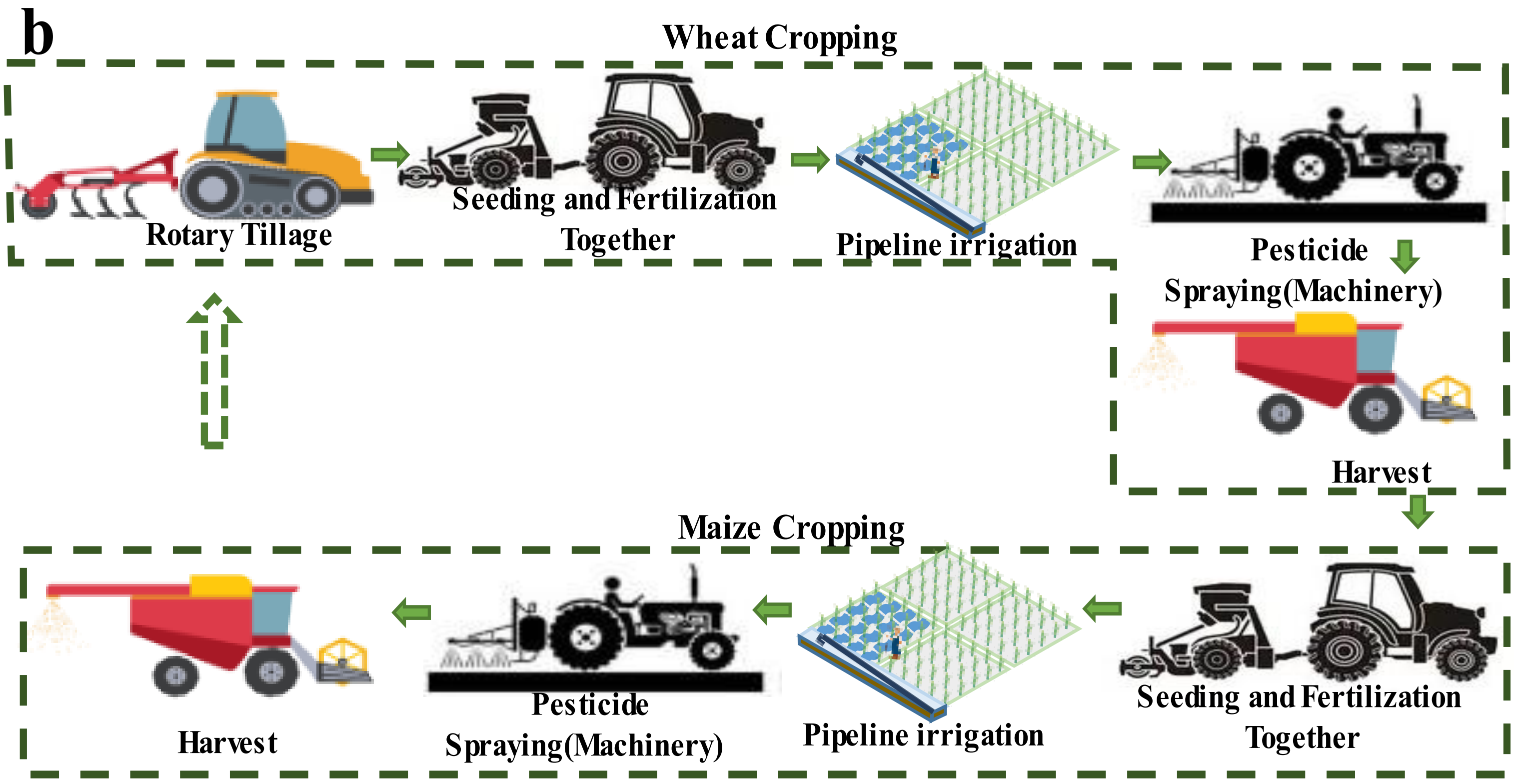


Fig. S 2 Farming systems: Smallholder farming mode under the conventional farmland (a), Intensive farming mode under the High-standard farmland (b)

1.2.1 Cropping management

Table S 2

Items	Unit	GHG emissions (kg CO_2 eq unit^{-1})
N fertilizer production and transportation	kg N	8.30 kg CO_2 eq unit^{-1}
P fertilizer production and transportation	kg P_2O_5	7.90 kg CO_2 eq unit^{-1}
K fertilizer production and transportation	kg K_2O	5.50 kg CO_2 eq unit^{-1}
Pesticide production and transportation	kg	19.10 kg CO_2 eq unit^{-1}
Diesel	kg	3.10 kg CO_2 eq unit^{-1}
Electricity for irrigation and plant protection	kWh	1.14kg CO_2 eq unit^{-1}
Wheat Seed	kg	0.40 kg CO_2 eq unit^{-1}
Maize Seed	kg	3.85 kg CO_2 eq unit^{-1}
		N_2O emissions (kg N eq unit^{-1})
Direct N_2O emission from N fertilizer (EF_1)	kg	2.47×10^{-3} kg N eq unit^{-1}
Indirect N_2O emission from N fertilizer volatilization (EF_{2SN})	kg	0.01 kg N eq unit^{-1}
Indirect N2O emission from N fertilizer leaching and runoff (EF_3)	kg	7.50×10^{-3} kg N eq unit^{-1}

2. The optimization pathway of modes

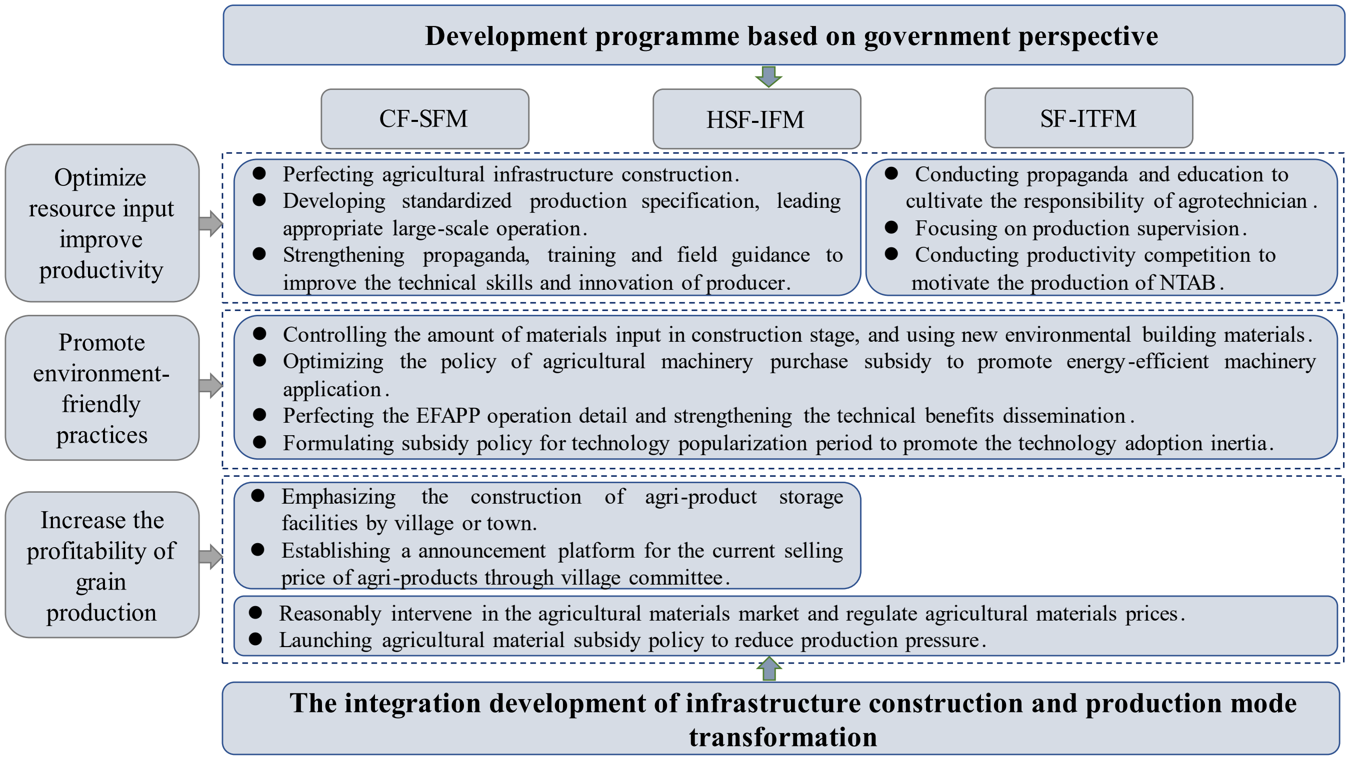


Fig. S 3 The optimization pathway of modes

3.7 Appendix B: Additional description of chapter 5

1. Description of SF

SFD is mentioned in the paper as an upgraded version of high-standard farmland development, so the details related to high-standard farmland development are described to distinguish and link between it and SF.

Table S 3 shows the tasks and targets of China's high-standard farmland development action. Thus, the mode of farmland development focuses on engineering practices to achieve the goal of efficient resource utilization, but it neglects the promotion of agronomic measures. Related studies show that the number of chemical fertilizer inputs has significantly exceeded the optimal interval for economic and environmental efficiency in agriculture in China, which not only decreased the international competitiveness of agricultural products but also aggravated the problems of resource consumption and environmental pollution, which is not conducive to the development of sustainable agriculture(Gu et al., 2015; Jingjing et al., 2019). The latest general rules of high-standard farmland development put forward the concept of sustainable development throughout farmland development. It aims to strengthen the intensive and economical utilization of water and soil resources' ecological and environmental protection by optimizing the construction of farmland infrastructure and reasonably setting up soil quality improvement activities[38].

Table S 3 The major activities and targets of high-standard farmland development[39]

Activities	Targets
Irrigation Engineering	Improving the efficiency of agricultural irrigation water utilization and enhancing the drought-resistant capacity of farmland.
Drainage Engineering	Conversion of saline land and enhancement of farmland resistance to flooding.
Farmland consolidation engineering	Realization of land consolidation and management to reduce the degree of fragmentation of cultivated land.

[38] General Rules for the Construction of High-standard Farmland (GB/T30600-2022) (jsgg.com.cn)
[39] China High-Standard Farmland Construction Plan (2021-2030) (ndrc.gov.cn)

Field road paving and hardening	To meet the requirements of agricultural machinery to operate and transport of agricultural products.
Agricultural forestry network construction	Regulate microclimate and maintain eco-balance of farmland.

