Land Potential Productivity and Population Carrying Capacity of Yan'an City

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Abstract The productivity attenuation method is adopted to calculate land potential productivity of counties of Yan'an City and calculate population carrying capacity at current productivity level. Result shows that high photosynthetic potential productivity area and high light and temperature potential productivity area are mainly situated in the north, while high climatic potential area and high land potential productivity area are mainly concentrated in the south. From solar radiation, moisture and landform, the attenuation amplitude of land potential productivity in northern counties (districts) is greater than that in southern counties (districts). In the whole city, the population carrying capacity of 9 counties reaches well-off living level, and 1 district still does not reach the level of adequate food and clothing. These results can provide reference for land resource use, agricultural production distribution and population growth control.

Key words Land, Potential productivity, Population carrying capacity, Yan'an City

1 Introduction

With constant growth of world population, industrialization advances rapidly, and land, especially agricultural land, has to bear higher and higher pressure. In this situation, the conflict between population, land and environment is increasing. Construction, water loss and soil erosion, desertification and human damage degrade land quality, reduce land area and seriously threaten grain security. China has to feed 22% of world population on 7% of the world cultivated land, so it is a paramount task to explore land potential productivity and find out population carrying capacity. Land potential productivity reflects the maximum theoretical yield of crops to be reached in ideal production condition[1]. Accurate estimation and evaluation of land potential productivity play a significant role in objectively understanding land use degree, revealing major factors limiting land yield, scientifically forecasting prospect of yield increase and population carrying capacity, as well as formulating land and population policies. This study takes counties (districts) in Yan'an City of Shaanxi Province as object, calculates the land potential productivity by productivity attenuation method, and measures population carrying capacity of counties (districts) at current economic level and on existing living conditions. It is expected to provide reference for land resource use, agricultural production distribution and population growth control of Yan'an City.

2 Overview of study area

Yan'an City (35°21′N - 37°71′, 107°41′E - 110°31′ E) is situated in southern area of Shaanbei Loess Plateau, includes 1 district and 12 counties, covers a total area of 37 030.4 km^2, ranking the second in Shaanxi Province. Yan'an has a humid continental climate that borders on a steppe climate with cold, dry, and moderately long winters, and hot and somewhat humid summers. Spring and autumn are short transition seasons in between. The temperature difference between day and night is great and sunshine is sufficient. Annual mean temperature is 9.1 ℃, annual mean precipitation is about 539 mm, and annual mean evaporation is about 1 570 mm. In each year, there are about 165 frost-free days. The terrain of Yan'an City is high in northwest and low in southeast with above mean sea level of 800 to 1 200 m. In 2009, the cultivated land was 393 799.06 hm^2, the proportion of dry land, irrigated field and paddy field accounts for 97.72%, 2.00% and 0.28% of the total cultivated land respectively. The sown area of grain reached 208 982.00 hm^2 with total grain yield up to 771 000 tons, and major cereal crops include corn, wheat and millet.

3 Land potential productivity and analysis

Land potential productivity refers to potential capability of agricultural land (cultivated land, garden land, forest land and grazing land) producing substances in certain technical input conditions. It is potential ability of land and ability of providing utility jointly determined by natural elements (such as light, temperature, water, and nutrient, and photosynthesis of crop itself[3]. Since the position of grain is irreplaceable in agricultural production, the study of land potential productivity will always focus on potential of cultivated land in producing grain[4].

With more than 7 decades of development, our predecessors have summed up many methods for calculating land potential productivity. It can be classified into three categories: empirical formula method, theoretical calculation and productivity attenuation method. Actual meaning of land potential productivity obtained from each method is different: empirical formula method is mainly applied to calculate climatic potential productivity; theoretical calculation method is to calculate the potential productivity of crop in one or several ideal growth conditions, representing the upper lim-

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it of the potential productivity; the productivity attenuation method is to study the potential productivity at each level. This study adopts the productivity attenuation method to study land potential productivity of Yan'an City.

In the process of formation of land potential productivity, solar radiation, temperature, precipitation, evaporation and ground slope factors wield great influence in varying degrees. In their combined action, the photosynthetic potential productivity of crops decreases gradually, and generates "light and temperature productivity", "light, temperature and water productivity" and "light, temperature, water and soil productivity".

