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Ecological footprint analysis of food consumption of rural residents in China in the latest 30 years

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Abstract

Food consumption appropriates not only arable land but grassland and other various agricultural land resources. It is of great use to analyse time series of ecological appropriation for food consumption of Chinese rural residents from the perspective of total agricultural land resources and then overall evaluation of resource basis to ensure food security with structure upgrading of food consumption. Firstly the appropriated land categories and domestic conversion factors of food consumption items were discussed. Accordingly, the ecological footprint (EF) model with refined factors was applied to macro-estimate the ecological pressure of food consumption and the changes of Chinese rural residents in the latest 30 years. The study indicated that ecological appropriation increased from 1.465 national standard acre (nsa) in 1980 to 1.782 nsa in 2006 with the changes of Chinese food consumption structure of rural residents, and especially the direct appropriated arable land has declined dramatically since 2000. The consumption category of grain was the largest category per capita in spite of decreasing percentage, so staple foods like grain products, vegetables were always laid the first place even though the consumption pattern has changed greatly. Food EF had a strong correlation with expenditure on food over the period; furthermore, it can be evidently proved by an elasticity of per capita meat and aquatic products EF 0.43. The overall ecological pressure of food EF of Chinese rural residents has increased unsteadily, as the grain-consuming animal products and aquatic product contributed to this. The comparison of dynamic analysis of food EF calculated by fixed yields and variable yields indicated that higher productivity of arable land has greatly alleviated the pressure on resources demanded by the process of structure upgrading of the food consumption of rural residents in China.

Keywords: Food consumption; Ecological footprint; Conversion factors; Expenditure elasticity

1. Introduction

Food security has been by far the greatest world-wide impact of human beings on land. From the perspective of food, it includes not only grain and its related meat, eggs and milk livestock products, but oil, vegetables and sugar even else non-grain food categories. Accordingly food production depends on the whole agricultural land

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resources. Food consumption appropriates not only arable land but grassland and other various agricultural land resources (Lu, 2005). With structure upgrading of food consumption, it is necessary to calculate the agricultural land requirement for food production by different populations. China feed one-fifth population of the total world population with less than 8% of the total world arable land and about 15% of world grass and pasture areas, at the same time rural residents are very important and the concerns in China. This study evaluates the ecological appropriation for food consumption of Chinese rural households to reflect the changes of their land requirement in the latest 30 years, and it is of particular value in the near future for overall evaluation of resource basis to ensure food security.

The land area needed to feed the population depends on the ecological production system and food consumption pattern. Duchin(2005) believes some diets with characteristics of helpful to human beings' health and relatively low environmental impact as sustainable ones. However, food consumption patterns have large effects on total land requirements. In recent years some researchers have paid much attention to ecological footprint as the tool of calculating the agricultural land requirement for regional food consumption (Deutsch et al.,2005, Ferng,2005). A method, other than compound approach of ecological footprint, is applied for the Dutch situation in 1990 and resulted in changes in Dutch food consumption during the period 1950–1990 were quantified and related land requirements assessed (Gerbens-Leenes et al., 2002a,2002b). In China there have been many cases applying EF model, which focused on method introduction and local application in national, regional, metropolitan and county scales and majority of analyzed in compound approach(Liu et al.,2005; Lu et al.,2001; Du et al.,2004;Yuan et al.,2007; Min et al.,2004). While the other approach called component-based approach is more suitable for household consumption, though it is not very popular in food consumption research in China. This study is to apply it to assess agricultural land requirements for food consumption of rural residents in order to measure ecological pressure caused by Chinese rural residents rationally on macro scale. Another deficit occurred in many case studies is the parameter in EF calculation, using world average yield not actual regional yield. So the standardization procedure is carried out by adjusting for local yield factors.

The paper is organized as follows. First, the calculation method and national factors of food EF are discussed. The paper presents a method that combines available data on food consumption with data on specific land requirements for foods. Next, it assesses food EF over the period of 1978-2006 on the basis of refined factors. Finally, the key discussion and conclusions are explained in detail.

2. Methods and data sources

The ecological footprint (EF) analysis, originally proposed as a metric by Wackernagel and Rees, measures the amount of natural resources to satisfy the consumption requirements and waste assimilation needs by a defined population in a given year. The consumption of these populations is converted into the amount of biologically productive area, expressed in units of hectares per capita at world-average productivity (Wachernagel and Rees, 1995). EF is promoted as a policy guide and planning tool for sustainability by comparing EF to the regional available land, usually referred as bio-capacity (BC).

