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Journal of Waste Resources and Reprocessing

RESEARCH ARTICLE

Mulch Film Usage and Pollution Control in China: A Spatial, Temporal, and Social Analysis

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Citation: Wenfeng Li, Xinxia Chang, Rong Chen, Wenqing He, Jin Guo, et al. (2022) Mulch Film Usage and Pollution Control in China: A Spatial, Tem-poral, and Social Analysis. J Waste Resources Reprocessing 1(1): 104

Abstract

The time–space distributions and trends of mulch film consumption in China were analyzed by combining GIS displays and model fitting of data from Year 2000 to 2019. The trends and influence factors in respect of mulch film use in China were studied using GIS and the R programming language. [1] The mulch film consumption and film mulching rates in China first rose and then declined from Year 2000 to 2019. Mulch film consumption linearly increased until a peak in Year 2016 and then dropped at an annual rate of 3.05×10^7 kg. Mulch film consumption in China is expected to drop to 1.19×10^9 kg, the level from Year 2010, by 2025. The trends in mulch film consumption in seven geographical regions of China are basically consistent, and already showed a downturn by Year 2018. The mulch film consumption and mulching rates are significantly different between regions, and the maximum values and fastest rate of both indices were found in northwest China. [2] In addition to mulch film area, the mulch film consumption of China is also significantly affected by the per capita net income of rural residents, the number of agricultural technical staff members, and the planting proportion of economic crops, but is insignificantly correlated with total agricultural output. working population in the primary industry significantly and negatively promotes mulch film consumption.

Keywords: Mulch Film Usage; GIS; China; Trends

Introduction

Mulch film are important production materials that are widely used in modern agriculture [1]. Through enabling water conservation, temperature increase, and weed suppression, mulch films can promote higher crop yields and production benefits and thus guarantee the high-quality and high-yield agricultural development [2,3]. Since their introduction to China in the 1970s, mulch film have been extensively applied in the production of corn, cotton, and vegetables [4,5]. According to statistics, the annual global use of mulch film is 2 × 109 kg. The mulch film consumption in China far exceeds that in other countries[1, 6] , accounting for more than 75% of global consumption (Figure 1). Due to the continual increment, adverse effects of mulch film usage have occurred, and residual mulch film pollution in farmland is increasingly severe. Specifically, the continual accumulation of residual mulch film in soils causes pollution, disturbed farming, and soil tillage layer destruction, which lead to water–fertilizer transport blockage, crop growth and development interference, and agricultural production threats [7,8]. "White pollution," caused by delayed residual mulch film recycling, has become one of the main sources of agricultural non-point-source pollution in China [9,10]. Various countries are actively developing new mulch film replacement technology; degradable mulch film technology is becoming more mature, and photodegradable, biodegradable, and liquid mulch film and other products are constantly being tested and promoted. In particular, countries such as Japan, the United States, and France have a high level of research and development into biodegradable mulch film, with a large range of applications, while ordinary mulch film in China still dominate the market [6,11]. It cannot be ruled out that, in the next few Years, biodegradable mulch film will be more commonly used, which may change the trend in the consumption of standard polyethylene mulch film.

Figure 1: Mulch film plays a critical role in the agricultural industry. Photo taken by Yao Lu on a pomegranate plantation farm in Yongsheng county of Lijiang prefecture on 31 July 2020

Recently, domestic and foreign researchers have analyzed mulch film consumption at national, provincial, and county scales. Existing state-wide research focuses on macroscopic and qualitative analysis based on farmer planting characteristics, and national/local policies and measures [5, 8, 12]. However, there is little research from the perspective of geographical division. Based on an analysis of historical data in China, relevant research generally holds that mulch film consumption is on the rise. With an autoregressive moving average model[4], predicted that mulch film consumption in China in Year 2020 would exceed 2.0 × 109 kg. Mulch film consumption in China would consistently rise. Some researchers have studied mulch film consumption in different provinces and regions. Research on Hebei, Inner Mongolia, and Sichuan reveals that mulch film usage is significantly different between provinces [13]. In terms of factors influencing mulch film use, Heilongjiang Province from Year 1990–2016 to study the evolutionary characteristics between agricultural non-point-source pollution and agricultural economic growth[14] . They found that the applied mulch film density linearly increased with the actual total outputs of agriculture, forestry, fishing, and husbandry, and their logarithmic vector error correction (VEC) model proved a bidirectional promoting effect between applied mulch film density and agricultural economic growth. Rumeng Gao used the panel data from 31 provinces from Year 2006–2015 to verify the agricultural environmental Kuznets curve and found that increased urbanization will increase mulch film consumption[15] .

