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Evaluation for Use Efficiency of Agricultural Resources in Grain Production: A Case Study of Changshu, Taihe and Ansai in China

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Abstract: This paper aims to establish an index system for evaluation of agricultural resources use efficiency (ARUE) in grain production and discuss the causes of low efficiency and high consumption of agricultural resources in Changshu of Jiangsu Province, Taihe of Jiangxi Province and Ansai of Shaanxi Province in China by analyzing the data about meteorology, soil, water consumption and grain production. Agro-ecological Zone (AEZ) method was adopted to calculate the potential productivity, and synthetically multivariate equation was used to evaluate the ARUE of study areas. This paper can be concluded as: 1) the agricultural resources in grain production can be classified into five categories, i.e., climatic resources, water resources, land resources, biological resources and assistant resources, and 15 indexes were selected to evaluate their use efficiency in grain production; 2) the values of ARUE in grain production are 0.5868, 0.6368 and 0.5390 respectively in Changshu, Taihe and Ansai; and 3) Changshu ranks the highest among the three study areas in terms of the use efficiency of climatic resources and biological resources (evaluation values are 0.0277 and 0.1530), but Taihe tops the three in terms of the use efficiency of water resources, land resources and assistant resources (evaluation values are 0.0502, 0.2945 and 0.1379 respectively). However, the ARUE remains always low in Ansai for all the resources. The inefficiencies are caused by poor grain revenue in Changshu, deficient agriculture investments in Taihe and unfavorable natural conditions in Ansai.
Keywords: agricultural resources use efficiency; grain production; Changshu; Taihe; Ansai

1 Introduction

China enjoys a general abundance of agricultural resources. However, due to its large population the agricultural resources per capita remain limited, especially the cultivated land and water resources, which have hindered the sustainable development of Chinese agriculture. In 2006, the area of cultivated land per capita in China was only 0.09ha and the volume of fresh water per capita was only 1900m^3. China's total water deficit has reached 36×10^9t, including an agriculture water deficit of 30×10^9t (Zhang, 2005). Moreover, with the increase in population, the conflict will be aggravated between population and agricultural resources. The solution to this problem is supposed to increase the use efficiency of the resources rather than to increase the exploitation of the resources at a large scale (Shi and Feng, 1997). However, the agricultural resources use efficiency (ARUE) in China keeps at a low level. Because of extensive cultivation, the average solar energy use efficiency is below 0.5% for grain crops in China; the common water use efficiency ranges from 30% to 40% for agricultural irrigation; and the use efficiency averages 36% for chemical fertilizers. Yet the loss rate of nitrogen fertilizer is as high as 70% to 80% (Zheng, 2004; Lei and Wang, 2001). Therefore, increasing ARUE and reducing resources consumption are necessary for the sustainable development of agriculture in China.

The evaluation for ARUE in grain production aims to understand the advantages and disadvantages in agricultural resources use in different regions, so as to lay a scientific foundation for increasing the ARUE (Zheng, 2004). Previous studies on ARUE focused mainly on the

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use efficiency of water resources and chemical fertilizers. The research on water resources use efficiency at the lamina level started in the early 1960s and has become popular since the 1980s in the world (Ausin et al., 1982; Frank et al., 1987; Kumar et al., 1994). Water use efficiency from the leaf to the field was described (Sinclair et al., 1984) and its importance to irrigation was recognized (Howell, 2001). China initiated such research systematically in the 1980s. One of the major researches was the Study of Crop Water Requirement, Crop Reference Evapotranspiration and Water Resources Use Efficiency conducted by the Chinese Academy of Sciences (Xie et al., 1991). As for chemical fertilizers use efficiency, researchers proposed some indexes for evaluation, such as chemical fertilizers productivity, harvest index of chemical fertilizers and the increase yield efficiency of chemical fertilizers (Xu, 1999). However, these studies were intended to tackle several aspects of ARUE rather than analyzing it comprehensively, and involved no further comparison of ARUE in different regions. Therefore, three areas, namely Changshu City in Jiangsu Province, Taihe County in Jiangxi Province and Ansai County in Shaanxi Province were selected in this thesis, and evaluation indexes were systemically grouped about ARUE in grain production for comparison of the ARUE in those areas, in order to bring forward the measures to improve ARUE.

