

Study on Multifunctional Development Models of Urban Agriculture Based on Multidimensional Evaluation Model: Postprint

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Abstract

Cities and urban agriculture constitute a unified system through functional complementarity and promotion mechanisms, wherein multifunctionality represents a significant connotation manifested when urban agriculture integrates into urban economic, social, ecological, and spatial systems. However, Chinese cities exhibit pronounced regional disparities across the eastern, central, and western regions in terms of natural environment, resource endowment, development foundation, and comprehensive strength, resulting in varying emphases in urban agricultural function development and consequently diverse multifunctional development models of urban agriculture. Evaluating the current status and rationality of urban agriculture multifunctional development and exploring suitable multifunctional development models for different regional cities in China can facilitate the coordination between urban functions and urban agricultural functions and enable the formulation of context-specific multifunctional development strategies. How to coordinate urban functions with urban agricultural functions constitutes an urgent issue requiring exploration for achieving regional sustainable development. This paper employs a four-dimensional evaluation model to quantitatively assess the production, economic, social, and ecological functions of urban agriculture across 22 Chinese cities, and utilizes hierarchical clustering based on different combination types among these four functions to classify China's urban agriculture into ten categories of multifunctional development models. The findings indicate that, influenced by spatial differentiations in China's natural environment and socio-economic development levels across the eastern, central, and western regions, both the development level of individual functions and the comprehensive multifunctional level of urban agriculture demonstrate significant variations among cities, generally exhibiting an east-central-west regional differentiation pattern. From western Chinese cities to central and eastern cities, urban agriculture development models gradually transition from weak multifunctional synergy models to basic synergy, synergy,

and strong synergy development models, shifting from ecological priority development models to socio-ecological dominant development models and to development models dominated by production (or economic or social) functions based on ecology. For cities whose urban agriculture development models belong to the ecological priority development model, the ecological function development level has reached above 0.40; for those belonging to the social priority development model, the social function development level exceeds 0.55; for those belonging to the economic priority development model, the economic function development level approaches 0.80; and for those belonging to the production priority development model, the production function development level reaches 0.75.

Full Text

Preamble

Exploring Multifunctional Development Models of Urban Agriculture Based on a Multi-dimensional Evaluation Model

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Abstract

Urban development and urban agriculture constitutes an integrated system due to the complicated interaction mechanism of functional complementation and promotion. The multi-functionality of agriculture has been increasingly highlighted during urbanization and the gradual integration of urban agriculture into urban economic, social and ecological development and spatial formation. Urban development, encompassing the natural environment, resource endowment, development foundation and comprehensive strength, is significantly different in the eastern, central and western regions of China. Therefore, diversified development models have been tailored for urban agriculture constantly highlighting the related advantages and characteristics in different regions of China. Evaluating the developing rationality and current characteristics of urban agricultural multi-functionality and exploring the related development models suitable for specific regions are helpful in coordinating urban functions, urban agricultural multi-functions and for formulating urban agriculture development strategies based on region-specific conditions. It is necessary to coordinate the development between urban functions and functions produced by urban agriculture for sustainable development of urbanization areas. We quantitatively assessed urban agriculture multifunction from the aspects of production function, economic function, social function and ecological services in 22 cities of China using a four-dimension evaluation model. We classified and proposed ten development models of multifunctional development of urban agriculture based on the assembly of the related four functions using the system clustering method. The research