3.1 Calculation of potential productivity

(1) Photosynthetic potential productivity: photosynthesis is the foundation for crop yield, and the essence of crop production is the production of photosynthesis. This productivity can objectively reflect the maximum potential productivity of land resource in a certain region[5]. It is assumed that temperature, moisture, CO_2, soil fertility, crop colony structure and agricultural technical measures are in the best suitable conditions. The yield is solely determined by solar radiation and thus it is the theoretical upper limit.

$$Y_r = K \cdot Q$$

where Y_r signifies photosynthetic potential productivity, Q stands for total solar radiation, and K is calculation coefficient. On the basis of photosynthesis theory of crops and Loomis calculation model, K can be calculated by the following expression:

$$K = (1-\alpha) \cdot (1-\beta) \cdot (1-\rho) \cdot [(E \cdot \theta \cdot CH \cdot CL)/C] \cdot (1-R) \cdot (1-I)^{-1} \cdot (1-W)^{-1} \cdot 10^5$$

where CH signifies harvest index, R is breathing loss rate, other parameters can be deemed as constant, and meaning and experimental value are shown in Table 1.

Table 1 Summary of experimental value of parameters for photosynthetic potential productivity calculation model[3]

Constant	Meaning	Value	Remarks
α	Reflectance of ideal crop colony to effective solar radiation	0.1	
β	Leakage reflectance of ideal crop colony to effective solar radiation	0.065	
ρ	Ineffective absorption rate of ideal crop colony to effective solar radiation	0.1	
E	Proportion of effective solar radiation to total radiation	0.45	
θ	Conversion efficiency of light quantum in photosynthesis	0.2177	
CL	Correction coefficient of average leaf area of field crops in growth period	0.48	Average value of cereal crops
C	Energy conversion coefficient	4 250	Determined by combustion (kcal/kg)
I	Proportion of mineral substance into air dry matter of crops	0.07	
W	Proportion of water content into air dry matter of crops	0.12	
105	Conversion coefficient of g/mm^2 and kg/hm^2		

Substitute these constants into the above expression, we obtain K = 1.01 · CH · (1 − R), the photosynthetic potential productivity model is evolved to:

$$Yr = 1.01 \cdot CH \cdot (1-R) \cdot Q \ (\text{kg/hm}^2)$$

In this study, the potential productivity is calculated for different crops, (rice is 0.42, corn is 0.40, wheat is 0.35 and millet is 0.40[6]), so CH is 0.4, R = 0.3[7].

(2) Light and temperature potential productivity: potential productivity of crops using local light and temperature resources in certain light and temperature conditions with other environmental factors (water content, CO_2, and nutrients) and crop colony factor in optimal state. It is often estimated through photosynthetic potential productivity multiplying by the temperature correction function. Light and temperature potential productivity can be considered roughly as the upper limit of local crop yield, and is the scientific basis for planning crop production.

$$Y_t = Y_r \cdot f(t)$$

where Y_t is the light and temperature potential productivity, $f(t) = n/365$ is the temperature correction function, and n signifies frost-free days.

(3) Climatic potential productivity (also called light, temperature and water potential productivity): the maximum biological yield or agricultural yield of crops through taking full advantage of local light, heat, and water resources and other conditions (such as soil, nutrients and CO_2) in unit area land of optimal situation.

$$Y_w = Y_r \cdot f(t) \cdot f(w)$$

where Y_w signifies climatic potential productivity, and $f(w)$ is correction function of water content.

f(w) = annual mean precipitation (mm)/annual mean evaporation (mm)

$$f(w) = \begin{cases} \text{Actual ratio} & (\text{precipitation} < \text{evaporation}) \\ 1 & (\text{precipitation} - \text{evaporation} < \text{run-off depth}) \\ < 1 & (\text{precipitation} > \text{evaporation} + \text{run-off depth}) \end{cases}$$

(4) Land potential productivity (also called light, temperature, water and soil potential productivity): the role of soil in crop production can not be neglected. Soil can provide water and necessary trace elements to support crop growth. Although it is easier to improve soil quality than changing light and temperature conditions, it is impossible to keep it in the ideal state for crop growth. Thus, it still needs land attenuation multiplying soil correction coefficient to obtain the final land potential productivity (also called agricultural potential productivity).

$$Y = Y_r \cdot f(t) \cdot f(w) \cdot f(s)$$ where Y is land potential productivity, $f(s)$ is soil correction function. The $f(s)$ reflects soil quality coefficient of crop yield and depends on soil quality composition of cettain area. In this study, we divide soil into different categories as per slope, and then calculate the effective coefficient of soil $f(s)$ by weighted average method[8].