Fig. S 4 Green Farming System Design Framework

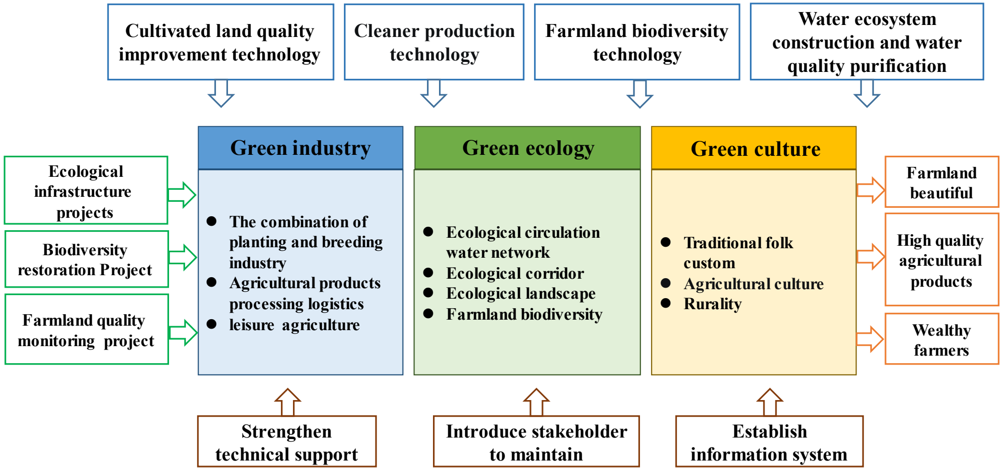


Table S 4 The major activities and targets of SFD

Developing Sustainable Farmland	Engineering and production management indicators	Facilities and technical specifications
Farmland ecological infrastructure construction project	Land consolidation	**Land integration** **cultivated land building**
	Farmland ecological circulation water network	**Integrated water and fertilizer facilities** **Ecological drainage and irrigation ditches** Ecological weir

		Irrigation water pretreatment system
		Water quality online monitoring station
	Farmland ecological corridor	**Mechanized farming road**
		Ecological field ridge
		Alley cropping zone
	Farmland ecological landscape	lounge bridge
		Plank road
		pergola
	Restoration of farmland biodiversity	Habitat of pollinators
		Natural enemy conservation area
		Field ecological forest island
	Farmland quality control and inspection	Location monitoring of cultivated land quality
		On-line monitoring of farmland drainage and irrigation
Environmental-friendly agricultural production practices	Chemical input reduction control	**Fertilizer reduction, organic fertilizer replacement technology**
		Soil testing and formula fertilization technology
		Physical and biological prevention and control
		Water-saving irrigation technique
	Disposal of waste resources	**Straw-return**
		Recycling of agricultural waste plastics

1.1 Questionnaire and Survey

The survey was created primarily utilizing the theoretical framework depicted in Fig. 3. The initial questionnaire included five sections: farmers' demographic characteristics, farmers' understanding of SFD, APCs, farmers' evaluation of SFD policy, and farmers' behavioral intention to participate in SFD. The researcher disclosed the post-sustainable farmland effects to the farmers before the formal questions were asked so that they could fully understand the SF. Meanwhile, SFD activities are introduced one by one. To obtain more valid information about the farmers and their farmland, we conducted a chat-style exchange with each farmer except for the questionnaire. These included farmers' concerns about answering formal questions, doubts about related issues, etc. Furthermore, the survey team investigated all the farmlands in the sample villages and the current status of land utilization, including the facilities' condition, cultivation system, and production and operation practices. The survey questionnaire was N based on activities, including a literature review, pilot study, and group discussions among agricultural experts and researchers from various research institutes and universities. A pilot survey was also conducted in Ningxia in September 2021 to improve the quality of the questionnaire. Finally, based on pilot data analysis, the official version of the questionnaire was achieved, which included 128 indicators be used for the formal survey.

A combination of typical and random sampling was used to select counties, towns, villages, and respondents. First, the sample towns were chosen using the typical sampling technique. This is explained by the fact that SFD focuses on improving the farmland’s eco-environment and soil quality so that the cropping areas are selected as survey regions. Secondly, the demand for SF in many areas is limited by natural and agricultural resources, combined with insufficient program support from local administrations. There will most likely be a sample selectivity bias if these counties are chosen. As a result, the sample farmers were drawn randomly from the target villages. The sample size of each province(autonomous region) was shown in Table S 5.

Table S 5 Distribution of samples

Provinces (autonomous region)	County	Sample size	Ratio
Ningxia	Qingtongxia	75	7%
	Xingqing	117	10%
	Pengyang	79	7%
Subtotal		271	24%
Henan	Kaifeng	94	8%
	Jiaozuo	104	9%

	Luoyang	104	9%
Subtotal		302	27%
	Huzhu	57	5%
Qinghai	Datong	112	10%
	Huangyuan	87	8%
Subtotal		256	23%
	Ningyang	94	8%
Shandong	Yuncheng	103	9%
	Yanggu	107	9%
Subtotal		304	27%
Total size		1133	100%

2. Figures and Tables from the Results

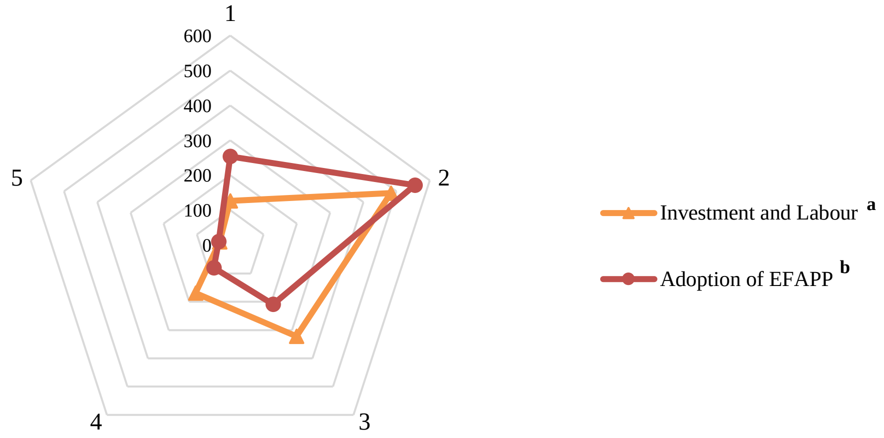


Fig. S 5 Farmers' response on the forms of participation in SFD

a: Descriptions of Investment and Labor (1-5): 1=Not Adopted, 2=Adopt 1 practice, 3=Adopt 2-3 practice, 4= Adopt 4 practice, 5= Adopt 5-6 practice;

b: Descriptions of Adoption of EFAPP (1-5): 1=No contribution, 2=Contribution CNY1-200/mu or Work 1-14 days, 3= Contribution CNY 200-500/mu or Work 14-30 days, 4= Contribution CNY 500-1000/mu or Work 30-90 days, 5= Contribution more than CNY 1000/mu or Work more than 90 days.

Note: 1mu=0.667ha

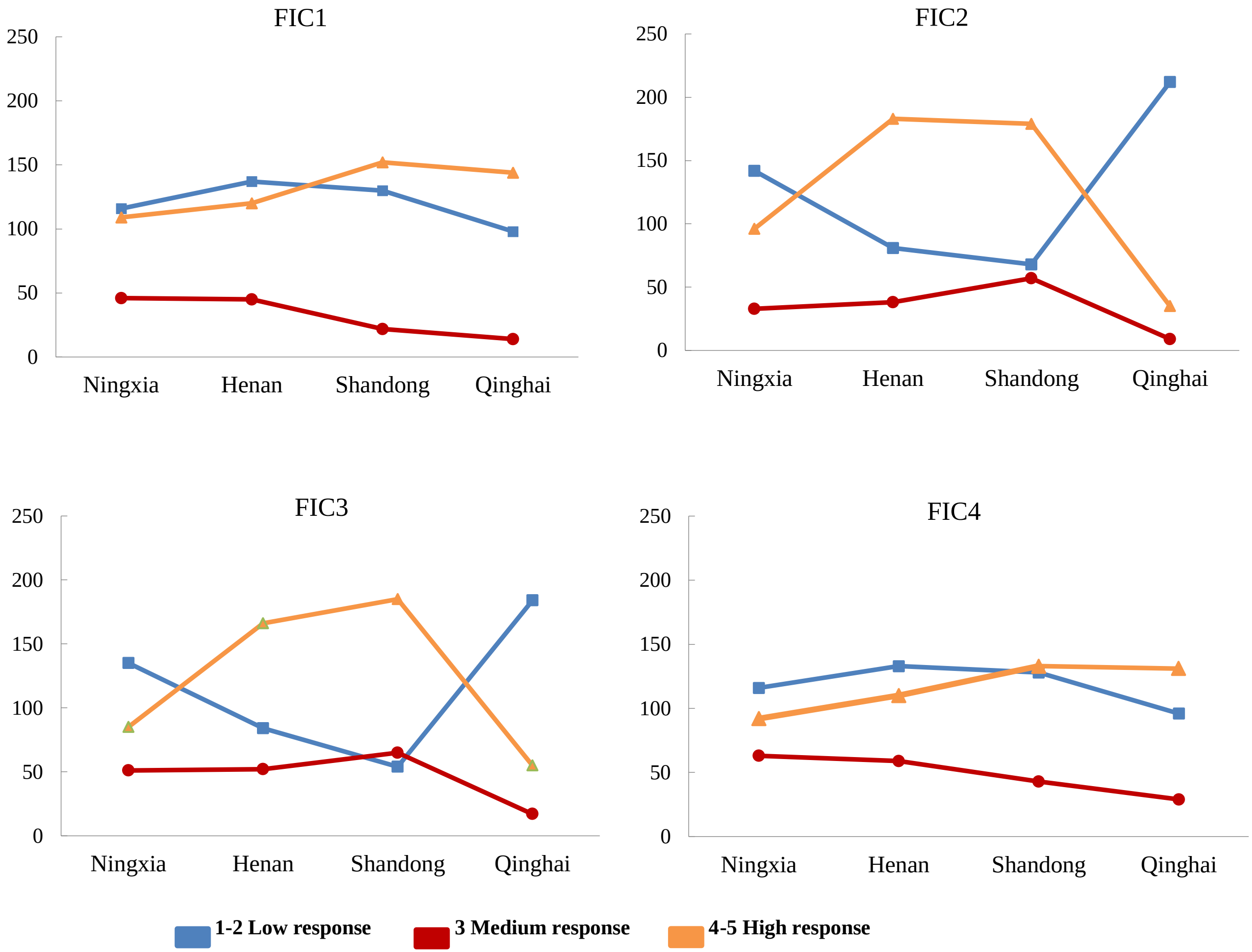

FIC1
FIC2
FIC3
FIC4
250
200
150
100
50
0
Ningxia
Henan
Shandong
Qinghai
1-2 Low response
3 Medium response
4-5 High response

Fig. S 6 The characteristics of the distribution in regional FIC

Table S 6 Respondents' socioeconomic characteristics

Index	Definition	Number	Ratio (%)
Gender	Male	712	62.8
	Female	421	37.2
Age	<40	128	11.3
	41-50	256	22.6
	51-60	417	36.8
	61-70	241	21.3
	≥70	91	8.0
Family income (CNY/a)	<10000	152	13.4
	10001-30000	317	28.0
	30001-50000	262	23.1
	50001-70000	150	13.2
	≥70000	252	22.2
Occupation	Professional Farmer	415	36.6
	Part-time farmer	718	63.4
Education	Primary school and Illiteracy	370	32.7
	Illiteracy	489	43.2
	Senior high and above	274	24.2
Household farming size (0.0667 ha)	<1	149	13.2
	1-10	563	49.7
	11-50	295	26.0
	≥50	126	11.1
Land transfer	No	689	60.8