showed that an individual or comprehensive functions provided by urban agriculture presented obvious differences among the eastern, central and western regions of China. This was due to the differentiation of natural environment, and social and economic development of different regions. From cities in the western region of China to cities in the central and eastern regions, urban agriculture multifunction development models shifted gradually from weakly coordinated development to generally coordinated development and then to strongly coordinated development. It shifted gradually from ecological priority development to predominantly social and ecological development model and then to production, social and economic development model. The development level of ecological services of urban agriculture exceeded 0.40 for cities with the model of ecological priority development. Then, the development level of social functions of urban agriculture was more than 0.55 in cities with the model of social priority development. Next, the development level of economic functions of urban agriculture reached 0.80 in cities for which the model was economic priority development. Finally, the development level of production of urban agriculture reached 0.75 in cities for which the model was provisioning priority development. This series of multi-functional urban agricultural development models suggested that multi-dimensional evaluation method actually reflected the development level of urban agriculture multifunction and the related regional differences in China. Furthermore, it not only provided accurate measurements for evaluation of development degree of urban agricultural functions under different urbanization level, but also clearly indicated the development of the internal structure of urban agricultural services and functions in each city and the related development merits and demerits. The research had important implications for the optimization of urban agricultural multifunction, scientific adjustment of urban agriculture structure, and implementation of coordinated policies on the development of urban agriculture multifunction with the development of urban socio-economy.

Keywords

Urban agriculture; Multifunction; Development model; Regional difference; Multi-dimensional evaluation

Method

Urban agriculture refers to agriculture distributed in highly urbanized metropolitan areas and their extended zones. Relying on urban radiation and developed according to urban demands, it is a modern agricultural system that integrates multiple functions including production, living, and ecology, characterized by high-level scaling, industrialization, technological advancement, and market orientation [1-5]. Rapid urbanization in China has triggered a series of economic, social, and environmental problems that significantly impact urban agriculture development. Currently, urban agriculture in China faces severe challenges including lack of planning, environmental vulnerability, insufficient funding, confused functional positioning, low specialization, slow industrialization, and

outdated systems, which are extremely uncoordinated with rapid urbanization development. How to develop urban agriculture that coordinates with urbanization and achieve sustainable urban-rural development has been a hot topic among Chinese scholars [6-7]. In recent years, significant progress has been made in research areas including summarizing foreign development experiences [8-9], evaluating development levels [10], industrial spatial layout and optimization [11], functional spatial distribution patterns [5,12], ecological security assessment [13], and development models [14] and mechanisms [15].

Cities and urban agriculture form a unified system through functional complementation and promotion mechanisms, with multifunctionality representing a significant connotation of urban agriculture' s integration into urban economic, social, ecological, and spatial systems [16-17]. Based on related research [11,18], this paper defines urban agriculture multifunctionality as the diverse functions of urban agriculture integrated into urban systems, including safe food supply, ecological conservation, sightseeing and leisure, demonstration and radiation, social stability assurance, urban-rural integrated development, and reservation of urban development space, encompassing production, economic, social, and ecological functions. Practice has demonstrated that agricultural market and production layouts in urban regions are gradually integrating, with diminishing space for economically-driven structural adjustments and slow growth in production economic benefits. The key to breaking this bottleneck lies in the transformation of urban agriculture toward multifunctionality. Cultivating multifunctionality in urban agriculture represents an inevitable development trend and concerns regional sustainable development capacity [19]. Many scholars have conducted extensive research from the perspective of urban agriculture multifunctionality, combining it with China' s urban agriculture development practice, progressing from initial functional connotation descriptions to functional positioning [20], functional zoning [21], and functional spatial distribution patterns [5,12]. Research indicates that the selection and structure of urban agriculture functions are determined by a comprehensive system composed of urban society, economy, environment, and space. Consequently, functional selection and structure differ significantly across different development stages of the same city and among different cities during the same period. The multiple functions of urban agriculture transition toward an optimal coupling state of diverse functions through a series of agricultural activities [20,22], ultimately forming functional combination patterns suited to urban development characteristics—namely, urban agriculture multifunctional development models. Evaluating the current status and rationality of urban agriculture multifunctional development and exploring suitable models for different regional cities in China undoubtedly helps coordinate urban functions with urban agriculture functions and formulate development strategies tailored to local conditions.