2 Data and Methods

2.1 Study areas

Changshu, a county-level city in the southern Jiangshu Province, is located between 31º31'–31º50'N and 120º33'–121º03'E (Fig. 1), with a total area of 1264km^2. The plain accounts for 80% of its total land area. In 2005, the GDP of this city totaled about 67.9×10^9 yuan (RMB), and the proportions of the primary, secondary and tertiary industries were 1.24%, 83.03% and 15.73% respectively (Changshu Bureau of Statistics, 2006). The net income per capita was 8148 yuan for the peasants in 2005 (Changshu Bureau of Statistics, 2006). The cropping system of Changshu is winter wheat and summer rice, two harvests in one year.

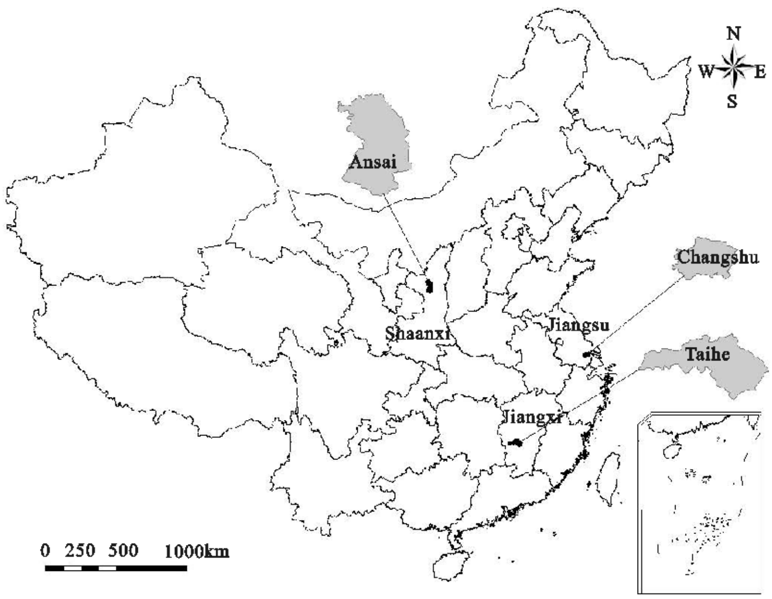

Fig. 1 Location of study areas

Taihe County, in the central Jiangxi Province, is located between 26º27'–26º58'N and 114º27'–114º17'E (Fig. 1) covering an area of 2667km^2, of which hilly land occupies 54.52%, plain 27.6%, and mountainous area 5.91%. Its GDP was about 3.71×10^9 yuan, and the proportions of the three industries were 78.17%, 18.54% and 3.30% respectively in 2005 (Jiangxi Bureau of Statistics, 2006). The net income per capita was 3748 yuan for peasants in 2005 (Jiangxi Bureau of Statistics, 2006). The cropping system of Taihe is early rice, late rice and winter green manure (such as *Astragalus sinicus*, *Villose vetch*) or rape, three harvests in one year.

Ansai County, located in the northern Shaanxi Province, is the inner land of the Loess Plateau, ranging between 36º31′–37º20′N and 108º52′–109º26'E (Fig. 1) with a total area of 2950km^2. Loess hilly area accounts for 90% of the total land area. Its GDP reached around 1.37×10^9 yuan in 2005, and the proportions of the three industries were 17.32%, 57.81% and 24.86% respectively (Ansai Bureau of Statistics, 2006). The net income per capita was 2399 yuan for peasants in 2005 (Ansai Bureau of Statistics, 2006). The cropping system of Ansai is spring maize, one harvest in one year.

2.2 Data sources

The analysis on ARUE is mainly based on the data of meteorology, soil, water consumption and grain production. The meteorological data, such as precipitation, sunshine percentage, temperature and wind speed from 2000 to 2005, were obtained from the meteorological stations of Ansai, Changshu and Taihe. The soil data, such as the maps of soil nutrient, soil types and soil erosion in 1986, were cited from the database of the Institute of Geographic Sciences and Natural Resources Research (IGSNRR), Chinese Academy of Sciences. The data of grain yield, crop area, crop structure, valid irrigation area, fertilizer investment and labor input in grain production were from the Statistical Yearbooks of Changshu, Taihe and Ansai from 1996 to 2005. The volume of irrigation water and the popularization rate of superior seeds were provided by the Agriculture Bureaus of the study areas in 2005. In addition, the rate of straws retuned to soil in these areas resulted from household survey in 2005.

