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Life Cycle Energy Consumption of China's Major Crops from 2012 to 2018

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ABSTRACT

A comprehensive and detailed energy consumption inventory of crop production is of considerable significance to agricultural management because of the great changes in agricultural mechanization. In this study, a cost-input method was used to calculate the energy consumption of seven major crops in China from 2012 to 2018. Ten energy consumption phases of crop production were considered, including tilling, sowing, field management, harvesting, and treatment. The energy consumption of major crops in China increased by 25% over this time period, with indirect energy consumption accounting for a large proportion of the total, and direct energy consumption increasing rapidly. Of the grain crops, corn consumed the most energy in 2018, followed by rice and wheat. Among the oil crops, the total energy consumption of peanut was greater than that of rapeseed. There were differences in the energy consumption phases of crops per hectare and per unit yield. Considering the total energy consumption structure in 2018, the consumption of compound fertilizer was the highest, followed by nitrogen fertilizer use, mechanical tilling, mechanical harvesting, and mechanical sowing. The crops studied showed different life cycle energy consumption structures. Agricultural machinery operation was the prominent contributor to energy consumption for soybean and rice production, while chemical fertilizer was the primary contributor for cotton production; both contributed to the energy consumption for other crops.

Keywords: Life cycle energy consumption, Agricultural machinery operation, Cost-input method

NONMENCLATURE

Abbreviations	
APEN	Applied Energy
Symbols	
n	Year

1. INTRODUCTION

Agricultural production requires considerable energy and is a major contributor of greenhouse gases. According to the 2016 UN Food Report, agriculture accounts for at least one-fifth of greenhouse gas emissions, posing a severe threat to the environment. Agricultural production and mechanization have seen rapid expansion and improvement in recent years. Between 1990 and 2019, China's grain yield increased 1.5-fold, the use of fertilizer increased 1.1-fold, and the power of agricultural machinery increased 2.6-fold. The increasing use of these resources is likely to cause a rise in both energy consumption and environmental pollution [1]. Understanding China's agricultural energy consumption is crucial for energy conservation, emissions reduction, and environmental protection. Such studies would be a significant contribution to efforts to reduce global carbon emissions, especially in the face of emissions peaks and carbon neutrality challenges.

To date, there have been many evaluations of agricultural energy consumption. Zhang et al. calculated the direct energy consumption of diesel, electricity, animal power, and human power in agricultural production and the indirect energy consumption of agricultural machinery and chemical fertilizers and pesticides required for crop growth in China from 1995 to 2011 using the energy consumption coefficient method. They discussed the relationship between energy utilization and economic output and emissions in crop production systems [2]. Xu calculated the energy consumption of diesel, electric power, chemical fertilizers, and pesticides required for the growth of major crops in China using compiled data on agricultural revenue [3]. Mousavi-Avval et al. conducted face-to-face surveys with farmers from 130 randomly selected rapeseed farms in Golestan Province, Iran, and calculated the energy needed for rapeseed production [4]. These studies provide a relatively comprehensive system for the study of agricultural energy consumption but there is a lack of more detailed classifications for calculating the use of diesel, electricity, and other energy requirements. With the rapid development and popularization of mechanization, almost every stage of crop production involves mechanical energy consumption. These stages include machine farming, machine sowing, machine harvesting, plant protection, plastic film covering, etc, but previous studies rarely calculated energy consumption for these phases. Olaniran et al. studied the energy consumption of 1 ha of cassava production, dividing consumption into soil preparation, planting, crop protection, and harvest stages, in line with the actual energy usage. Data were collected from the farm and related research institutions. Considering the difficulty of obtaining data, this approach is not suitable for energy consumption calculations for a large area or a variety of crops [5].

Based on the above studies, here, we used the cost-input method and life cycle perspective to calculate the energy consumption of the production process for China's major crops: grain crops (rice, wheat, corn, soybean), oil crops (rapeseed, peanut), and economic crops (cotton). The calculation framework used is suitable for large-scale energy consumption analyses of a variety of crops. Diesel energy requirements were divided into those for mechanical field operations and those for drainage and irrigation; the energy consumption of farm machinery operations was refined as mechanical sowing, tilling, harvesting, plant protection, plastic film covering, straw baling, and straw return. This approach provides more detailed and realistic energy consumption inventories for crop production.

