SIN-CHN SCIENTIFIC PRESS PTE.LTD.

Molecular & Cellular Biomechanics 2025, 22(4), 1577.
https://doi.org/10.62617/mcb1577

Article

Biomechanical insights: Paths of change in the organizational model and operational mechanism of agricultural socialization services to meet farmers' needs

Siqi Nie, Guoyong Liu*

College of Economics and Management, Xinjiang Agricultural University, Urumqi 830052, China
*** Corresponding author:** Guoyong Liu, xjaulgy1234@163.com

CITATION

Nie S, Liu G. Biomechanical insights: Paths of change in the organizational model and operational mechanism of agricultural socialization services to meet farmers' needs. Molecular & Cellular Biomechanics. 2025; 22(4): 1577. https://doi.org/10.62617/mcb1577

ARTICLE INFO

Received: 17 February 2025
Accepted: 27 February 2025
Available online: 17 March 2025

Abstract: In order to explore the change path of agricultural socialized service organization mode and operation mechanism to adapt to the needs of farmers, a fitness analysis framework is constructed based on biomechanics theory, and the operation characteristics of the organization mode are measured from the perspectives of mechanical equilibrium, resource flow and dynamic adjustment. Taking the North China Plain, the Middle Yangtze River Plain and the Northeast Plain as examples, we measured the density of socialized service supply, the resource flow rate and the fitness index, and the results show that the Middle Yangtze River Plain has the highest fitness index (0.83), the resource flow rate reaches 324.7 tons/day, the information transmission efficiency is 5.21 bit/s, and the response time to the farmer's demand is the shortest (5.7 h), which indicates that the organizational structure is stable and the precision of resource allocation is high. Resource allocation precision is high. The biomechanics theory can effectively optimize the agricultural socialized service model and improve the adaptability and operational efficiency of the agricultural production system.

Keywords: biomechanics; agricultural social services; organizational models; fitness mechanisms; dynamic regulation

1. Introduction

The role of agricultural socialized service organization model in the process of agricultural modernization is becoming more and more prominent, and its operation mechanism directly affects the efficiency of resource allocation and the matching degree of farmers' needs. Biomechanics theory mainly focuses on the stability, force equilibrium and structural optimization of the system under the action of external forces, and its basic theoretical framework can effectively explain and guide the organizational optimization of agricultural socialized service model. In the agricultural service system, the core concepts of biomechanics such as mechanical equilibrium and dynamic adaptability provide theoretical support for the design of the service model. By applying the optimization of mechanical equilibrium and resource flow to the organizational structure of the agricultural socialized service model, the adaptability and operational efficiency of the service system can be improved. By analyzing the internal mechanics structure of the agricultural service organization and the external demand changes, the precise allocation and dynamic adjustment of resources can be realized, which in turn improves the response efficiency of the farmers' demand.

The role of agricultural socialized service organization model in the process of agricultural modernization is becoming more and more prominent, and its operation mechanism directly affects the efficiency of resource allocation and the matching degree of farmers' needs. Biomechanics theory mainly focuses on the stability, force equilibrium and structural optimization of the system under the action of external forces, and its basic theoretical framework can effectively explain and guide the organizational optimization of the agricultural socialized service model. In the agricultural service system, the core concepts of biomechanics, such as mechanical equilibrium and dynamic adaptability provide theoretical support for the design of the service model. By applying the optimization of mechanical equilibrium and resource flow to the organizational structure of the agricultural socialized service model, the adaptability and operational efficiency of the service system can be improved. By analyzing the internal mechanics structure of the agricultural service organization and the external demand changes, the precise allocation and dynamic adjustment of resources can be realized, which in turn improves the response efficiency of the farmers' demand.

To ensure the close integration of the theoretical framework and practical application, the study proposes a biomechanics-based fitness assessment model, which includes core variables such as organizational stability, resource flow rate and functional coordination, and then optimizes and adjusts the actual service model. The combined effect of all these factors enables agricultural socialized services to operate efficiently in complex production environments and enhances their precise adaptation to farmers' needs. The complexity of agricultural production requires a stable structure and efficient adaptability of the organizational model in order to reduce system friction and achieve equilibrium between supply and demand. The analytical framework based on biomechanics theory can reveal the internal mechanism of the agricultural socialized service organization model, promote the improvement of resource utilization, and optimize the overall operation of the agricultural production system.

2. Development status of the agricultural socialized service organization model

The importance of the agricultural socialized service organization model in the modern agricultural system is becoming more and more prominent, and its development status is subject to the multiple influences of economic structural adjustment, scientific and technological progress and changes in farmers' needs [1]. Currently, the service organization model mainly presents the trend of diversification, intelligence and synergism, in order to adapt to the complexity of agricultural production and the dynamic change of farmers' needs. From the perspective of biomechanics, the development of these modes needs to fit the mechanical characteristics of the main body of agricultural production and realize the optimal matching of resource allocation. Diversified development is reflected in the agricultural socialized service organizations gradually forming a combination of government-led, market-driven and social participation models, covering agricultural production services, business services and integrated service systems. Various types of service subjects in the agricultural production process, like biological systems in the synergistic role of different functional units through the balance of force and coordination, to achieve the stable operation of the agricultural production system. Intelligent trends promote the cross-application of information technology and biomechanics, such as precision agriculture, intelligent irrigation and other technical means to optimize the structural mechanical design of agricultural equipment, improve operational accuracy and adaptability. In addition, the development of synergization has prompted various types of service organizations to rely on the supply chain network to realize the efficient flow of elements, similar to the force balance of the internal structure of organisms, so as to make the distribution of resources in each link of the agricultural production chain more reasonable, reduce the friction of the system, and realize the dynamic optimization of the adaptability of the needs of farmers [2].

3. Analysis of biomechanical theory and fitness of agricultural social service organization

3.1. Basic principles of biomechanical system

The basic principle of a biomechanical system is to study the mechanical response of organisms under the action of external forces and their adaptive mechanisms, including the core theories of structural mechanics, kinematics and material mechanics. Biomechanics emphasizes the structural stability and functional coordination, and its core lies in the mechanical balance and energy conversion between the units within the system to maintain the stable operation of the organism. This theory can effectively analyze the dynamic adjustment mechanism of agricultural socialized service organizations in terms of resource allocation, factor flow and adaptation to farmers' needs. The mechanical system of organisms relies on homeostatic equilibrium to adapt to changes in the external environment; similarly, the model of agricultural socialized service organization needs to optimize the allocation of resources to achieve the dynamic adaptation of agricultural production [3]. The biomechanical system emphasizes structural optimization and load balancing, which is in line with the principle of fitness of agricultural socialized service organization in matching supply and demand, i.e., to reduce redundancy and improve efficiency through precise resource placement and technical support. In addition, the motion characteristics of biological systems emphasize the reasonable transmission of internal forces to maintain the coordination of the overall function, which means that for agricultural socialized service organizations, the functional units need to form organic synergy to ensure the efficient operation of the production service system. The analysis of the basic principles of biomechanical systems can provide theoretical support for the optimization of the agricultural socialized service organization model so that it can better meet the actual needs of the agricultural production system.