The above studies were mostly based on data from before Year 2016, but mulch film use control was adopted in China in Year 2013 for environmental protection purposes, which restricted the growth in mulch film use. Nevertheless, research based on data after Year 2016 is rare. In this study, based on historical data on mulch film consumption between Year 2000 and 2019 in China, the time and space variation trends in mulch film consumption at the national scale and between different geographical regions were investigated by using indices of mulch film consumption, mulching rate, and increase rate.
The objectives of this research were as follows:

(1) To uncover the evolving characteristics of mulch film consumption in China in the last 20 years as well as predict future change trends;
(2) To analyze the relationships between the agricultural practice, socioeconomic factors, science and technology, and labors contribution and mulch film usage;
(3) To create recommendations for stakeholders on reducing residual mulch film pollution.

Materials and Methods

Variable selection and data sources

In this study, panel data from 31 provinces of China between Year 2000 and 2019 were collected from the China Agricultural Statistics Yearbooks, China Statistical Yearbooks on Science and Technology, China Statistics Yearbooks, and provincial Statistics Yearbooks. The main influence factors used here are listed below (Table 1).

(1) The mulch film area and proportion of economic crops in each province were selected as the agricultural practice. The mulch film area is the land-related factor that most directly affects mulch film consumption. Because of the high economic value of economic crops, farmers are more willing to use mulch film to increase their output. Since regional differences in the planting areas of economic crops lead to differences in mulch film consumption, the planting proportion of economic crops and the total planting areas of crops were used to represent the proportion of economic crops according to a reported method [16].

(2) Per capita net income of rural residents and agricultural total output were selected as the socioeconomic factors. Studies on the relationship between economic growth and agricultural non-point-source pollution demonstrate that mulch film investment and economic growth are in accordance with the agricultural environmental Kuznets curve [15, 17]. Hence, the per capita net income of rural residents and agricultural total output were selected as the two socioeconomic factors that affected the changing trend in mulch film consumption in China.

(3) Science and technology. The level of scientific and technological development is critical in all stages of mulch film popularization and application, and at the early stage of mulch film coverage, mulch film coverage machines and other scientific achievements can save on labor force investment and raise working efficiency during agricultural production activities. Given the accessibility of data, we used the number of agricultural technical staff members to represent the agricultural technical level of each province.

(4) Labors contribution. labors contribution used here is working population in the primary industry who are capable labor force members aged above 18 years and engaged in primary industry labor activities. The number of employees in primary industry includes the total number of people actually engaged in agricultural, forestry, animal husbandry, fishery and other production activities. There is research shows that from Year 2000 to 2012, the proportion of the working population in the primary industry in China had a declining trend, with the maximum value being 51.87% in Year 2002 and the minimum value being 36.49% in Year 2012, decreasing by 14.53% in the past 12 years. The proportion of the working population in the primary industry declined[18].

Type	Variables	Unit
Agricultural practice	Mulch film area	10,000 hectares
	Proportion of economic crops	%
Science and technology	Agricultural technical personnel	people
Socioeconomic	Agricultural total output	0.1 billion yuan
	Per capita net income of rural residents	yuan/person
labors contribution	working population in the primary industry	10,000 people

Table 1: Independent variables used in this study

Research Methods

When evaluating the difference in the use of mulch film, two indicators are used: the average mulch film usage and mulch film coverage (the proportion of mulch film coverage (%) = mulch film coverage area / crop sown area). The results were imported into ArcGIS10.2 for spatial analysis, and we drew a spatial distribution map of the use of mulch film. All statistical analyses were performed in the R programming language.

(1) Analysis of mulch film use trends: Indices of mulch film consumption relative increment and film mulching rate were adopted. The relative increment and mulching rate were calculated as follows:

$$PM_{ij} = \frac{AM_{ij}}{AC_{ij}} \times 100\% \quad (1)$$

$$RI_{ij} = \frac{UM_{ij} - UM_{2000\text{-}j}}{UM_{2000\text{-}j}} \times 100\% \quad (2)$$

where PM_{ij} is the film mulching rate of region j in year i; AM and AC are the film mulching area and crop sowing area that year, respectively; RI_{ij} is the relative increment of mulch film consumption in region j at year i; and UM is the mulch film consumption.

The growth rate and drop rate were fitted using function lm() in R, where the independent variable is the year, and the dependent variable is mulch film consumption. A segmentation method was adopted during model fitting, as the years before and after the mulch film consumption peak were fitted separately, where the slope is the increasing or decreasing rate. Based on data on the relative increase in mulch film use in Year 2013–2019, the changing trend in the relative increase in mulch film use was fitted by a quadratic function, which is expressed as follows:

$$y = a + bx^2 + cx + \varepsilon \quad (3)$$

where y is the relative increment of mulch film consumption, x is the year; and a, b, and c are constants, and ε is the random error.
(2) For analysis of the relationship between mulch film consumption and all factors, a multiple linear regression model was built and used to uncover the inner relationships between various influence factors and mulch film consumption. The model was set as follows:

$$Y = f(x_{it}) = a + b_1 x_{1it} + b_3 x_{2it} + b_4 x_{4it} + b_5 x_{5it} + b_6 x_{6it} + \varepsilon \qquad (4)$$

where Y is the mulch film consumption of each province in Year 2000–2019, i is each province, t is the year, $x_1, x_2, x_3, x_4, x_5, x_6$ is the mulch film area, per capita net income of rural residents, agricultural technology level, proportion of economic crops, agricultural total output, and working population in the primary industry, a, b are constants and ε is the random error.

