

Postprint: The Impact of Farmland Transfer on Agricultural Ecosystems

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Abstract

To evaluate the eco-environmental effects of the transformation in agricultural management modes, this study selected a typical farmland transfer area in Rongchang County, Chongqing Municipality. By combining field surveys and energy analysis methods, the inputs and outputs of ordinary smallholder farmers and large-scale operators were respectively used to characterize the inputs and outputs of the agroecosystem before and after farmland transfer, and a comparative analysis was performed on the energy changes in the study area's agroecosystem before and after farmland transfer. The results indicate that following farmland transfer, the purchased energy input of the agroecosystem in the study area decreased by 70.48% compared to pre-transfer levels, while energy output increased by 2.15%. This elevated the net energy yield ratio of the agroecosystem from 0.01 before farmland transfer to 0.04 after transfer, representing a 300% increase. The substitution of agricultural machinery for labor was the primary factor in reducing per-unit input, thereby substantially improving agricultural production efficiency. For individual inputs with a renewable coefficient lower than the system's renewable coefficient, reducing their input quantity can lower the system's environmental loading ratio; for individual inputs with a renewable coefficient higher than the system's renewable coefficient, increasing their input quantity can lower the system's environmental loading ratio. However, changes in individual inputs of the agroecosystem in the study area all resulted in increased environmental pressure. Specifically, labor input decreased substantially, while inputs such as electricity and diesel increased to varying degrees. Consequently, the environmental loading ratio of the agroecosystem in the study area rose from 0.12 before farmland transfer to 0.65 after transfer, an increase of 441.67%; the sustainability index declined from 0.08 before transfer to 0.06 after transfer, with ecological sustainability decreasing by 25.00%. The study reveals that moderate-scale operation can effectively reduce production costs and enhance product market competitiveness; however, the pursuit of high value-added orientation and high yields through

planting structure adjustment has led to substantial increases in purchased resources such as pesticides and chemical fertilizers, exacerbating the potential eco-environmental risks of the agroecosystem. The study concludes that the key to sustainable development of agroecosystems lies in the selection of agricultural intensification development pathways. Therefore, within the policy system guiding farmland transfer and developing moderate-scale operations, the state must provide guidance and impose regulations on this matter.

Full Text

Impact of Farmland Transfer on Agro-Ecosystems*

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Abstract

Farmland transfer, supported by both national and local governments, has significantly promoted the transformation of agricultural management and modernization. The expanding scope and scale of farmland transfer have dramatically altered agricultural industrial structure and input-output patterns, thereby exerting substantial effects on the agro-ecosystem. To assess the eco-environmental consequences of this transformation, this study examined three key dimensions—production efficiency, environmental impact, and overall sustainability of agro-ecosystems—through a case study in Rongchang County, Chongqing, China. The input-output patterns of ordinary farmers and agricultural contractors were analyzed to represent pre- and post-transfer agricultural management systems, respectively. The emergy evaluation method, which integrates different energy forms into a common physical basis known as solar emergy, proved effective for analyzing ecosystem efficiency and sustainability while overcoming limitations of traditional energy analysis by incorporating factors such as natural resources, labor, and ecosystem services often neglected by other methods.

The results demonstrated that after farmland transfer, purchased resource inputs decreased by 70.48% while emergy output increased by 2.15%. Consequently, the emergy yield ratio (EYR) rose from 0.01 before transfer to 0.04 after transfer, representing a 300% improvement. This increase was primarily attributable to agricultural machinery substituting for labor, which reduced overall inputs and enhanced production efficiency. For individual input items, decreasing inputs with renewability factors lower than the system average reduced the environmental loading ratio (ELR), while increasing inputs with higher renewability factors achieved the same effect. However, the dramatic reduction in labor input combined with increased use of pesticides, fertilizers, and other purchased resources intensified environmental pressure. Consequently, the ELR increased from 0.12 to 0.65 (a 441.67% rise), while the emergy sustainability index (ESI) declined from 0.08 to 0.06 (a 25.00% decrease), indicating reduced ecological sustainability.

The study concludes that moderate-scale operations effectively reduce production costs and enhance market competitiveness, yet the pursuit of high yields and high value-added production has substantially increased pesticide and fertilizer use, intensifying potential ecological risks. The key to sustainable agro-ecosystem development lies in careful selection of intensive agricultural development models. Therefore, national policies guiding farmland transfer and moderate-scale operations should provide direction and establish regulations to ensure sustainable outcomes.