	Yes	444	39.2

Table S 7 Variable definition and descriptive statistics

Name of variable	Variable definition	Mean value	Standard deviation
Dependent variable			
INT	The response values for the three sets of INT-related questions were averaged.	3.246	1.040
Independent variable			
Gender	Gender of respondents' farmers: 0=female, 1=male	0.628	0.483
Age	Age of respondents' farmers (years)	54.673	11.632
Family income (CNY/a)	Annual household income of respondents' farm households (10 thousand CNY)	6.314	9.768
Occupation	Whether the farmer respondents are part-time farmers: 0=no, 1=yes	0.366	0.482
Education	Years of education for respondents' farmers (years)	6.865	3.787
Household farming size (0.0667 ha)	The cultivated land area of respondent farmers' operations (0.0667 ha)	25.673	97.117
Land transfer	Whether the respondent farmers conduct land transfer: 0=No, 1=Yes	0.392	0.488

Table S 8 Results of OLS

Independent variable	Coef.	Std. Err.
Gender	0. 164**	0. 066
Occupation	−0. 079	0. 069
Age	−0. 002	0. 003
cultivated area	0. 000	0. 000
Household farming size (0.0667 ha)	−0. 003	0. 004
Land transfer	−0. 181***	0. 065
Education	−0. 003	0. 009
Constant	3. 517	0. 203

“***”, “**”, “*” significant at 1%, 5%, 10% level, respectively.

Structure model: testing for multigroup invariance

Table S 9 Constant row test of the model across education levels

Model	χ^2	*df*	CFI	TLI	RMSEA	Model Comparison	△DF	△CMIN	P	△NFI	△IFI	△RFI	△TLI	△CFI
Unconstrained(M1)	428.850	247.000	0.981	0.979	0.026									
Measurement weights(M2)	455.701	257.000	0.980	0.979	0.025	M2 vs. M1	10.000	16.852	0.078	0.002	0.002	0.000	0.000	-0.001
Structural weights(M3)	450.766	260.000	0.980	0.979	0.025	M3 vs. M2	3.000	5.065	0.167	0.001	0.001	0.000	0.000	0.000
Structural covariances(M4)	456.815	266.000	0.980	0.980	0.025	M4 vs. M3	6.000	6.049	0.418	0.001	0.001	0.000	0.000	0.000
Structural residuals(M5)	457.504	267.000	0.980	0.980	0.025	M5 vs. M4	1.000	0.690	0.406	0.000	0.000	0.000	0.000	0.000
Measurement residuals(M6)	507.614	281.000	0.977	0.977	0.027	M6 vs. M5	14.000	50.110	0.000	0.005	0.005	0.003	0.003	-0.003

Table S 10 Parameter estimates of model 1 to model 3 (Education level groups)

Model	Unconstrained(M1)						Measurement weights(M2)						Structural weights(M3)					
Education Level	edu-low		edu2-medium		edu3-high		edu-low		edu2-medium		edu3-high		edu-low		edu2-medium		edu3-high	
Parameters	Unstd.	Std.	Unstd.	Std.	Unstd.	Std.	Unstd.	Std.	Unstd.	Std.	Unstd.	Std.	Unstd.	Std.	Unstd.	Std.	Unstd.	Std.
F1→F4	0.242	0.231	0.308	0.241	0.242	0.231	0.246	0.227	0.296	0.245	0.246	0.227	0.263	0.238	0.263	0.223	0.263	0.238
F2→F4	0.281	0.263	0.235	0.199	0.281	0.263	0.293	0.262	0.228	0.205	0.293	0.262	0.263	0.231	0.263	0.243	0.263	0.231
F3→F4	0.240	0.214	0.368	0.346	0.240	0.214	0.235	0.214	0.376	0.343	0.235	0.214	0.299	0.267	0.299	0.282	0.299	0.267
F1→AT1	1.000	0.851	1.000	0.754	1.000	0.851	1.000	0.849	1.000	0.762	1.000	0.849	1.000	0.849	1.000	0.763	1.000	0.849
F1→AT2	1.019	0.871	1.073	0.811	1.019	0.871	1.033	0.873	1.033	0.804	1.033	0.873	1.034	0.873	1.034	0.804	1.034	0.873
F1→AT3	0.997	0.831	0.964	0.747	0.997	0.831	0.985	0.824	0.985	0.763	0.985	0.824	0.985	0.824	0.985	0.764	0.985	0.824
F1→AT4	1.057	0.880	1.125	0.829	1.057	0.880	1.075	0.883	1.075	0.819	1.075	0.883	1.075	0.883	1.075	0.819	1.075	0.883
F2→SN1	1.000	0.786	1.000	0.782	1.000	0.786	1.000	0.778	1.000	0.791	1.000	0.778	1.000	0.778	1.000	0.791	1.000	0.778
F2→SN2	1.104	0.873	1.188	0.913	1.104	0.873	1.143	0.878	1.143	0.908	1.143	0.878	1.143	0.879	1.143	0.907	1.143	0.879
F2→SN3	1.069	0.882	1.107	0.875	1.069	0.882	1.087	0.881	1.087	0.877	1.087	0.881	1.087	0.881	1.087	0.877	1.087	0.881
F2→SN4	0.846	0.698	0.878	0.689	0.846	0.698	0.860	0.697	0.860	0.690	0.860	0.697	0.861	0.696	0.861	0.690	0.861	0.696
F4→INT1	1.000	0.898	1.000	0.922	1.000	0.898	1.000	0.909	1.000	0.906	1.000	0.909	1.000	0.911	1.000	0.901	1.000	0.911

F4→INT2	0.952	0.843	0.835	0.810	0.952	0.843	0.901	0.831	0.901	0.826	0.901	0.831	0.902	0.836	0.902	0.820	0.902	0.836
F4→INT3	0.915	0.809	0.829	0.785	0.915	0.809	0.879	0.802	0.879	0.795	0.879	0.802	0.880	0.808	0.880	0.788	0.880	0.808
F3→PBC1	1.000	0.779	1.000	0.835	1.000	0.779	1.000	0.800	1.000	0.805	1.000	0.800	1.000	0.799	1.000	0.806	1.000	0.799
F3→PBC2	1.066	0.830	0.918	0.812	1.066	0.830	1.000	0.824	1.000	0.823	1.000	0.824	1.001	0.823	1.001	0.825	1.001	0.823
F3→PBC3	1.101	0.841	0.918	0.795	1.101	0.841	1.021	0.829	1.021	0.813	1.021	0.829	1.021	0.827	1.021	0.815	1.021	0.827
e1	0.367	0.276	0.557	0.432	0.367	0.276	0.369	0.280	0.549	0.419	0.369	0.280	0.369	0.280	0.549	0.418	0.369	0.280
e2	0.319	0.242	0.439	0.343	0.319	0.242	0.317	0.238	0.446	0.354	0.317	0.238	0.317	0.238	0.445	0.353	0.317	0.238
e3	0.430	0.310	0.540	0.443	0.430	0.310	0.434	0.320	0.530	0.418	0.434	0.320	0.434	0.321	0.528	0.416	0.434	0.321
e4	0.313	0.225	0.422	0.313	0.313	0.225	0.310	0.220	0.433	0.330	0.310	0.220	0.310	0.221	0.433	0.329	0.310	0.221
e5	0.574	0.383	0.544	0.388	0.574	0.383	0.580	0.394	0.538	0.374	0.580	0.394	0.580	0.395	0.539	0.374	0.580	0.395
e6	0.351	0.237	0.242	0.167	0.351	0.237	0.344	0.228	0.252	0.176	0.344	0.228	0.344	0.228	0.252	0.176	0.344	0.228
e7	0.302	0.222	0.322	0.234	0.302	0.222	0.303	0.224	0.318	0.230	0.303	0.224	0.303	0.224	0.318	0.230	0.303	0.224
e8	0.697	0.512	0.733	0.526	0.697	0.512	0.700	0.515	0.732	0.523	0.700	0.515	0.700	0.515	0.732	0.523	0.700	0.515
e9	0.254	0.193	0.210	0.150	0.254	0.193	0.235	0.174	0.243	0.179	0.235	0.174	0.237	0.170	0.244	0.187	0.237	0.170
e10	0.392	0.289	0.436	0.344	0.392	0.289	0.407	0.310	0.421	0.317	0.407	0.310	0.406	0.301	0.419	0.328	0.406	0.301

e11	0.469	0.346	0.511	0.384	0.469	0.346	0.476	0.356	0.500	0.368	0.476	0.356	0.474	0.346	0.500	0.379	0.474	0.346
e12	0.542	0.393	0.459	0.303	0.542	0.393	0.521	0.360	0.503	0.352	0.521	0.360	0.521	0.362	0.503	0.350	0.521	0.362
e13	0.430	0.311	0.458	0.340	0.430	0.311	0.438	0.321	0.444	0.323	0.438	0.321	0.440	0.323	0.441	0.320	0.440	0.323
e14	0.423	0.294	0.518	0.368	0.423	0.294	0.439	0.313	0.494	0.338	0.439	0.313	0.441	0.315	0.493	0.336	0.441	0.315

Table S 11 Parameter estimates of model 4 to model 6 (Education level groups)

Model	Structural covariances(M4)						Structural residuals(M5)						Measurement residuals(M6)					
Education Level	edu-low		edu-medium		edu-high		edu-low		edu-medium		edu-high		edu-low		edu-medium		edu-high	
Parameters	Unstd.	Std.	Unstd.	Std.	Unstd.	Std.	Unstd.	Std.	Unstd.	Std.	Unstd.	Std.	Unstd.	Std.	Unstd.	Std.	Unstd.	Std.
F1→F4	0.263	0.230	0.263	0.237	0.263	0.230	0.263	0.232	0.263	0.232	0.263	0.232	0.265	0.233	0.265	0.233	0.265	0.233
F2→F4	0.263	0.233	0.263	0.240	0.263	0.233	0.265	0.237	0.265	0.237	0.265	0.237	0.264	0.237	0.264	0.237	0.264	0.237
F3→F4	0.299	0.269	0.299	0.277	0.299	0.269	0.297	0.271	0.297	0.271	0.297	0.271	0.297	0.271	0.297	0.271	0.297	0.271
F1→AT1	1.000	0.838	1.000	0.783	1.000	0.838	1.000	0.838	1.000	0.783	1.000	0.838	1.000	0.811	1.000	0.811	1.000	0.811
F1→AT2	1.034	0.864	1.034	0.823	1.034	0.864	1.034	0.864	1.034	0.823	1.034	0.864	1.039	0.846	1.039	0.846	1.039	0.846
F1→AT3	0.984	0.812	0.984	0.784	0.984	0.812	0.984	0.812	0.984	0.784	0.984	0.812	0.985	0.798	0.985	0.798	0.985	0.798
F1→AT4	1.075	0.874	1.075	0.837	1.075	0.874	1.075	0.874	1.075	0.837	1.075	0.874	1.081	0.858	1.081	0.858	1.081	0.858