2.3 Methods

2.3.1 Agro-ecological Zones method

Agro-ecological Zones (AEZ) method was developed by the Food and Agriculture Organization of the United Nations (FAO) and the International Institute for Applied Systems Analysis (IIASA) (FAO, 1996). As a mechanism method, it was frequently adopted to calculate potential productivity of crops at regional level (Fischer and Sun, 2001; Deng et al., 2006). In terms of the influential factors, the potential land productivity may be divided into four degrees: photosynthetic potential productivity (PP), photosynthetic-thermal potential productivity (PTP), photosynthetic-thermal-water potential productivity (PTWP) and photosynthetic-thermal-water-land potential productivity (PTWLP). As expected, the AEZ maintains a definite geographic meaning and ensures a relatively more accurate result in calculation. Therefore, an AEZ model simplified and improved by Liu and Chen's (2004) research was hereby applied, which can be expressed in the following equations:

$$Y_Q = \sum_{i=1}^{m} 0.219 \times Q_i \times L_i \times E_j \quad (1)$$

where Y_Q is the photosynthetic potential productivity (PP); 0.219 is the empirical coefficient; Q_i is the global solar radiation of month i; L_i is the ratio of crops' growth days to total days of month i; E_j is the harvest index of crop j.

$$Y_T = \sum_{i=1}^{m} Y_Q \times f(t_i) \quad (2)$$

For cryophilous crops

$$f(t_i) = \begin{cases} 0, & t_i \le 3 \;\&\; t_i \ge 25 \\ (t_i - 3)/15, & 3 < t_i < 18 \\ 1, & 18 \le t_i \le 21 \\ (25 - t_i)/4, & 21 < t_i < 25 \end{cases} \quad (3)$$

For thermophilous crops

$$f(t_i) = \begin{cases} 0, & t_i \le 8 \\ (t_i - 8)/15, & 8 < t_i < 23 \\ 1, & t_i \ge 23 \end{cases} \quad (4)$$

where Y_T is the photosynthetic-thermal potential productivity (PTP); $f(t_i)$ is the temperature effective coefficient of month i; t_i is the temperature of month i.

$$Y_W = Y_T \times f(w) \quad (5)$$

$$f(w) = \begin{cases} 1 - k_y(1 - ET_a/ET_m), & ET_a < ET_m \\ 1, & ET_a \ge ET_m \end{cases} \quad (6)$$

$$ET_m = k_c \times ET_0 \quad (7)$$

where Y_W is the photosynthetic-thermal-water potential productivity (PTWP); $f(w)$ is the water effective coefficient; k_c and k_y are crop coefficient and yield response coefficient respectively; ET_a and ET_m are the actual and potential (maximum) evapotranspiration respectively; ET_0 is the reference evapotranspiration which can be calculated by Penman-Monteith equation.

$$Y_S = Y_W \times f(s) \quad (8)$$

$$f(s) = [\sum_{i=1}^{n} (\sum_{j=1}^{m} w_j \times I_{ij}) \times A_i] / \sum_{i=1}^{n} A_i \quad (9)$$

where Y_S is the photosynthetic-thermal-water-land potential productivity (PTWLP); $f(s)$ is the soil effective coefficient; I_{ij} is the index value of soil effective evaluation for factor j in land unit i; Wang's research results (2006) (Table 1) are adopted hereby as the references for the index factors and their values; w_j is the weight of soil effective factor j (Table 1); and A_i is the area of land unit i.

Table 1 Index values (I_{ij}) and their weights in soil effective evaluation

Factor	Weight	Item	Index value				
SOM	0.352	Content (%)	<1.00	1.00–1.49	1.50–2.49	2.50–3.49	≥3.50
		I_{ij}	0.2	0.4	0.6	0.8	1.0
STN	0.068	Content (%)	<0.050	0.050–0.074	0.075–0.090	0.100–0.190	≥0.200
		I_{ij}	0.2	0.4	0.6	0.8	1.0
STP	0.045	Content (%)	<0.050	0.050–0.069	0.070–0.090	0.100–0.190	≥0.200
		I_{ij}	0.2	0.4	0.6	0.8	1.0
STK	0.031	Content (%)	<0.50	0. 50–0.99	1.00–1.49	1.50–2.90	≥3.00
		I_{ij}	0.2	0.4	0.6	0.8	1.0
pH	0.103	Range	<4.50 or ≥8.50	4.50–5.49	7.50–8.49	5.50–6.49	6.50–7.49
		I_{ij}	0.2	0.5	0.7	0.9	1.0
ST	0.241	Type	Tighten sandy soil, clay	Sandy clay, loam clay	Clay loam	Sandy clay loam	Loam soil, sandy loam soil
		I_{ij}	0.3	0.4	0.8	0.9	1.0
SEI	0.160	Erosion degree	Very high	High	Middle	Low	Slight
		I_{ij}	0.2	0.4	0.6	0.8	1.0