Keywords: Farmland transfer; Agroecosystem; Energy evaluation; Production efficiency; Sustainable development

Introduction

Agro-ecosystems constitute the most fundamental system for human survival. Analyzing their structure and function while evaluating and quantifying resource-environment values enhances understanding and protection of agricultural resources and environments. Transformations in agricultural management modes have significantly altered the types and combinations of agricultural production factors in agro-ecosystems, profoundly influencing material and energy flows. For instance, circular agriculture can improve the utilization relationship of matter and energy in farmland ecosystems, reduce environmental pressure, and enhance sustainability. Similarly, three-dimensional agriculture can rationally configure various organisms at different ecological niches to maximize the development and utilization of temporal and spatial niches, thereby improving ecological conditions. Previous research has empirically examined these management types from ecological, environmental, and sustainability perspectives, advancing understanding of agricultural management modes and providing valuable guidance for promoting efficient and sustainable development of agro-ecosystems.

In contrast, farmland transfer and its resulting changes in agricultural management have more universal significance. Farmland transfer has become a policy priority at both central and local levels in recent years, strongly promoting the transformation of agricultural management modes and facilitating moderate-scale operations and agricultural modernization. As the scope and scale of farmland transfer continue expanding, significant changes have occurred in agricultural management modes, industrial structure, and input-output patterns, generating important impacts on agro-ecosystems. However, existing research on farmland transfer has primarily focused on its current status, transfer models, influencing factors, and economic benefits, with limited literature specifically addressing its impacts on agro-ecosystems. This raises critical questions: What changes does farmland transfer bring to farmland ecological environments? How does it affect regional agricultural sustainability? Can it help prevent farmland pollution and ensure agricultural product quality and safety?

To address these questions, this study selected typical farmland transfer areas in Rongchang County, Chongqing, and conducted a comparative energy analysis of agro-ecosystem changes before and after transfer. Based on extensive field surveys, the study examined energy variations from the perspectives of material flow, energy flow, and monetary flow to objectively evaluate the impacts of farmland transfer on regional agro-ecosystems and discuss measures for improving farmland ecological environments.

1. Study Area Overview

Rongchang County is located in the western corridor of Chongqing Municipality, between 105°17' -105°44' E and 29°15' -29°41' N, covering a total area of 1,075.37 km² [Figure 1: see original paper]. The terrain consists primarily of gentle hills with an average elevation of 380 m. The region belongs to the mid-subtropical humid monsoon climate zone, with an average annual frost-free period of 336 days, mean annual temperature of 17.4°C, accumulated temperature of 6,482.4°C, annual sunshine hours of 1,077.1 h, and average annual precipitation of 1,092.8 mm. Characterized by hot summers, mild winters, concurrent heat and light, abundant rainfall, and high humidity with frequent overcast conditions, Rongchang has a long agricultural tradition with high land utilization rates and well-developed agriculture. As a major commercial grain and oil production base in Chongqing, agriculture plays a crucial role in the county's economy, with crop cultivation being the primary component. Therefore, this study focuses exclusively on cropping agro-ecosystems.

According to data from the Rongchang County Agricultural Committee, by the end of 2013, farmland transfer area reached 2.73×10^4 ha, with moderate-scale operations covering 2.44×10^4 ha (89.38% of transferred land). This study selected areas with stable farmland transfer conditions lasting over five years as research objects. Before transfer, rice (*Oryza sativa*) was typically grown in a single annual crop, with paddy fields left idle in winter. Upland crops mainly included corn (*Zea mays*), wheat (*Triticum aestivum*), and sweet potato (*Ipomoea batatas*), mostly cultivated in a three-crop rotation/intercropping system of wheat-corn-sweet potato. The average farmland management scale was only 0.29 ha, with scattered plots—some as far as 2 km from farmers' residences—making agricultural operations highly inconvenient. Due to hilly terrain constraints, agricultural mechanization levels were low, with most production processes completed manually. Consequently, low agricultural returns led most households to engage in part-time farming, with young laborers migrating to cities for work and returning only during busy seasons, leaving elderly laborers responsible for daily farm management.