Results and Discussion

Spatial variation characteristics of mulch film consumption and film mulching rate in China

During the 20 years from Year 2000 to 2019, the annual average mulch film consumption was 1.15×10^9 kg in China, while the average consumption over the past five years has been 1.43×10^9 kg. Mulch film consumption is affected by industries and farmland area to different degrees in different regions (Figure 2 and Figure 3). The 20-year average mulch film consumption is the largest in northwest China, accounting for 28.6% of total consumption in China, followed by east China (20.56%), southwest China (16.37%), and south China (5.41%). Mulch film consumption is the highest in Xinjiang and Shandong, where the 20-year annual average mulch film consumption is 2.83×10^8 kg, which is far larger than in other provinces and accounts for 24.56% of total consumption in China. The consumption is below 1×10^7 kg in seven provinces: Tibet, Qinghai, Beijing, Tianjin, Shanghai, Ningxia, and Hainan. The annual average consumption of Tibet is the smallest (0.07×10^7 kg), which is only 0.45% of that of Xinjiang, which is the largest mulch film consumer.

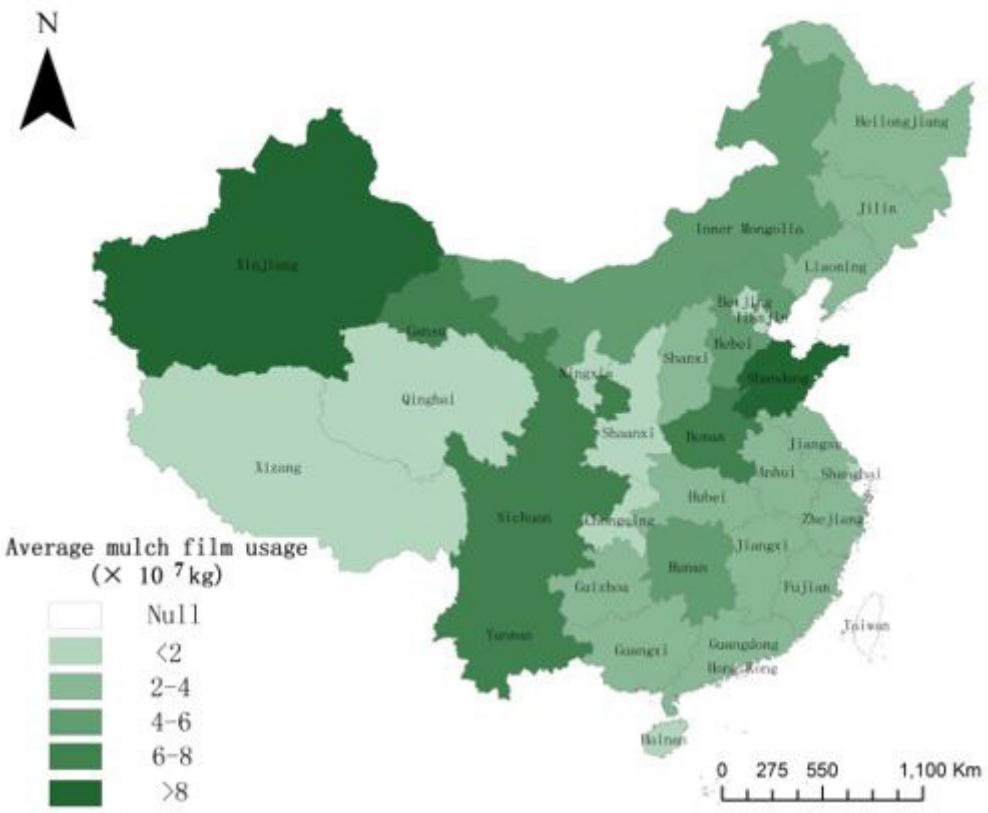

Figure 2: Average mulch film usage of provinces in China from Year 2000 to 2019

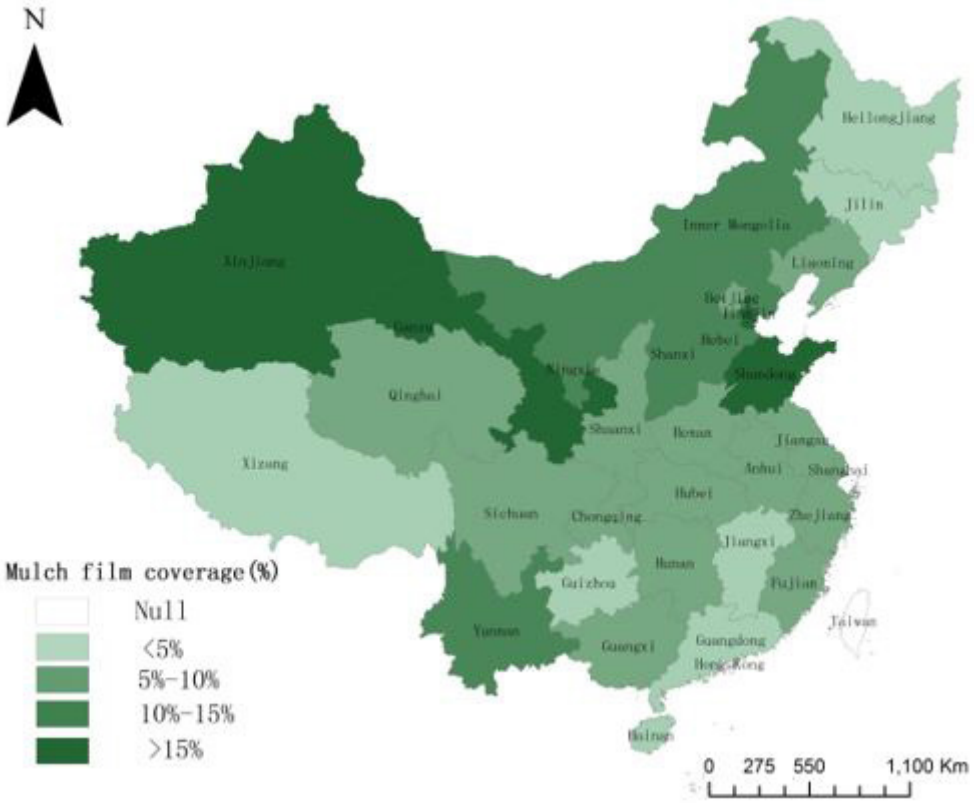

Figure 3: Mulch film coverage of provinces in China from Year 2000 to 2019

The state-wide film mulching rate, averaged for the last 20 years, is 9.66%. The average film mulching rate in Xinjiang ranks first (50.42%) and is far larger than in other provinces (Figure 2), followed by Gansu (26.60%) and Shandong (19.09%), and ending with Tibet (only 0.95%). Compared with spatial distributions of mulch film consumption, both mulching rate and consumption are high in northwest and north China, and low in south China, indicating that regions with high mulch film consumption also have high film mulching rates. However, this is not a definite rule and does not apply to Shandong, Heilongjiang, and Hainan because of differences in the cultivated land area between regions.