2. MATERIAL AND METHODS

2.1 Data resources

The energy consumption of the production processes of seven major crops in 31 provinces of China from 2012 to 2018 was calculated. Data were obtained from the China Rural Yearbook, China Agricultural Product Income and Cost Data Compilation, China Price Yearbook, and China Agricultural Machinery Industry Yearbook.

2.2 Methods

First, energy consumption of crop growth was considered for the following four aspects: energy consumption of agricultural machinery ($E_{A\text{-}M}$), drainage and irrigation ($E_{D\text{-}I}$), pesticides (E_{pes}), and fertilizers (E_f). The former two belong to direct energy consumption (E_{dir}), while the latter two belong to indirect energy consumption ($E_{in\text{-}dir}$). The crop lifecycle can be roughly divided into 10 energy consumption phases: mechanical tillage (M-til), mechanical sowing (M-sow), plastic film covering (M-cover), drainage and irrigation, chemical fertilizer use, mechanical plant protection (M-pro), pesticide use, straw baling (M-bal), straw return (M-re) to the field, and mechanical harvesting (M-har). Drainage and irrigation energy consumption includes both diesel and electric. Fertilizers include nitrogen, phosphate, potash, and compound fertilizers. Next, the cost-input method was applied. The input amounts or quantity of production materials for different crops per hectare were combined with the price of different production materials in the same year to obtain the total inputs[3]. Finally, the energy consumption of different stages was obtained from the energy consumption coefficient.

The energy consumption of different stages of the crop life cycle was calculated as follows:

(1) *Energy consumption of agricultural machinery operation*.

E_{1ij}, the total energy consumption of agricultural machinery operations, was calculated as

$$E_{1ij} = \sum_{n=1}^{7} \frac{P_{1ij} * U_{ij}}{P_1} \alpha \quad (1)$$

where P_{1ij} is the fuel consumption cost of machinery operation per hectare; U_{1ij} is the area of machinery operation of *j* crops in province *I*; P_1 is the unit price of diesel oil in the current year; and α is the coefficient of diesel energy consumption. *N* = 1, 2,…7 represent the mechanical tillage area, mechanical sowing area, mechanical harvesting area, plant protection area, plastic film covering area, straw bundling area, and straw return area.

Considering the multifunctional characteristics of agricultural machinery in crop production processes and the empirical rule of mechanical use, the plant protection and plastic film covering areas for different crops were obtained according to the sowing area. The straw bundling and straw return areas of different crops were obtained according to the proportion of machine harvesting area.

(2) *Energy consumption of drainage and irrigation*

Electromechanical drainage and irrigation include diesel engine and electric. Diesel irrigation and drainage energy consumption ($E_{dieseal-ir}$) was calculated as

$$E_{2ij} = \sum_{n=1}^{7} \frac{P_{2ij} * S_{2ij}}{P_1} \alpha \quad (2)$$

where P_{2ij} is the cost per acre of diesel engine drainage and irrigation and S_{2ij} is the diesel engine drainage and irrigation area.

Electric power irrigation and drainage energy consumption ($E_{eletric-ir}$) was calculated as

$$E_{3ij} = \frac{P_{3ij} * S_{3ij}}{P_{el}} \beta \quad (3)$$

where P_{3ij} is the cost per hectare of electric power irrigation and drainage; S_{3ij} is the area of drainage and irrigation; and β is the coefficient of power consumption.

(3) *Energy consumption of fertilizer*

The energy consumption of fertilizer was calculated as

$$E_{4ij} = \sum_{l=1}^{4} C_{ij} * S_{ij} * \omega_l \quad (4)$$

where C_{ij} is the input per acreof each chemical fertilizer for j crops in province i; S_{ij} is the planting area of j crops in province i; $l = 1,2,3,4$ represent nitrogen, phosphate, potassium, and compound fertilizer, respectively; and ω_l is the energy consumption coefficient of fertilizer l.

(4) *Energy consumption of pesticide energy*

The cost of pesticide per hectare, E_{5ij}, was calculated as

$$E_{5ij} = \frac{P_{5ij} * S_{ij}}{P_5} * \omega_3 \quad (5)$$

where P_5 is the price of pesticide in that year.