After farmland transfer, paddy fields adopted rice-rapeseed (*Brassica campestris*) rotation, while upland areas primarily grew fruits [watermelon (*Citrullus lanatus*), kiwi (*Actinidia chinensis*)] or greenhouse vegetables [ginger (*Zingiber officinale*), Chinese cabbage (*Brassica pekinensis*)]. The average management scale expanded to 13.86 ha with concentrated plots. To accommodate

large-scale operations and agricultural modernization, contractors invested in infrastructure improvements, including roads, water conservancy, and power facilities. Survey results revealed total investments exceeding 11.8 million yuan for infrastructure construction, land leveling of 44.73 ha, construction of 101 vegetable greenhouses, and 675 m² of storage and processing facilities. All contractors purchased agricultural machinery covering cultivation, irrigation, harvesting, and transportation, with some even acquiring packaging production lines to achieve integrated production and processing. This study uses the pre-transfer ordinary farmer agro-ecosystem as a baseline for comparative energy analysis with post-transfer contractor systems.

2.1 Data Sources

Data used in this study were categorized into local resource data, purchased resource data, and system output data. Local resource data (including solar energy, wind energy, rainfall potential energy, rainfall chemical energy, and Earth rotation energy) were obtained from the China Meteorological Data Sharing Service System. Purchased resource and system output data were derived from aggregated survey data collected in 2014 from ordinary farmers and contractors. The survey used ordinary farmers' input-output data to represent pre-transfer agro-ecosystem patterns and contractors' data for post-transfer patterns. A total of 285 questionnaires were collected, with 253 valid responses (88.77% validity rate), including 231 farmer questionnaires and 22 contractor questionnaires.

Fieldwork was conducted from September 5 to October 21, 2014. Under local government guidance, the research team selected 11 villages across six townships—Panlong (Sanhe Village, Dajian Community), Guchang (Chongfeng Village, Yudai Village), Shuanghe (Meishiba Community, Gaofeng Village), Qingliu (Macao Village), Anfu (Tong'an Village, Banzhu Village), and Wujia (Shuangliu Village, Gaofeng Village)—representative in transfer scale, mode, and effectiveness [Figure 1: see original paper]. Survey content primarily included transfer methods, management scale, cropping structure, input-output patterns, and economic returns. The investigation involved three components: (1) collecting general information on farmland transfer at each sample site, (2) conducting household interviews and questionnaires to understand farmers' land transfer situations, and (3) performing in-depth interviews with representative contractors to understand post-transfer operations.

2.2 Research Methods

Energy analysis overcomes the challenge of comparing different energy categories by converting various forms of energy flowing through and stored in eco-economic systems into a unified energy baseline, enabling comprehensive analysis of energy, material, and monetary flows. This approach reveals the value of natural resources and economic activities and their interrelationships, providing crucial insights for balancing ecological and economic development,

scientifically evaluating natural resources, and formulating sustainable development strategies.

The emergy calculation formula is:

$$E = e \times t \quad \text{or} \quad E = m \times t \quad (1)$$

where E represents emergy (sej), e represents energy (J), m represents mass (g), and t represents transformity ($\text{sej} \cdot \text{J}^{-1}$ or $\text{sej} \cdot \text{g}^{-1}$).

Transformity values were referenced from studies of regions with similar natural and economic conditions to the study area, using the updated emergy baseline of $15.83 \times 10^2 \text{ sej} \cdot \text{a}^{-1}$. RMB-USD conversion used the 2013 average exchange rate of 6.19. Buildings and machinery were amortized into annual energy inputs based on their service life.

From the perspective of purchase requirements, inputs were classified as local resources or purchased resources; from the renewability perspective, they were categorized as renewable or non-renewable. Notably, certain resources are composed of both renewable and non-renewable components during production or formation, making them neither completely renewable nor non-renewable. Traditional emergy accounting practices that classify such resources as entirely renewable or non-renewable lack scientific justification. Following Odum's methodology, emergy analysis begins with constructing an emergy diagram to clarify system structure and reflect overall input-output conditions. This study developed an emergy flow diagram for the research area's agro-ecosystem [Figure 2: see original paper].

To objectively evaluate ecosystem output efficiency, sustainability capacity, and eco-economic benefits before and after farmland transfer, this study selected three emergy evaluation indicators. Additionally, based on local conditions and referencing relevant studies, a renewability coefficient was introduced to enhance analytical precision.

3.1 Emergy Input Structure Analysis of the Study Area

Calculations revealed that pre- and post-transfer emergy inputs per unit area were $1.86 \times 10^1 \text{ sej} \cdot \text{hm}^{-2}$ and $5.49 \times 10^1 \text{ sej} \cdot \text{hm}^{-2}$, respectively [TABLE:2, TABLE:4], representing a 70.48% reduction after transfer. This demonstrates that post-transfer farmland ecosystems required substantially lower emergy inputs per unit area, reflecting economies of scale. Renewable resource inputs accounted for 89.25% and 60.66% of total emergy inputs before and after transfer, respectively, indicating that the agro-ecosystem remained primarily driven by renewable resources, though dependence decreased post-transfer. Survey results showed that among purchased resources, only labor and electricity had relatively high renewability coefficients, while other inputs exhibited low or zero coefficients.