So far, there have been at least two alternatives in calculating the footprint components that are associated with the consumption of a defined human population. One is the original EF model formulated by wackernagel and Rees (1995), and the other, suggested by Bicknell et al. (1998) and its later development(Ferng,2001; Hubacek et al,2003; McDonald et al., 2004) is input-output based on the EF model in which final consumption can be traced and calculated by input-output table(IOT). Regarding the former it calculates 'apparent consumption' of the resources of concern by adding imports to domestic production and subtracting exports. However, the apparent consumption varies from real household consumption, so it can be further divided into two approaches, compound approach and component-based approach. Compound approach is popular when calculating national and regional EF in China. But two specific problems exist: The smaller the area and population under investigation the more difficult it becomes generally to obtain accurate data. Moreover, in adjusting to world-average productivity, much regional detail is lost. These problems lead to a lack of policy relevance. In our work, the component-based model is applied.

2.1 The calculation steps of food ecological footprint

The component-based approach sums the ecological footprint of all relevant components of a population's resource consumption and waste production. Rather than larger governmental units in compound approach, it measures the impact of different lifestyles, organizations, sub-national regions, products and services by adopting a 'bottom-up' analytical approach (Simmons et al., 2000). The componential approach is more valuable for household consumption, and we consider two key merits of this model, accuracy and utility. The relationship between food consumption patterns and land requirements is complex. Food items or foodstuffs are originated from different food production systems and with different land requirements. The analysis is complicated by the different communities and regional differences between food consumption patterns as well as by yield differences. In food production system, a rough division can be made between primary and secondary production systems. Secondary products are goods derived from primary products, including meat, milk and farmed fish. Large amounts of primary products, by-products and industrial energy are used in livestock production systems. To determine relatively accurate ecological demands for food items, information on yields, food industry recipes and proportions of animals and plants planted are needed.

Estimating the food EF is a multi-stage process. First step is to build food consumption account and to list a menu of main consumption categories. The next step is to obtain date on per capita average consumption (kg per year) of particular items directly investigation or indirectly available from statistical data. The third step is to estimate per capita land area appropriated for production of each major consumption item by dividing average annual consumption of that item（Q_{ij}， kg） by its average global or local yield（p_{ij}， $kg{\cdot}hm^{-2}$ or $kg{\cdot}m^{-2}$）. The EF_{fc} based on the local yields represents the actual land use associated with consumption in a defined situation. Then the total per capita ecological footprint (EF_f, hm^2 or m^2) is arrived at by summing all the ecosystem areas appropriated by all the items consumed when the equivalent factor r_i should be applied as depicted in Equation 1. Conversion factor T denotes the ratio of primary products to the manufactured goods.

$$EF_f=\sum(r_i{\cdot}T{\cdot}Q_{ij}/p_{ij}) \qquad (1)$$

Where i is land-use categories here including cropland, grassland, fishing land and energy land. Energy land of the food footprint（Eq.2）is energy used for the production and transportation of foodstuff based on embodied energy, which is expressed by the additional biologically productive area needed to sequester CO_2 emissions through afforestation.

$$EF_c=r{\cdot}\sum(Q_j{\cdot}TF_j{\cdot}C_n) \qquad (2)$$

Where EF_c is the footprint of fossil energy, r is its equivalence factor, TF_j is energy intensity of product j ($Gj{\cdot}t^{-1}$ or $Mj{\cdot}kg^{-1}$), and C_n ($hm^2{\cdot}GJ^{-1}$ or $m^2{\cdot}MJ^{-1}$) is carbon sequestration ratio of a given fossil fuel n (coal, natural gas and fuels derived from crude oil).

2.2 Data sources

Food consumption involves hundreds of food items, and the study considers eight main consumption categories: (1)grain; (2)fresh vegetables; (3)edible vegetable oil; (4) meat including pork, mutton, beef ,poultry and aquatic products; (5) fresh milk; (6) eggs; (7) sugar; (8) alcoholic beverages. Information on actual food consumption is obtained from Rural Household Survey by National Bureau of Statistics of China, and information on yields is available from the National Bureau of Statistics of China. Yield per year for each crop varied. The cropland is based on specific grain yield in 2000 convenient for analysis at first, and then the changes of yields are considered.

