Multi-agent Collaborative Participation of Agricultural Machinery Service, High Quality Operation and Agricultural Production Efficiency: A Case Study of Conservation Tillage Technology

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Multi-agent Collaborative Participation of Agricultural Machinery Service, High Quality Operation and Agricultural Production Efficiency: A Case Study of Conservation Tillage Technology

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Abstract: The improvement of agricultural production efficiency is of great significance to eliminate rural poverty and ensure food security. Taking conservation tillage technology as an example, this paper analyzes the background and characteristics of multi-agent collaborative participation in agricultural machinery service. It analyzes the direct impact of agricultural machinery services provided by multi-service agents on farmers' agricultural production efficiency and the intermediary effect transmitted through high-quality conservation tillage operation by using intermediary effect model, based on survey data of four locations in the black soil region of China in 2021. The results show that: (1) The Agricultural Machinery Service with Multi-agent Collaborative Participation is characterized by its comprehensive service content, full service content, and high service availability, and the cooperative mode primarily demonstrates technical collaboration, service collaboration, and benefit collaboration; (2) The agricultural machinery service with multi-agent collaborative participation has a direct positive effect on agricultural production efficiency; (3) The agricultural machinery service with multi-agent collaborative participation has a significant impact on the high-quality operation of conservation tillage. The better the collaborative effect of multi-agent collaborative participation of agricultural machinery service, the higher the quality of farmers' conservation tillage operation; (4) High-quality conservation tillage operation can effectively improve agricultural production efficiency and play an intermediary effect in the influence of service of agricultural machinery with the cooperation of multiple service subjects on agricultural production efficiency. Under the background of the shortage of agricultural labor force and the increasingly serious pressure of aging in China, we should upgrade the service of agricultural machinery based on single transactional service to multi-agent cooperation, improve the development quality of multi-agent service consortium of agricultural machinery, and provide corresponding policy support measures such as compensation, financial credit and management evaluation, so as to promote the improvement of agricultural production efficiency and ensure national food security.

Key words: Agricultural machinery service; High quality operation; Agricultural production efficiency; Conservation tillage;

1 Introduction

As the driving force of basic economic growth and development, agricultural production is a key factor in eradicating rural poverty and addressing food security in the world (Jian Z et al, 2020). Since the reform and opening up of China, the country's grain industry has made outstanding achievements, with total grain production increasing from 305 million tonnes in 1978...
to 68.3 million tonnes in 2021, and since 2004, grain production has been consistently "eighteen consecutive years of abundance". Behind the increase in food production is a dramatic overdraft of productive resources such as fertilizers and pesticides. The threat of natural disasters, ecological and environmental pressures and the growing shortage of arable land and water resources have threatened national food security. Under unfavourable endowment conditions and limited resource and environmental constraints, as well as development conditions that do not sacrifice resource factors to rely excessively on sloppy growth, the improvement of agricultural production efficiency has become the main driver of increased grain production and the fundamental way out of China's food security problems.

China is a typical country with low agricultural productivity and a shortage of agricultural labour. According to relevant statistics, the US uses 1.9% of China's agricultural labour to produce 1.17 times China's arable land area, and China's agricultural productivity is only 6.4% of that of the US. And the labour costs for corn, rice, wheat, soybeans and cotton in China are 14.78 times, 4.11 times, 16.33 times, 8.5 times and 28.23 times higher than those in the US respectively. Inefficient agricultural production has brought about a series of urban-rural problems such as widening urban-rural income gap, rural poverty and rural decline (Cai & Wang, 2008; Minale, 2018).

A stream of literature has focused on the transformation of agricultural production patterns (Liu et al., 2019), land leasing (Adamie, BA 2021), input factor allocation (Chen T, Rizwan M, Abbas A 2022), rural labor migration (Long Qian, Hua Lub, Qiang Gao, Hualiang Lu 2022), The impact of agricultural mechanization (Yan L et al. 2022) on agricultural production efficiency. A paradoxical phenomenon is that China's agricultural productivity has been greatly improved, but the efficiency of agricultural production has not been correspondingly improved. The problem is China's small-scale farming model, in which the average farmer tills less than one hectare of land.

In the small-scale agricultural production system, farmers cannot afford large investments in purchasing agricultural machinery, and the replacement of labor force by agricultural machinery is constrained, which restricts the improvement of agricultural production efficiency (Lu Q et al., 2022).

There are two ways for farmers to obtain agricultural machinery. First, farmers purchase agricultural machinery themselves (Ji et al., 2012; Qiu et al., 2021), the second is to purchase agricultural machinery operation service (Belton et al., 2021; Diao et al., 2014). China has a large number of small-scale farmers, so it is often not cost-effective for rural families to buy agricultural machinery (Qiu and Luo, 2021), but farmers still need agricultural machinery for production (Long Qian, Hua Lu, Qiang Gao, Hualiang Lu, 2022). In this context, service organizations providing agricultural machinery have gradually emerged in China, which are mainly family farms, farmers' cooperatives, agricultural socialization service organizations and other types of new agricultural operating and service subjects. Moreover, the number of agricultural machinery operating service providers has increased from 165,600 in 2008 to 194,800 in 2020. The labor force in mechanized agricultural services nearly quadrupled from 730,000 to 2.12 million. In recent years, the agricultural machinery service market has developed rapidly (Zhang et al., 2017; Zheng et al., 2021), the agricultural production and operation environment has changed accordingly, and the use of agricultural machinery services has become an important approach to improve agricultural production efficiency (Huan ML, Dong FX, Chi L, 2022). Most scholars focus on the supply of agricultural machinery services, taking the single service subject of
mechanized rice planting, rice supply and transplanting as the research object, and discuss the service price of agricultural machinery (Dumortier J, Elobeid A, 2021) and service availability (Liao WD, Zeng FS, Chanieabate M, 2022), service effect (Huan ML, Dong FX, Chi L, 2022) and other factors on agricultural production efficiency, a few scholars from the aspect of agricultural machinery service demand, From the land scale (Meng Qu, Kai Zhao, Renhui Zhang, Yuan Gao, Jing Wang, 2022), household income (Huan ML, Dong FX, Chi L, 2022) and farmers' education level (Long Qian, Hua Lub, Qiang Gao, Hualiang Lu, 2022). The influences of different agricultural machinery service demands on agricultural production efficiency were studied. For example, Yang et al pointed out that the number and types of service outsourcing purchased by large-scale farmers and farmers with higher family income and education level increased significantly (Yang et al., 2013; Chen et al., 2022), improved the efficiency of agricultural production by improving the efficiency of resource allocation (Deng et al., 2020).