Within purchased resources, labor input accounted for 96.24% and 57.01% of total energy inputs before and after transfer, respectively, showing a dramatic decline post-transfer. Despite this reduction, labor remained the primary input item, reflecting agriculture's labor-intensive nature. Chemical fertilizer and pesticide inputs increased from 1.04% to 7.78% of total energy inputs. Field investigations revealed substantial increases in usage: fertilizer application rose from 652 kg · hm² to 1,414 kg · hm², and pesticide application increased from 23 kg · hm² to 112 kg · hm². Construction costs represented 21.49% of total inputs, primarily for land leveling, road maintenance, and water and power infrastructure, characteristic of hilly regions adapting to mechanization through large-scale infrastructure improvements. Post-transfer, plastic film and machinery inputs accounted for 3.28% of total energy inputs, representing unique investments in facility agriculture. Electricity and diesel inputs increased from less than 1% pre-transfer to 2.02% post-transfer.

3.2.1 Emergy Yield Ratio

Agricultural production represents the development of land productivity under specific external inputs. With fixed external economic investment, higher land output indicates greater exploitation of production potential and stronger market competitiveness due to lower costs. The emergy yield ratio (EYR), defined as the ratio of system output emergy to economic feedback (purchased resources), measures a system's capacity to acquire and utilize local resources through external economic feedback. Based on , , and , calculations summarized in show that the study area's EYR increased from 0.01 pre-transfer to 0.04 post-transfer—a threefold improvement indicating enhanced market competitiveness.

Post-transfer purchased emergy inputs decreased by 70.48% while emergy output increased by 2.15%. The substantial reduction in purchased emergy primarily resulted from agricultural machinery substituting for labor. Although most individual input items increased, the dramatic decline in labor input (from 6 workers · hm² to 1 worker · hm²) offset these increases. This confirms that labor reduction was the dominant factor in decreasing purchased emergy inputs, consistent with research demonstrating clear substitution relationships between agricultural machinery and labor inputs. Pre-transfer surveys indicated only 42% of households used agricultural machinery, whereas post-transfer, all contractors employed machinery. Furthermore, while farmers primarily used small equipment like micro-tillers, contractors utilized large and medium-sized machinery including harvesters, light trucks, and tractors. Increased machinery usage and mechanization levels drove the substantial reduction in total emergy inputs.

Additionally, post-transfer output increased due to several factors. Large-scale operations adopted crop rotation systems, replacing traditional intercropping practices on small plots. Rapeseed cultivation also utilized previously idle winter paddy fields, improving land use efficiency and multiple cropping indices. Support services from agricultural extension stations and pest control centers

further contributed to output increases.

3.2.2 Environmental Loading Ratio

The environmental loading ratio (ELR) measures the pressure exerted on the environment by non-renewable resource use, with higher values indicating greater ecological stress. shows that ELR increased from 0.12 pre-transfer to 0.65 post-transfer, indicating substantially greater environmental pressure. Field investigations revealed that all non-renewable resources were purchased inputs, with only labor and electricity having relatively high renewability coefficients (0.90 and 0.81, respectively), while other inputs had low or zero coefficients.

For inputs with renewability coefficients smaller than the system average, reducing their input decreases ELR, while increasing inputs with higher coefficients reduces ELR. However, all individual input changes in the study area increased environmental pressure. The significant labor reduction combined with increased electricity, diesel, pesticide, and fertilizer inputs elevated ecosystem stress. Although machinery inputs have zero renewability and theoretically increase environmental pressure, their contribution to ELR was only 8.33%, suggesting their role remains neutral overall and beneficial for achieving moderate-scale operations.

3.2.3 Sustainability Index

Sustainable development requires balancing economic growth and environmental protection—neither sacrificing ecology for development nor pursuing inefficient production for environmental preservation. The emergy sustainability index (ESI), calculated as the ratio of EYR to ELR, comprehensively measures ecosystem sustainability capacity. shows ESI declined from 0.08 pre-transfer to 0.06 post-transfer, indicating reduced sustainability. Both values remain far below 1, classifying the system as consumption-oriented with low net emergy yield and high environmental loading, rendering the current development model unsustainable in the long term.