2.3 Conversion factors of food footprint

The standardization procedure is the important process for calculating food ecological footprint. In this study, it is carried out by adjusting for local yield factors in order to measure the resources requirement accurately and directly.

(1) Conversion factors of cropland for different food items

Many food items originate from crops grown in the farmland like grain or soybeans, and secondary products including meat, milk, egg, and farmed fish are fed by crops and by-products derived from farmland, these all have different cropland requirements. When we convert these food items to cultivated area, an easy way is to convert them into grain equivalents by equivalent factors as presented in table 1 (Liu, 2005), then cropland requirements for food items were calculated by dividing the consumption by the grain yield(kg per hm^2). Specific grain yield in 2000(4262kg·hm^{-2}) is applied for the yield is closer to the average yield in the past 30 years.

Grain equivalents are derived from ecological principles of energy conversion efficiency. For example, the equivalent factor of pork is 5, which is arrived at by the ratio of the live weight of pork to fodders multiplied the ratio of pork at carcass weight to at live weight（ATEH, 1984）, so 1kg pork needs about 5kg corn or other fodders grown on the farmland. The equivalent factor of vegetables is available from the ratio of the yield to the grain's yield. Meat types (e.g. pork) have larger land requirements than cereals and vegetables. This implies a shift to a more meat diet appropriate more land resources. Some studies estimated that an affluent diet requires more than three times as much land as a vegetarian diet (Groot et al., 1998).

Table 1 Equivalent factors of grain land per food item (kg)

Food items	Grain (unprocessed)[a]	Vegetable oil[a]	Vegetables	Liquor	Sugar[a]	Pork[a]	Poultry[a]	Eggs[a]	Aquatic products[a]
equivalent factors	1	4	0.15	2.2	2	5	5	2	2

a Source: Liu (2005); the equivalent factor of liquor is taken from CSSD（2004）

It's stressed that no land requirements were assigned to by-products and wastes from the food industry that are used in the fodders of domestic animals to avoid double counting. No land is assigned to animal fat because the equivalent factor of meat has considered the whole land appropriation. For soya oil the equivalent factor is decided by the ratio of soybean- to grain-average yield and conversion efficiency in the food industry. Soya oil generates large amounts of oil cakes that are used for livestock fodders and no land is assigned. Farmed fish is fed by fodder from cropland, and aquatic products by fish catch are calculated by conversion factor of fishing land.

(2) Conversion factors of cropland and grassland for beef, mutton and milk

In some livestock production systems one food items are produced, while in other systems two food items are produced. Pig keeping results in the production of only pork, whereas dairy farming results in raw milk and beef. When more products are made in a production system, the total land requirements were divided over the products proportional to their energy output, like milk and beef. Another reason for the difference between their conversion factors is the livestock such as cattle and sheep are fed by grass, hay intake from the rangeland. In China livestock husbandry are located mainly in cultivated areas, which decrease the pressure on grazing land by making good use of straw, silage to feed livestock. The grain accounted for 70% of the total fodder production (Wang, 1996). Combination of farming and grazing plays a crucial role in China, and they developed synchronously on macro scale. Conversion factors of cropland for beef, mutton and milk is taken from CAAS(1989), and conversion factors of grassland for beef, mutton and milk shown in table 2 are determined by the proportions of animal products from grazing and farming(Deng et al.,2005). Because the balance of net imports of animal products is small and import footprint only accounts for 4%(Liu, 2005), the weighted average land requirement for the Chinese products and imported meats can be omitted.

Table 2 Conversion factors of cropland and grassland for beef, mutton and milk

Consumption items	Beef	Mutton	Milk
Conversion factors of cropland (kg·kg^{-1})	3.6	2.3	0.3
Conversion factors of grassland (kg·hm^{-2})	18	24.3	216
Proportion from grazing	14%	35%	26%
Modified mean conversion factors of grassland (kg·hm^{-2})	128.6	69.4	830.8

(3) Conversion factor of fisheries for fishing products

Since 1980 farmed fish developed fast in freshwater fish production and the proportion of aquatic products of inland aquaculture averages 87% of the total amount. At the same time farmed marine products have increased from 13.6% in 1980 to 41.8% in 2000, and even reached 50% in 2006. Except for farmed fish fed by crops the majority of the marine fish catch occurs on the continental shelves, and the area comprise 280 million ha, currently providing nearly half of China's aquatic products. Inland waters add another 17.47 million ha, then the weighted average yield of fish catch (kg·hm^{-2}) for the marine and inland waters was calculated for nearly 30 years.