Total energy consumption in crop production (E_T) was calculated as

$$E = E_{1ij} + E_{2ij} + E_{3ij} + E_{4ij} + E_{5ij} \quad (6)$$

3. RESULTS

3.1 Multiyear life cycle energy consumption of major crops in China

From 2012 to 2018, the planting area of major crops in China did not change significantly but the working area of farmland machinery showed a continuous upward trend. The total energy consumption of crops also increased, from 1184 × 10^{12} KJ in 2012 to 1480 × 10^{12} KJ in 2018, an increase of 25% year-on-year and an average

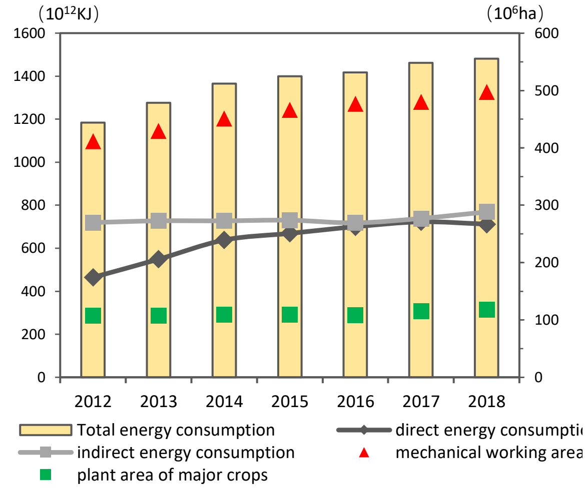

Fig. 1. Energy consumption results of seven crops from2012 to 2018

annual growth of 3.6% (Fig.1). The gap between direct energy consumption and indirect energy consumption gradually narrowed, and the energy use structure changed.

(1) Direct energy consumption

a. The direct energy consumption of agricultural machinery operations increased by 52% between 2012 and 2018. Although mechanical straw baling was consistently the smallest contributor, it also showed the fastest growth rate (5-fold increase). The energy consumption of mechanical plastic film covering increased the least (16.72%), followed by that of mechanical plant protection (29.02%). Other stages showed the following trend of energy consumption: machine farming (33.63%) < machine sowing (51.27%) < machine harvesting (76.53%) < straw return (89.39%). Mechanization is rapidly spreading to all aspects of crop production.

b. The average energy consumption of drainage and irrigation increased by 75% between 2012 and 2018, including 77% for diesel and 69% for electric drainage and irrigation.

(2) Direct energy consumption

a. The energy consumption of chemical fertilizers increased by 14.6% between 2012 and 2018. Of these, the consumption of nitrogen and phosphate fertilizers decreased by 6% and 37%, respectively.

b. Pesticide energy consumption decreased by 24.8% over the study period. Overall, although indirect agricultural energy consumption grew slowly, the internal energy consumption structure changed considerably

3.2 Life cycle energy consumption of major crops in China in 2018

In 2018, the total energy consumption of major crops in China was 1480×10^{12} KJ. The proportions of direct and indirect energy consumption were 48% and 52%, respectively (Fig.2). In 2018, the proportions of E_f, $E_{A\text{-}M}$, E_p, and $E_{D\text{-}I}$ were 44.72%, 44.52%, 7.19%, and 3.57%, respectively. The energy consumption of agricultural machinery operations showed the trend machine tilling (12.21%) > machine harvesting (10.11%) > machine sowing (9.01%) > plant protection (6.75%) > other practices (6.44%). The energy consumption of fertilizers comprised both compound and nitrogen fertilizers.