F2→SN1	1.000	0.779	1.000	0.790	1.000	0.779	1.000	0.779	1.000	0.790	1.000	0.779	1.000	0.784	1.000	0.784	1.000	0.784
F2→SN2	1.143	0.879	1.143	0.907	1.143	0.879	1.143	0.879	1.143	0.907	1.143	0.879	1.139	0.890	1.139	0.890	1.139	0.890
F2→SN3	1.087	0.882	1.087	0.877	1.087	0.882	1.086	0.882	1.086	0.877	1.086	0.882	1.086	0.880	1.086	0.880	1.086	0.880
F2→SN4	0.860	0.697	0.860	0.689	0.860	0.697	0.860	0.697	0.860	0.689	0.860	0.697	0.859	0.693	0.859	0.693	0.859	0.693
F4→INT1	1.000	0.910	1.000	0.903	1.000	0.910	1.000	0.907	1.000	0.907	1.000	0.907	1.000	0.908	1.000	0.908	1.000	0.908
F4→INT2	0.902	0.834	0.902	0.823	0.902	0.834	0.901	0.831	0.901	0.827	0.901	0.831	0.900	0.829	0.900	0.829	0.900	0.829
F4→INT3	0.880	0.807	0.880	0.791	0.880	0.807	0.879	0.803	0.879	0.795	0.879	0.803	0.878	0.799	0.878	0.799	0.878	0.799
F3→PBC1	1.000	0.800	1.000	0.805	1.000	0.800	1.000	0.800	1.000	0.804	1.000	0.800	1.000	0.802	1.000	0.802	1.000	0.802
F3→PBC2	1.001	0.824	1.001	0.823	1.001	0.824	1.001	0.824	1.001	0.823	1.001	0.824	1.001	0.823	1.001	0.823	1.001	0.823
F3→PBC3	1.021	0.829	1.021	0.814	1.021	0.829	1.021	0.829	1.021	0.814	1.021	0.829	1.020	0.822	1.020	0.822	1.020	0.822
e1	0.369	0.298	0.549	0.386	0.369	0.298	0.369	0.298	0.549	0.386	0.369	0.298	0.448	0.342	0.448	0.342	0.448	0.342
e2	0.317	0.254	0.443	0.322	0.317	0.254	0.318	0.254	0.443	0.322	0.318	0.254	0.371	0.284	0.371	0.284	0.371	0.284
e3	0.436	0.340	0.529	0.385	0.436	0.340	0.435	0.340	0.528	0.385	0.435	0.340	0.477	0.363	0.477	0.363	0.477	0.363
e4	0.311	0.236	0.430	0.299	0.311	0.236	0.311	0.236	0.430	0.299	0.311	0.236	0.363	0.264	0.363	0.264	0.363	0.264
e5	0.580	0.393	0.539	0.376	0.580	0.393	0.580	0.393	0.539	0.376	0.580	0.393	0.562	0.386	0.562	0.386	0.562	0.386

e6	0.343	0.227	0.253	0.178	0.343	0.227	0.343	0.227	0.253	0.178	0.343	0.227	0.305	0.208	0.305	0.208	0.305	0.208
e7	0.302	0.222	0.318	0.232	0.302	0.222	0.302	0.222	0.318	0.232	0.302	0.222	0.308	0.226	0.308	0.226	0.308	0.226
e8	0.700	0.514	0.732	0.525	0.700	0.514	0.700	0.514	0.732	0.525	0.700	0.514	0.715	0.519	0.715	0.519	0.715	0.519
e9	0.237	0.172	0.244	0.185	0.237	0.172	0.239	0.177	0.239	0.177	0.239	0.177	0.238	0.176	0.238	0.176	0.238	0.176
e10	0.406	0.304	0.419	0.323	0.406	0.304	0.406	0.310	0.420	0.317	0.406	0.310	0.413	0.313	0.413	0.313	0.413	0.313
e11	0.475	0.349	0.500	0.375	0.475	0.349	0.475	0.355	0.501	0.368	0.475	0.355	0.486	0.361	0.486	0.361	0.486	0.361
e12	0.521	0.360	0.505	0.353	0.521	0.360	0.522	0.360	0.505	0.353	0.522	0.360	0.514	0.357	0.514	0.357	0.514	0.357
e13	0.439	0.321	0.441	0.322	0.439	0.321	0.439	0.321	0.441	0.322	0.439	0.321	0.441	0.322	0.441	0.322	0.441	0.322
e14	0.440	0.313	0.493	0.338	0.440	0.313	0.440	0.313	0.493	0.338	0.440	0.313	0.463	0.325	0.463	0.325	0.463	0.325

Table S 12 Model constant row test with random groups

Model	χ^2	df	CFI	TLI	RMSEA	Model Comparison	△DF	△CMIN	P	△NFI	△IFI	△RFI	△TLI	△CFI
Unconstrained(M1)	276.193	142.000	0.986	0.982	0.029									
Measurement weights(M2)	282.611	152.000	0.986	0.984	0.028	M2 vs. M1	10.000	6.419	0.779	0.001	0.001	-0.002	-0.002	0.000
Structural weights(M3)	287.420	155.000	0.986	0.984	0.027	M3 vs. M2	3.000	4.809	0.186	0.000	0.000	0.000	0.000	0.000
Structural covariances(M4)	292.685	161.000	0.986	0.985	0.027	M4 vs. M3	6.000	5.265	0.510	0.001	0.001	-0.001	-0.001	0.000
Structural residuals(M5)	292.731	162.000	0.986	0.985	0.027	M5 vs. M4	1.000	0.046	0.830	0.000	0.000	0.000	0.000	0.000
Measurement residuals(M6)	335.181	176.000	0.983	0.983	0.028	M6 vs. M5	14.000	42.449	0.000	0.004	0.004	0.002	0.002	-0.003

Table S 13 Parameter estimates of model 1 to model 3 (Random groups)

Model	Unconstrained(M1)				Measurement weights(M2)				Structural weights(M3)			
Group	Group1		Group2		Group1		Group2		Group1		Group2	
Parameters	Unstd.	Std.	Unstd.	Std.	Unstd.	Std.	Unstd.	Std.	Unstd.	Std.	Unstd.	Std.
F1→F4	0.183	0.160	0.333	0.298	0.180	0.158	0.336	0.299	0.262	0.227	0.262	0.235
F2→F4	0.313	0.285	0.223	0.196	0.321	0.285	0.220	0.198	0.267	0.236	0.267	0.242
F3→F4	0.287	0.264	0.296	0.267	0.295	0.264	0.290	0.268	0.294	0.260	0.294	0.274
F1→AT1	1.000	0.820	1.000	0.807	1.000	0.826	1.000	0.800	1.000	0.826	1.000	0.800
F1→AT2	1.084	0.865	0.993	0.828	1.041	0.858	1.041	0.837	1.041	0.857	1.041	0.838
F1→AT3	1.008	0.827	0.970	0.779	0.990	0.827	0.990	0.778	0.990	0.826	0.990	0.779
F1→AT4	1.090	0.844	1.064	0.870	1.079	0.846	1.079	0.868	1.078	0.846	1.078	0.868
F2→SN1	1.000	0.783	1.000	0.782	1.000	0.782	1.000	0.783	1.000	0.782	1.000	0.783
F2→SN2	1.129	0.900	1.157	0.884	1.142	0.902	1.142	0.881	1.142	0.902	1.142	0.880
F2→SN3	1.098	0.889	1.079	0.871	1.089	0.885	1.089	0.876	1.090	0.886	1.090	0.876
F2→SN4	0.834	0.679	0.881	0.703	0.858	0.688	0.858	0.694	0.858	0.689	0.858	0.694
F4→INT1	1.000	0.889	1.000	0.926	1.000	0.897	1.000	0.918	1.000	0.898	1.000	0.918
F4→INT2	0.947	0.838	0.862	0.823	0.901	0.826	0.901	0.833	0.901	0.829	0.901	0.832
F4→INT3	0.898	0.804	0.861	0.794	0.878	0.802	0.878	0.796	0.878	0.805	0.878	0.794
F3→PBC1	1.000	0.789	1.000	0.814	1.000	0.785	1.000	0.817	1.000	0.785	1.000	0.817
F3→PBC2	0.999	0.817	1.014	0.830	1.007	0.817	1.007	0.830	1.008	0.817	1.008	0.830
F3→PBC3	1.007	0.823	1.039	0.824	1.024	0.826	1.024	0.820	1.024	0.826	1.024	0.820
e1	0.395	0.327	0.500	0.349	0.391	0.317	0.505	0.361	0.391	0.318	0.505	0.360
e2	0.320	0.251	0.421	0.314	0.328	0.264	0.413	0.299	0.328	0.265	0.412	0.298
e3	0.382	0.317	0.569	0.393	0.381	0.316	0.570	0.394	0.382	0.317	0.570	0.393

e4	0.390	0.288	0.339	0.243	0.388	0.284	0.342	0.247	0.388	0.285	0.341	0.246
e5	0.554	0.386	0.575	0.388	0.554	0.389	0.576	0.386	0.554	0.388	0.576	0.386
e6	0.263	0.190	0.341	0.219	0.260	0.186	0.346	0.225	0.260	0.186	0.347	0.226
e7	0.280	0.209	0.336	0.241	0.285	0.216	0.330	0.233	0.285	0.216	0.329	0.233
e8	0.715	0.539	0.721	0.505	0.712	0.526	0.725	0.518	0.712	0.526	0.725	0.519
e9	0.281	0.210	0.195	0.143	0.267	0.195	0.210	0.156	0.269	0.194	0.209	0.158
e10	0.402	0.297	0.414	0.323	0.417	0.318	0.404	0.306	0.415	0.313	0.403	0.308
e11	0.468	0.354	0.506	0.369	0.471	0.357	0.502	0.366	0.470	0.353	0.503	0.370
e12	0.545	0.378	0.486	0.337	0.550	0.384	0.482	0.333	0.550	0.384	0.482	0.333
e13	0.445	0.332	0.443	0.311	0.445	0.332	0.442	0.311	0.445	0.332	0.442	0.310
e14	0.434	0.323	0.489	0.322	0.430	0.318	0.494	0.327	0.430	0.318	0.493	0.327

Table S 14 Parameter estimates of model 4 to model 5 (Random groups)