3.2. Operational characteristics of agricultural social service organizations

The operation characteristics of agricultural socialized service organizations are affected by market demand, policy orientation and technological progress, and their operation mode presents significant features in resource allocation, service supply and synergistic effect [4]. Combined with the theory of biomechanics, the operation mechanism of agricultural socialized service organizations can be compared to the mechanical adaptation of biological systems, the core of which lies in the dynamic balance, structural optimization and functional coordination, in order to achieve the efficient adaptation of agricultural production, as shown in **Figure 1**. Agricultural socialized service organizations follow the principle of dynamic adaptability in the process of operation, i.e., adjusting the service structure according to the changes in the external environment to achieve the balance of supply and demand. This is consistent with the mechanism by which biological systems automatically adjust internal stress distribution under different stress conditions, enabling the organization to continuously optimize resource input and reduce the risk of structural imbalance. The operational characteristics reflect synergistic effects, forming a close connection between the functional units, similar to the interaction of different organs within a biological organism under a mechanical system, and realizing the optimization of the overall function through the efficient flow of information, capital and materials [5]. In addition, agricultural socialized service organizations need to pay attention to load balancing in the process of operation, that is, through the precise deployment of various types of production factors, so that the mechanical load between different regions and different operational links is reasonably distributed, so as to improve the stability and continuity of the overall operation.

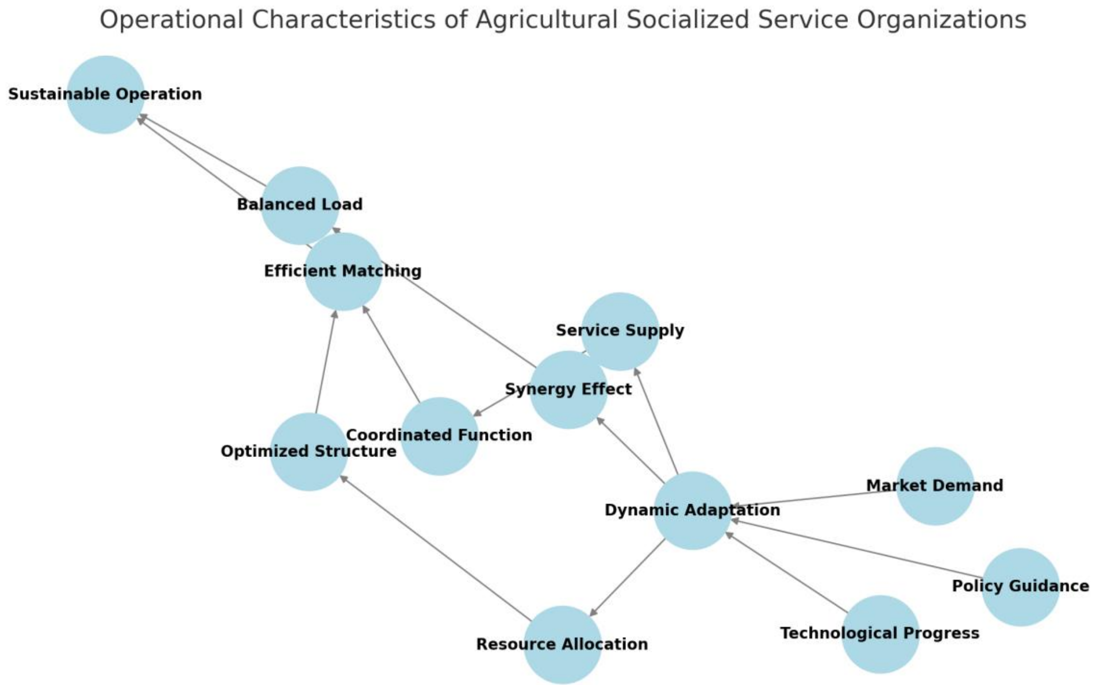

Figure 1. Framework diagram of operational characteristics of agricultural social service organizations.

3.3. Application of biomechanical theory to organizational models

The application of biomechanical theory in the model of agricultural socialized service organization, especially through the stress-strain analogy, is the rationality of choosing this theory. The principle of biomechanics provides deep theoretical support for agricultural socialized service organization through the study of the stress response and adaptation mechanism of organisms under external forces. Under this framework, agricultural service organizations can be regarded as dynamic and complex systems, and the resource flow and coordination among their internal functional units are similar to the stress distribution and adaptation in biological systems. Through structural optimization and functional synergy, the service organization is able to adjust its structure and function under changes in the external environment like a living organism, ensuring efficient resource flow and organizational stability. This analogy not only provides a theoretical basis for understanding the dynamic adaptability of agricultural service organizations but also provides guidance for optimizing resource allocation and enhancing system stability so that the agricultural production system can effectively respond to the diversity and complexity of farmers' needs.

The structural optimization of the organizational model can draw on the mechanical characteristics of biological systems, i.e., adjusting the internal resource allocation according to different agricultural production demands, similar to the strengthening of different stressed parts of biological organisms, in order to achieve load balancing and improve the overall stability [6]. Functional synergy requires that all links within the organizational model form an organic link through mechanical action to ensure that the flow of information, funds and materials has a low-resistance characteristic, similar to the stress transfer mechanism in biological systems, so as to make resource allocation more accurate. In addition, dynamic adaptability is the key to the long-term stable operation of the organizational model, which is consistent with the deformation response mechanism of the biological system, i.e., under the stimulation of different external environments, it relies on the feedback adjustment mechanism to adjust the structural layout and optimize the combination of production factors in response to the changes in the market demand and to improve the adaptability of services.