China' s cities exhibit obvious regional differences in natural environment, resource endowment, development foundation, and comprehensive strength across eastern, central, and western regions, leading to different emphases in urban agriculture functional development and the formation of diverse urban agriculture

multifunctional development models. Current research on agricultural development models has focused on modern agriculture development models [23-24], eco-agriculture development models [25-26], and low-carbon agriculture development models [27-28], among others. However, few studies have examined the regional differences and sustainability of China's urban agriculture multifunctional development models. Based on a multi-dimensional evaluation model, this paper constructs an urban agriculture functional evaluation index system, taking 22 representative Chinese cities as research objects, to explore spatial differentiation characteristics of urban agriculture functional development levels and multifunctional development models. This research holds important practical significance for addressing current problems in China's urban agriculture development, including confused functional positioning, unreasonable structure, and mismatch with urban development characteristics.

1.1 Data Sources

This study selected 22 Chinese cities as research objects. Geographically, these include eastern region cities: Beijing, Shanghai, Tianjin, Guangzhou, Hangzhou, Nanjing, Suzhou, Fuzhou, Ningbo, Jinan, Shenyang, and Qingdao; central region cities: Wuhan, Hefei, Zhengzhou, Nanchang, Taiyuan, and Changsha; and western region cities: Chengdu, Xi'an, Kunming, and Lanzhou. These cities exhibit substantial differences in comprehensive urban strength, resource endowment, and urban agriculture development levels, enabling them to represent the urban agriculture development status across different Chinese cities. Data were obtained from the 2014 statistical yearbooks of these cities and relevant government websites.

1.2.1 Construction of Evaluation Index System

Multi-dimensional evaluation models possess a hierarchical structure that allows analysis of research objects from different perspectives [29], which helps reflect the complex composition of urban agriculture multifunctionality. This paper constructed a multi-dimensional evaluation model for urban agriculture multifunctionality [29-30], using the value of each dimension to represent the corresponding functional development level. The polygon area formed by values of all dimensions serves as the comprehensive evaluation value for urban agriculture multifunctionality, with larger values indicating more significant multifunctionality. This model can intuitively reflect the dominant and weak functions of urban agriculture in individual cities and enable comparative studies among cities regarding specific functions or comprehensive multifunctional development levels.

Based on principles of comprehensiveness, dominance, operability, and data availability, an evaluation index system was established from four dimensions: production function, economic function, social function, and ecological function of urban agriculture (Table 1).

Table 1 Evaluation index system for urban agriculture multifunctionality

Service	Index	Calculation method	Weight(wij)	Efficiency
Production function	Cultivated land productivity (x11)	Total production value of the urban agriculture / area of cultivated land		
	Agricultural labor productivity (x12)	Agricultural gross output value / number of labours in farming, forestry, animal husbandry and fishery		
	Agricultural and sideline products amount per capita (x13)	Amount of agricultural and sideline products / total population of city		
	Per capita output of urban agricultural sector (x14)	Agricultural gross output value / total population of city		
Economic function	Per capita net income of rural households (x21)	Data from statistical yearbook		

Service	Index	Calculation method	Weight(wij)	Efficiency
Social function	Total export value of urban agricultural sector (x22)	Data from statistical yearbook		
	Agricultural products processing value-added (x23)	Agricultural and sideline products processing industry production value / agricultural gross output value		
	Proportion of urban agricultural output value to GDP (x24)	Agricultural gross output value / GDP of the city		
	Total value of employment of urban agriculture (x31)	Number of labours in village × per capita net income of rural households		
	Rural employment structure level (x32)	Number of labours in farming, forestry, animal husbandry and fishery / number of labours in village		

Service	Index	Calculation method	Weight(wij)	Efficiency
	Income ratio of urban to rural residents (x33)	Per capita disposable income of urban households / per capita disposable income of rural households		
	Engle Coefficient ratio of urban to rural residents (x34)	Urban residents Engle Coefficient / rural residents Engle Coefficient		
	National and provincial modern agricultural demonstration park number (x35)			
	Agricultural modernization level (x36)	Total power of agricultural machinery / area of cultivated land		
	Proportion of rural female laborers (x37)	Number of rural female laborers / total number of rural laborers		