Although single agricultural machinery service can promote the improvement of agricultural production efficiency, with the generation and application of complex systematic agricultural technology, a new form of agricultural machinery service market has emerged, that is, multi-subject cooperative participation of agricultural machinery service. This is due to the improvement of the scale and intensification of agriculture, the service demands of farmers are constantly upgraded, and the personalized, diversified and integrated demands of farmers promote the coordinated development of agricultural machinery service subjects. Compared with a single agricultural machinery service, in order to maximize the benefits of agricultural production, the supplier of agricultural machinery service will meet the diversified service demands of the demander and provide high-quality agricultural machinery service. In addition, it can affect transaction costs such as searching and signing contracts, and save operational costs through scale effect. However, agricultural production efficiency is not only affected by explicit production input costs such as land, labor and capital, but also related to implicit costs such as supervision and transaction costs (Paudel, GP et al, 2020). In previous studies, few studies took into account the hidden costs of agricultural production, but it does not mean that the effect of hidden costs on agricultural production efficiency can be negligible. Therefore, it has become inevitable to integrate supply and demand into a unified framework. It is necessary to understand whether agricultural machinery services with the collaborative participation of multiple agents improve agricultural production efficiency, which has a far-reaching impact on the protection of food security.

Thus, the purpose of this study is to explore the effects and channels of multi-agent cooperative participation of agricultural machinery services on farmers' agricultural production efficiency. The results of this study will help to explain the influence and obstacles of the development of agricultural machinery service with multi-body collaborative participation on the improvement of agricultural production efficiency. Finally, the results of this study will provide policy makers with some possible solutions to improve the service quality of agricultural machinery operations and improve production efficiency in China. The data we used came from the survey data of farmers in four areas of China's black soil region in 2021. With the high-quality operation of conservation tillage as the intermediary variable, we explored the influence of multi-agent collaborative participation of agricultural machinery services on farmers' agricultural production efficiency. Mediation analysis has been widely used in psychology and behavioral economics (VanderWeele, 2015; Fairchild & Mcquillin, 2010; Zhao, Lynch & Chen, 2010).
Some studies have used this approach in agricultural economics (Hailu, Nkote & Munene, 2017; Wang et al., 2019; Liao, Chang & Su, 2020).

Our study extends previous research findings and contributes in three ways. First, the supply behavior and demand behavior of agricultural machinery services are incorporated into a unified framework. Based on farmers' demand for agricultural machinery services when implementing conservation tillage technology, the generation background of multi-subject cooperative provision of agricultural machinery services is revealed, and the characteristics and cooperative ways of multi-subject cooperative participation of agricultural machinery services are analyzed. Second, this study enhances the existing understanding of agricultural machinery services and agricultural production in China by providing additional information on potential relationships and intermediate influence paths between multi-agent collaborative participation of agricultural machinery services and agricultural production efficiency. This analysis makes sense because improving agricultural production efficiency is in line with China's current goals of protecting food security and rural revitalization. Finally, this study uses the mediation effect model to establish the analysis path between the high quality operation and the multi-agent collaborative participation of agricultural machinery services and agricultural production efficiency.

The rest of this article follows. Section 2 describes the background and characteristic performance of the multi-subject cooperative participation of agricultural machinery service. Section 3 establishes the theoretical framework. Section 4 describes the data, models, and variables. In Section 5, the empirical results are introduced and discussed. Section six summarizes the whole paper and puts forward relevant policy suggestions.

2. Background and Characteristics of Multi-agent Collaborative Participation in Agricultural Machinery Socialization Service: A Case Study of Conservation Tillage

2.1 Background of Multi-agent Collaborative Participation in Agricultural Machinery Socialization Service

In the past, the service of agricultural machinery was mainly based on a single transactional service, with a single service subject and a single service content on the service supply side, lacking comprehensive services, and the connection between different service subjects was not close, lacking effective division of labor and coordination, which made the service supply show the characteristics of decentralization and fragmentation (Liu et al., 2019; Ji et al., 2017; Qian et al., 2019). The advantage of single transactional agricultural machinery socialization service is that it relies on organized agricultural machinery and provides farmers with agricultural machinery service to meet their operation needs through manual operation of agricultural machinery (Ji X et al., 2021), but its disadvantages are also obvious, that is, farmers' service needs are gradually diversified, and service supply and demand begin to mismatch (Yang et al., 2013), that is, single transactional agricultural machinery socialization service makes farmers' personalized and multi-field service needs unable to be met. The resulting problem is that farmers need to trade with different service subjects in order to meet their diversified service needs, and every transaction needs to pay enough time and energy to search for each other, resulting in high search costs, tedious selection costs, price negotiation costs and contracting costs (He P et al., 2021).
which have a negative impact on the realization of their service needs, which will not only lead to the loss of service supply efficiency, but also lead to the failure of service supply behavior.

At present, with the emergence and application of complex systematic agricultural technology, a new form of agricultural machinery service market has emerged, that is, multi-agent collaborative participation in agricultural machinery service (Caunedo & Kala, 2021). In fact, the multi-agent cooperation of agricultural machinery socialization service has become the necessary demand for farmers to implement the complex multi-stage modern agricultural production technology system. Taking conservation tillage technology as an example, in recent years, with the proposal of China's black land protection project, the application and implementation of multi-stage and complex technical systems (Ward P S, Bell A R, 2018), such as conservation tillage technology system, is imminent. Different from a single agricultural technology, conservation tillage technology is a technical system composed of several technical processes, such as straw mulching and returning to the field, no-tillage and less tillage sowing, weeding, pest control, etc. This paper selects the straw mulching and no-tillage planting mode in pear tree mode as an example, and the necessary implementation subjects and agricultural machinery equipment for each process of this mode are shown in Figure 1, that is, the implementation of straw mulching and returning to the field requires the straw returning machine to cut, crush and cover the straw, the implementation of no-tillage and less tillage requires the no-tillage planter to carry out no-tillage and less tillage sowing, and the implementation of supporting comprehensive plant protection requires the plant protection machinery to carry out herbicide spraying. However, the fragmented land state in China and the existence of many farmers with weak economic ability determine that the implementation of conservation tillage requires rural collective economic organizations, farmers, new business entities, enterprises and other agricultural machinery socialization service entities to participate in various implementation processes (Caunedo & Kala, 2021). Through the cooperation among agricultural machinery socialization service entities, farmers can provide integrated, organized and standardized "one-stop" agricultural machinery services (At & Thomas, 2019), so that farmers can implement conservation tillage in a standardized, high-quality and efficient manner, and then achieve the ultimate goal of protecting black land and improving production efficiency. Therefore, under the background that China needs to apply and implement complex agricultural technology system, and with the formation of multi-form and multi-subject competition pattern in China's agricultural service market, it is inevitable for multi-subject to participate in agricultural machinery service at present.
2.2 Characteristics of Multi-agent Collaborative Participation in Agricultural Machinery

Socialization Service

Multi-agent collaborative participation in agricultural machinery socialization service means that family farms, large grain growers, agricultural service enterprises, agricultural machinery cooperatives and other subjects can be widely absorbed to form a town-based service alliance, which provides a number of affairs services to farmers in the form of service consortium. Most of the service subjects who participate in multi-agent collaborative provision of agricultural machinery services grow up for local farmers, including large grain growers, family farms and agricultural machinery cooperatives. These agricultural business entities mainly purchase agricultural machinery by themselves, and all of them have certain agricultural machinery resources. The relationship between subjects is mainly based on acquaintance advantage, and is manifested in comprehensive service division and coordination.