3.4. Mechanisms for matching farmers' needs with service organizations

The matching mechanism between farmers' demand and agricultural socialized service organizations determines the rational allocation of agricultural production factors, the core of which lies in the matching of supply and demand, the optimization of resource flow and the dynamic adjustment of the system. Combined with the theory of biomechanics, this adaptation mechanism is similar to the adaptive adjustment process of biological systems under the action of external forces, and the key lies in the balance of forces, functional coordination and feedback adjustment within the system so as to ensure the accuracy of resource injection and the sustainability of agricultural production [7]. The adaptation mechanism relies on the principle of matching supply and demand, i.e., adjusting the service model according to the changes in farmers' demand and realizing the mechanical equilibrium of resource supply. This process is similar to the morphological adjustment of organisms under different external stress conditions to maintain structural stability and functional adaptability. The optimization of resource flow requires the establishment of low-resistance channels within the service organization so that production factors such as capital, technology and information can be efficiently transferred among various links, which is consistent with the force transfer process in the biomechanical system and ensures the coordinated operation of various functional units. In addition, the dynamic adjustment mechanism ensures the continuous adaptation of the organizational model to the needs of farmers, similar to the strain mechanism of living organisms, i.e., optimizing the structural layout and adjusting the load distribution based on the feedback adjustment under the change of the external environment, so as to improve the production efficiency and the accuracy of the adaptation. Through the construction of this adaptation mechanism, agricultural socialized service organizations can accurately match the needs of farmers and realize the optimization and upgrading of the agricultural production system [8].

4. Model construction of agricultural socialized service organization based on the principle of biomechanics

4.1. Model design ideas

The construction of the agricultural socialized service organization model needs to rely on the principle of biomechanics to ensure the optimization of the organizational structure and operation mechanism. The core of the model is based on the balance of system mechanics to build a dynamic structure that adapts to changes in the external environment so as to improve the adaptability and efficiency of the agricultural production system. The model design idea emphasizes the stability and flexibility balance of the system structure and establishes the dynamic regulation system of the agricultural socialized service organization to ensure the optimal path of resource flow by drawing on the adaptive mechanism of living organisms under different stressful environments. The identification and measurement of core variables is the key link in model construction. It is necessary to define the variables such as resource carrying capacity, information transmission rate, and coordination of production factors from the perspective of mechanics and measure the dynamic relationship between the variables by combining with data analysis methods to ensure that the model has a high degree of accuracy [9].

In the construction of the evaluation index system of organizational fitness, the mechanical coupling degree of the agricultural production chain, service transmission efficiency and system stability should be comprehensively considered, and the operational fitness of the service organization should be measured through a quantitative index system. Further, the design of farmers' demand response mechanism needs to simulate the stress transmission process of biological systems to ensure that external demand can be rapidly applied to the organization and form feedback regulation so as to realize the precise injection of agricultural resources. The construction of the organizational operation efficiency optimization model needs to be combined with the principle of structural optimization to ensure the optimal operation of agricultural socialized service organizations in terms of supply and demand matching, resource allocation and functional linkage, so as to provide stable and continuous support for the agricultural system, as shown in **Figure 2**.

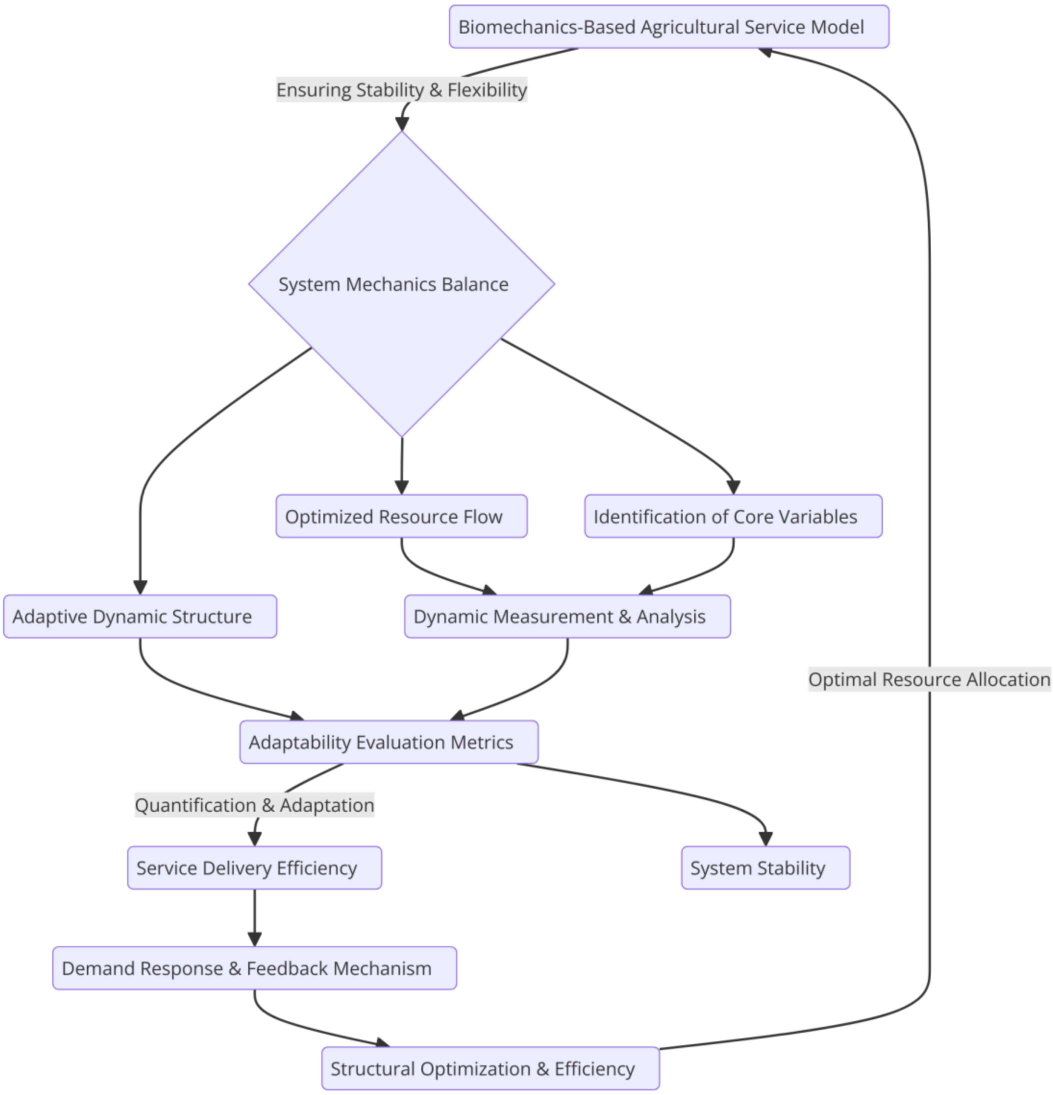

Figure 2. Design a conceptualization of the biomechanical agricultural services model.