Notes: SOM: soil organic matter; STN: soil total nitrogen; STP: soil total phosphorus; STK: soil total potassium; pH: hydrogen ion concentration; ST: soil type; SEI: soil erosion intensity

2.3.2 Evaluation indexes for ARUE

The agriculture resources hereby refer to all natural, economic and social resources pertaining to grain production, which are classified into climatic (light and heat), water (precipitation and irrigation water), land, biological (seed and straw) and associate resources (fertilizer and labor). In accordance with Liu's research (2005) and Wang's research (2006), 15 indexes are listed in Table 2 hereby for those five categories to evaluate the ARUE in grain production.

2.3.3 Evaluation method for ARUE

ARUE in grain production was evaluated by synthetically multivariate equation, which is expressed as:

$$V=\sum_{i=1}^{n} w_i\left(\sum_{j=1}^{m} w_{ij}\times V_{ij}\right) \quad (10)$$

where V is the value of synthetic ARUE; w_i is the weight of resources type i; w_{ij} is the weight of index j of resources type i; V_{ij} is the ARUE value of index j of resources type i. The weights in Equation (10) can be calculated by Analytic Hierarchy Process (AHP) according to Table 2.

In order to eliminate the difference produced by the unit of ARUE indexes, each index value of ARUE has been normalized (Normalized value=real value/aim value) before evaluation. Aim value is brought forward based on the high yield and high efficiency experiment in the study areas.

3 Result and Analyses

3.1 Evaluation for use efficiency of climatic resources

The PP and PTP in Changshu, Taihe and Ansai are calculated (Table 3) by equations (1), (2), (3) and (4). The values are higher in Changshu but lower in Ansai because of different latitudes. The use efficiencies of solar energy and PTP are also calculated according to their connotations in Table 2. However, as determined by the differences in GYPU, the use efficiencies are higher in Taihe than those in Changshu, but much lower in Ansai. The GYPU of Taihe is as 3.71 times higher than that of Ansai and as 1.11 times high as that of Changshu.

Table 2 Index system for evaluation of ARUE in grain production

Resources type	Evaluation index	Connotation of index
Climatic resources	Use efficiency of solar energy	Crop energy output/solar global radiation×100%
	Use efficiency of PTP	GYPU/PTP ×100%
Water resources	Irrigation index	Valid irrigation area/total cultivated land area×100%
	Rainwater productivity	GYPU/annual precipitation
	Total water productivity	GYPU/total water consumption
	Use efficiency of PTWP	GYPU/PTWP×100%
Land resources	Land productivity	GYPU
	Cropping index	Sown area for major crops/cultivated land area×100%
	RSAC	Sown area for grain/sown area for major crops×100%
	Soil effective coefficient	$f(s)$ (Calculated by Equation (9))
	Use efficiency of PTWLP	GYPU/PTWLP×100%
Biological resources	Popularization ratio of superior seeds	Superior seeds in grain production/total seeds in grain production×100%
	Ratio of straw to soil	Quantity of straw to soil/total straw quantity×100%
Associate resources	Fertilizer productivity	Grain yield/fertilizer input
	Labor productivity	Grain yield/labor input

Notes: GYPU: grain yield per unit; PTP: photosynthetic-thermal potential productivity; PTWP: photosynthetic-thermal-water potential productivity; PTWLP: photosynthetic-thermal-water-land potential productivity; RSAC: ratio of sown area for grain to sown area for major crops; crop energy output=GYPU (kg/ha) $\times 1.779\times 10^7$(J/g); total water consumption=irrigation water volume+precipitation