Compared with the service provided by a single subject, multi-agent cooperative participation in agricultural machinery service is considered as an effective way to reduce transaction costs and enhance the market participation ability of decentralized service subjects, which is embodied in two aspects: on the one hand, multi-agent cooperative participation in agricultural machinery service has service diversity, which can not only meet the needs of farmers for complex...
technology implementation, but also avoid the disadvantages of multiple negotiations and transactions with different decentralized service subjects, thus reducing the transaction frequency, at the same time, it also reduces the possibility of absence of service subjects, and can also provide quality supervision and guarantee for service organizations (Zhang, Yang, & Thomas, 2017); On the other hand, multi-agent cooperative participation in agricultural machinery socialization service has systematic service. The consortium organizes scattered farmers to form scale advantages (Wang et al., 2021), which can improve bargaining position and bargaining power, thus generating economies of scale in the unified purchase of means of production or product sales, and can also uniformly sign contracts with service organizations, thus realizing negotiation, signing contracts, transactions and reducing production costs (Deng et al., 2020).

Multi-agent cooperative participation in agricultural machinery socialization service has the characteristics of comprehensive service content, whole service content and high service availability. From the perspective of service content integration, the service demand content will change from a single service to different composite services. Farmers can achieve the coverage of the whole planting link through the service of agricultural machinery, and can achieve a high degree of "integrated" service; From the perspective of the whole process of service content, the demand content will extend from some planting links to the whole planting process, forming the agricultural machinery service demand covering the whole production chain (Fang and Huang, 2019), which can achieve farmers' full planting production by adopting agricultural machinery services; From the perspective of high service availability, agricultural machinery services are mostly grown up by local agricultural machinery households, which have endogenous advantages of local society. They can not only get the trust and support of surrounding farmers in providing services, but also improve the efficiency of resource allocation and increase the service availability of farmers under the comprehensive effect of agricultural machinery resources advantages and acquaintance social advantages.

3 Theoretical framework and hypotheses

There are differences in technology, service and benefit among the main bodies of agricultural machinery social service, and the matching of supply and demand of differences provides the possibility for cooperation among agricultural machinery social services. The collaborative mode of multi-service subjects is mainly manifested as technical collaboration, service collaboration and benefit collaboration. To sum up, multi-agent collaborative participation in agricultural machinery service can have a direct impact on agricultural production efficiency through the following three aspects.

First, technical collaboration is oriented by technical specifications to reduce the operating costs of labor input and agricultural machinery purchase, so as to improve agricultural production efficiency. Its influence path is mainly manifested in two aspects: on the one hand, technical cooperation can unify the standard requirements of agricultural machinery, such as sprayer in plant protection operation stage and subsoiler in subsoiling operation stage in conservation tillage technology system, which can be installed and used with tractors of the same paragraph (Xing et al., 2017), which can greatly reduce the operation cost of service subjects of agricultural machinery, thus reducing the service price of agricultural machinery (Deng et al., 2020), reducing the production and operation cost of farmers and improving the agricultural production efficiency of farmers; On the other hand, technical cooperation can improve the collaborative effect between
the service subjects of agricultural machinery in different stages by formulating the technical standards of agricultural machinery operation in coordination with agronomy. For example, in the conservation tillage technical system, the crushing effect of straw crusher in the straw mulching stage should meet the sowing requirements in the no-tillage sowing stage, so as to ensure the emergence rate (Ma et al., 2018). Technical collaboration can ensure that the operation effect of the previous stage meets the operation requirements of the later stage, reduce the probability of extra labor input generated by the secondary operation (Zhou et al., 2020), reduce the production cost input, and then improve the agricultural production efficiency.

Secondly, service collaboration is oriented by service specialization, which reduces the transaction cost of agricultural machinery services and improves agricultural production efficiency. Its impact on agricultural production efficiency is mainly manifested in two aspects: on the one hand, service collaboration can reduce farmers' search cost and contract cost. Through the formation of multi-agent collaborative agricultural machinery service market, farmers can obtain the "one-stop" integrated service of agricultural machinery from it, which can make farmers no longer have to pay a lot of time and experience for each stage of operation to search for service subjects, thereby reducing hidden costs such as the high search cost and tedious signing cost (Paudel et al., 2019), and effectively improving the supply efficiency of agricultural machinery services, thus improving agricultural production efficiency; On the other hand, service collaboration can reduce the supervision cost of farmers. Farmers can sign an "integrated" agricultural machinery operation service agreement with multiple agricultural machinery service subjects in the multi-agent cooperative agricultural machinery service market, which can make the service subjects participating in service coordination consciously guarantee the service quality of the whole operation process, and the service alliance will actively supervise and manage the whole operation service (Qin and Lü, 2020), so that farmers do not need to supervise the operation effect of each agricultural machinery service subject, which can greatly reduce the supervision cost of farmers and further improve the efficiency of agricultural production.

Thirdly, benefit collaboration is oriented by benefit balance, and improves agricultural production efficiency by reducing the cost of price negotiation. Multi-agents cooperate to provide services of agricultural machinery, and their service subjects have formed an benefit alliance (Tang, L., 2018). In order to maximize the overall benefit, each service subject will consciously determine the balanced distribution mode of benefit and uniformly position the service price to the optimal price. This saves the cost of price negotiation for farmers to obtain lower service prices, makes it easier for farmers to obtain lower agricultural machinery service prices (Peng, J., 2022), reduces the cost for farmers to invest in agricultural machinery services, reduces production input and improves agricultural production efficiency.

H1: The service of agricultural machinery in conservation tillage based on the cooperation of multiple service subjects has a positive impact on agricultural production efficiency.