4.2. Core variable identification and measurement

In the process of constructing an agricultural socialized service organization model based on the principle of biomechanics, the identification and measurement of core variables are the basis for ensuring the optimization and stable operation of the system. The selection of core variables needs to be based on the analysis of system dynamics in order to reveal the internal mechanism of the organization's operation and to ensure the mechanical equilibrium relationship between variables. By analyzing the internal structure of the system, the role of the external environment, and the resource transmission path, key variables can be identified and precisely measured. The core variables can be categorized as structural, functional and environmental variables.

Structural variables mainly measure the network topological characteristics of agricultural socialized service organizations, including node connectivity, resource flow paths and carrying capacity, etc., to quantify the stability of the organizational structure [10]. Functional variables involve system operation efficiency and fitness, such as information transfer rate, farmers' demand response time and resource deployment accuracy, reflecting the organization's adaptive capacity in the dynamic environment. Environmental variables include market fluctuations, policy influences and farmers' behavioral characteristics, and the impacts of these external factors on the organizational model can be simulated by the mechanistic model to optimize the organizational operation strategy.

4.3. Construction of the evaluation index system for organizational fitness

The construction of the organizational fitness evaluation index system needs to be combined with biomechanics theory to ensure the stability, coordination and rationality of resource allocation of agricultural socialized service organizations in different environments. The system mainly quantifies the fitness through mathematical modeling, and comprehensively considers the structural stability, functional matching and environmental adaptability to ensure the optimal operation of the agricultural production system. Organizational fitness can be calculated through the stress-strain analysis method in biomechanics, defining fitness F as the responsiveness of the organization to changes in the external environment:

$$F = \frac{\sum_{i=1}^{n} w_i S_i}{\sum_{i=1}^{n} w_i} \tag{1}$$

where S_i is the first i fitness indicator and w_i is its weight to ensure that the contribution of different indicators to the overall fitness is weighted by importance. This formula reflects the fitness of each functional unit of the organization under different environmental pressures. Organizational structural stability can be calculated by using a topology optimization model to calculate its network connectivity:

$$C = \frac{2E}{N(N-1)} \tag{2}$$

where C indicates the connectivity of nodes within the organization, E is the number of effective connections, and N is the number of service nodes in the organization. A high value of C indicates a smooth flow of resources within the organization, which improves the overall fitness. In addition, functional fitness can be assessed by the response time to farmers' needs at T_r:

$$T_r = \frac{L}{V} \tag{3}$$

where, L is the information transmission path length and V is the service response speed. A smaller value of T_r means that the organization responds to farmers' needs more efficiently and improves the fitness, **Table 1** shows the evaluation index system of organization fitness:

By constructing the above index system, a quantitative assessment of the operation status of agricultural socialized service organizations can be realized, providing a decision-making basis for optimizing the organization model and making it more stable, precise and adaptable to meet the needs of the agricultural production system.

Table 1. Indicator system for evaluating organizational fitness.

evaluation dimension	variable name	Range of indicator values
Structural stability	Organizational network connectivity	0–1
	Load Balancing Index	0–100
Functionality Match	Demand Response Time	0–72
	Precision of resource placement	0–100
adaptability	Composite Fitness Index	0–1
environmental adaptation	Agricultural market volatility	0–50
	Resource adaptive capacity index	0–1

4.4. Design of demand response mechanisms for farmers

The design of farmers' demand response mechanism needs to be combined with the principle of biomechanics to ensure that agricultural socialized service organizations can accurately perceive and adapt to farmers' demand, optimize the allocation of resources, and quickly adjust when there is an imbalance between supply and demand so as to improve the overall operational efficiency. Farmers' demand does not change linearly but is affected by market fluctuations, policy regulation and agricultural production cycles, showing complex dynamic characteristics [11]. It is necessary to build a system that includes demand signal transmission, resource allocation optimization and feedback regulation to achieve efficient demand response capability. Changes in farmers' demand can be modeled on the principle of signal decay in biomechanics, where demand fluctuations are regarded as periodic oscillatory signals and described by an exponential decay model:

$$D(t) = D_0 e^{-\alpha t} sin(2\pi\omega t) \tag{4}$$

where D_0 is the initial demand intensity of farmers, α represents the demand decay coefficient, which controls the rate of demand decline over time, and ω reflects the cyclical fluctuation characteristics of demand. The model shows that farmers' demand is strong at the initial stage, but the demand intensity gradually declines over time, and is affected by the market supply and demand cycle and shows oscillating changes. The length of farmers' demand response time directly determines the fitness efficiency of agricultural socialized service organizations, and the optimization process of resource allocation can be described by the supply and demand balance equation:

$$\sum_{i=1}^{n} R_i(t) = \sum_{j=1}^{m} D_j(t) + \in \tag{5}$$

where $R_i(t)$ represents the supply of agricultural resources of type i, D_j represents the demand of farmers of type j, and $\in$ is the loss factor in resource transmission of the system. The equation shows that in order to maintain the dynamic equilibrium of the agricultural socialized service organization, the supply of resources needs to match the demand of farmers as much as possible, while taking into account the impact of loss. If the deviation of matching supply and demand is too large, it will lead to the waste or insufficient supply of production resources and reduce the overall operational efficiency. Accurate prediction of farmers' demand and optimization of resource placement paths based on the principle of matching supply and demand are the keys to ensuring the stable operation of the service organization [12]. In addition, the feedback adjustment of farmers' demand can be borrowed from the adaptive mechanism of force in biomechanics, i.e., the service organization needs to adjust the resource placement strategy according to the dynamic changes of farmers' demand. The process can be described by the following state adjustment equation:

$$S(t+1) = S(t) + \gamma(D(t) - R(t)) \quad (6)$$

where $S(t)$ is the current state of the organization's fitness and γ represents the adjustment factor, which controls the rate of correction for supply and demand deviations. This equation indicates that when the demand of farmers is higher than the current supply, the system automatically increases the resource supply capacity to meet the demand growth; conversely, if the supply is in excess, it reduces the supply to prevent resource wastage. This mechanism is similar to the adaptive regulation process of an organism under external forces, which maintains mechanical homeostasis by continuously adjusting its internal structure, thus ensuring the efficient operation of the overall system [13]. **Figure 3** shows the trend of farmers' demand response over time, in which the demand is initially high in intensity and then exponentially decaying, while being affected by the cyclical fluctuations of the market, showing certain oscillatory characteristics.