Service	Index	Calculation method	Weight(wij)	Efficiency
Ecological service	Recreation value of urban agriculture (x38)[31]	Total value of agro-ecosystem service $\times 0.075$		
	Urban tourism production efficiency (x39)	Total value of urban tourism industry / number of labours in farming, forestry, animal husbandry and fishery		
	Per capita public green areas (x41)	Data from statistical yearbook		
	Forest coverage rate (x42)	Forestland area / total area of the urban land		
	Cultivated land coverage (x43)	Area of cultivated land / total area of the urban land		
	Ecosystem service value per capita (x44)[32]	Total value of agricultural ecosystem service / total area of the urban land		
Intensity of fertilizer application (x45)	Amount of chemical fertilizer input / area of cultivated land			

“+” refers to positive effect index, “-” refers to negative effect index.

1.2.2 Evaluation of Urban Agriculture Function Development Level

This paper adopts the entropy method to determine index weights. The entropy method determines weights based on the amount of information transmitted to decision-makers by each index, which can profoundly reflect the utility value of index information entropy. The weights obtained through this method are more reliable than those from analytic hierarchy process and expert evaluation methods, making it suitable for comprehensive evaluation of multiple indicators [33-34].

The calculation process for urban agriculture function development level evaluation values proceeds as follows: First, the efficacy function method is applied to standardize raw data [35]; second, the development level x_i of the i th function for each evaluation unit is calculated through formula (1). ($i=1, 2, 3, 4$) (1) Where: x_i represents the development level of the i th function, w_{ij} represents the weight of the j th index for the i th function, and x_{ij} represents the j th evaluation index of the i th function.

1.3 Scenario Pattern Clustering of Evaluation Results

Using systematic clustering analysis, this study conducted cluster analysis on the multifunctional evaluation results of urban agriculture for the 22 research objects based on combinations of the four functional development levels. Combined with comprehensive urban agriculture function levels, this classification yielded urban agriculture multifunctional development models. By analyzing and evaluating the formation causes and sustainability capacity of various development models, reasonable suggestions for optimizing urban agriculture functions are proposed.

Results and Analysis

2.1 Urban Agriculture Functions by City

The development levels of urban agriculture production, economic, social, and ecological functions exhibit significant differences.

2.1.1 Analysis of Urban Agriculture Production Function Based on urban agriculture function evaluation results (Fig. 1 [Figure 1: see original paper]), cities with lower urban agriculture production functions include eastern megacities such as Beijing, Tianjin, Shanghai, and Guangzhou, as well as central and western cities like Taiyuan, Xi'an, Chengdu, Kunming, and Lanzhou. Cities with higher production functions include Ningbo, Fuzhou, Qingdao, and Jinan. Using the mean value of 0.3 for urban agriculture production function development level as a threshold, 67% of eastern cities exceed the average level, compared to 33% of central cities and 0% of western cities. Apart from eastern megacities, urban agriculture production function generally demonstrates a spatial distribution pattern gradually decreasing from eastern to central and

western cities. As shown in Table 2, the mean values of both cultivated land productivity and labor productivity exhibit the pattern of eastern > central > western, reflecting a spatial distribution trend of decreasing urban agriculture production efficiency from eastern to central and western cities. The mean levels of per capita agricultural and sideline products ownership and per capita urban agricultural output value in eastern cities are higher than those in central and western cities. However, the mean values of these indicators in eastern megacities are far lower than those in central and western cities. Although these megacities have relatively high urban agriculture production efficiency, problems such as drastic reduction of cultivated land resources and huge population size caused by high-level urbanization have further intensified the contradiction between decreasing total production and excessive total demand.