High-quality operation refers to the operation behavior of standardizing the application of agricultural production technology and ensuring the implementation quality and effect on the premise of ensuring stable and high yield. Taking conservation tillage as an example, its core requirement is "more coverage and less soil breaking". In order to effectively reduce soil wind erosion and water erosion, increase soil fertility, preserve soil moisture and resist drought, and better improve agricultural ecological and economic benefits. According to the classification of collaborative modes of multi-service subjects, the service of agricultural machinery with
multi-agent collaborative participation mainly affects the high-quality operation of conservation tillage through three aspects: technical collaboration, service collaboration and benefit collaboration:

First, technical collaboration can unify technical specifications to ensure the service quality of agricultural machinery, and then realize the high-quality operation of conservation tillage. Different production links of conservation tillage adopt different production technology and production standardization degree (Shikuku, 2019), such as no-tillage sowing, plant protection operation and straw mulching, different technical standards and different machinery and equipment required (Zhou et al., 2020). Moreover, the implementation of conservation tillage technology needs a series of large-scale agricultural machinery as guarantee, and the reasonable purchase of agricultural machinery has great influence on the implementation effect of conservation tillage technology (Yu et al., 2021). Therefore, the purchase of no-tillage planter, sprayer, subsoiler and other equipment must be combined with the actual production situation to ensure that the purchased mechanical equipment has good applicability. At the same time, attention should be paid to the cooperation between machines and tools, that is, whether the crushing effect of straw crusher meets the requirements of no-tillage sowing, whether the spray penetration force of sprayer can meet the requirements of straw covering spraying, and whether the subsouiling form of subsoiler meets the requirements of tractor power and subsouiling effect. Therefore, technical coordination unifies technical specifications to ensure the final effect of conservation tillage, so as to achieve high-quality operation.

Secondly, service collaboration can improve the service quality of agricultural machinery through the specialization of service quality and service means, and then realize the high-quality operation of conservation tillage. In the aspect of service quality specialization, in order to ensure the service quality of agricultural machinery service, the service subjects in the service alliance reach a consensus through service coordination, that is, each subject needs to provide agricultural machinery service in a standardized and high-quality way, so that the implementation of the whole conservation tillage technology system can get professional and high-quality services (Qiao, 2020), and then realize the high-quality operation of conservation tillage technology system. At the same time, in terms of specialization of service means, service alliances will sign full-process service agreements with farmers in the form of alliances through service collaboration (Tang et al., 2018). Professional service agreements will clarify the technical standards to be followed by services and specifically guarantee the technical effects. Specialized service means make the main body of agricultural machinery mechanization service need to provide services according to clear technical standards and be responsible for service quality, so as to achieve high-quality operation effect, and then benefit the high-quality operation of conservation tillage.

Third, benefit collaboration can realize the service supply of agricultural machinery with high quality and low price, and then realize the high quality operation of conservation tillage. In the agricultural machinery service market, there are many service machines in different stages of conservation tillage, and there are differences in service stages, use intervals and applicable land area, which makes it difficult for farmers with insufficient technical knowledge to choose suitable agricultural machinery services to effectively implement conservation tillage (Zhu, Y., 2019). In practice, because of their own culture and economic man attributes, farmers often choose agricultural machinery services with lower prices within the information range, and agricultural machinery services with lower prices may not guarantee service quality. Under the benefit
cooperation among the main bodies of agricultural machinery service, farmers can choose integrated conservation tillage agricultural machinery service, which can not only reduce the search cost of farmers and save the operation cost through scale effect (Qu, M, 2022), but also provide high-quality agricultural machinery service for farmers, so as to achieve excellent operation effect, and then benefit the high-quality operation of conservation tillage.

H2: Multi-agent collaborative participation in service of agricultural machinery has a positive impact on high-quality operation.

High-quality conservation tillage has the effects of labor substitution and technology introduction, which affect agricultural production efficiency. On the one hand, the high-quality operation of conservation tillage can cause labor substitution effect, which alleviates the situation that the opportunity cost of agricultural labor keeps rising when rural labor enters non-agricultural sectors (Zhang et al., 2018), and also enables farmers to choose the channel of factor substitution. Farmers adopt high-quality operation to replace relatively expensive and scarce labor with relatively cheap and abundant agricultural machinery (Yi et al., 2019), which alleviates the labor constraint of farmers and breaks through the limitation of original resource endowment, thus helping to improve agricultural production efficiency. On the other hand, the high-quality operation of conservation tillage can cause the technology introduction effect, which breaks through the limitation that small-scale farmers must use large-scale agricultural machinery to implement agricultural technology (Zhou et al., 2020). The high-quality conservation tillage operation acts as the transmitter of human capital and knowledge capital, and realizes the introduction of advanced technologies such as plant protection drone, no-tillage planter and straw returning machine into agricultural production. Through efficient management methods and modern organization system, the scientific and technological content and output of agricultural production are improved, and the agricultural production efficiency is improved to a certain extent.

H3: High-quality operation has a positive role in promoting agricultural production efficiency

H4: High-quality operation plays an intermediary role in the influence of multi-agent collaborative participation in agricultural machinery service on agricultural production efficiency.

![Figure 2 Theoretical framework](image_url)

4 Data, Models and Variables

4.1 Data and variables

4.1.1 Data sources

In this study, questionnaire interviews were used to collect data. The content of the questionnaire includes three parts: (1) the socioeconomic characteristics of the respondents' families, including the disposable income of small farmers, education level and the government's
support for conservation tillage policies; (2) Input-output factors of agricultural land; (3) Small farmers adopt protective agricultural technology. It includes the decision of smallholder farmers to adopt conservation agricultural techniques, the extent to which conservation agricultural techniques are adopted, and the reasons for adoption and non-adoption.

The data used in this study comes from the rural household/sample survey conducted in four places (Heilongjiang, Jilin, Liaoning and Neimenggu) from July to December, 2021. At each survey site, stratified sampling method was used to select samples. More specifically, according to the economic development level and population size of each town, three towns are selected in each place. Then, according to the status of small farmers adopting conservation tillage, 3 ~ 4 villages were selected in each town. Finally, 15 farmers in each village were selected by random sampling. A total of 775 sample families were collected in this survey, of which 704 (90.84%) were valid. In addition, DEA model is very sensitive to outliers, which will lead to serious distortion of results. Therefore, this paper excludes outliers, and finally the model includes 695 small farmers.

4.1.2 Variable selection and descriptive statistics

(1) Dependent variable. The dependent variable is the agricultural production efficiency of farmers. Data envelopment analysis (DEA) is used to estimate after eliminating management inefficiency and environmental factors. The specific input-output variables are shown in the table: the agricultural land output variable is the total grain output of farmers; Farmland input variables are land input, labor input and capital input, which are measured by farmers' sown area, farmers' own and employed labor force and planting investment funds (pesticides, fertilizers, seeds, etc.). The results show that the average value of pure technical efficiency is 0.897, the average value of scale efficiency is 0.737, and the average value of agricultural production efficiency is 0.661.