For lack of statistical data of trade documenting the distribution of farmed fish and capture and considering its little effect on the fish footprint the weighted process is negligible. Finally the conversion factor of fishing land is determined by the fraction of fishing products to total aquatic products, the weighted average capture yield and discard rate in the process of fish food manufacture. Thus the average capture productivity of 71.1 $kg \cdot hm^{-2}$ was estimated as the conversion factor of fisheries in China.

(4) Conversion factors of national average energy

In Eq.2, Energy intensity is applied to account the embodied energy production and transportation of foodstuff, and it can be obtained from Redefining Progress. About more than 80% of the food consumption items are processed and packaged in developed countries, but the percentage reaches only 40% in China, for Chinese rural areas it is even lower. So Energy consumed in food production and transportation is calculated by multiplying the international energy density with the coefficient 0.4 for the sake of simplifying the calculation.

Energy land represents the amount of forest land needed to uptake anthropogenic carbon emissions. The adjusting carbon absorption rate of forest is determined considering the carbon pool, carbon dioxide dynamics of tropical mountain rain (Li et al., 1998) forest ecosystem and the actual forest productivity yearly in China, and it is more reasonable for the situation. Carbon intensity represents carbon emissions of different type of fossil energy (Gao et al.,1994). The conversion factor of domestic fossil energy is calculated by carbon intensity divided absorption rate through afforestation deducting the fraction absorbed by ocean (Monfreda, 2004). The ultimate results are shown in table 3.

China has a quite different energy consumption structure from some other countries and organizations. By comparison of primary energy consumption structure in 2001, coal, oil and natural gas accounted for 62%, 27.5% and 3.0% of total Chinese energy consumption respectively, while for the world the proportions of coal was only 24.7% , and that of oil and gas is 62.2%(Lang et al., 2004). The CO_2 emissions of coal burning are much more than the other types of fossil fuel, for instance, almost no emissions for hydropower and nuclear energy. The average of carbon sequestration ratio is 0.036 $hm^2 \cdot GJ^{-1}$ (0.36 $m^2 \cdot MJ^{-1}$) by weighting averages of land requirements for three types of fossil fuels (coal, crude oil and natural gas).

(5) Equivalence Factors

According to the comparative analysis on Chinese actual agricultural land productivity (Liu Xunhao, 2005), the actual primary productivity(APP) is deduced by net primary productivity(NPP) of present arable land, forest and grassland multiplied with economic coefficient. As used here, APP can measure food footprint more accurately than NPP. The research suggested that the ratio of APP among arable land, forest and grassland is 1:0.04:0.16, which can be as the equivalent factor of these three types of land. From Liu Yuhui's study(2004), per unit seawater area is equivalent to 0.1 acre of arable land in China. The equivalent factor of fisheries is calculated by weighting the proportions of fish catch in seawater and freshwater. We define the biomass above ground (dry weight of seeds, stem and leaves) of 667 m^2 grain land area one year as a standardized acreage, then the agricultural land requirement for food consumption will be converted into national standard acres(nsa) or national standard hectare(1 hectare=15 acres in Chinese metrology) applying the equivalent factors of forest, grassland and fisheries to measure the total ecological appropriation and the proportion of various agricultural land.

Table 3 Conversion factors of fossil energy

Energy categories	Carbon intensity ($t\ C \cdot GJ^{-1}$)	carbon absorption factors ($hm^2 \cdot GJ^{-1}$)
Coal	0.0230	0.0423
Crude oil	0.0183	0.0339
Natural gas	0.0137	0.0254

3. Results and discussions

Along with rapid increasing economic development and personal income in China, great changes have taken place in main food consumption categories in rural area over the period 1978-2006. Time series analyses of food EF of Chinese rural residents with refined factors are helpful to reflect the changes of the ecological pressure on agricultural land resources including arable land, grassland and fisheries. The effect can occur in the country itself or outside its border.