Table 2 Mean values of evaluation indexes of urban agriculture production function of typical cities in different regions of China

Region(x11)	Cultivated land productivity (x12)	Agricultural labor productivity (x13)	Agricultural and sideline products amount per capita (x13)	Per capita output of urban agricultural sector (x14)
Eastern				
Eastern megacities				
Central				
Western				

2.1.2 Analysis of Urban Agriculture Economic Function The economic function of urban agriculture generally shows a pattern of eastern cities > central and western cities, with little difference between central and western cities (Table 3). In terms of mean values, urban agriculture performance in per capita net income of rural households and total agricultural export value follows the pattern of eastern > central > western cities. However, the proportion of urban agriculture added value to urban GDP shows eastern (0.047) < central (0.069) < western (0.072), indicating that the status of urban agriculture in urban economic development follows the pattern of eastern < central < western. Nevertheless, the capacity to increase local farmers' income and drive rural economic development demonstrates a pattern of eastern far exceeding central and western regions, with central and western cities showing insufficient capacity to drive rural economic development through urban agriculture. Therefore, eastern cities should not neglect the significant role of urban agriculture in driving rural economic development due to its low economic status, while central and western cities should prioritize improving urban agriculture production efficiency and enhancing economic functions as major tasks for urban agriculture

development.

Table 3 Mean values of evaluation indexes of urban agriculture economic function of typical cities in different regions of China

	Per capita net income of rural households (x21)	Total export value of urban agricultural sector (x22)	Agricultural products processing value-added (x23)	Proportion of urban agricultural output value to GDP (x24)
Eastern				
Central				
Western				

2.1.3 Analysis of Urban Agriculture Social Function Except for Shenyang in eastern cities and Changsha in central cities, the social function of urban agriculture generally demonstrates a pattern of eastern cities > central and western cities, with central and western cities being roughly similar. However, significant differences exist in five aspects: employment, urban-rural coordination, demonstration and radiation, cultural leisure, and women's status improvement. Based on mean values of urban agriculture employment and demonstration radiation indexes x31, x35, and x36 in Table 4, the total employment value of urban agriculture, agricultural modernization level, and demonstration radiation capacity all show a pattern of eastern > central > western. Indexes x33 and x34 indicate that the urban-rural economic coordination capacity of urban agriculture in eastern and central cities is superior to that in western cities, while the urban-rural living coordination capacity of urban agriculture in eastern and western cities is superior to that in central cities. The mean level of index x37 is basically the same across the three regions, proving that urban agriculture plays a positive and important role in improving women's status in all cities. Indexes x38 and x39 reveal that the cultural inheritance and sightseeing leisure value of urban agriculture in central cities are at the lowest level, while the cultural inheritance value of urban agriculture in western cities is higher than that in eastern regions, but the leisure and sightseeing value is far lower than that in the east.

Table 4 Mean values of evaluation indexes of urban social agriculture function of cities in different regions of China

Total value of employment of urban agriculture culture (x31)	Rural employment structure level (x32)	Income ratio of urban to rural residents (x33)	Engle coefficient of urban to rural residents (x34)	National and provincial modern agricultural demonstration park number (x35)	Proportion of Recreation Urban			
					Agricultural modernization level (x36)	female laborers (x37)	value of urban agriculture (x38)	urban production efficiency (x39)
Eastern								
Central								
Western								

2.1.4 Analysis of Urban Agriculture Ecological Function The ecological function of urban agriculture demonstrates a distribution pattern of eastern and western cities > central cities. High-level urbanization development in eastern cities seriously threatens urban ecological environment security, making it imperative to utilize urban agriculture's ecological service functions. Western cities, constrained by natural conditions, are vulnerable to ecological limitations, so urban agriculture development primarily supports their ecological service functions. Central cities have development levels lower than eastern cities but roughly equivalent to western cities, with relatively weaker natural environmental constraints compared to western cities, resulting in less intense urban demand for urban agriculture ecological functions than in eastern and western regions. As shown in Table 5, the mean per capita green space area in eastern cities reaches 17.31 m² per person, ranking at the highest level, indicating greater emphasis on urban agriculture's role in beautifying the urban environment. The mean per-unit-area ecological service value of urban agriculture in eastern cities reaches 42,693 ten thousand yuan · hm⁻², far exceeding that of central and western cities. Central cities have abundant cultivated land resources and lower urbanization levels than eastern cities, giving them an advantage in cultivated land coverage. However, judging from the maximum fertilizer application level of 1.014 t · hm⁻², urban agriculture faces considerable ecological and environmental security pressure due to overexploitation. Western cities are mostly located in mountainous areas, with mean forest coverage rates higher than those in eastern and central regions, forming an important guarantee for urban ecological environment security. Western cities have fewer cultivated land resources, and factors such as urban development occupying cultivated land result in lower cultivated land coverage. Their fertilizer application amount is 0.466 t · hm⁻², at the lowest level, reflecting stronger local awareness of protecting ecological security of urban agriculture cultivated land resources.