$$f(s) = \sum P_i \times A_i = \sum [(B_i \times A_i)/C]$$

where P_i signifies the ratio of each type of cultivated land to gross cultivated land area, A_i refers to suitability of cultivated land type for crop growth, B_i stands for the area of each type of cultivated land, and C is the gross area of cultivated land. A_i can be calculated by following expression, where g is ground slope ($g \leqslant 7°$ optimal and $g \geqslant 25°$ not suitable for cultivated land).

$$A = \begin{cases} 1 & (g \leqslant 7°) \\ 1 - 2.5\sin(g - 7°) & (7° < g < 25°) \\ 0 & (g \geqslant 25°) \end{cases}$$

Influence factors of photosynthesis, light, temperature, climate and land potential productivity of counties (districts) of Yan'an City are listed in Table 2, and the calculation results are shown in Table 3.

Table 1 Influence factors of photosynthesis, light, temperature, climate and land potential productivity

Area	Annual mean solar radiation cal/cm^2)	Frost-free days	Precipitation mm	Evaporation mm	Suitability of cultivated for crop growth		Effective coefficient of soil f(s)
					$g \leqslant 7°$	$7° < g < 25°$	
Baota District	113 950	178	500	1601	0.13	0.56	0.69
Huangling County	112 297	172	596	1421	0.37	0.45	0.82
Huanglong County	113 584	186	602	1576	0.32	0.52	0.84
Yichuan County	113 990	167	571	1542	0.35	0.37	0.72
Luochuan County	114 467	152	622	1715	0.40	0.43	0.83
Fu County	115 980	140	550	1738	0.29	0.49	0.78
Ganquan County	114 901	148	536	1500	0.23	0.56	0.79
Wuqi County	119 850	146	483	1474	0.14	0.53	0.67
Zhidan County	119 300	142	520	1469	0.07	0.60	0.67
Ansai County	128 543	157	505	1618	0.11	0.55	0.66
Zichang County	124 500	175	515	1521	0.08	0.58	0.66
Yanchuan County	122 660	185	485	1576	0.09	0.54	0.63
Yanchang County	121 430	186	523	1576	0.13	0.53	0.66

Table 3 Photosynthesis, light, temperature, climate and land potential productivity of counties (districts) in Yan'an City (kg/ hm^2)

Area	Photosynthetic potential productivity Yr	Light and temperature potential productivity Yt	Climatic potential productivity Yw	Land potential productivityY
Baota District	32 564	15 881	4 960	3 422
Huangling County	32 040	15 098	6 333	5 193
Huanglong County	32 122	16 369	6 253	5 252
Yichuan County	32 745	14 982	5548	4 494
Luochuan County	32 635	14 932	5 160	4 334
Fu County	32 799	12 580	3 981	3 105
Ganquan County	32 296	13 095	4679	3 463
Wuqi County	33 155	13 262	4 346	2 912
Zhidan County	32 324	12 575	4 451	2 982
Ansai County	36 352	15 636	4 880	3 221
Zichang County	34 643	16 610	5 624	3 712
Yanchuan County	34 688	17 582	5 411	3 517
Yanchang County	34 340	17 499	5 807	3 833

3.2 Analysis on potential productivity

(1) Photosynthetic potential productivity: solar radiation increases from south to north[9] and takes on regional distribution. Northern Ansai, Zichang, Yanchuan and Yanchang counties have rich solar radiation, so their photosynthetic potential productivity remains high; middle Ganquan County and southern Huangling and Huanglong counties have weak solar radiation, so their productivity is low.

(2) Light and temperature potential productivity: mainly depends on annual frost-free days. Northeastern Yanchuan and Yanchang counties have long frost-free days, so their light and temperature potential productivity stays high, while northwestern Wuqi, Zhidan, Ganquan and Fu counties is the lowest due to short frost-free days.

(3) Climatic potential productivity: Huanglong and Huangling counties have high precipitation, low evaporation, moist climate and high light and temperature potential productivity, so their climatic potential productivity remains high; Fu County has low precipitation and high evaporation, so its climatic potential productivity is low.

(4) Land potential productivity: southern Huangling and Huanglong counties have small average slope of cultivated land and better cultivation environment, so their land potential productivity ranks the first in Yan'an City; northern Wuqi and Zhidan counties have high average slope of cultivated land and worse cultivation environment, so their land potential productivity is relatively low.