3.1Food EF and its land composition

Based on the modified conversion factors and equivalent factors mentioned above, the food consumption items of Chinese rural residents are converted into the appropriated land which is expressed in unit nsa as shown in Fig 1. As a whole, the general tendency of food EF indicated that ecological appropriation increased from 1.465 nsa in 1980 to 1.782 nsa in 2006 with the changes of China's food consumption structure of rural residents, with the average rate of 1% per year. After a fast-speed increase in 1980s' and a steady growing in 1990s' the food EF moved into a short term of decline since 2000, and it rallied in the latest 2 years. Table 4 further visualizes the components of food EF due to the changes in per capita food consumption in the selected years.

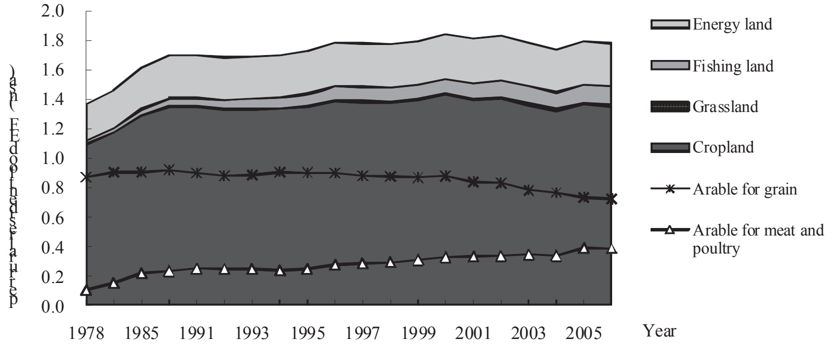

Fig. 1 Changes of food EF of rural residents from 1978 to 2006 (fixed yield)

The cropland EF per rural resident has the same trend as the total food EF and decreased since 2000 because grain, vegetables and edible oil consumption has fallen fast in the period. The grassland EF rose steadily but has a little percentage depending on the factors: e.g. Chinese residents' diet preference for pork meat which is produced based farmland, and a lower conversion factor of grassland determined by the characteristic of combination of farming and grazing. The fishery EF increased dramatically. This reflects more residents in rural areas tended to consume more fishing products, meat and fewer cereals on table diets. The energy land dropped in the mid-1990s' and in the recent years for the decreases in consumption of grain and vegetables.

From the composition of the four land EF the results illustrate that cropland area EF accounts for approximate 80% of the total food EF before the mid-1990s', and it slowed down and later keep a percentage of 76%-77%. Decreasing grain consumption and increasing meat, eggs and fish appropriate more farmland indirectly by secondary production than before, which is manifest at a glance from the curves of arable EF in Fig. 1. Although the grassland EF possessed a little share, mutton consumption constituted more than half of the grazing land requirement, more and more milk consumption exerted stress on the pasture as well.

Over the last decades, food ecological footprint increased because pork, poultry, eggs and other grain-based food and aquatic products consumption contributed to it. Contrary to this, the arable land, energy land reduced because of decreased cereals and vegetables consumption after 2000 year which can't be offset by the increment of fishery and grassland, and the overall ecological appropriation declined. Results showed that the direct cropland appropriation has fallen greatly since 2000 with the changes in food consumption patterns for the Chinese rural residents, and decreasing per rural resident food EF gave a signal that in rural areas per capita land requirements have shrunk instead of expanded.

Table 4 Structure and changes of food EF of rural residents from 1980-2006(nsa/cap)

Items	1980	1985	1990	1995	2000	2006
Cropland EF	1.173	1.288	1.349	1.348	1.433	1.350
Grassland EF	0.003	0.005	0.006	0.005	0.008	0.010
Fishery EF	0.028	0.042	0.054	0.085	0.099	0.127

Energy EF	0.261	0.282	0.294	0.289	0.305	0.292
Food EF of rural residents	1.465	1.616	1.702	1.726	1.846	1.782

3.2 Food EF and its consumption categories

Food EF can also tell us the ecological appropriation per consumption category per rural residents, and it is expressed in centage as shown in Table 5. The consumption category of grain was the largest category per capita, but the percentage fell from 73.9% in 1980 to 48.6% in 2006. The information indicated that staple foods like grain products, vegetables were always laid the first place even though the consumption pattern has changed greatly. Meat, milk and eggs have increased nearly to 30% in recent years, and pork consumption is the preference among meat products with personal income rising. The Aquatic products EF rose from 0.03 nsa in 1978 to 0.20 nsa in 2006 with the average rate of 6.8% per year and accounts for 10.6% of the total food EF per rural resident in 2006.