The fundamental production approach remained unchanged, characterized by high-input, high-output systems. Farmland transfer primarily altered management scale and mechanization levels, improving production efficiency but neglecting potential ecological consequences of excessive and intensive use of production materials, particularly pesticides, fertilizers, and plastic films. Field observations confirmed fertilizer application increased from $652 \text{ kg} \cdot \text{hm}^{-2}$ to $1,414 \text{ kg} \cdot \text{hm}^{-2}$ and pesticide use from $23 \text{ kg} \cdot \text{hm}^{-2}$ to $112 \text{ kg} \cdot \text{hm}^{-2}$, substantially increasing pollution risks and environmental pressure.

4. Conclusions and Discussion

Farmland transfer promoted agricultural mechanization, which proved crucial for enhancing production efficiency. Machinery usage increased from 42% pre-

transfer to 100% post-transfer, with greater adoption of large and medium-sized equipment like harvesters and trucks. Substantial infrastructure investments in roads, water conservancy, power facilities, and land leveling created favorable conditions for mechanization and large-scale operations. The average management scale expanded from 0.29 ha to 13.86 ha, reducing unit inputs by 70.48% while increasing unit output by 2.15%, demonstrating that scale operations effectively lower production costs and enhance market competitiveness. The efficiency gains primarily stemmed from reduced unit inputs, with machinery substituting for labor as the dominant factor, underscoring the practical importance of mechanization in moderate-scale operations.

However, changes in input structure, particularly dramatically increased pesticide and fertilizer use, intensified ecological risks. Net energy yield ratio and environmental loading ratio increased by 300.00% and 441.67%, respectively, while sustainability index decreased by 25%, indicating that environmental costs exceeded efficiency gains. Cropping structure shifted significantly: pre-transfer systems focused on grain crops (rice, corn) with some vegetables (water spinach, pepper) and minimal fruit cultivation (grain:vegetable:fruit ratio of 11:3:1). Post-transfer, intensive greenhouse production rapidly expanded high-value vegetable (ginger, eggplant) and fruit (watermelon) cultivation, changing the ratio to 1:2:1 and increasing the vegetable-fruit proportion from 26.67% to 75.00%. This structural adjustment and yield pursuit drove the substantial increase in purchased resources, with fertilizer and pesticide use more than doubling.

Research indicates that most Chinese farmland lacks balanced fertilization and scientific pesticide application, with utilization efficiencies of only 30-40%. After application, only a portion is absorbed by crops while most enters the environment through precipitation and irrigation, causing pollution. With increasing agricultural intensification and inadequate countermeasures, non-point source pollution from pesticide and fertilizer loss is worsening. Therefore, production processes must employ rational application based on crop types and structures, adopting pollution prevention technologies such as formula fertilization and biological pesticide alternatives to improve utilization efficiency and reduce environmental loading.

Farmland transfer represents a double-edged sword, with outcomes depending on the direction of agricultural intensification. If intensification is interpreted as simply increasing capital and labor inputs per unit area, environmental loading will continue rising while EYR growth slows due to diminishing returns, further reducing sustainability and creating ecological and food safety risks. Conversely, if intensification emphasizes improving agricultural technology and equipment to reduce inputs and increase efficiency, moderate-scale operations can achieve sustainable development. Therefore, national policies guiding farmland transfer and moderate-scale operations must establish sustainable intensification pathways and implement strict regulations through agricultural investment, support, and management measures.