Table 3 Results of valuation for use efficiency of climatic resources

Region	PP (kg/ha)	PTP (kg/ha)	Use efficiency of solar energy (%)	Use efficiency of PTP
Changshu	41466.70	32947.97	0.33	28.23
Taihe	36808.63	30308.87	0.41	33.99
Ansai	20193.52	13467.80	0.09	16.86

3.2 Evaluation for use efficiency of water resources

On the base of equations (5), (6), (7) and the connotation of water resources' evaluation indexes in Table 2, the use efficiency of water resources are evaluated (Table 4). Among the three study areas, Changshu' irrigation index ranks the highest thanks to its high annual precipitation (12,587.52mm) and abundant surface water storage. However, since the annual precipitation averages only 555.86mm in Ansai, the water resources there are limited and the irrigation index remains low. With the annual precipitation of 1332mm, Taihe maintains relatively abundant rainwater resources but less irrigating water than Changshu. Therefore, the irrigation index of Taihe is at the medium level. Due to high GYPU and precipitation, the rainwater productivity, total water productivity and use efficiency of PTWP are all higher in Taihe but lower in Ansai or Changshu.

Table 4 Results of evaluation for use efficiency of water resources

Region	Irrigation index (%)	Rainwater productivity (kg/(mm·ha))	Total water productivity (kg/(mm·ha))	Use efficiency of PTWP (%)
Changshu	99.00	7.39	4.90	28.23
Taihe	86.62	7.73	5.13	35.43
Ansai	6.23	4.99	4.99	26.62

3.3 Evaluation for use efficiency of land resources

The use efficiency of land resources are evaluated (Table 5) according to the equations (8), (9) and the connotation of land resources evaluation indexes in Table 2. From Table 5, we can see higher land productivity and cropping index in Taihe, lower in Changshu and lowest in Ansai. But RSAC and use efficiency of PTWLP are higher in Ansai, lower in Taihe and the lowest in Changshu. In addition the soil effective coefficients are higher in Changshu, lower in Taihe and the lowest in Ansai.

Before 1985, Changshu boasted a diverse crop structure, but afterwards it mainly grew winter wheat and summer rice, i.e., two harvests a year. In recent years, in Chagshu peasants had to abandon cultivated lands because of the poor revenue in grain production. Consequently the cropping index of Changshu reduced steadily to the second among the three study areas. Different from Changshu, Taihe is an agriculture-focused county where the agricultural tax has been alleviated recently to promote the peasants to grow grains. Therefore, its cropping index increased year by year and became the highest among the three study areas. Because of deficient light and heat, the cropping index of Ansai is the lowest among the three. As a result, the land productivity is higher in Taihe, lower in Changshu and the lowest in Ansai.

Because of the low profit in grain production in Changshu, its RSAC is the lowest among the three study areas. However, the RSAC in Taihe is higher than that in Changshu but lower than that in Ansai. With a tight grain supply, Ansai managed to achieve an unexpected grain production and the highest RSAC. From 2000 to 2005, the GYPU in Changshu averaged 9302.68kg/ha, a moderate one in consideration of its excellent conditions. Its use efficiency of PTWLP was the lowest among the three areas. However the GYPU of Taihe reached 10,300.51kg/ha, a high one in consideration of its moderate land and water conditions and use efficiency of PTWLP. Restrained by land and water conditions, the GYPU remained low in Ansai. Despite of the low PTWLP, the use efficiency of PTWLP there reached 59.24%, the highest among three study areas.

Changshu enjoys a plain terrain favorable for agriculture. Thus the soil effective coefficient there is the highest among the three study areas. Ansai is located within the hilly region on the Loess Plateau with poor land quality. Its soil effective coefficient is the lowest. With hills and mountains, Taihe has a lower soil effective coefficient than Changshu.

Table 5 Results of evaluation for use efficiency of land resources

Region	Land productivity (kg/ha)	Cropping index (%)	RSAC (%)	Soil effective coefficient	Use efficiency of PTWLP (%)
Changshu	9302.68	146.74	55.29	0.71	39.77
Taihe	10300.51	237.95	60.03	0.66	53.67
Ansai	2775.00	122.18	83.14	0.45	59.24

3.4 Evaluation for use efficiency of biological resources

In accordance with the connotation of biological resources evaluation indexes in Table 2, the use efficiency of biological resources is evaluated (Table 6). The results show that the popularization ratio of superior seeds is higher in Changshu but lower in Taihe and the ratio of straw to soil is higher in Changshu but lower in Ansai.