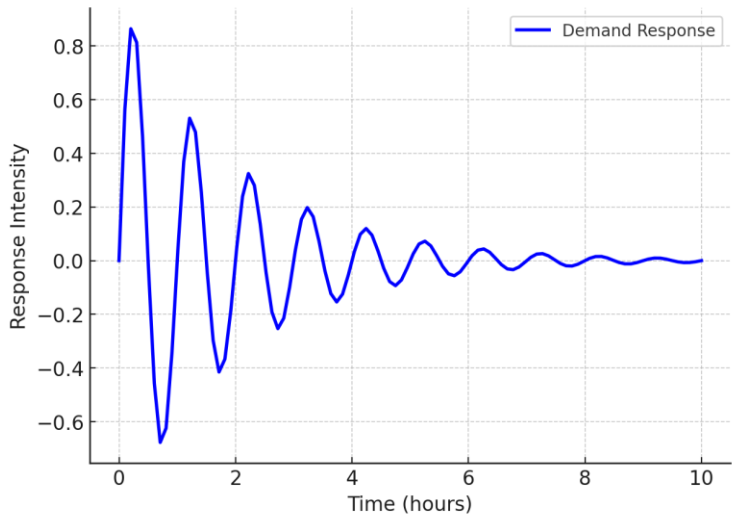

Figure 3. Demand response trends.

The curve shows that farmers' demand gradually decays over time under the influence of external factors and fluctuates within a certain period. Agricultural socialized service organizations can make use of this trend, combined with the feedback regulation mechanism, to optimize the resource allocation strategy in order to improve the matching of supply and demand and achieve precise response. Constructing a demand response mechanism for farmers based on biomechanical principles can enable agricultural socialized service organizations to accurately perceive changes in demand and optimize supply strategies through the synergistic effects of signal transmission, resource allocation, and feedback regulation to improve the overall operational efficiency [14].

4.5. Organizational operational efficiency optimization model

The construction of the optimization model of organizational operation efficiency needs to be based on the principle of biomechanics to ensure that the agricultural social service organization can realize the optimal allocation of resources, reduce the operational resistance and improve the stability of the system under the complex environment. The efficient operation of the organization depends on the rationality of its internal structure, the smoothness of information transmission, the balance of the resource load and the dynamic adaptability, so it can be modeled and analyzed from the four aspects of the system's energy distribution, the resistance of the information flow, the optimization of the load distribution and the dynamic adjustment mechanism. The stability of the organizational system is closely related to energy consumption, which can be quantified by the energy distribution equation:

$$E_{sys} = \sum_{i=1}^{n} \left(\frac{M_i V_i^2}{2} + U_i \right) \tag{7}$$

where E_{sys} represents the total energy of the organizational system, M_i is the quality factor of the i-th node, V_i is the resource flow rate, and U_i represents the potential energy of the node. This formula reveals the energy distribution of different nodes within the organization in the process of resource flow and ensures the reasonable distribution of energy in the system in order to reduce the local energy consumption and improve the overall operational efficiency. Information flow efficiency determines the transfer rate of resources within the organization, and its resistance can be described by the flow impedance model:

$$R_f = \frac{L_f}{A_f \cdot \eta} \tag{8}$$

where R_f represents the transmission resistance of information flow within an organization, L_f is the information flow path length, A_f is the cross-sectional area of the transmission channel, and η is the flow efficiency coefficient of information flow. The formula shows that in the information network, the increase of the path length and the narrowness of the channel will lead to the increase of the transmission resistance, thus affecting the information fluency within the organization. Therefore, optimizing the information transmission path and improving the data flow efficiency is the key to improving the efficiency of organizational operation. In addition, the smoothness of organizational operation is related to load balance, which can be solved by the load optimization equation:

$$F_{eq} = \frac{\sum_{i=1}^{n} F_i W_i}{\sum_{i=1}^{n} W_i} \tag{9}$$

where F_{eq} is the optimal load allocation value of the system, F_i is the load carried by the i-th organizational unit, and W_i is its weight factor. This formula shows that in order to avoid excessive concentration or uneven distribution of resources, the organization should carry out reasonable load distribution based on the carrying capacity of each unit to reduce the waste of resources and improve the stability of the organization as a whole. The dynamic adjustment mechanism determines the organization's ability to adapt to changes in the external environment, and its rate of adjustment can be represented by an adaptive feedback model:

$$S(t+1) = S(t) + \lambda\left(\frac{D(t)}{R(t)} - 1\right) \tag{10}$$

where $S(t)$ is the current operating state of the organization, λ is the adjustment coefficient, $D(t)$ represents the demand of farmers, and $R(t)$ is the resource supply of the organization. The equation describes the automatic adjustment process of the organization's operation when the external demand changes. When the demand is higher than the resource supply, the organization will increase the resource input, and vice versa, it will reduce the supply so as to achieve the dynamic balance of supply and demand [15]. The optimization model of organizational operational efficiency based on the principle of biomechanics can realize the efficient operation of agricultural social service organizations through the system energy distribution, information flow resistance, load balance and dynamic adjustment mechanism. Through quantitative calculations, the organization can accurately predict the internal energy consumption of the system, optimize the information flow path, balance the load of resources, and dynamically adjust the relationship between supply and demand so as to ensure its long-term stability and efficient adaptability in the agricultural production environment.

5. Experimental results and analysis

5.1. Experimental area selection and choice

The experimental data come from three typical agricultural areas, namely, the North China Plain, the Middle Yangtze River Plain and the Northeast Plain, and the specific data include the density of socialized service supply, the rate of resource flow and the index of farmers' demand fitness. In order to ensure the accuracy and representativeness of the data, the study adopts a variety of data collection methods, including field research, questionnaire surveys of farmers, and operational data collection of agricultural socialized service organizations. For the density of socialized service supply, field counts of service organizations per square kilometer were conducted to ensure coverage of different sizes and types of service entities. Resource flow rate is measured by collecting actual data on the flow of agricultural resources in each region and quantitatively analyzing the flow of resources by using a flow measurement tool, with a one-year data collection cycle. Farmers' demand fitness index, on the other hand, is dynamically measured through regular interviews and data feedback, combined with statistics on farmers' demand changes and service response time. In addition, all data were cleaned and validated to ensure the accuracy and reproducibility of the study results.

The North China Plain (35° N–40° N, 113° E–120° E) is the core region for the transformation of China's agricultural socialized service model, with a high degree of agricultural operation scale, strong demand for mechanization, and the main problems of water resource pressure and intensive land use. The middle reaches of the Yangtze River (27° N–32° N, 110° E–118° E) have a strong capacity for comprehensive agricultural services, which is mainly characterized by a large proportion of small farmers and a high demand for the flexibility and precision of agricultural socialized service organizations. The Northeast Plain (42° N–50° N, 122° E–130° E) is dominated by large-scale mechanized operations, and its agricultural socialized service model is characterized by a high degree of synergism, which puts high demands on the efficiency of factor flows. In terms of data selection, the study is based on regional socialized service system operation data, agricultural production factor distribution data and biomechanical fitness measurement data. The core variables include the supply density of agricultural socialized services (the number of service organizations per unit area), the resource flow rate (the turnover of agricultural resources per unit time) and the farmers' demand fitness index; see **Table 2**.