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References

- [1] Shao M W. A full researching review on the management mode of Chinese agriculture[J]. *Reformation & Strategy*, 2011, 27(5): 183-186
- [2] Zhong Z M, Huang Q L, Weng B Q, et al. Energy analysis on planting-breeding circulating agriculture ecosystem linked by biogas[J]. *Transactions of the CSAE*, 2012, 28(14): 196-200
- [3] Yin C B, Zhou Y, Liu L H. Theory and practice of recycle agriculture in China[J]. *Chinese Journal of Eco-Agriculture*, 2013, 21(1): 47-53
- [4] Fu W, Zhao J Q, Du G Z. Ecological analysis of the mountainous three-dimensional agriculture[J]. *China Population Resources and Environment*, 2013, 23(11): 62-65
- [5] Zhang S G. Between the transfer of the use of land and agricultural modernization[J]. *Management World*, 2010, 26(7): 66-85
- [6] Huang Z H, Wang P. Farmland transfer and its impacts on the development of modern agriculture: Status, problems and solutions[J]. *Journal of Zhejiang University: Humanities and Social Sciences*, 2008, 38(2): 38-47
- [7] Zhang Z, Tan R, Shi C, et al. The selection mechanism of forestland transfer modes and its policy implications[J]. *China Land Sciences*, 2014, 28(5): 11-18
- [8] Liu W B, Li Z. Operating performance for the modes of rural land transfer and strategies in new times[J]. *Economic Geography*, 2011, 31(2): 300-304
- [9] Hao L L, Wu Q, Wang Z, et al. Rural land circulation models and benefits based on property rights in rapid urbanization areas: A case of Xiongzhou Town in Hubei Province[J]. *Progress in Geography*, 2015, 34(1): 55-63
- [10] Zhang L, Feng S Y, Qu F T. Regional differences of farmland transfer and its influencing factors: A case study of Jiangsu Province[J]. *China Land Sciences*, 2014, 28(5): 73-80
- [11] Xu H Z, Guo Z X. Theoretic and empirical research on influential factors of rural land transfer based on the perspective of hierarchy differentiation and property rights preference[J]. *China Population Resources and Environment*, 2011, 21(3): 94-97
- [12] Zhang S C, Wei C F, Shao J A, et al. Resources integration and change in land value affected by land transfer and consolidation of rural villages in hilly areas[J]. *Transactions of the CSAE*, 2014, 30(12): 1-17
- [13] Cheng F, Xin G X, Wei C F, et al. An evaluation system for comprehensive performance of farmland circulation and its application[J]. *Journal of Southwest University: Natural Science Edition*, 2015, 37(1): 110-117
- [14] Lan S F, Qin P, Lu H F. Emergy Analysis of Ecological Economic

- System[M]. Beijing: Chemical Industry Press, 2002: 38-42
- [15] Zhang W Z. Emergetic ternary diagram based on eco-economic analysis and sustainable development of Youyang County[D]. Chongqing: Southwest University, 2014
- [16] Zhang W Z, Xie S Y, Ji J C. Economic system energy analysis and sustainability development of agroecosystem in Beibei District[J]. Hubei Agricultural Sciences, 2013, 52(9): 2057-2062
- [17] Wu C, Hu X D. Study on energy ecological carrying capacity of Chongqing based on energy theory[J]. Journal of Southwest University: Natural Science Edition, 2010, 32(4): 26-30
- [18] Zhang X M. Study on the dynamic changes of ecological security in Chongqing based on the energy-ecological footprint model[D]. Chongqing: Southwest University, 2014
- [19] Odum H T. Environmental Accounting: Emergy and Environmental Decision Making[M]. New York: John Wiley and Sons, 1995: 101-117
- [20] Wang X L, Han Y, Chen Y Q, et al. Efficiency and sustainability evaluation of a pollution-free vegetable production system based on emergy analysis[J]. Acta Ecologica Sinica, 2015, 35(7): 2136-2145
- [21] Cavalett O, de Queiroz J F, Ortega E. Emergy assessment of integrated production systems of grains, pig and fish in small farms in the South Brazil[J]. Ecological Modelling, 2006, 193(3/4): 205-224
- [22] Agostinho F, Diniz G, Siche R, et al. The use of emergy assessment and the geographical information system in the diagnosis of small family farms in Brazil[J]. Ecological Modelling, 2008, 210(1/2): 37-57
- [23] Chen G Q, Jiang M M, Chen B, et al. Emergy analysis of Chinese agriculture[J]. Agriculture, Ecosystems & Environment, 2006, 115(1/4): 161-173
- [24] Ma K, Shi C L, Wang Z P. Analysis of substitute relation between rural labor agro-mechanism in grain production[J]. Journal of Agricultural Mechanization Research, 2011(8): 6-9
- [25] Zhu Y L, Li M J, Long Y Z, et al. Structure function and efficiency of agro-ecosystem around Dongting Lake region of Hunan Province, South-central China based on emergy analysis[J]. Chinese Journal of Ecology, 2012, 31(12): 3086-3093
- [26] Li L K. The research on how utilization factors of agricultural production impact grain production and environment—Taking fertilizer an example[D]. Beijing: China Agricultural University, 2015
- [27] Ye B X, Tang H M, Tang X M, et al. Status and prevention measurements of farmland pollution in China[J]. Chinese Agricultural Science Bulletin, 2010, 26(7): 295-298
- [28] Yang Z L. Estimation of cropland pollution in China and advisable approaches for its prevention and cure[J]. Chinese Agricultural Science Bulletin, 2006, 22(9): 415-419

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