Table 6 Results of evaluation for use efficiency of biological resources

Region	Popularization ratio of superior seeds (%)	Ratio of straw to soil (%)
Changshu	95	75
Taihe	80	63
Ansai	85	28

In order to increase GYPU, superior seeds are introduced and widely cultivated in Changshu. But the popularization ratios of superior seeds in Taihe and Ansai are much lower than that in Changshu. The result of household survey of Changshu showed that the wheat straws were returned to field with a high rate, but the rice straws were often burned as fuel. The return rate of wheat and rice straws averages about 75% in Changshu. But the data from Statistic Bureaus show that the return rate is only 63% in Taihe and 28% in Ansai.

3.5 Evaluation for use efficiency of associate resources

The use efficiency of assistant resources is evaluated (Table 7) in accordance with the connotation of evaluation indexes of assistant resources in Table 2. The results show (Table 7) that the fertilizer productivity is higher in Taihe, lower in Changshu and the lowest in Ansai. But the labor productivity is higher in Changshu, lower in Taihe and the lowest in Ansai.

Table 7 Results of evaluation for use efficiency of associate resources

Region	Fertilizer productivity (kg/kg)	Labor productivity (kg/person)
Changshu	20.89	2460.25
Taihe	28.13	2027.00
Ansai	19.58	1433.52

Fertilizers are largely applied in Changshu, but the fertilizer productivity of Changshu remains moderate among the three study areas because of the improper combination and quantity in use. Less fertilizers are applied but with better efficiency. Therefore, the fertilizer productivity of Taihe is the highest among the three study areas. Because the soil can not retain well the fertilizers, the fertilizer productivity of Ansai is the lowest.

Recently many peasants in Changshu go into non-agricultural businesses. Consequently, agricultural machines are widely applied. The labor productivity in Changshu hence becomes the highest among the three study areas. Taihe and Ansai both enjoy abundant labor force. But as limited by the landform and economic situation, agriculture machines are not popularized and the labor productivity is not high in these two areas.

3.6 Synthetic evaluation for use efficiency of all resources

In accordance with Equation (10), the values of use efficiency are calculated for all resources hereby concerned. The integral values of use efficiency for Changshu, Taihe and Ansai are 0.5868, 0.6368 and 0.5390 (Table 8) respectively.

However, the values of use efficiency are distributed differently among the five agricultural resources. In terms of the evaluation results (Table 8), both the climatic and biological resources use efficiencies are higher in Changshu, lower in Taihe and the lowest in Ansai. The water and the associate resources use efficiencies are higher in Taihe, lower in Changshu and the lowest in Ansai. But the land resources use efficiency is higher in Taihe, lower in Ansai and the lowest in Changshu.

Table 8 Results of synthetic evaluation for use efficiency of all resources

Resources type	Evaluation value of Changshu	Evaluation value of Taihe	Evaluation value of Ansai
Climatic resources use efficiency	0.0277	0.0256	0.0149
Water resources use efficiency	0.0468	0.0502	0.0384
Land resources use efficiency	0.2529	0.2945	0.2844
Biological resources use efficiency	0.1530	0.1286	0.1017
Associate resources use efficiency	0.1064	0.1379	0.0996
Total evaluation value	0.5868	0.6368	0.5390

4 Discussion

For three study areas, there are different causes for the low efficiency and high consumption of agricultural resources. Therefore, according to the analyses of the causes, we can raise some suggestions to improve the ARUE of different areas.

4.1 Changshu

The use efficiencies of climatic and biological resources in Changshu are the highest among the three study areas, but the use efficiencies of water, land and associate resources remain lower than those in Taihe. Thanks to the abundant surface water and irrigation water resources, the water requirement for rice is smaller than the sum of the precipitation and irrigation water volume. Therefore, water supply will not be a restriction for grain production in Changshu. However the surplus water there sometimes hinders the development of grain production. Furthermore, due to abundant water resources, flood irrigation is always adopted in Changshu, which is a great waste of water resources, and thus leading to the low use efficiency of water resources.

From 2000 to 2005, the GYPU averaged 9302.68 kg/ha in Changshu. But in consideration of the favorable eco-environment, it is not high due to the low cropping index. Recently, encouraged by the urbanization of Chagnshu and the wide gap between agricultural and non-agricultural incomes, many peasants hunt part time or full time non-agricultural jobs. Hence, the labor resources in grain production become insufficient, and cultivated lands are abandoned. This greatly decreases the cropping index, GYPU and use efficiency of land resources in Changshu.