Table 2. Data on key variables of agricultural socialized service organizations in the experimental region.

study area	Density of socialized service provision (units/km^2)	Resource flow rate (tons/day)	Farmers' demand fitness index (0–1)
North China plain	3.8	275.4	0.72
Plain in the middle reaches of the Yangtze River	5.2	324.7	0.81
Tohoku Plain	2.9	198.6	0.68

The data in **Table 2** illustrate that the densities of socialized service supply are 3.8/km^2 in the North China Plain, 5.2/km^2 in the middle reaches of the Yangtze River Plain, and 2.9/km^2 in the Northeast Plain, respectively; the rates of resource flow are 275.4 tons/day in the North China Plain, 324.7 tons/day in the middle reaches of the Yangtze River Plain, and 198.6 tons/day in the Northeast Plain; and the fitness indices of farmers' demand are measured through the data of the farmer household survey. The fitness index of the middle reaches of the Yangtze River Plain is the highest at 0.83, and the shortest response time of farmers' demand is 5.7 h. To further enrich the diversity of data, questionnaire surveys from 5000 farmers and in-depth interviews with a sample of 300 farmers were also integrated, and the overall satisfaction rating of farmers with the service was 78.5 out of 100. In addition, the study conducted a comparative analysis with the agricultural service models of other countries (e.g., the U.S., Brazil, and India) and found that the resource flow rate in the U.S. was 430 tons/day, in Brazil was 350 tons/day, and in India was 210 tons/day, which provides a cross-country comparative perspective and helps to reveal the differences in the service models in different policy contexts and agricultural environments. All data have been rigorously validated to ensure their accuracy and reliability.

5.2. Model validation and parameter estimation

The core of the model validation is to test the biomechanical fitness of the agricultural socialized service organization model through quantitative analysis, and to ensure that its parameter estimation is scientific and stable. The validation process adopts structural stability assessment, resource flow effectiveness measurement and fitness function fitting to quantify the dynamic characteristics of the organization's operation. The structural stability validation is based on the node connectivity and load balance index of the agricultural socialized service organization to ensure that the network topology has the force balance characteristics of biological systems. Resource flow efficacy measurement analyzes the precision of resource allocation within the organization through the factor transmission rate and path optimization parameters. The fitness function fitting adopts a non-linear regression method to calculate the contribution of different variables to organizational fitness in order to optimize the model parameters; see **Table 3**.

Table 3. Estimates of the parameters of the model of the organization of agricultural socialization services.

variable name	estimated value	Confidence interval (95%)	Contribution of variables (%)
Structural stability	0.84	(0.78, 0.89)	31.2
Load Balancing Index	73.5	(69.1, 77.2)	24.8
Resource flow rate	312.7	(298.3, 328.4)	28.5
fitness function	0.79	(0.74, 0.83)	15.5

The data in **Table 3** show that structural stability contributes the most to model fitness, indicating that the network connectivity of the organizational model has a decisive impact on the overall effectiveness. The load balance index and resource flow rate have a high impact on the optimization results, proving the necessity of accurately matching the needs of farmers and rationally allocating resources. The estimated value of the fitness function is close to 1, indicating that the model can better reflect the operational characteristics of agricultural socialized service organizations.

5.3. Results of the evaluation of the fitness of the organizational model

Based on the principle of biomechanics, the evaluation of the adaptability of organizational models takes structural stability, resource flow efficiency and functional synergy as the core indicators to measure the adaptive characteristics of agricultural socialized service organizations in different regions. By constructing a quantitative evaluation system, we can systematically analyze the stability and adaptability of the organizational model in the dynamic environment. Structural stability analysis shows that the network topological characteristics of agricultural socialized service organizations in different regions directly affect their resource integration efficiency. Its stability can be quantitatively evaluated by calculating the organization node connectivity, load balance index and fitness, as shown in **Table 4**.

From the structural stability evaluation data in **Table 4**, there are obvious differences in network connectivity and load balance of agricultural socialized service organizations in different regions. Among them, the organization node connectivity of the middle reaches plain of the Yangtze River is 0.88, the load balance index is 78.5, and the composite index of fitness reaches 0.83, which indicates that its socialized service organization has a stable structure and a strong ability to balance the allocation of resources, and it can be better adapted to the needs of agricultural production. The organizational node connectivity of the North China Plain is 0.82, and the composite index of fitness is 0.79. Although the structural stability is higher, the load balance index is slightly lower than that of the middle reaches of the Yangtze River, indicating that there is still room for optimization of its resource allocation. The organizational node connectivity of the Northeast Plain is only 0.76, with a load balance index of 69.7 and the lowest fitness composite index (0.75), reflecting the weak network connectivity of socialized service organizations in the region, which leads to an unbalanced distribution of resources among different farmers and affects the overall stability of the organizational model. Resource flow and functional coordination capacity determine the adaptability of the organizational model to the needs of farm households. Resource flow efficiency and functional coordination can be measured by resource flow rate, information transmission efficiency and response time to farmers' needs, as shown in **Table 5**.

Table 4. Structural stability evaluation of the organizational model.

Table 4. Structural stability evaluation of the organizational model.

study area	Organizational node connectivity (0–1)	Load Balancing Index (0–100)	Fitness composite index (0–1)
North China plain	0.82	74.3	0.79
Plain in the middle reaches of the Yangtze River	0.88	78.5	0.83
Tohoku Plain	0.76	69.7	0.75

Table 5. Evaluation of resource flows and functional synergies.

study area	Resource flow rate (tons/day)	Information transmission efficiency (bit/s)	Farmer demand response time (hours)
North China plain	275.4	4.82	6.3
Plain in the middle reaches of the Yangtze River	324.7	5.21	5.7
Tohoku Plain	198.6	4.36	7.2

The resource flow and functional synergy evaluation data in **Table 5** show that the middle reaches of the Yangtze River plain have the highest resource flow rate (324.7 tons/day), the highest information transmission efficiency (5.21 bit/s), and the shortest response time to farmers' demand (5.7 h), indicating that the agricultural socialized service organizations in the region have a strong coordinating ability in resource flow and information sharing, which helps to reduce farmers' access to time cost of agricultural services and improve the efficiency of matching supply and demand. The resource flow rate (275.4 tons/day) and information transmission efficiency (4.82 bit/s) of the North China Plain are slightly lower than those of the Middle Reaches of the Yangtze River Plain, and the response time to farmers' demand is 6.3 h, indicating that there is still room for improvement of its organizational model in terms of resource mobility and information interaction. The Northeast Plain has the lowest resource mobility rate (198.6 tons/day), relatively low information transmission efficiency (4.36 bit/s), and the longest response time to farmers' demand (7.2 h), reflecting the low efficiency of socialized service organizations in this region in terms of information flow and resource allocation, which makes it difficult for farmers to obtain the services they need in a timely manner, and the suitability of the services needs to be improved.