(5) Index of potential productivity (H): we use H to signify

current land potential productivity. H = [land potential productivity − actual productivity)/ land potential productivity] × 100%. The smaller is the H value, the more suitable is the production condition and the better use is the land. Otherwise, there will be high potential. Through calculation, the index of potential productivity of counties (districts) in Yan'an City is higher than 20%, indicating relatively low grain production level. However, the great difficulty in transforming soil presents a considerable challenge to land production work of Yan'an City.

4 Calculation of population carrying capacity

The population carrying capacity of land reflects the size of population fed at certain living level in certain land productivity condition[10]. It is a key criterion of grain production capacity and per capita grain consumption[11]. According to *Outline for the Development of Food and Nutrition in China* (2001 – 2010) issued by the State Council in 2000 and *Standard for Grain Security Category of China Food Development* proposed by State Food and Nutrition Consultant Committee in 2003, there are four types: subsistence, well-off, better-off and rich, and the annual per capita grain demand reaches 350 kg, 400 kg, 450 kg, and 500 kg respectively. According to the above standards and grain yield of counties (districts) in Yan'an City of *Statistical Yearbook* 2009 *of Shaanxi Province*, we calculate the population carrying capacity of each county and district, as shown in Table 4.

Table 4 Population carrying capacity of counties (districts) in Yan'an City

Area	Land potential productivity in 2009 // 10^4 tons	Population carrying capacity // 10^4 people				Population in 2009 // 10^4 people
		Subsistence	Well-off	Better-off	Rich	
Baota District	14.77	42.19	36.91	32.81	29.53	44.87
Huangling County	7.32	20.90	18.29	16.26	14.63	12.68
Huanglong County	9.86	28.18	24.66	21.92	19.73	5.15
Yichuan County	7.12	20.35	17.81	15.83	14.25	11.82
Luochuan County	8.42	24.05	21.04	18.70	16.83	20.91
Fu County	6.69	19.11	16.72	14.86	13.37	15.03
Ganquan County	7.93	22.67	19.84	17.63	15.87	8.46
Wuqi County	13.90	39.71	34.75	30.89	27.80	13.44
Zhidan County	15.22	43.49	38.05	33.83	30.44	14.94
Ansai County	12.79	36.53	31.96	28.41	25.57	17.69
Zichang County	13.16	37.60	32.90	29.25	26.32	26.87
Yanchuan County	11.92	34.05	29.80	26.48	23.84	20.28
Yanchang County	11.60	33.13	28.99	25.77	23.19	15.36

In accordance with annual per capital grain standard, Huangling, Huanglong, Yichuan, Ganquan, Wuqi, Zhidan, Ansai and Yanchuan counties reached the rich level in 2009, and the land can carry population growth in a long period. Zichang County is slightly lower than better-off level, Luochuan and Fu counties remain well-off level, and Bata District is still below the subsistence level. In the situation of constant population growth, Yan'an City should take necessary measures to improve agricultural production environment, explore land potential productivity and increase grain yield.

5 Recommendations

5.1 Optimizing agricultural production conditions and exploring land potential productivity Yan'an City is located in ravine area with severely undulating terrain and poor agricultural production conditions. The potential productivity index of the entire city is more than 20%, thus there is a big margin for potential productivity of explorable land, but the land development is difficult. It needs to optimize agricultural production conditions and improve land productivity by taking measures such as fragmented land consolidation, terraced field construction, agricultural infrastructure improvement and advanced planting technology introduction, etc. according to actual topographical and economic conditions of various counties.

5.2 Ensuring dynamic equilibrium of total cultivated land and controlling the purpose of land use strictly Yan'an City develops rapidly in economy, thus the continuous increase in construction land poses serious threats to the quantity and quality of cultivated land. Therefore, the land management departments of Yan'an City at all levels shall take measures such as implementing the control over the purposes of use of land, using land strictly based on the overall land use planning, employing dynamic monitoring technology, etc. in combination with land consolidation to ensure the balance between requisition and compensation of cultivated land.

5.3 Making proper population growth plan and improving the people's living standard The implementation of strict control over population growth is an effective means for reducing the grain demand and alleviating the pressure of land security[12]. At present, from the perspective of grain only, there is still 1 district in Yan'an City that does not reach the level of adequate food and clothing. Therefore, it needs to develop a population growth plan scientifically to carry out the exploration of land potential productivity and control over population growth simultaneously, thus improving the population carrying capacity of land, making great efforts in bringing the average ling standard of the entire city to the well-off level and improving the people's living standard.