Model	Structural covariances(M4)				Structural residuals(M5)				Measurement residuals(M6)			
Group	Group1		Group2		Group1		Group2		Group1		Group2	
Parameters	Unstd.	Std.	Unstd.	Std.	Unstd.	Std.	Unstd.	Std.	Unstd.	Std.	Unstd.	Std.
F1→F4	0.262	0.230	0.262	0.232	0.261	0.230	0.261	0.230	0.261	0.231	0.261	0.231
F2→F4	0.268	0.239	0.268	0.240	0.268	0.240	0.268	0.240	0.266	0.239	0.266	0.239
F3→F4	0.293	0.266	0.293	0.268	0.293	0.267	0.293	0.267	0.294	0.268	0.294	0.268
F1→AT1	1.000	0.830	1.000	0.795	1.000	0.830	1.000	0.795	1.000	0.813	1.000	0.813
F1→AT2	1.041	0.861	1.041	0.834	1.041	0.861	1.041	0.834	1.036	0.847	1.036	0.847
F1→AT3	0.990	0.831	0.990	0.774	0.990	0.831	0.990	0.774	0.986	0.800	0.986	0.800
F1→AT4	1.079	0.850	1.079	0.865	1.079	0.850	1.079	0.865	1.076	0.857	1.076	0.857
F2→SN1	1.000	0.786	1.000	0.780	1.000	0.786	1.000	0.780	1.000	0.783	1.000	0.783
F2→SN2	1.140	0.904	1.140	0.877	1.140	0.904	1.140	0.877	1.142	0.890	1.142	0.890
F2→SN3	1.090	0.889	1.090	0.874	1.090	0.889	1.090	0.874	1.088	0.880	1.088	0.880

F2→SN4	0.858	0.693	0.858	0.690	0.858	0.693	0.858	0.690	0.859	0.692	0.859	0.692
F4→INT1	1.000	0.898	1.000	0.917	1.000	0.898	1.000	0.918	1.000	0.907	1.000	0.907
F4→INT2	0.901	0.829	0.901	0.831	0.901	0.828	0.901	0.832	0.903	0.830	0.903	0.830
F4→INT3	0.878	0.805	0.878	0.793	0.878	0.804	0.878	0.794	0.879	0.799	0.879	0.799
F3→PBC1	1.000	0.793	1.000	0.811	1.000	0.793	1.000	0.811	1.000	0.802	1.000	0.802
F3→PBC2	1.007	0.825	1.007	0.824	1.007	0.825	1.007	0.824	1.008	0.825	1.008	0.825
F3→PBC3	1.023	0.833	1.023	0.813	1.023	0.833	1.023	0.813	1.024	0.823	1.024	0.823
e1	0.390	0.310	0.505	0.368	0.390	0.310	0.505	0.368	0.448	0.339	0.448	0.339
e2	0.328	0.258	0.413	0.305	0.328	0.258	0.413	0.305	0.370	0.283	0.370	0.283
e3	0.382	0.310	0.571	0.402	0.382	0.310	0.571	0.402	0.479	0.361	0.479	0.361
e4	0.388	0.277	0.342	0.253	0.388	0.277	0.342	0.253	0.364	0.265	0.364	0.265
e5	0.553	0.382	0.576	0.392	0.553	0.382	0.576	0.392	0.564	0.387	0.564	0.387
e6	0.260	0.183	0.350	0.232	0.260	0.183	0.350	0.231	0.305	0.207	0.305	0.207
e7	0.283	0.210	0.329	0.237	0.283	0.210	0.329	0.237	0.307	0.225	0.307	0.225
e8	0.712	0.520	0.725	0.524	0.712	0.520	0.725	0.524	0.717	0.521	0.717	0.521
e9	0.269	0.193	0.209	0.159	0.270	0.194	0.208	0.157	0.239	0.177	0.239	0.177
e10	0.415	0.312	0.403	0.309	0.415	0.314	0.404	0.308	0.409	0.311	0.409	0.311
e11	0.470	0.351	0.503	0.371	0.470	0.353	0.503	0.369	0.487	0.362	0.487	0.362
e12	0.548	0.372	0.483	0.343	0.548	0.372	0.483	0.343	0.515	0.358	0.515	0.358
e13	0.441	0.319	0.445	0.322	0.441	0.319	0.445	0.322	0.443	0.320	0.443	0.320
e14	0.427	0.306	0.498	0.340	0.427	0.306	0.498	0.340	0.463	0.323	0.463	0.323

Table S 15 The moderating effect of CLQ on the decision path of farmers' INT

DV	IV	Hypothesis	Unstd.	S.E.	T	P	95% LLCI	95% ULCI	Supported
INT	Constant	H4a	3.251	0.028	115.124	***	3.196	3.307	YES
	AT		0.411	0.028	14.709	***	0.356	0.466	
	CLQ		0.057	0.029	2.006	**	0.001	0.113	
	AT×CLQ		**-0.072**	0.028	-2.614	*******	-0.126	-0.018	
	Constant		3.251	0.028	115.123	***	3.195	3.306	
	SN		0.406	0.028	14.790	***	0.352	0.460	
	CLQ		0.055	0.029	1.937	-	-0.001	0.112	
	SN×CLQ		**-0.062**	0.027	-2.282	******	-0.115	-0.009	
	Constant		3.252	0.028	115.953	***	3.197	3.307	
	PBC		0.405	0.027	15.154	***	0.352	0.457	
	CLQ		0.061	0.028	2.157	**	0.006	0.117	
	PBC×CLQ		**-0.095**	0.027	-3.475	*******	-0.148	-0.041	

"***", "**", "*" significant at 1%, 5%, 10% level, respectively.

Table S 16 The moderating effect of FIC on the decision path of farmers' INT

DV	IV	Hypothesis	Unstd.	S.E.	T	P	95% LLCI	95% ULCI	Supported
INT	Constant	H4b	3.252	0.028	115.453	***	3.197	3.308	YES
	AT		0.410	0.028	14.709	***	0.356	0.465	
	FIC		0.031	0.022	1.447	-	-0.011	0.074	

	AT×FIC		**-0.078**	0.021	-3.731	***	-0.120	-0.037	
	Constant		3.272	0.029	112.759	***	3.215	3.329	
	SN		0.415	0.028	14.651	***	0.360	0.471	
	FIC		-0.039	0.022	-1.737	*	-0.082	0.005	
	SN×FIC		**-0.074**	0.021	-3.532	**	-0.116	-0.033	
	Constant		3.256	0.028	116.187	***	3.201	3.311	
	PBC		0.401	0.027	15.003	***	0.348	0.453	
	FIC		0.023	0.021	1.072	-	-0.019	0.065	
	PBC×FIC		**-0.090**	0.020	-4.598	***	-0.129	-0.052	

"***", "**", "*" significant at 1%, 5%, 10% level, respectively.

Table S 17 The moderating effect of PE on the decision path of farmers' INT

DV	IV	Hypothesis	Unstd.	S.E.	T	P	95% LLCI	95% ULCI	Supported
	Constant		3.242	0.028	115.011	***	3.187	3.298	
	AT		0.405	0.028	14.446	***	0.350	0.460	
	PE		0.059	0.033	1.774	*	-0.006	0.124	
	AT×PE		**0.095**	0.030	3.166	***	0.036	0.154	
INT	Constant	**H5**	3.242	0.028	115.992	***	3.187	3.297	**YES**
	SN		0.391	0.027	14.271	***	0.337	0.445	
	PE		0.077	0.033	2.335	**	0.012	0.142	
	SN×PE		**0.152**	0.030	5.112	***	0.093	0.210	
	Constant		3.246	0.028	115.689	***	3.191	3.301	

PBC	0.400	0.027	14.936	***	0.348	0.453
PE	0.073	0.032	2.208	**	0.008	0.137
PBC×PE	**0.086**	0.030	2.877	***	0.028	0.145

“***”, “**”, “*” significant at 1%, 5%, 10% level, respectively.

Table S 18 Scenario analysis results

	Status of resource consumption		SF-Resource consumption			
Regin	Fertilizer application intensity(kg/ha)	Irrigation water consumption(m^3/ha)	Fertilizer-saving (kg/ha)	Water-saving (m^3/ha)	GHG emission (kg CO_2-eq·kg^{-1})	Farmer’s investment (CNY/ha)
Qinghai	96.25	6630	67.38-48.13	4641.00-3315.00	14343910000-20081474000	3861.63
Ningxia	324.48	7980	227.13-162.24	5586.00-3990.00		2243.72
Shandong	349.80	1725	244.86-174.90	1207.50-862.50		6624.27
Henan	441.18	2475	308.82-220.59	1732.50-1237.50		6159.50

3.8 Appendix C: Additional description of chapter 6

3.9 Questionnaire

3.9.1 Basic Information

1. Gender: □ Female □ Male
2. Age:
3. Education level:

☐ Not attended school

☐ Primary school

☐ Junior high school

☐ High school or vocational school

☐ College degree or above

4. Years of Education:
5. Career: □ Professional farmer □ Part-time farmer
6. In 2021, your total household income was ___________ (including wage income__________, property income__________, agricultural gross income__________, total agricultural product output value__________, agricultural costs__________, industry and commerce income__________, transfer income__________, and other income__________).

Among them, the gross income of the planting is ___________, the total output value of the planting is__________ _, and the total cost of the planting is ___________ (Unit: 10 thousand Chinese yuan (CNY))

Note:

The total household income is the sum of wage income, property income, the maximum value of agricultural gross income and total output value of agricultural products, transfer income, and other income

Wage income includes all labor remuneration obtained by employees through various means;

Property income includes income generated by households owning movable property (bank deposits, etc.) and immovable property (houses, vehicles, etc.)

Agricultural gross income includes the income obtained from buying and selling agricultural, forestry, animal husbandry and fishery products and their by-products;

The total output value of agricultural products is calculated by multiplying the output of agricultural, forestry, animal husbandry, and fishery products and their by-products by their respective unit product prices;

Agricultural cost includes the total cost of agricultural inputs, rental equipment, and labor costs;

Industry and commerce income?

Transfer income includes the transfer payments made by the state, units, and social organizations to resident households, as well as income transfers between resident households, such as compensation for housing demolition, land acquisition, government subsidies, reimbursements, insurance, retirement benefits, etc;

Other income refers to income other than the four types of income mentioned above.

7. In 2021, your total household expenses were _______ (including _______ for food expenses, _______ for clothing expenses, _______ for residential expenses, _______ for household equipment and services expenses, _______ for transportation and communication expenses, _______ for education and entertainment expenses, _______ for medical and health care expenses, and _______ for other expenses) (Unit: 10 thousand CNY)

Note:

Residential expenses include housing rent, water, electricity and fuel fees, property management fees, heating fees, housing maintenance fees, etc;

The expense of household equipment services includes expenses for durable goods, daily necessities, housekeeping, beauty, etc;

The expense of Transportation and communication includes transportation fees, telephone bills, etc;

The expense of Education and entertainment includes education expenditure, entertainment expenditure, tourism expenditure, etc;

Other expenses include luxury goods expenses, legal services expenses, etc.

8. If land transfer has been carried out: □ No □ Yes

9. Your attitude towards risk:

Assuming there are 6 bags now, each containing 2 balls with the same appearance and different amounts of cash, you would first choose 1 bag and then randomly pick out 1 ball from the bag you selected. Which bag would you choose?