Table 5 Ecological space appropriation (% of the total food EF) for food consumption of rural residents

Food Items	1980	1985	1990	1995	2000	2006
Grain(unprocessed)	73.9	67.1	64.8	62.5	57.1	48.6
Vegetables	7.5	7.0	6.8	5.2	5.0	4.9
Vegetable oil	1.4	2.4	3.1	3.7	4.5	4.0
Pork	10.4	13.4	13.0	12.9	15.1	18.3
Beef and mutton	0.7	0.8	1.0	0.9	1.3	1.8
Poultry	0.9	1.3	1.5	2.2	3.1	4.0
Milk ,eggs and processed products	0.6	1.1	1.3	1.5	2.2	2.6
Aquatic products	2.8	3.8	4.7	7.3	8.0	10.6
Other food products	1.7	3.0	3.8	3.8	3.8	5.3
Total	100.0	100.0	100.0	100.0	100.0	100.0

Food EF per food item can further explain changes of land component of food EF mentioned above. Data on land requirements for detailed individual food items on household consumption obtained at the bottom of the food system can give a more valuable contribution to further discussion on different populations. The method presented here can be used to study other combinations of consumption patterns and production systems, for example urban residents or future perspectives.

3.3 Variations of the ecological footprint with food expenditure and policy implications

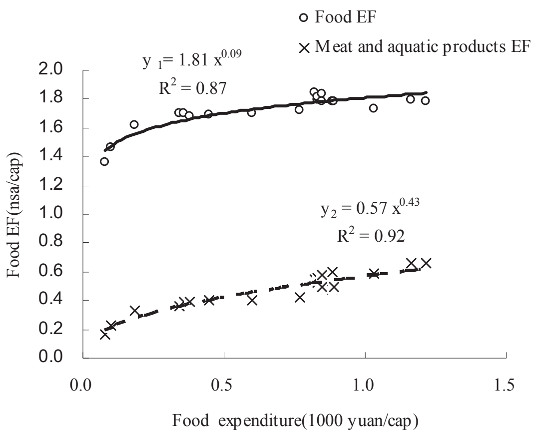

Fig. 2 Per capita food EF as a function of per capita food expenditure of rural residents

The influence of demographic variables can be investigated by applying ecological footprint multipliers to the Chinese food expenditure survey（Lenzen et al.,2001）. Fig. 2 shows the influence of per-capita expenditure (*x*) and the per-capita food EF(y_1). It can be observed that y_1 increases with x. This increase is can be characterized by an elasticity 0.09(exponent in regression formula in Fig.2). This means that, for an expenditure increase of 10%, the food EF increases by only 0.9%. Y_1 exhibits a correlation factor of 0.87. Since meat and aquatic products consumption contributed to the increase of food EF, we define per capita meat and aquatic products EF as variable y_2. Y_2 is more elastic than Y_1 with an elasticity factor 0.43, in addition, the correlation with per rural resident expenditure is much better at R^2=0.92, which indicate that meat and aquatic products EF is a better proxy for ecological appropriation than food EF. Similarity, an expenditure increase of 10%, the meat and aquatic products food EF increases by only 4.3%. This suggested that within consumption items, spending money on meat and aquatic products exerts environmental pressure.

In this way the study presented here can give a contribution to the discussion on the ability to produce enough food in the next decades. According to per capita food EF as a function of per capita food expenditure, if per capita food expenditure rise from 1217 yuan in 2006 to 2848 yuan in 2015, per capita food EF will result in 1.98 nsa in 2015, increasing by 0.22 nsa than in 2006.

3.4 Comparisons of food EF calculated by fixed yield and variable yield

Per rural resident food EF is calculated based on fixed yield or average yield, and the results separated only the factor of food consumption pattern which affected per capita agricultural land resources. Considering the changes of technical efficiency at the same time and based on variable yield of cropland, food EF per rural resident and its land components are shown in Fig 3. As a whole, the fluctuate tendency of food EF indicated that ecological appropriation decreased from 2.12 nsa in 1980 to 1.65 nsa in 2006, with the average decline rate of 1% per year. The real land appropriation fell gradually in the 1980s', and then remained stable in the 1990s' because of improved cropland productivity. It can be illustrated that per capita food EF is 1.81 nsa in 1991, but it's the same value in 2001 after a 10 years' slight wave, and then it began to drop since 2002 affected by double factors of China's food consumption structure and technical efficiency. It proved that higher productivity of arable land has greatly alleviated the pressure on resources demanded by the process of structure upgrading of the food consumption of rural residents in China.