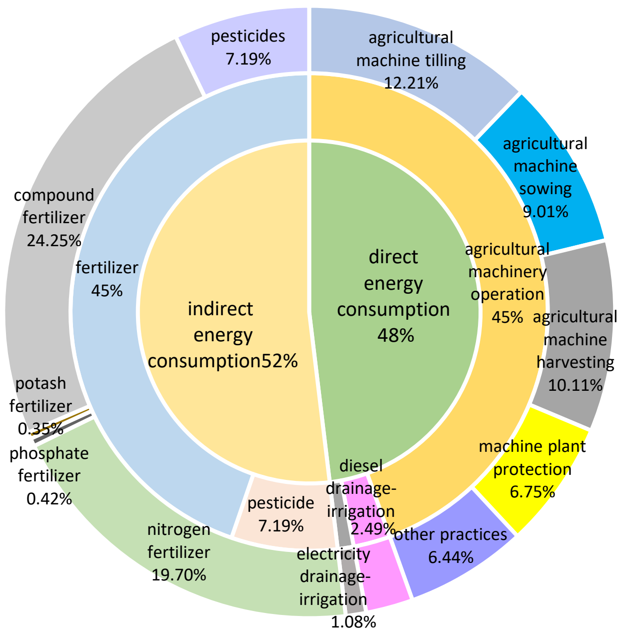

Fig. 2. Energy consumption structure of crop life cycle in 2018

The energy consumption per hectare of grain crops showed the trend wheat > rice > corn > soybean. The energy consumption of peanut was higher than that of rape. The energy consumption of commercial cotton was 56866 KJ/ha In terms of energy consumption per unit yield, grain crops showed the trend soybean > wheat > maize > rice. The energy consumption of rapeseed was higher than that of peanut. Energy consumption per unit yield of commercial cotton was 15833 KJ/kg. In the production process of different crops, the energy consumption of agricultural machinery operations was largest for soybean, followed by that for rice, and was smallest for cotton. The energy consumption of other crops was approximately 40%. The use of chemical fertilizer accounted for the largest proportion of cotton energy consumption, and was approximately 45% for corn, rape, wheat, and peanut. Cotton production, followed by peanut, used the greatest amount of pesticides. In terms of drainage and irrigation, diesel accounted for a greater proportion of energy consumption than electricity.

4. RESULTS

(1) From 2012 to 2018, the energy consumption of major crops in China increased by 25%, and the structure of direct and indirect energy consumption changed significantly. This shift was mainly a result of a rapid increase in direct energy consumption, with an average annual growth rate of 7.6%. The energy consumption of both agricultural machinery operations and drainage and irrigation increased in all aspects. In view of the irreversibility of agricultural mechanization, direct energy consumption is likely to become even more prominent in the future. It is necessary, therefore, to improve the operating efficiency of agricultural machinery and develop measures, such as clean energy, that can be used to reduce the fuel consumption of agricultural machinery. In addition, the average annual growth rate of indirect energy consumption was 1%. Although this rate is low, indirect consumption still represents the majority of agricultural energy consumption, especially nitrogen and compound fertilizer use. It is worth noting that the energy consumption associated with pesticide use decreased. The use of nitrogen and phosphate fertilizers also decreased, which is closely related to China's long-term agricultural fertilizer and pesticide regulations. In the future, more attention should be paid to the production and use of compound and nitrogen fertilizers, with the aim of reducing soil, air, and water pollution from agricultural fertilizer application.

(2) In 2018, direct and indirect energy consumption of major crops accounted for 48% and 52%, respectively. Indirect consumption is still the main form of agricultural energy consumption. Compound and nitrogen fertilizers accounted for 43.95% of energy consumption, which is equivalent to that of agricultural machinery operations (44.52%). Nitrogen and compound fertilizers are the most commonly used fertilizers and the main contributors to energy consumption and environmental pollution. In agricultural machinery operations, machine tilling, sowing, and harvesting were the main consumers of direct energy. These three practices should be a focus for improving the efficiency of mechanical equipment, scientific operation level, and strengthening the training of operational personnel.

(3) In general, the greater the per hectare energy consumption, the greater the adverse effects on local soil conditions and adjacent ecosystems. Higher energy consumption per unit yield means that agricultural trade and production need to consider the effects of crop production, such as soybean, canola, and cotton, on the local environment, not just the costs and price of inputs. From the energy consumption structure of different crops, it can be seen that agricultural machinery operation is a prominent contributor to the energy consumption of soybean and rice production. Chemical fertilizer is a prominent contributor to the energy consumption of cotton production, and both are major contributors to the production of other crops. The energy consumption information for different crop life cycles can be used to manage energy consumption in a targeted manner, maximizing the benefits and minimizing the losses associated with agricultural energy consumption.

5. RESULTS

In this study, an energy consumption calculation framework was established for each phase of a crop life cycle. Previously, mechanical energy consumption was not refined for the various stages of crop growth. The method presented here provides detailed and comprehensive energy consumption data of agricultural energy use for agriculatural regulation. These inventories of crop life cycle energy consumption are beneficial for the control and management of agricultural inputs and outputs. The results also provide a timely picture of the energy consumption of different agricultural machinery operations, which can be used to explore the relationships between mechanical use and crop yield. More informed targeted management measures can support the sustainable development of agricultural production.

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