From 2000 to 2005, the productivity of chemical fertilizers in Changshu averaged 20.89kg/kg, an intermediate one among the three study areas. According to the long-time field experiment conducted by the Changshu Agro-ecological Experiment Station of Chinese Academy of Sciences, the optimum nitrogen application for a high productive rice system is between 225kg/ha and 270kg/ha, and the optimum ratio of ($N:P_2O_5:K_2O$) is 1:0.18:0.4. However, as proved by the related research (Song et al., 2007), the average household application of nitrogen in Changshu rises up to 343.13kg/ha, and the ratio ($N:P_2O_5:K_2O$) is 1:0.14:0.09. The high nitrogen application and the low proportion of K_2O reduce greatly the use efficiency of chemical fertilizer.

To raise ARUE in Changshu, three measures have to be adopted, i.e., pushing the policy of cultivated land management in a moderate size, applying fertilizers scientifically and readjusting the price of irrigation water.

4.2 Taihe

The use efficiencies of water, land and associate resources in Taihe are the highest among the three study areas, but the use efficiencies of climatic and biological resources in Taihe rank lower than those in Changshu. At present, the crops in Taihe can be planted three times every year, but for the first and the last, the low temperature results in the low use efficiency of climatic resources.

Due to the narrow application of agricultural technology in Taihe, the ratio of superior seeds is 80% against the total in grain production, much lower than that in Changshu, which leads to the low GYPU and low use efficiency of biological resources. Furthermore, affected by the landform, the application of agricultural machines remains at a low level, thus causing the low rate of straws returned to soil and low use efficiency of associate resources.

To raise ARUE in Taihe, more investment for sustainable agricultural development need to be involved and more application of N and K fertilizer is expected.

4.3 Ansai

All use efficiencies of agricultural resources in Ansai remain at a low level. Although Ansai can provide the necessities to grow crops as located in the northwestern China with sufficient solar radiation, natural disasters, such as drought, frost and hailstone, are frequent in this place and cause severe reduction in grain output. From 2000 to 2005, the average rate was about 56% for the area suffering yield reduction caused by natural disasters, which greatly decreased the use efficiency of climatic resources in Ansai.

Because most cultivated lands in Ansai afford no irrigation conditions, precipitation becomes the main water supply in Ansai. But the grudging and fluctuating precipitation there greatly limits the grain productivity and decreases the use efficiency of water resources. Due to the inadequate policy of "taking grain as the key link" in the past, a great deal of slope land unsuitable to grow crops has been cultivated in Ansai, which results in severe soil erosion and decreases the use efficiency of land resources in Ansai. Furthermore, the use efficiency of biological resources also remains low, because the chemical fertilizers and agricultural machines are not widely applied and the popularization ratio of superior seeds is not high.

To raise ARUE in Ansai, three measures should be adopted, i.e., constructing the facilities to store rainwater for irrigation, applying properly more fertilizers and improving the diversity of grain seeds.

5 Conclusions

Based on the meteorological data from 2000 to 2005, soil data in 1986 and grain production data from 2000 to 2005, the use efficiency of Changshu in Jiangsu Province, Taihe in Jiangxi Province and Ansai in Shaanxi Province are evaluated. AEZ method and synthetically multivariate equation are applied to calculate agriculture potential productivity and evaluate ARUE in the study areas. Among the three areas, the synthesis use efficiency is higher in Taihe, lower in Changshu and the lowest in Ansai. But both the climatic and biological resources use efficiencies are higher in Changshu, lower in Taihe and the lowest in Ansai. And the land resources use efficiency are higher in Taihe, lower in Ansai and the lowest in Changshu.

The low efficiency and high consumption of agricultural resources are attributable to different causes in the three study areas. In Changshu, the main cause for low efficiency and high consumption of water, land and assistant resources is the poor revenue in grain production, which leads to a low cropping index and GYPU. In Taihe, the main cause for low efficiency and high consumption of climate and biological resources is the deficient agriculture investment, which limits the input of fertilizer and agriculture mechanics in grain production. In Ansai, many reasons lead to the low use efficiency in agriculture resources. But the most important one is the unfavorable natural conditions, such as frequent disasters, insufficient irrigation, and poor land quality.

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