☐ Bag 1: Two balls, both of which are 14 CNY

☐ Bag 2: Two balls, 12 CNY in 1 ball and 18 CNY in 1 ball

☐ Bag 3: Two balls, 10 CNY in 1 ball and 22 CNY in 1 ball

☐ Bag 4: Two balls, 8 CNY in 1 ball and 26 CNY in 1 ball

☐ Bag 5: Two balls, 6 CNY in 1 ball and 30 CNY in 1 ball

☐ Bag 6: Two balls, 1 CNY in 1 ball and 37 CNY in 1 ball

10. How do you evaluate your satisfaction with the current quality of cultivated land?

□ 1=Very dissatisfied,
□ 2=Less satisfied,
□ 3=Average,
□ 4=Relatively satisfied,
□ 5=Very satisfied

11. Do you think the current infrastructure of farmland (ditches, canals, roads, water, electricity) is complete?

□ 1=Very imperfect,
□ 2=Less complete,
□ 3=Average,
□ 4=Relatively complete,
□ 5=Very complete

3.9.2 Farmers' preferences for participating in SF (SF) construction

DEC Block 1

1. S1

   The country will conduct SF infrastructure construction projects in this village (such as field production road, irrigation facility, land consolidation, and ecological facility construction activities). If you need to participate, you will share the construction costs with the country.

   At present, there are 3 options we have seen. Option 1 is for you to expand 400 CNY/0.067ha, which can level the farmland and construct the contiguous farmland (**LF and CF)**; Option 2 is for you to expand 600 CNY/0.067ha, which can complete construction of **Mechanized Production Road (MPR)** and **Ecological Ditches (ED)**. You can also choose not to participate in the project and maintain the current level of facilities. Which option do you choose

S1

Attributes	Alternative 1	Alternative 2	Alternative 3
Field production road	Maintain the status	MPR 	Maintain the status
Land consolidation	LF & CF 	Maintain the status	Maintain the status
Irrigation facility	Maintain the status	ED 	Maintain the status
Farmland protective facility	Maintain the status	Maintain the status	Maintain the status
Cost per householder	400 CNY	600 CNY	0 CNY

☐ Option 1

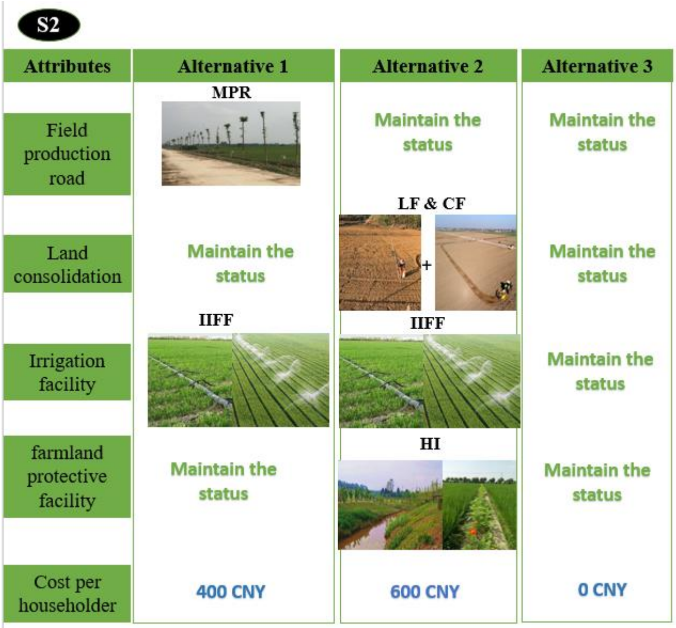
☐ Option 2

☐ Option 3

2. S2

   The country will conduct SF infrastructure construction projects in this village (such as field production road, irrigation facility, land consolidation, and ecological facility construction activities). If you need to participate, you will share the construction funds with the country.

   At present, there are 3 options we have seen. Option 1 is for you to expand 400 CNY/0.067ha, which can complete construction of **MPR** and **Integrated Irrigation and Fertilization Facility (IIFF)**; Option 2 is for you to expand CNY/0.067ha, which can complete **LF and CF**, construction of **IIFF**， and **Highly Improved (HI)** ecological environment of farmland. You can also choose not to participate in the project and maintain the current level of facilities. Which option do you choose

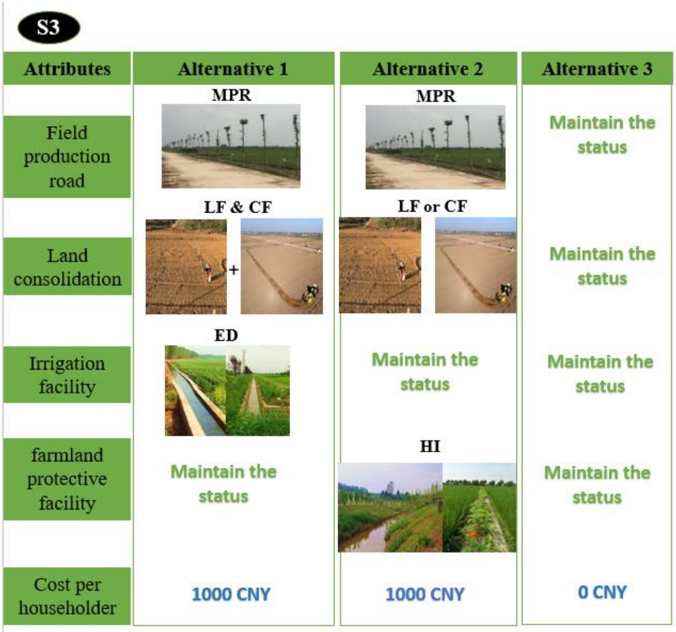


☐ Option 1
☐ Option 2
☐ Option 3

3. S3

The country will conduct SF infrastructure construction projects in this village (such as field production road, irrigation facility, land consolidation, and ecological facility construction activities). If you need to participate, you will share the construction funds with the country.

At present, there are 3 options we have seen. Option 1 is for you to expand 1000 CNY/0.067ha, which can complete construction of **MPR**, **LF and CF**, and **ED**; Option 2 is for you to expand 1000 CNY/0.067ha, which can complete construction of **MPR**, **Level Farmland or Construct Contiguous Farmland (LF or CF)**, and **HI the** ecological environment of farmland. You can also choose not to participate in the project and maintain the current level of facilities. Which option do you choose

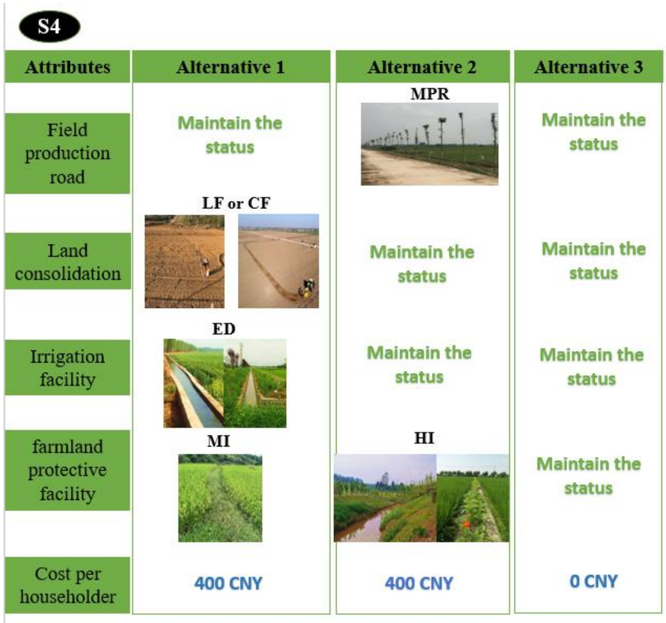


☐ Option 1
☐ Option 2
☐ Option 3

4. S4

The country will conduct SF infrastructure construction projects in this village (such as field production road, irrigation facility, land consolidation, and ecological facility construction activities). If you need to participate, you will share the construction funds with the country.

At present, there are 3 options we have seen. Option 1 is for you to expand 400 CNY/0.067ha, which can complete **LF or CF, ED**, and **Moderately Improve (MI)** the ecological environment of farmland; Option 2 is for you to expand 400 CNY/0.067ha, which can complete the construction of **MPR** and HI the ecological environment of farmland. You can also choose not to participate in the project and maintain the current level of facilities. Which option do you choose



☐ Option 1
☐ Option 2
☐ Option 3

5. S5
The country will conduct SF infrastructure construction projects in this village (such as field production road, irrigation facility, land consolidation, and ecological facility construction activities). If you need to participate, you will share the construction funds with the country.
At present, there are 3 options we have seen. Option 1 is for you to expand 600 CNY/0.067ha, which can complete construction of **MPR** and **MI** the ecological environment of farmland; Option 2 is for you to expand 1000 CNY/0.067ha, which can complete construction of **IIFF** and **MI** the ecological environment of farmland. You can also choose not to participate in the project and maintain the current level of facilities. Which option do you choose

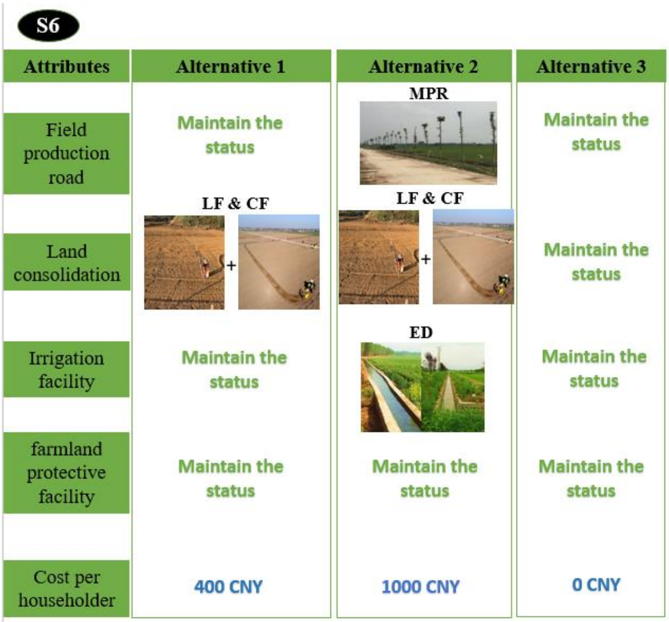
S5

Attributes	Alternative 1	Alternative 2	Alternative 3
Field production road	MPR 	Maintain the status	Maintain the status
Land consolidation	Maintain the status	Maintain the status	Maintain the status
Irrigation facility	Maintain the status	IIFF 	Maintain the status
farmland protective facility	MI 	MI 	Maintain the status
Cost per householder	600 CNY	1000 CNY	0 CNY