(2) Independent variable. The independent variable is the technology cooperation, service cooperation and benefit cooperation mode among the multi-agents of agricultural machinery service. In a broad sense, service of agricultural machinery refers to the related agricultural machinery services provided by social service organizations or individuals for each link of agricultural production and planting. The collaboration between multi-agents of agricultural machinery service has a key impact on agricultural production efficiency. Therefore, this paper measures the collaboration of multi-agents participating in agricultural machinery service from three angles: technology, service and benefit.

(3) Mediation variable. The medium variable is the high-quality operation of conservation tillage, and the conservation tillage technology mainly includes straw mulching, no-tillage (less tillage) sowing and plant protection technology. According to which conservation tillage techniques are specifically adopted by farmers in planting production, it is used as a standard to measure the degree of high-quality operation.

(4) Control variable. Control variables include individual characteristics, family characteristics and agricultural land characteristics. Individual characteristics select the gender, age and educational level of the head of household; Family characteristics select the number of family population and whether there are village cadres in the family; Planting area is selected for agricultural land characteristics.

Table 1 Variable definition and descriptive statistical results

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
<th>Mean</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output variable</td>
<td>Food production</td>
<td>325.150</td>
<td>322.967</td>
</tr>
<tr>
<td>Input variable</td>
<td>Description</td>
<td>Value 1</td>
<td>Value 2</td>
</tr>
<tr>
<td>----------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>Land input</td>
<td>Planting area of farmers (hm²)</td>
<td>25.150</td>
<td>23.635</td>
</tr>
<tr>
<td></td>
<td>Number of people involved in planting (people)</td>
<td>2.750</td>
<td>1.090</td>
</tr>
<tr>
<td>Labor input</td>
<td>Input of planting cost (10,000 yuan)</td>
<td>53.725</td>
<td>44.608</td>
</tr>
<tr>
<td>Capital input</td>
<td>Actual amount of per capita income of villagers (10,000 yuan)</td>
<td>2.350</td>
<td>0.380</td>
</tr>
<tr>
<td>Per capita income</td>
<td>Distance from village committee to county seat (km)</td>
<td>9.200</td>
<td>4.214</td>
</tr>
<tr>
<td>Environment variable</td>
<td>Number of agricultural support policies implemented in villages (pieces)</td>
<td>1.650</td>
<td>1.314</td>
</tr>
<tr>
<td>Distance to county seat</td>
<td>Distance from village committee to county seat (km)</td>
<td>9.200</td>
<td>4.214</td>
</tr>
<tr>
<td>Level of policy support</td>
<td>Number of agricultural support policies implemented in villages (pieces)</td>
<td>1.650</td>
<td>1.314</td>
</tr>
<tr>
<td>Dependent variable</td>
<td>Agricultural production efficiency</td>
<td>Use three-stage DEA to measure the comprehensive efficiency</td>
<td>0.661</td>
</tr>
<tr>
<td>Technical collaboration</td>
<td>T1: Do you think the agricultural machinery matches in the implementation of conservation tillage?</td>
<td>2.450</td>
<td>0.865</td>
</tr>
<tr>
<td></td>
<td>1 (complete mismatch) — 4 (perfect match)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>T2: Do you think the effect of the previous stage of conservation tillage can meet the next stage of conservation tillage?</td>
<td>2.250</td>
<td>0.994</td>
</tr>
<tr>
<td></td>
<td>1 (totally unsatisfied) — 4 (perfectly satisfied)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Service collaboration</td>
<td>S1: When you get agricultural machinery services, do all service subjects have uniform service quality standards?</td>
<td>2.500</td>
<td>0.671</td>
</tr>
<tr>
<td></td>
<td>1 (none at all) — 4 (always)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>S2: When you obtain agricultural machinery services, do each service subject have some service means, such as signing a unified service agreement as monitoring and guarantee?</td>
<td>2.250</td>
<td>0.698</td>
</tr>
<tr>
<td></td>
<td>1 (none at all) — 4 (always)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benefit collaboration</td>
<td>B1: Do you think there are mutual introductions and preferential services among different stages of conservation tillage?</td>
<td>3.050</td>
<td>0.805</td>
</tr>
<tr>
<td></td>
<td>1 (none at all) — 4 (always)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B2: Will your service providers at all stages of conservation tillage work together to obtain operation subsidies?</td>
<td>1 (none at all)-4 (always)</td>
<td>2.450</td>
<td>0.805</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Mediation variable</td>
<td>High-quality operation</td>
<td>Not adopting any conservation tillage technique = 1, adopting one conservation tillage technique = 2, adopting two conservation tillage techniques = 3, adopting three conservation tillage techniques = 4</td>
<td>2.150</td>
</tr>
<tr>
<td>Gender</td>
<td>Male = 1, female = 0</td>
<td>0.750</td>
<td>0.433</td>
</tr>
<tr>
<td>Age</td>
<td>Actual age</td>
<td>50.450</td>
<td>5.661</td>
</tr>
<tr>
<td>Education level</td>
<td>Primary school and below = 1, junior high school = 2, senior high school = 3, junior college and above = 4</td>
<td>1.900</td>
<td>0.624</td>
</tr>
<tr>
<td>Control variable</td>
<td>Number of family members engaged in agricultural production (persons)</td>
<td>Number of labors</td>
<td>2.050</td>
</tr>
<tr>
<td>Number of labors</td>
<td>Non-village cadres = 0, village cadres = 1</td>
<td>Social stratum</td>
<td>0.250</td>
</tr>
<tr>
<td>Farmland size</td>
<td>Planting area (hm²)</td>
<td>25.150</td>
<td>23.635</td>
</tr>
</tbody>
</table>

4.2 Model Setting

4.2.1 Three-stage DEA model

The three-stage DEA model is used to calculate the agricultural production efficiency, which eliminates the influence of external factors such as environmental factors and random errors on the production efficiency. Compared with the traditional DEA analysis, it can calculate the agricultural production efficiency more objectively and accurately. The specific steps of model construction are as follows:

The first stage: traditional DEA analysis. Because different farmers have different planting areas and different output levels, this study adopts the variable return to scale model (BCC) to measure the original production efficiency of growers. The model settings are as follows:

\[
\begin{align*}
\min_{\theta, \lambda} & \quad \lambda[\theta - \varepsilon(e^t s^- + e^t s^+)] \\
\text{s.t.} & \quad \sum_{i=1}^{n} \lambda_i y_{ir} - s^+ = y_{0r} \\
& \quad \sum_{i=1}^{n} \lambda_i x_{ij} + s^- = \theta x_{0j}
\end{align*}
\]
\[
\sum_{i=1}^{n} \lambda_i = 1, \lambda_i \geq 0, s^+ \geq 0, s^- \geq 0 \quad (4)
\]

Where \( i = 1,2,...,n; j = 1,2,...,m; r = 1,2,...,s \) is the number of decision-making units, \( m \) and \( s \) is the number of input and output variables respectively. \( y_{ij} (j = 1,2,...,m) \) is the input factor and \( y_{ir} (r = 1,2,...,s) \) is the output factor. \( \theta \) is a valid value for Decision Unit DMU\(_{0}\). If \( \theta = 1 \), and \( s^+ = s^- = 0 \), the decision-making unit is effective; If \( \theta = 1 \), at the same time \( s^+ \neq 0 \) or \( s^- \neq 0 \), the decision-making unit is weakly efficient; If \( \theta = 1 \), the decision unit is invalid.

The efficiency value calculated by BCC model is the comprehensive technical efficiency value, which is equal to the scale efficiency multiplied by the pure technical efficiency.

The second stage: input factor adjustment based on stochastic frontier model (SFA). SFA model is used to eliminate the influence of external factors such as environmental factors, management inefficiency and statistical errors on the input slack variables in the first stage. The expression is:

\[
s_{ni} = f^n(z_i, \beta^n) + u_{ni} + v_{ni} \quad n = 1,...,N, i = 1,...,I \quad (5)
\]

In the formula, \( s_{ni} \) is a relaxation variable, \( z_i \) is an environmental variable, \( \beta^n \) is a parameter to be estimated, and \( u_{ni} + v_{ni} \) is a mixed error term. The hypothesis \( u_{ni} \sim N(0, \delta_{un}^2) \) reflects the influence of random error term, \( v_{ni} \sim N^+(V^n, \delta_{vn}^2) \) and \( v_{ni} \geq 0 \) reflects the inefficiency, \( u_{ni} \) and \( v_{ni} \) is independence and irrelevance of management. According to \( \gamma = \frac{\delta_{vn}^2}{\delta_{vn}^2 + \delta_{un}^2} \) is the size of the judgment of the main factors affecting inefficiency, the value closer to 0 indicates that it is greatly affected by random error terms, and close to 1 indicates that management inefficiency is dominant.

Next, the original input amount is adjusted according to the regression results. The formula is:

\[
x_{ni}' = x_{ni} + [max(z_i\beta^n) - z_i\beta^n] + [max(v_{ni}) - v_{ni}] \quad (6)
\]

Where, \( x_{ni}' \) and \( x_{ni} \) respectively represent the input amount before and after adjustment. The first item \([max(z_i\beta^n) - z_i\beta^n]\) of adjustment is to adjust all decision-making units in the same environment, and the second item \([max(v_{ni}) - v_{ni}]\) is to adjust the random errors of all decision-making units to the same state.

The third stage DEA: the calculation of adjusted agricultural production efficiency. Using DEA model, based on the adjusted input, the agricultural production efficiency is measured again, and the result is the efficiency value after eliminating environmental impact and ineffective management.

4.2.2 Mediating effect model

The service of agricultural machinery with multi-agent cooperative participation not only has a direct impact on agricultural production efficiency, but also indirectly affects agricultural production efficiency through high-quality transmission mechanism. Analysis framework of mediating effect:

\[
P_E_{it} = a_0 + a_1TA_{it} + a_2TA^2_{it} + a_3Z_{it} + \mu_{it} + \gamma_{it} + e_{it} \quad (7)
\]

\[
PA_{it} = b_0 + b_1TA_{it} + b_2TA^2_{it} + b_3Z_{it} + \mu_{it} + \gamma_{it} + e_{it} \quad (8)
\]

\[
PE_{it} = c_0 + c_1TA_{it} + c_2TA^2_{it} + c_3PA_{it} + c_4PA^2_{it} + c_5Z_{it} + \mu_{it} + \gamma_{it} + e_{it} \quad (9)
\]

In the above model, \( i \) represents farmers, \( t \) represents the period, \( PE \) represents the dependent variable agricultural production efficiency, \( TA \) represents the independent variable.
multi-agent cooperative participation of agricultural machinery service status, $PA$ represents the intermediary variable high-quality operation degree, and $Z$ represents the control variable; $\mu_i$ represents the fixed effect of individual, $\gamma_{1t}$ represents the fixed effect of time and $e_{it}$ represents the random disturbance term. Formula 7 is the total effect model, which is used to investigate the overall influence of agricultural machinery service status with multi-agent collaborative participation on agricultural production efficiency, and the square term is introduced into the model to capture the nonlinear effect of agricultural machinery service status with multi-agent collaborative participation on agricultural production efficiency; Equation 8 is used to estimate the influence of service of agricultural machinery with multi-agent cooperative participation on high-quality operation; Equation 9 introduces high-quality operation, multi-agent cooperative participation of agricultural machinery service status and its square term at the same time, which is used to estimate the direct effect of multi-agent cooperative participation of agricultural machinery service status on agricultural production efficiency, and the intermediary effect of farmers’ high-quality operation on agricultural machinery service status affecting multi-agent cooperative participation of agricultural machinery service status on agricultural production efficiency. When all of $a_1, a_2, b_1, b_2, c_1, c_2, c_3, c_4$ are significant, it is considered that the service of agricultural machinery with multi-agent cooperative participation not only has a direct nonlinear effect on agricultural production efficiency, but also indirectly affects agricultural production efficiency through the transmission mechanism of high-quality operation. In this paper, the step-by-step method and Bootstrap method are combined to test the significance of mediating effect by using the test steps provided by Wen Zhonglin and others.

5 Results and Analysis

5.1 The overall effect of multi-agent collaborative participation in agricultural machinery service on agricultural production efficiency

Based on the sample of farmers obtained from investigation, using SPSS 24 software, the regression results of the overall effects of technology collaboration, service collaboration and benefit collaboration on agricultural production efficiency in Formula (1) were obtained (Table 2). In the model, technical collaboration, service collaboration, benefit collaboration, gender of the head of household, age of the head of household, education level of the head of household, number of family labor force, whether there are village cadres in the home, and land management scale are standardized. Technology collaboration, service collaboration and benefit collaboration have a significant positive impact on agricultural productivity in general, among which technology collaboration and service collaboration are significant at 1% statistical level, and benefit collaboration is significant at 5% statistical level. The F statistic is significant at 1% statistic level, which indicates that the fitting effect of the overall effect estimation is good and accords with the conditions of further analysis.