References

[1] ZHOU ZG, MENG YL, CAO WX. Knowledge model and GIS-based crop potential productivity evaluation [J]. Scientia Agricultura Sinica, 2005, 38(6):1142-1147. (in Chinese).
[2] Shaanxi Provincial Bureau of Statistics, NBS Survey Office in Shaanxi. Shaanxi Statistical Yearbook(2010) [M]. Beijing: China Statistics Press, 2010. 82-85. (in Chinese).
[3] WANG WM, DONG ZJ, WANG Q, *et al*. Land utilization plan study [M]. Beijing: Science Press, 2006. 82-85. (in Chinese).
[4] Shaanxi Bureau of Land Management. Shaanxi land resources[M]. Shaanxi:. Shaanxi People's Publishing Press, 2000: 330-345. (in Chinese).
[5] WANG QB. Land resource science [M]. Beijing: China Agriculture Press, 2002. 195-196. (in Chinese).
[6] GAO WB, JIANG D, YANG XH. Potential productivity model of cultivated land and its application based on remote sensing data driven [J]. Progress in Geography, 2009, 28(4):597-602. (in Chinese).
[7] CHENG CZ, YANG XH, LI YJ, *et al*. Calculation and analysis of cropland potential productivity in Shandong Province with different models [J]. Resources Science, 2010, 32(11): 2165-2171. (in Chinese).
[8] YANG D, LIU Q, GUO PP, *et al*. Study on the potential land productivity and population carrying capacity in the Hexi Region: A case study in Ganzhou area, Zhangye City [J]. Northwest Population Journal, 2010, 2(31): 85-88. (in Chinese).
[9] WU LR, WANG JM, LIU HJ, *et al*. Spatiotemporal variation of solar radiation and sunshine hours in Shaanxi Province [J]. Bulletin of Soil and Water Conservation, 2010, 30(2):212-214. (in Chinese).
[10] RONG X, CUI D. Study on the land supporting for population in Liaoning Province based on farmland productivity [J]. Agricultural Science & Technology and Equipment, 2011, 10(208): 8-10. (in Chinese).
[11] YANGLIU QQ, WEN Q, HUO JW. A study on the potential land productivity and population carrying capacity in the West Dongting Lake region—taking the case of Anxiang County, Hunan Province [J]. Hunan Agricultural Sciences, 2009, (4): 137-139. (in Chinese).
[12] MEI WJ, ZHOU WL, CAI LT. Study on population carrying capacity of district land —taking the case of Zoucheng City, Shandong Province [J]. Journal of Southwest Agricultural University(Social Sciences Edition), 2010, 8(1):5-8. (in Chinese).

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decision-making; for regions with effective agricultural land security function, it should execute the legal provisions in principle. (2) It is necessary to make clear legislative definition of how the transferor exercises the consent right. The consent right of the transferor is a type of right to know or right to supervise, rather than power to make decision. Thus, in exercising the consent right, the party giving out the contract should firstly respect willingness of the owner of land contractual management right. The definition of consent right should follow the principle of allowing transfer, instead of restricting transfer[4]. Except following cases, it should approve the contractor' requirement for transferring his land contractual management right: (i) the contractor does not have stable non-agricultural occupation or stable income source, and transfer of agricultural land will lead to difficulty in living; (ii) if the contract of transfer is signed by force; (iii) the purpose of agricultural land use is changed; (iv) the transferee does not have agricultural production capacity; (v) the period of transfer exceeds remaining term of land contractual period.

References

[1] HU KS. Interpretation of Rural Land Contract Law of the People's Republic of China[M]. Law Press, 2002: 102-103. (in Chinese).
[2] DING GL. Study on the transfer of rural land contractual management right [J]. Economic Geography, 2006(supplement): 188-192. (in Chinese).
[3] GAO SP. The power structure and system rebuilding of stable and constant land contracted management right [A]. Macroeconomic Research Office of Rural Development Institute, Chinese Academy of Social Science. An international comparison of rural land reform [C]. Social Sciences Academic Press(China), 2009. (in Chinese).
[4] ZUO PL. Study on legal issues of the transfer of rural land contractual management right[M]. Central South University Press, 2007: 140-153. (in Chinese).