☐ Option 1
☐ Option 2
☐ Option 3

DEC Block 2

1. S6
The country will conduct SF infrastructure construction projects in this village (such as field production road, irrigation facility, land consolidation, and ecological facility construction activities). If you need to participate, you will share the construction funds with the country.
At present, there are 3 options we have seen. Option 1 is for you to expand 400 CNY/0.067ha, which can complete **LF and CF**; Option 2 is for you to expand 1000 CNY/0.067ha, which can complete construction of **MPR**, **LF and CF, and ED**. You can also choose not to participate in the project and maintain the current level of facilities. Which option do you choose

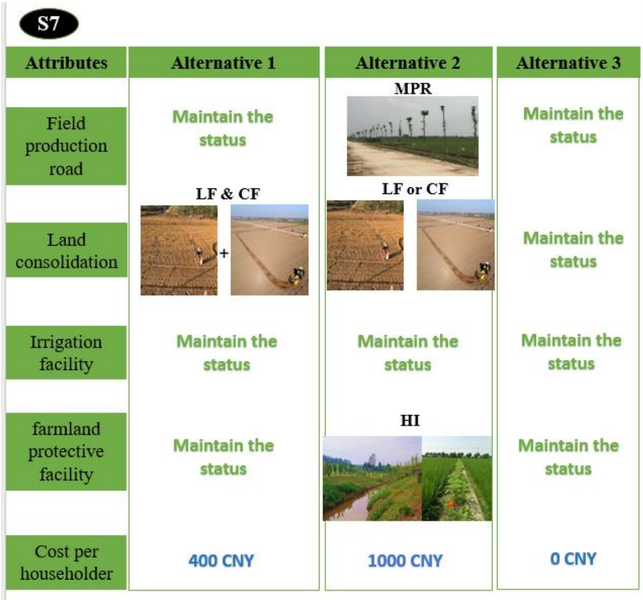


- ☐ Option 1
- ☐ Option 2
- ☐ Option 3

2. S7

   The country will conduct SF infrastructure construction projects in this village (such as field production road, irrigation facility, land consolidation, and ecological facility construction activities). If you need to participate, you will share the construction funds with the country.

   At present, there are 3 options we have seen. Option 1 is for you to expand 400 CNY/0.067ha, which can complete **LF and CF**; Option 2 is for you to expand 1000 CNY/0.067ha, which can complete construction of **MPR**, **LF or CF**, and **HI** the ecological environment of farmland. You can also choose not to participate in the project and maintain the current level of facilities. Which option do you choose

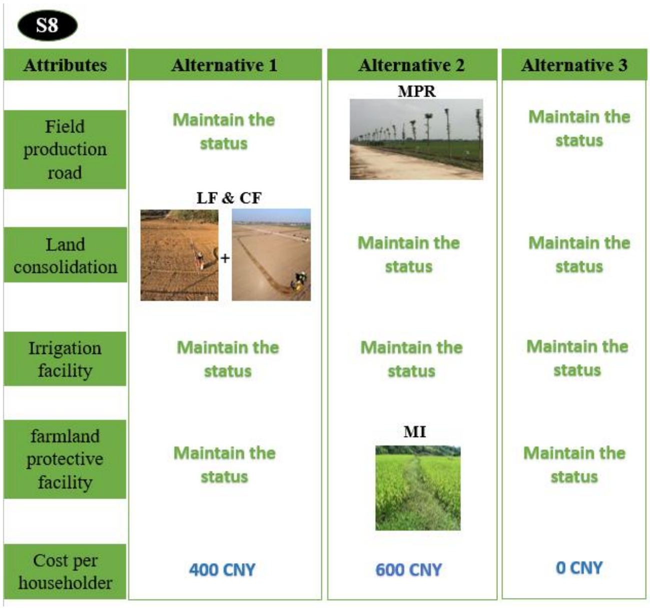


☐ Option 1
☐ Option 2
☐ Option 3

3. S8

The country will conduct SF infrastructure construction projects in this village (such as field production road, irrigation facility, land consolidation, and ecological facility construction activities). If you need to participate, you will share the construction funds with the country.

At present, there are 3 options we have seen. Option 1 is for you to expand 400 CNY/0.067ha, which can complete **LF and CF**; Option 2 is for you to expand 600 CNY/0.067ha, which can complete construction of **MPR** and **MI** the ecological environment of farmland. You can also choose not to participate in the project and maintain the current level of facilities. Which option do you choose

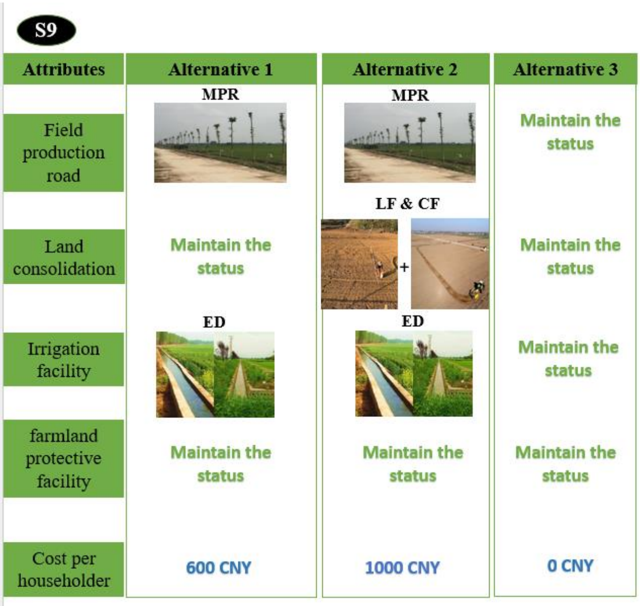


☐ Option 1
☐ Option 2
☐ Option 3

4. S9

   The country will conduct SF infrastructure construction projects in this village (such as field production road, irrigation facility, land consolidation, and ecological facility construction activities). If you need to participate, you will share the construction funds with the country.

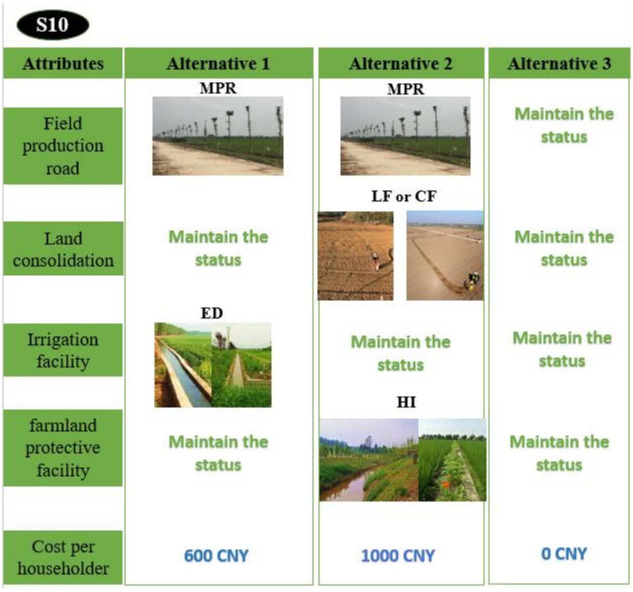
   At present, there are 3 options we have seen. Option 1 is for you to expand 600 CNY/0.067ha, which can complete construction of **MPR** and **ED**; Option 2 is for you to expand 1000 CNY/0.067ha, which can complete construction of **MPR**, **LF and CF, and ED**. You can also choose not to participate in the project and maintain the current level of facilities. Which option do you choose



☐ Option 1
☐ Option 2
☐ Option 3

DEC Block 3

1. S10
   The country will conduct SF infrastructure construction projects in this village (such as field production road, irrigation facility, land consolidation, and ecological facility construction activities). If you need to participate, you will share the construction funds with the country.
   At present, there are 3 options we have seen. Option 1 is for you to expand 600 CNY/0.067ha, which can complete construction of **MPR** and **ED**; Option 2 is for you to expand 1000 CNY/0.067ha, which can complete construction of **MPR**, **LF or CF**, and **HI** the ecological environment of farmland. You can also choose not to participate in the project and maintain the current level of facilities. Which option do you choose



☐ Option 1
☐ Option 2
☐ Option 3

2. S11

The country will conduct SF infrastructure construction projects in this village (such as field production road, irrigation facility, land consolidation, and ecological facility construction activities). If you need to participate, you will share the construction funds with the country.

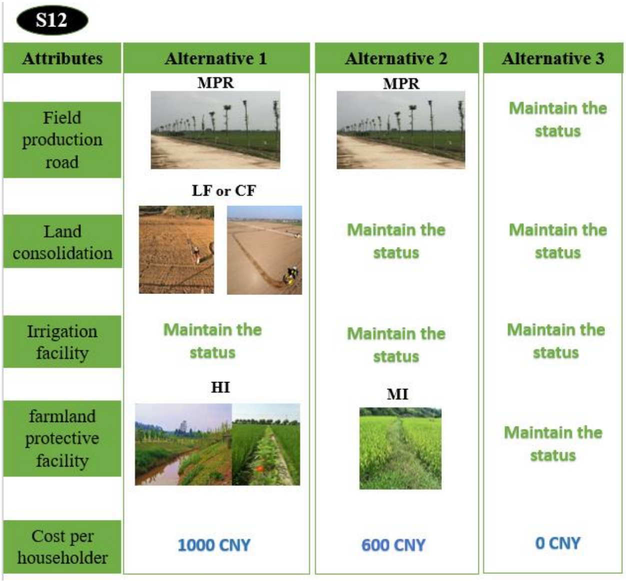
At present, there are 3 options we have seen. Option 1 is for you to expand 600 CNY/0.067ha, which can complete construction of **MPR** and **ED**; Option 2 is for you to expand 400 CNY/0.067ha, which can complete construction of **MPR** and **HI** the ecological environment of farmland. You can also choose not to participate in the project and maintain the current level of facilities. Which option do you choose

S11

Attributes	Alternative 1	Alternative 2	Alternative 3
Field production road	MPR 	MPR 	Maintain the status
Land consolidation	Maintain the status	Maintain the status	Maintain the status
Irrigation facility	ED 	Maintain the status	Maintain the status
farmland protective facility	Maintain the status	HI 	Maintain the status
Cost per householder	600 CNY	400 CNY	0 CNY

☐ Option 1
☐ Option 2
☐ Option 3

3. S12
The country will conduct SF infrastructure construction projects in this village (such as field production road, irrigation facility, land consolidation, and ecological facility construction activities). If you need to participate, you will share the construction funds with the country.
At present, there are 3 options we have seen. Option 1 is for you to expand 1000 CNY/0.067ha, which can complete construction of **MPR**, **LF or CF**, and **HI** the ecological environment of farmland; Option 2 is for you to expand 1000 CNY/0.067ha, which can complete construction of **MPR** and **MI** the ecological environment of farmland. You can also choose not to participate in the project and maintain the current level of facilities. Which option do you choose