Table 5 Mean values of evaluation indexes of urban ecological agriculture function of typical cities in different regions of China

Region	Per capita public green areas (x41)	Forest coverage rate (x42)	Cultivated land coverage (x43)	Ecosystem service value per capita (x44)	Intensity of fertilizer application (x45)
Eastern					
Central					
Western					

In summary, regarding urban agriculture functional structure, cities where ecological and social functions exceed production and economic functions account for 68% of the total. Most cities' urban agriculture functional structures generally exhibit weakened production and economic functions with prominent ecological and social functions, particularly evident in eastern and western cities. Eastern megacities such as Beijing, Guangzhou, Tianjin, and Shanghai have urban agriculture dominated by social and ecological functions with weakened economic and production functions. Western cities have basically formed structural characteristics of prioritized ecological and social function development with lagging economic and production functions. Some eastern provincial capital cities and central cities have not formed obvious functional structure characteristics, showing small differences among functions and presenting synchronous development features.

2.2 Analysis of Urban Agriculture Multifunctional Development Models

The multifunctional attributes of urban agriculture have gradually been recognized by cities with diversified and advanced demands and actively implemented in practice. However, due to the complex composition of urban agriculture multifunctionality, numerous influencing factors, and differences in cities' own development status and goals, the comprehensive performance of urban agriculture multifunctionality varies significantly among cities. Various cities have formed urban agriculture development models based on multifunctionality while exploring how to scientifically handle the complex relationships among numerous functions. By decomposing and evaluating the composition of urban agriculture multifunctionality in each city, the patterns of urban agriculture multifunctional development models can be explored. In view of this, this paper conducted systematic cluster analysis based on urban agriculture function evaluation results and their combination relationships, classifying the above Chinese cities into ten categories of urban agriculture multifunctional development models, as shown in Table 6 .

Table 6 Classification of development models of urban agriculture multifunction of China

Development Model	City (Production, Economic, Social, Ecological)
Model of multi-functional weakly coordinated development	Taiyuan (0.076, 0.218, 0.267, 0.222)
Model of ecological priority development	Lanzhou (0.098, 0.197, 0.197, 0.233) Xi' an (0.149, 0.276, 0.376, 0.467)
Model of multifunctional relatively coordinated development	Chengdu (0.179, 0.313, 0.386, 0.417) Kunming (0.151, 0.216, 0.319, 0.472) Zhengzhou (0.237, 0.271, 0.357, 0.305)
Model of multifunctional coordinated development	Hefei (0.231, 0.284, 0.242, 0.397) Nanchang (0.221, 0.289, 0.284, 0.365) Nanjing (0.347, 0.280, 0.399, 0.381)
Model of multifunctional strongly coordinated development	Jinan (0.427, 0.276, 0.328, 0.384) Wuhan (0.356, 0.251, 0.411, 0.363) Hangzhou (0.342, 0.350, 0.554, 0.506)
Model of priority to the social and ecological development	Changsha (0.339, 0.321, 0.520, 0.479) Beijing (0.178, 0.400, 0.587, 0.447)
Model of ecological priority social development	Tianjin (0.182, 0.371, 0.550, 0.418) Shanghai (0.147, 0.298, 0.556, 0.479) Guangzhou (0.220, 0.424, 0.672, 0.575) Shenyang (0.391, 0.423, 0.288, 0.578)