So the method presented in this study gives us a path to describe a full picture of the reliable changes of agricultural land resources and the reasons by comparison the results calculated by fixed yield and variable yield. It helps to reveal the correlation of food consumption, agricultural productivity with ecological pressure. Yield levels, production systems and consumption patterns change in time and vary between populations so that data obtained here are only valid for the Chinese rural residents in a given scenario. Equivalent factors and conversion factors such as livestock products and fishing products based on the average productivity should be further calibrated integrated the newest progress, and the calculation of energy EF, in a simple way, is dealt with by adjusting international energy intensity. Eating out as an aspect which is not weighted in calculation food EF considering smaller proportion for rural residents should be included in further research work.

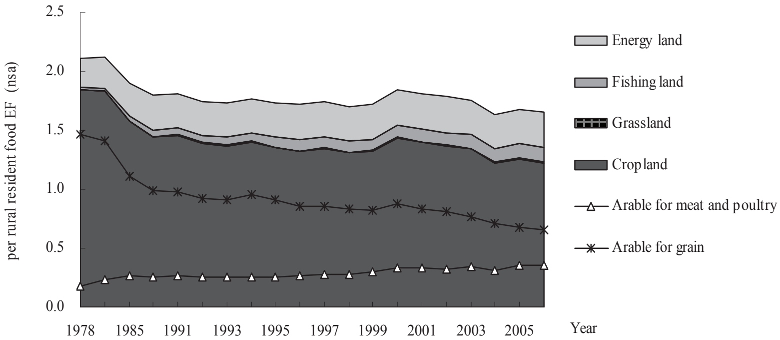

Fig. 3 Changes of food EF of rural residents from 1978 to 2006 (viable yield)

In conclusion, based on the componential approach the paper discusses the domestic conversion factors of calculating food EF for the first time, and the method builds "consumption-land" matrices to map the compound relation more reasonably, for instance, not only arable land but grassland are assigned to some livestock products like mutton and beef. Hence, the method overcomes the limit of compound approach to convert consumption items into only one land resource. Furthermore, methods with local yield are more meaningful for policy-making, since most policies are designed and implemented at a regional level. As a whole, the changes of resource flow measured by modified EF model have a good simulation function; it is valuable for us to research and compare different consumption patterns, different regions and social groups in the future.

4. Conclusions

The current study discusses the conversion factors and equivalent factors of ecological footprint analysis based on local yield and then the ecological footprint model with refined factors is applied to macro-estimate the ecological pressure of food consumption and the changes of Chinese rural residents in the latest 30 years. The study indicats that if fixed yield is applied, per capita ecological appropriation increased from 1.465 national standard acre (nsa) in 1980 to 1.782 nsa in 2006 and especially the direct appropriated arable land has declined dramatically since 2000 with the changes in food consumption patterns for the Chinese rural residents, which means in rural areas per capita land requirements have shrunk instead of expanded. The overall ecological pressure of food EF of Chinese rural residents has increased unsteadily as the grain-consuming animal products and aquatic product contributed to this. The consumption category of grain was the largest category per capita in spite of decreasing percentage, so staple foods like grain products, vegetables were always laid the first place even though the consumption pattern has changed greatly, and pork consumption is the preference among meat products with personal income rising.

Food EF had a strong correlation with expenditure on food over the period, and it can be evidently proved by an elasticity of per capita meat and aquatic products EF 0.43. The comparison of dynamic analysis of food EF calculated by fixed yields and variable yields indicates that higher productivity of arable land has greatly alleviated the pressure on resources demanded by the process of structure upgrading of the food consumption of rural residents in China. The method presented here makes a contribution to reveal the correlation of food consumption, agricultural productivity with ecological pressure.

This model provides a valuable link to how food consumption patterns can be related to aggregate demand of resources. The study also provides a new framework for application ecological economy methodology in agroecosystem. Data obtained at the bottom of the food system can be used to evaluate and compare consumption pattern of different populations and by assessing the resource costs of varied food consumption options, it is valuable for the discussion on future land requirements and food security.

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