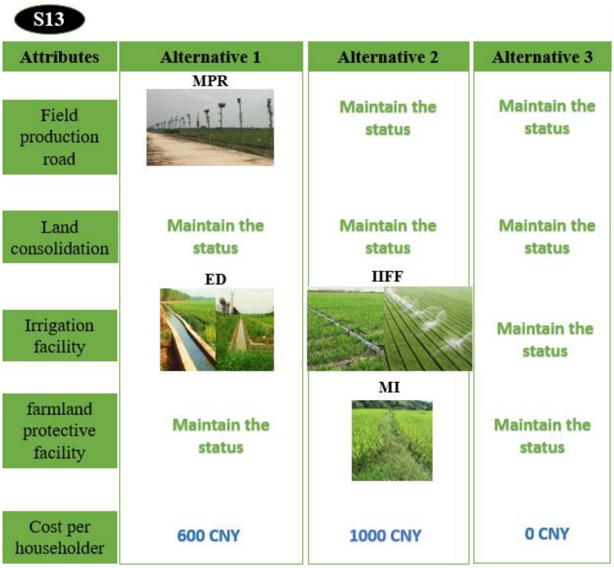


S12

Attributes	Alternative 1	Alternative 2	Alternative 3
Field production road	MPR	MPR	Maintain the status
Land consolidation	LF or CF	Maintain the status	Maintain the status
Irrigation facility	Maintain the status	Maintain the status	Maintain the status
farmland protective facility	HI	MI	Maintain the status
Cost per householder	1000 CNY	600 CNY	0 CNY

☐ Option 1
☐ Option 2
☐ Option 3

4. S13
The country will conduct SF infrastructure construction projects in this village (such as field production road, irrigation facility, land consolidation, and ecological facility construction activities). If you need to participate, you will share the construction funds with the country.
At present, there are 3 options we have seen. Option 1 is for you to expand 600 CNY/0.067ha, which can complete construction of **MPR** and **ED**; Option 2 is for you to expand 1000 CNY/0.067ha, which can complete the construction of **IIFF** and **MI** the ecological environment of farmland. You can also choose not to participate in the project and maintain the current level of facilities. Which option do you choose

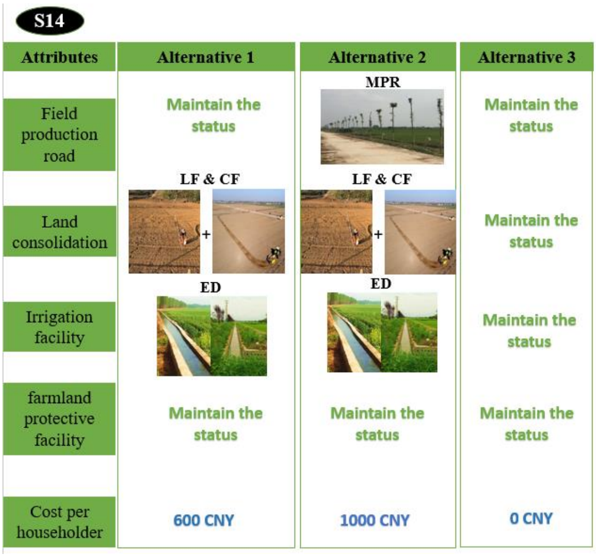


☐ Option 1
☐ Option 2
☐ Option 3

5. S14

The country will conduct SF infrastructure construction projects in this village (such as field production road, irrigation facility, land consolidation, and ecological facility construction activities). If you need to participate, you will share the construction funds with the country.

At present, there are 3 options we have seen. Option 1 is for you to expand 600 CNY/0.067ha, which can complete construction of **LF or CF** and **ED;** Option 2 is for you to expand 1000 CNY/0.067ha, which can complete construction of **MPR**, **LF or CF,** and **ED**. You can also choose not to participate in the project and maintain the current level of facilities. Which option do you choose

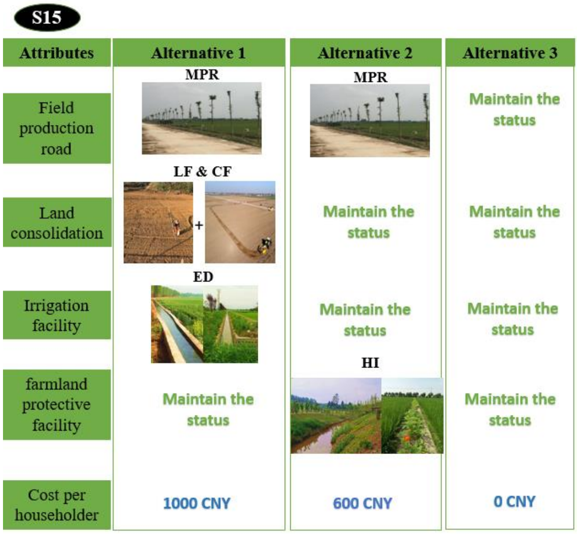


☐ Option 1
☐ Option 2
☐ Option 3

6. S15

The country will conduct SF infrastructure construction projects in this village (such as field production road, irrigation facility, land consolidation, and ecological facility construction activities). If you need to participate, you will share the construction funds with the country.

At present, there are 3 options we have seen. Option 1 is for you to expand 1000 CNY/0.067ha, complete construction of **MPR**, **LF or CF,** and **ED**; Option 2 is for you to expand 600 CNY/0.067ha, which can complete construction of **MPR** and **HI** the ecological environment of farmland. You can also choose not to participate in the project and maintain the current level of facilities. Which option do you choose



☐ Option 1
☐ Option 2
☐ Option 3

1.3 Pre-survey Questionnaire

1.3.1 payment card setup

At present, there is a relative scarcity of research on the willingness to pay and its levels among farmers in specific agricultural infrastructure construction activities. To ensure the accuracy of the research and to minimize the potential bias that the Contingent Valuation Method (CVM) might introduce, the research team conducted a preliminary survey before the formal research. By integrating feedback from agricultural construction management departments, it was understood that the cost of farmland development varies under different topographical conditions such as plains, hills, and mountains, as well as under the current status of farmland conditions. Based on these actual situations, local agricultural management departments estimated that the costs for sustainable farmland upgrading are 6000-12000 CNY/ha, 9000-22500 CNY/ha, and 15000-45000 CNY/ha for the respective terrains and designed three types of payment cards referring to the budgets of agricultural construction projects.

Drawing on relevant literature, this study adopted the method of equidistant payment cards for questioning to ensure the accuracy and scientific nature of the research findings. The payment cards were set as follows:
Payment Card 1 covered a payment range from 400 CNY/0.067ha to 800 CNY/0.067ha, with each 100 CNY increase representing a payment option.
Payment Card 2 had a payment range from 600 CNY/0.067ha to 1500 CNY/0.067ha, with each 100 CNY increase representing a payment option.

Payment Card 3 had a payment range from 1000 CNY/0.067ha to 3000 CNY/0.067ha, with each 100 CNY increase representing a payment option, to fully consider the complexity and high cost of farmland development under this topographical condition.

Before initiating the formal inquiry, the research team conducted an in-depth understanding into the topographical conditions, infrastructure and environmental conditions of the farmland. Based on the actual situation, they then provided tailored payment cards to facilitate inquiries regarding the payment levels for farmland development. The results of investigation revealed a pattern in the farmers' expressed willingness to pay across three types of payment cards. Specifically, the payment amounts of 6000 CNY/ha, 9000 CNY/ha, and 15000 CNY/ha were identified as the most frequently cited preferences within their respective payment card categories. The results were instrumental in informing the selection of payment levels for the experimental study.

1.3.2 Identification of attributes for SF infrastructure construction

the research team conducted interviews with farmers and local agricultural management departments. We delved into the farmers' level of awareness of various types of infrastructure and their agricultural production needs (survey-related questions: 1. Which of the following infrastructures are closely related to your production activities? 2. Which of the following infrastructures would help you improve agricultural production efficiency? 3. Which of the following infrastructures are not familiar to you and cannot be applied in your production activities? 4. If you are required to pay for infrastructure construction, which facilities are you willing to pay for?). Through the sorting and analysis of the above questions, the five categories of attributes involved in this study were determined.

The major activities and targets of SFD

Developing Sustainable Farmland	Engineering and production management indicators	Facilities and technical specifications
Farmland ecological infrastructure construction project	Land consolidation	Land leveling
		Construct the contiguous farmland
	Farmland ecological circulation water network	Integrated irrigation and fertilizer facilities
		Ecological drainage and irrigation ditches
		Ecological ditches
		Irrigation water pretreatment system
		Water quality online monitoring station
	Farmland ecological corridor	Mechanized production road
		Ecological field ridge
		Alley cropping zone
	Farmland ecological landscape	lounge bridge
		Plank road
		pergola
	Restoration of farmland biodiversity	Habitat of pollinators
		Natural enemy conservation area
		Field ecological forest island
	Farmland quality control and inspection	Location monitoring of cultivated land quality

3.10 Sample rationality test

According to (Wang et al., 2019), when the number of potential respondents is large enough, the necessary connection does not exist between the minimum sample size available for study and the total population. At this time, it can be only affected by error and confidence level.

The minimum sample size can be calculated by the formula (1):

$$n = Z^2\sigma^2/d^2$$

Where n represents the sample size; Z denotes the statistics under a certain level of confidence. σ is the standard deviation of the population and is usually set to 0.5. d is the allowable error. Generally speaking, a confidence level of 95% and an allowable error of 5% are appropriate for the samples. We thus confirm that the minimum sample size is 384, which verifies that our sample size is adequate.

Sample Size Table for Different Confidence Intervals and Sampling Errors			
Sample Size	Z-Statistics for Different Confidence Intervals		
	90%	95%	99%
Sampling Errors	1.64	1.96	2.68
10%	67	96	166
5%	269	384	666
3%	747	1067	1849

***Method 2*：**

To estimate the sample size, according to the research of (Gonick and Smith, 1993) and (Pituch et al., 2007), the calculation method of the sample size is as follows:

$$x = Z_c^2 r(100 - r) \qquad (1)$$

$$n = \frac{N}{((N-1)E^2+x)} \qquad (2)$$

$$E = \sqrt[2]{(N-n)/(n(N-1))} \qquad (3)$$

where x represents the margin of error, 5% is a common choice; Z_c is the critical value for the confidence level c, the typical choice is 95%; N is the rural household population size of the study area; n is the number of sample size; E is the standard deviation. In 2022, the total rural household population of our study area was 10.7 million. It can be estimated that the minimum recommended size of the survey should be 385. Generally, lower margin of error and higher confidence level require a larger sample size, and the larger the sample size, the more representative of the sample. 573 valid questionnaires were obtained after removing invalid ones.

Method 3：

The study examined the rationality of sample size, and the minimum sample size suitable for this study was also assessed according to the formula proposed by (Agidew and Singh, 2018).

$$n = \frac{N}{1 + N * e^2}$$

where N is the population size of the study area (unit: ten thousand people), n is the minimum sample size, and e is 5% accuracy. In 2022, the number of rural households in Shanxi province was 5.23 million and in Shaanxi Province was 5.47 million. After calculation, the minimum number of sample households suitable on single province is 231, and minimum number of sample households suitable on study area is 291, which verifies that the provinces sample and total sample are adequate.

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