5.4. Analysis of farmers' satisfaction

Farmers' satisfaction is an important indicator for measuring the adaptability of agricultural socialized service organization models, the core of which lies in the precision of resource supply, service response efficiency and stability of organization operation. Based on the theory of biomechanics, the formation process of farmers' satisfaction is similar to the adaptation mechanism of biological systems to the external mechanical environment, i.e., through continuous optimization of the service structure, to improve the matching degree of supply and demand, in order to maintain the stability of the agricultural production system. The level of farmers' satisfaction is mainly affected by the timeliness of resource supply, service quality and the synergistic ability of the organizational model. In order to further quantitatively analyze the satisfaction of farmers with the socialized service model in different regions, a satisfaction measurement system is constructed, and the service supply satisfaction, information transfer efficiency and comprehensive fitness index are calculated, and the data results are shown in **Table 6**.

Table 6. Results of farmers' satisfaction evaluation.

study area	Satisfaction with service provision (0–100)	Messaging efficiency (bit/s)	Composite fitness index (0–1)
North China plain	78.4	4.67	0.76
Plain in the middle reaches of the Yangtze River	84.2	5.12	0.81
Tohoku Plain	72.5	4.32	0.73

The data in **Table 6** show that farmers in the middle reaches of the Yangtze River plain have the highest satisfaction, with a service supply satisfaction of 84.2, an information transfer efficiency of 5.12 bit/s, and a comprehensive fitness index of 0.81, indicating that the socialized service organization model of the region has a strong advantage in terms of service precision and information interaction. The North China Plain has the second highest level of satisfaction, with a service supply satisfaction of 78.4 and a comprehensive fitness index of 0.76, indicating that the resource allocation capacity is high but there is still room for optimization. The satisfaction level of the Northeast Plain is relatively low, with a composite fitness index of 0.73, reflecting that its socialized service organizations still have certain limitations in terms of the fitness of farmers' needs. Overall, the precision of service supply is positively correlated with farmers' satisfaction, and enhancing the coordination of resource flow while improving the stability of organizational operation is the key to optimizing the organizational model of agricultural socialized services.

5.5. Measurement of the efficiency of operational mechanisms

The efficiency of the operating mechanism of agricultural socialized service organizations directly affects the rationality and stability of their resource allocation. Based on the principle of biomechanics, the operation mechanism needs to meet the three core requirements of mechanical balance, structural optimization and dynamic adaptability to ensure that each functional unit achieves synergy and improves overall efficiency in the operation process. Mechanical equilibrium requires that the flow of services, funds and resources within the organization maintain a stable dynamic distribution, similar to the homeostatic adjustment mechanism of biological systems in a stressful environment. Structural optimization emphasizes adjusting the topology of the organizational network to shorten the path of resource supply, thus reducing the internal friction of the system and improving the smoothness of operation. Dynamic adaptability, on the other hand, relies on the feedback regulation mechanism to enable agricultural social service organizations to adjust their supply strategies in a timely manner according to changes in the external environment in order to maintain the long-term stability of the system. In order to quantitatively analyze the operational efficiency, it is necessary to measure the stability of the organizational network, the resource circulation rate and the dynamic adjustment capacity. **Table 7** statistics of the measurement results of different operational parameters and quantitative analysis of their fitness:

Table 7. Measurement of operational parameters of agricultural socialized service organizations.

operating parameter	**Indicator averages**	**(statistics) standard deviation**	**Fitness index (0–1)**
Organizational network connectivity	0.85	0.07	0.82
Resource flow rate	310.2	18.3	0.79
Load Balancing Index	75.8	5.6	0.81

As can be seen from the results in **Table 7**, the fitness index of organizational network connectivity is the highest (0.82), indicating that a reasonable topology helps to optimize the resource transmission path and improve the operational efficiency of agricultural socialized service organizations. Meanwhile, the fitness index of the resource circulation rate is slightly lower (0.79), indicating that in the actual operation process, resource flow is still affected by external factors and further optimization of the circulation chain is needed. The load balance index reaches 75.8%, and the fitness index is 0.81, indicating that the resource placement of agricultural socialized service organizations still needs to be deployed more accurately between different regions to ensure the rationality of load distribution. In addition, in order to optimize operational efficiency, agricultural socialized service organizations need to improve the efficiency of information transmission to ensure a synergistic match between farmers' demand and service supply. The stability of information transmission directly determines the response speed of the service system, and **Table 8** measures the operation of different transmission indicators:

As can be seen from **Table 8**, the stability index of feedback response time is the highest (0.87), indicating that the agricultural socialized service organization has a strong information interaction ability and is able to achieve the matching of farmers' needs and service resources in a short period of time. The mean value of data flow rate is 5.4 Mbps, and the stability index is 0.84, indicating that the transmission of information flow is smooth, but bandwidth resources still need to be optimized to further improve the efficiency of data transmission. The stability index of transmission delay is relatively low (0.80), indicating the existence of information lag in some links, and the need to improve the signal transmission mechanism to reduce time loss and improve service accuracy. Dynamic adjustment ability determines the organization's adaptability to changes in the external environment. Agricultural socialized service organizations need to dynamically adjust the supply of resources according to the fluctuation of farmers' demand in order to achieve a balance between supply and demand, as shown in **Table 9**.

Table 8. Measurement of information transmission efficiency of agricultural social service organizations.

Information transmission indicators	Indicator averages	(statistics) standard deviation	Transmission Stability Index (0–1)
data stream rate	5.4	0.6	0.84
Feedback response time	1.8	0.3	0.87
transmission delay	12.5	2.1	0.8

Table 9. Measurement of the dynamic adaptive capacity of agricultural social service organizations.