Development Model	City (Production, Economic, Social, Ecological)
Model of ecotype but priority to the social development	Ningbo (0.526, 0.425, 0.579, 0.389)
	Suzhou (0.415, 0.508, 0.679, 0.375)
Model of ecotype but priority to the production development	Fuzhou (0.750, 0.413, 0.423, 0.402)
Model of ecotype but priority to the economic development	Qingdao (0.513, 0.780, 0.491, 0.393)

Model of multi-functional weakly coordinated development: This model mainly includes Taiyuan and Lanzhou. Both cities have low comprehensive strength and urban agriculture development levels. Their urban agriculture functions develop synergistically but remain relatively weak, resulting in low comprehensive multifunctional development levels. Since both cities are located in western arid and semi-arid regions, they should focus on ecological service functions of urban agriculture and vigorously develop urban agriculture.

Model of ecological priority development: This model primarily includes western cities such as Xi' an, Chengdu, and Kunming. Due to stronger constraints of natural ecological environment on western city development compared to central and eastern cities, western cities prioritize ecological function development of urban agriculture to serve the city. The ecological function develops preferentially and reaches relatively high levels, while social function development reaches acceptable levels around 0.35. However, production and economic functions are relatively weak and lagging, resulting in low comprehensive multifunctional development levels. Future urban agriculture development should insist on enhancing production and economic functions based on ecological function development to improve comprehensive urban agriculture multifunctional levels.

Model of multifunctional relatively coordinated development: This model mainly includes central cities such as Zhengzhou, Hefei, and Nanchang. The evaluation values of various functions are basically around 0.3, showing characteristics of small differences and coordinated development without forming obvious dominant functions, resulting in low comprehensive multifunctional development levels. These cities face important tasks of comprehensively improving urban agriculture functional levels.

Model of multifunctional coordinated development: This model includes eastern and central cities such as Nanjing, Jinan, and Wuhan. The evaluation

values of various functions are basically around 0.4, with small differences among functions, no obvious dominant functions, and clear synchronous development characteristics, resulting in high multifunctional levels. Future development should insist on taking ecological functions as the foundation and cultivate dominant urban agriculture functions based on regional resource advantages.

Model of multifunctional strongly coordinated development: This model includes Hangzhou and Changsha. All functional development levels are relatively high with small differences, showing prioritized development of social and ecological functions, demonstrating strong coordinated development characteristics, good sustainability, and relatively high comprehensive multifunctional levels.

Model of priority to the social and ecological development: This model mainly includes eastern megacities such as Beijing, Tianjin, Shanghai, and Guangzhou. Urban agriculture development actively emphasizes social and ecological functions that serve urban development, with both functions at high levels and prominent development. Economic functions are acceptable, while production functions are relatively weak, which does not indicate low agricultural production efficiency. The main reason is that large urban populations and scarce cultivated land resources make production functions clearly unable to meet urban demands, though multifunctional levels remain high. The key focus of urban agriculture construction is how to effectively protect cultivated land resources and improve production efficiency to ensure food safety supply for urban residents.

Model of ecological priority social development: This model mainly includes Shenyang, where ecological function development level reaches 0.578, and production and economic functions are acceptable, but social function development level is as low as 0.288, indicating serious functional structure imbalance. Efforts should be made to further improve urban agriculture social service function levels.

Model of ecotype but priority to the social development (Ningbo, Suzhou), Model of ecotype but priority to the production development (Fuzhou), Model of ecotype but priority to the economic development (Qingdao): The common characteristics of these three models are that all functional development levels are relatively high, as are comprehensive multifunctional levels. Structurally, they exhibit lagging ecological functions with prominent development of a single function. However, lagging ecological function does not mean weak ecological function, as levels reach around 0.4, second only to western cities and higher than central cities. These cities have formed development characteristics based on ecological functions but should pay attention to maintaining and improving ecological functions to ensure sustainable urban agriculture development.