From the regression results in Table 2, it can be seen that multi-agent cooperative participation in agricultural machinery service has a significant positive impact on farmers’ production efficiency. This shows that the multi-agent cooperative participation of conservation tillage agricultural machinery service will promote the improvement of its agricultural production efficiency, in line with the expectations of this paper. The service of conservation tillage agricultural machinery with multi-agent cooperative participation can effectively implant modern production factors such as technology, information, capital and talents into the agricultural
industrial chain, break the constraints of labor shortage, backward production technology and rising production cost of small farmers, alleviate the problem of insufficient factors in agricultural production, and optimize the allocation of agricultural production factors, which is conducive to the improvement of agricultural production efficiency.

Table 2 Subject effect of agricultural machinery service with multi-agent collaborative participation on agricultural production efficiency

<table>
<thead>
<tr>
<th></th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural production efficiency</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical collaboration</td>
<td>0.0547</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Service collaboration</td>
<td></td>
<td>0.2654</td>
<td></td>
</tr>
<tr>
<td>Benefit collaboration</td>
<td></td>
<td></td>
<td>0.3503</td>
</tr>
<tr>
<td>Gender</td>
<td>0.6142</td>
<td>0.5078</td>
<td>0.3061</td>
</tr>
<tr>
<td>Age</td>
<td>0.3714</td>
<td>0.0437</td>
<td>0.121</td>
</tr>
<tr>
<td>Education level</td>
<td>0.251</td>
<td>0.1354</td>
<td>0.3966</td>
</tr>
<tr>
<td>Number of labors</td>
<td>0.2919</td>
<td>0.604</td>
<td>0.656</td>
</tr>
<tr>
<td>Social stratum</td>
<td>0.3788</td>
<td>0.3601</td>
<td>0.2134</td>
</tr>
<tr>
<td>Farmland size</td>
<td>0.5099</td>
<td>0.0498</td>
<td>0.0857</td>
</tr>
<tr>
<td>Number of observations</td>
<td>695</td>
<td>695</td>
<td>695</td>
</tr>
<tr>
<td>R^2</td>
<td>0.9331</td>
<td>0.9156</td>
<td>0.9126</td>
</tr>
<tr>
<td>F statistic</td>
<td>19.1803</td>
<td>14.9105</td>
<td>14.351</td>
</tr>
</tbody>
</table>

5.2 Influence of agricultural machinery service with multi-agent collaborative participation on high-quality operation

Among the effects of multi-agent collaborative participation in agricultural machinery service on high-quality operation, technical collaboration, service collaboration and benefit collaboration have significant positive effects on high-quality operation, among which technical collaboration and service collaboration are significant at 1% statistical level, and benefit collaboration is significant at 5% statistical level. The F statistic is significant at 1% statistic level, which indicates that the fitting effect of the overall effect estimation is good and accords with the conditions of further analysis. It can be seen from the regression results (Table 3) of the influence of the collaboration effect among the multi-agents of the service of agricultural machinery in conservation tillage on the high-quality operation of intermediary variables:

As far as technical collaboration is concerned, technical collaboration has a significant positive impact on the high-quality operation of conservation tillage, which indicates that technical collaboration among multi-subjects of service of agricultural machinery in conservation tillage can improve the quality of farmers' conservation tillage operation. Through unifying the technical specification of conservation tillage, it can promote the rational purchase of agricultural machinery, ensure the matching between agricultural machinery and tools, avoid the failure to meet the requirements of conservation tillage implementation due to machinery and equipment, improve the coordination between various machines and tools in various stages, and ensure the final effect of conservation tillage, so as to realize the high-quality completion of conservation tillage operations.

As far as service collaboration is concerned, service collaboration significantly positively affects the high-quality operation of conservation tillage, which indicates that service collaboration among multi-agents of service of conservation tillage agricultural machinery can
improve the completion rate of high-quality operation of conservation tillage for farmers. Farmers form the service alliance of the original process through the service subject of agricultural machinery with specialized service quality and service means, which can provide "integrated" agricultural machinery services and improve the availability of farmers to obtain a variety of agricultural machinery services at one time. By signing a whole process service agreement with farmers, the service quality of agricultural machinery operations can be guaranteed, the conservation tillage can be completed with high quality, and the completion rate of high-quality conservation tillage operations of farmers can be improved.

As far as benefit collaboration is concerned, benefit collaboration significantly positively affects the high-quality operation of conservation tillage, which indicates that the benefit collaboration among multi-subjects of service of conservation tillage agricultural machinery can promote the high-quality operation of conservation tillage for farmers. By choosing integrated conservation tillage agricultural machinery services, farmers can reduce the search cost of farmers and save the operation cost through scale effect. At the same time, it is also convenient for farmers to supervise and manage uniformly, and can ensure the quality and safety of agricultural machinery services, thus promoting farmers to achieve high-quality conservation tillage operations.

Table 3 Influence of intermediary variables of agricultural machinery service with multi-agent collaborative participation

<table>
<thead>
<tr>
<th></th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-quality operation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical collaboration</td>
<td>0.0903</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Service collaboration</td>
<td></td>
<td>0.0508</td>
<td></td>
</tr>
<tr>
<td>Benefit collaboration</td>
<td></td>
<td></td>
<td>0.218</td>
</tr>
<tr>
<td>Gender</td>
<td>0.7675</td>
<td>0.5187</td>
<td>0.306</td>
</tr>
<tr>
<td>Age</td>
<td>0.6538</td>
<td>0.7823</td>
<td>0.2394</td>
</tr>
<tr>
<td>Education level</td>
<td>0.111</td>
<td>0.161</td>
<td>0.1878</td>
</tr>
<tr>
<td>Number of labors</td>
<td>0.0362</td>
<td>0.0372</td>
<td>0.1229</td>
</tr>
<tr>
<td>Social stratum</td>
<td>0.4636</td>
<td>0.448</td>
<td>0.6485</td>
</tr>
<tr>
<td>Farmland size</td>
<td>0.5026</td>
<td>0.6153</td>
<td>0.8062</td>
</tr>
<tr>
<td>Number of observations</td>
<td>695</td>
<td>695</td>
<td>695</td>
</tr>
<tr>
<td>R²</td>
<td>0.8741</td>
<td>0.884</td>
<td>0.8584</td>
</tr>
<tr>
<td>F statistic</td>
<td>11.904</td>
<td>13.0683</td>
<td>10.3962</td>
</tr>
</tbody>
</table>