Adaptive variables	Indicator averages	(statistics) standard deviation	Adaptability index (0–1)
Match between supply and demand for resources	0.83	0.05	0.85
Organizational regulation of response speed	4.2	0.8	0.82
Resource placement adjustment rate	18.7	3.2	0.79

From the analysis of 3, the index of adaptability of matching the supply and demand of resources is the highest (0.85), indicating that agricultural socialized service organizations perform more stably in the dynamic matching of supply and demand. However, the index of the organization's adjustment response rate (0.82) indicates that there is still a certain delay in the supply of some services, and it is necessary to optimize the adjustment mechanism and improve the flexibility of adjustment. In addition, the adaptability index of the adjustment rate of resource placement is relatively low (0.79), indicating that agricultural socialized service organizations still need to further improve their precision in optimizing the placement path to better adapt to the changes in farmers' demand. The operational efficiency of agricultural socialized service organizations is relatively stable in terms of organizational network connectivity, information transmission efficiency and dynamic adaptive capacity, but further adjustments are still needed for optimization of resource flow, stability of data flow and precision of matching supply and demand.

Although the optimized application of the biomechanical principles proposed in this study provides an efficient operation mechanism for agricultural social service organizations, the results are still somewhat region-specific. The study mainly focuses on typical agricultural areas such as the North China Plain, the Middle Yangtze River Plain, and the Northeast Plain, and thus the applicability of its model and methods may be affected by regional differences. Especially in the application in non-plain areas or other countries, it needs to be adapted to the local ecological environment and agricultural production characteristics. The resource flow characteristics of mountainous or tropical regions differ significantly from those of plains regions, so the model may not be as effective as expected in these regions. In addition, with the diversification of global agricultural environments, future research should explore how to extend this framework to other regions and countries and verify its generalizability and operability.

6. Conclusion

Biomechanics theory provides an important theoretical support for the optimization of agricultural socialized service organization mode, which improves the accuracy and stability of agricultural service system through mechanical balance, structural optimization and dynamic adaptability. The efficient matching of agricultural production factors depends on the optimization of resource flow, functional synergy and feedback regulation, which ensures that the service organization can continuously adapt to the changes of farmers' needs in the complex environment. In addition to the field of agricultural socialized services, biomechanics theory also shows broad application prospects in other agricultural fields such as precision agriculture, crop growth modeling and optimal design of agricultural machinery. For example, optimizing the operating efficiency of agricultural machinery and crop growth dynamics through biomechanical principles can further improve resource utilization and reduce environmental impact. Combined with multi-dimensional data analysis to optimize the resource allocation strategy, and deepen the intelligent regulation mechanism, in order to improve the operational efficiency of agricultural socialized service organizations, and promote the stable development of the agricultural modernization system.

Author contributions: Conceptualization, SN and GL; methodology, SN; software, SN; validation, SN and GL; formal analysis, SN; investigation, SN; resources, SN; data curation, SN; writing—original draft preparation, SN; writing—review and editing, SN; visualization, SN; supervision, SN; project administration, SN; funding acquisition, GL. All authors have read and agreed to the published version of the manuscript.

Ethical approval: Not applicable.

Conflict of interest: The authors declare no conflict of interest.

References

1. Li R, Chen J, Xu D. The Impact of Agricultural Socialized Service on Grain Production: Evidence from Rural China. Agriculture. 2024; 14(5): 785. doi: 10.3390/agriculture14050785
2. Li P, He L, Zhang J, et al. Research on the Impact of Agricultural Socialization Services on the Ecological Efficiency of Agricultural Land Use. Land. 2024; 13(6): 853. doi: 10.3390/land13060853
3. Wang L, Lyu J, Zhang J. Explicating the Role of Agricultural Socialized Services on Chemical Fertilizer Use Reduction: Evidence from China Using a Double Machine Learning Model. Agriculture. 2024; 14(12): 2148. doi: 10.3390/agriculture14122148
4. Yao W, Zhu Y, Liu S, et al. Can Agricultural Socialized Services Promote Agricultural Green Total Factor Productivity?

From the Perspective of Production Factor Allocation. Sustainability. 2024; 16(19): 8425. doi: 10.3390/su16198425
5. Zahid N. Unlocking Agricultural Modernization: Economic Factors Shaping Maize Farmers' Adoption of Outsourced Services. International Journal of Agriculture and Sustainable Development. 2024; 6(1): 52-61.
6. Cheng Y, Zhang D. Theoretical framework and research prospects on the green development effect of agricultural socialization services. Chinese Journal of Eco-Agriculture. 2024; 32(3): 546-558. doi: 10.12357/cjea.20230434
7. Zhang B. The Impact of Organization Differences on the Coupling of Agricultural Production Trusteeship and Small Farmers: Based on the Pilot Case Study of National Agricultural Socialization Service in Anhui Province. Journal of Yunnan Agricultural University (Social Science). 2024; 18(2): 1-7. doi: 10.12371/j.ynau(s).202309053
8. Zhang YF, Zhang YH. Green pesticide practices and sustainability: empirical insights into agricultural services in China. International Journal of Agricultural Sustainability. 2024; 22(1). doi: 10.1080/14735903.2024.2306713
9. Yao R, Ma Z, Wu H, et al. Mechanism and Measurement of the Effects of Industrial Agglomeration on Agricultural Economic Resilience. Agriculture. 2024; 14(3): 337. doi: 10.3390/agriculture14030337
10. Chen X, Zhao L, Liu K. The role of specialization in increasing farmers' income: Horizontal or vertical? Engineering Reports. 2023; 6(5). doi: 10.1002/eng2.12761
11. Waithaka B. Policies and Mechanisms for Providing Insurance and Risk Management Tools to Livestock Farmers to Protect Them against Production Risks. Journal of Livestock Policy. 2024; 3(1): 31-41. doi: 10.47604/jlp.v3i1.2518
12. Ufua DE, Itai M, Kumar A, et al. Achieving operational resilience through kaizen practice: a case in a commercial livestock farm in Nigeria. The TQM Journal. 2023; 36(4): 1092-1112. doi: 10.1108/tqm-01-2023-0013
13. Zhao G, Vazquez-Noguerol M, Liu S, et al. Agri-food supply chain resilience strategies for preparing, responding, recovering, and adapting in relation to unexpected crisis: A cross-country comparative analysis from the COVID-19 pandemic. Journal of Business Logistics. 2023; 45(1). doi: 10.1111/jbl.12361
14. Zhang Y, Zheng Y, Xu J. The Impact of Agricultural Technology Services on the Efficiency of Green Grain Production: An Analysis Based on the Generalized Stochastic Forest Model. Journal of Resources and Ecology. 2024; 15(2). doi: 10.5814/j.issn.1674-764x.2024.02.001
15. Song D, Chen F, Ouyang X. The Impact of Changes in Rural Family Structure on Agricultural Productivity and Efficiency: Evidence from Rice Farmers in China. Sustainability. 2024; 16(10): 3892. doi: 10.3390/su16103892