The above analysis shows that factors such as comprehensive strength and ecological environmental conditions vary significantly among Chinese cities, leading

to notable differences in specific demands for urban agriculture functions and the levels at which urban agriculture provides various functions. This has ultimately resulted in diversified urban agriculture multifunctional development models with obvious regional differences. Specifically, from western Chinese cities to central and eastern cities, urban agriculture development models gradually shift from weakly coordinated multifunctional models to relatively coordinated, coordinated, and strongly coordinated models, and from ecological priority development models to social-ecological dominant models and models dominated by production (or economic or social) functions based on ecology. The research results on urban agriculture multifunctional development models based on the multi-dimensional evaluation model basically reflect current regional differences in urban agriculture functional development levels and structures in China. The study not only preliminarily measures urban agriculture functional development levels under different urbanization levels but also clearly identifies the current internal functional structure status and advantageous and disadvantageous functions in each city, which can scientifically guide the optimized development of urban agriculture functions and adjustment of urban agriculture industrial structure to achieve coordinated development between urban agriculture functions and urban socio-economic functions.

Conclusions and Discussion

This paper constructed an urban agriculture multifunctional evaluation index system based on a multi-dimensional evaluation model, integrating production, economic, social, and ecological functions of urban agriculture into a comprehensive system. The study evaluated the multifunctional development levels of urban agriculture in 22 Chinese cities and conducted cluster analysis on the evaluation results to obtain urban agriculture multifunctional development models for major Chinese cities. The results indicate that influenced by spatial differences in natural environment and socio-economic development levels among eastern, central, and western regions of China, both individual functional development levels and comprehensive multifunctional levels of urban agriculture show obvious differences among cities, generally presenting a regional differentiation pattern of east, central, and west. From western Chinese cities to central and eastern cities, urban agriculture development models gradually shift from weakly coordinated multifunctional models to relatively coordinated, coordinated, and strongly coordinated models, and from ecological priority development models to social-ecological dominant models and models dominated by production (or economic or social) functions based on ecology.

Urban agricultural resource conditions play a fundamental role in urban agriculture development, while urbanization dominates the evolution of urban agriculture multifunctionality. During urbanization, the total demand and structure for urban agriculture functions in cities tend toward scaling, diversification, and advancement, while factors such as infrastructure expansion, scientific and technological transformation, industrial structure adjustment, and urban land use

conversion constrain urban agriculture activities. Changes in urban agriculture multifunctionality represent an interactive coupling process between cities and regional agricultural resources under urbanization dominance. Consequently, urban agriculture multifunctional development levels differ significantly among different cities during the same development period and across different development periods of the same city. This paper applied a multi-dimensional evaluation model to assess the multifunctional development levels of urban agriculture in 22 Chinese cities and conducted cluster analysis. The results basically conform to the actual situation of urban agriculture functional development in various Chinese cities and objectively reveal the current multifunctional development status of urban agriculture in different cities during the same development period in China, playing an important role in guiding the optimization and adjustment of urban agriculture functions in each city. However, to better guide urban agriculture development, research should also examine the development patterns and models of urban agriculture multifunctionality in the same city across different periods. Urbanization development leads to changes and restructuring of urban agriculture functional structures. When urban agriculture functional output exceeds urban demand, causing resource waste, it hinders urbanization development. Urban agriculture multifunctional development should adhere to achieving a state where urban agriculture functions reasonably meet urban demands under conditions of sustainable agricultural resource development—that is, taking the optimal coupling state of diverse urban agriculture functions as the development goal. However, the premise of this research is that the urban agriculture development status in the above cities reflects a dynamic equilibrium state reached through the self-balancing process between urban systems and urban agriculture systems, which does not equal the optimal coupling state of diverse urban agriculture functions. For instance, excessive demand in eastern megacities such as Shanghai, Beijing, and Tianjin places significant pressure on urban agriculture production functions, while urban agriculture production efficiency contributes to relatively low production functions in western cities. The lagging economic production functions in western cities do not indicate that their satisfaction level for cities is lower than that in central and eastern cities. Therefore, how to measure the optimal coupling development degree of urban agriculture multifunctionality based on cities' own development characteristics to evaluate the quality of current urban agriculture multifunctional development models should become the focus of future research.

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