5.3 Intermediary effect of multi-agent collaborative participation in service of agricultural machinery on agricultural production efficiency

Regression results show (Table 4) that after adding intermediary variables, the impact of service of conservation tillage agricultural machinery with multi-agent collaborative participation on agricultural production efficiency is still significantly positive. Technology collaboration, service collaboration and benefit collaboration all have a significant positive impact on agricultural production efficiency at the statistical level of 1%. Combined with Bootstrap, the significance of mediating effect $b1c2$ of synergistic effect among multi-agents of service of agricultural machinery in conservation tillage was tested. Bootstrap results show that for agricultural production efficiency, the intermediary path of high-quality operation of conservation tillage is significant at the statistical level of 5%. To sum up, it can be seen that the collaboration
among multi-subjects of service of agricultural machinery in conservation tillage mainly improves agricultural production efficiency by promoting technical collaboration, service collaboration and benefit collaboration among multi-service subjects, and secondly, it can also promote agricultural production efficiency by improving high-quality operation of conservation tillage, which has intermediary effect.

First, the service of agricultural machinery with multi-agent collaborative participation in conservation tillage has a significant impact on agricultural production efficiency. Through the coordination of technology, service and benefit, the service technology of agricultural machinery is more standardized, the service is more professional, the income is more balanced, the planting investment is reduced, the planting quality is improved, and the planting efficiency is improved, which can significantly improve the agricultural production efficiency; Second, the high-quality operation of conservation tillage has a significant impact on agricultural production efficiency. Through labor substitution and technology introduction, the labor constraint of farmers can be alleviated, the cost of conservation tillage can be reduced, and advanced technology can be put into agricultural production to improve agricultural production efficiency. Third, the service of agricultural machinery with multi-agent cooperative participation in conservation tillage can provide farmers with diversified and systematic services, improve service efficiency, reduce operation costs, ensure high-quality operation of conservation tillage, and then improve agricultural production efficiency.

Table 4 Mediation effect of agricultural machinery service with multi-agent collaborative participation on agricultural production efficiency

<table>
<thead>
<tr>
<th>Agricultural production efficiency</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical collaboration</td>
<td>0.0547</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Service collaboration</td>
<td></td>
<td>0.2654</td>
<td></td>
</tr>
<tr>
<td>Benefit collaboration</td>
<td></td>
<td></td>
<td>0.3503</td>
</tr>
<tr>
<td>High-quality operation</td>
<td>0.6406</td>
<td>0.0846</td>
<td>0.3212</td>
</tr>
<tr>
<td>Control variables</td>
<td>Controlled</td>
<td>Controlled</td>
<td>Controlled</td>
</tr>
<tr>
<td>Number of observations</td>
<td>695</td>
<td>695</td>
<td>695</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.9331</td>
<td>0.9156</td>
<td>0.9126</td>
</tr>
<tr>
<td>$F$ statistic</td>
<td>19.1803</td>
<td>14.9105</td>
<td>14.351</td>
</tr>
</tbody>
</table>

6. Conclusions

Based on the investigation of 695 households in black soil regions of China, namely Heilongjiang Province, Jilin Province, Liaoning Province and Inner Mongolia Autonomous Region, taking conservation tillage as an example and high-quality operation as an intermediary variable, this paper explores the influence of service of agricultural machinery in conservation tillage with multi-agent collaborative participation on agricultural production efficiency. This paper draws the following conclusions:

(1) The agricultural machinery service with multi-agent collaborative participation refers to the service alliance of town, which can widely absorb family farms, large grain growers, agricultural service enterprises, agricultural machinery cooperatives and other subjects, and the consortium provides a number of affairs services to farmers in the form of service consortium. At the same time, the service of agricultural machinery with multi-agent collaborative participation
has the characteristics of comprehensive service content, whole service content and high service availability, and the collaborative mode is mainly realized as technical collaboration, service collaboration and benefit collaboration.

(2) Multi-agent cooperative participation of agricultural machinery service has a positive role in promoting agricultural production efficiency, and the technical cooperation among multi-agents of agricultural machinery service will reduce the price of agricultural machinery service and the production and operation cost of farmers; Service coordination can effectively improve the efficiency of farmers' service supply and reduce the supervision cost of farmers; benefit collaboration reduces the cost of farmers' investment in agricultural machinery services, reduces production input and improves agricultural production efficiency.

(3) The service of agricultural machinery with multi-agent cooperative participation has a significant impact on the high-quality operation of conservation tillage, and the technical cooperation among multi-agents of agricultural machinery service will improve the mechanical adaptability of each stage of conservation tillage and enhance the operation effect of each stage; service collaboration will ensure the high-quality operation effect of conservation tillage; benefit collaboration will reduce farmers' investment in conservation tillage and ensure that conservation tillage can be completed with higher quality.

(4) Conservation tillage high-quality operation can improve agricultural production efficiency in the influence of multi-agent cooperative participation of agricultural machinery service on agricultural production efficiency, and there is an intermediary effect.

The above research conclusions have three policy implications:

(1) Promote the upgrading of service of agricultural machinery to organization, guide the cooperation between service suppliers and demand subjects, establish family farm service alliances, comprehensive agricultural service centers and other consortia, change "fighting alone" into "developing in groups", and improve the organization level. Specifically, we can give full play to the social and organizational advantages of acquaintances of farmers' cooperatives and village collective economic organizations, form service consortia within villages or towns, and give full play to the network advantages and industrial chain resource integration advantages of agricultural enterprises.

(2) Improve the development quality of service consortia, guide multiple subjects to provide differentiated and complementary service contents according to the principle of comparative advantage, reduce the excessive supply of services in production, and tap various resources such as agricultural machinery extension departments and agricultural colleges to fill the shortcomings of prenatal and postnatal services. Improve the functions of service consortium such as information release, quality feedback, service dispute handling, service contract signing and management, integrate service capability, service feedback, social evaluation and other indicators, build an evaluation mechanism for the development of service consortium, and set up a reward and punishment system to force the consortium to improve its quality. With land, capital, technology and other factors as the link, establish a close benefit linkage mechanism of "revenue sharing and risk sharing" to promote long-term stable cooperation among consortium members.

(3) To provide diversified policy support, government departments should introduce corresponding compensation policies for conservation tillage according to the actual situation every year, encourage financial institutions to innovate financial products that meet the credit needs and operating characteristics of service subjects, highlight flexibility and diversity,
appropriately broaden the scope of collateral, take land management rights, production facilities and agricultural machinery resources as effective collateral, enhance the financing ability of subjects, increase the cultivation of new professional farmers such as large-scale operation subjects and large agricultural machinery households, and provide talent support for the development of services.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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