Temporal Characteristics of Mulch Film Consumption in China

Mulch film consumption has generally been on the rise over the last 20 years (Figure 4), increasing by 90% from 7.22×10^8 kg in Year 2000 to 1.37×10^9 kg in Year 2019. However, the consumption has been declining in the recent past, with a maximum of 1.47×10^9 kg in Year 2016.

In terms of change trends, mulch film consumption generally first increased and then decreased in all regions, but the mulch film consumption, increase rate, and peak time are very different between regions. During the 10 years after Year 2000, mulch film consumption peaked in east China; after that, the mulch film consumption in northwest China grew faster and eventually exceeded that of east China. A downward trend appeared earlier in east China, while mulch film consumption did not drop in other regions until Year 2015 (Figure 5). Given the large regional differences in the base data on mulch film consumption, we analyzed the rising rate of mulch film consumption relative to Year 2000. The growth rate was the fastest in south and northwest China, and slowest in east China (Figure 5). The change trends are basically consistent between provinces. Compared with Year 2000, the maximum growth rate and largest mulch film consumption occurred in Gansu, Chongqing, Inner Mongolia, and Zhejiang, with nearly doubled increasing. However, the mulch film consumption in Sichuan, Shaanxi, Henan, and Hebei has significantly declined recently and returned to the level of Year 2000. In fact, the cultivated land area of some provinces is small and largely affected by occasional factors

(the regional policy, etc) that decrease the representativeness and complicate the identification of rules. Hence, during the analysis of change trends at a provincial scale, the mulch film consumption of seven provinces with an annual mulch film usage of less than 1×10^7 kg (Tibet, Qinghai, Beijing, Tianjin, Shanghai, Ningxia, and Hainan) was not considered; the cultivated land area was smaller than 100×10^4 hm^2 in six provinces.

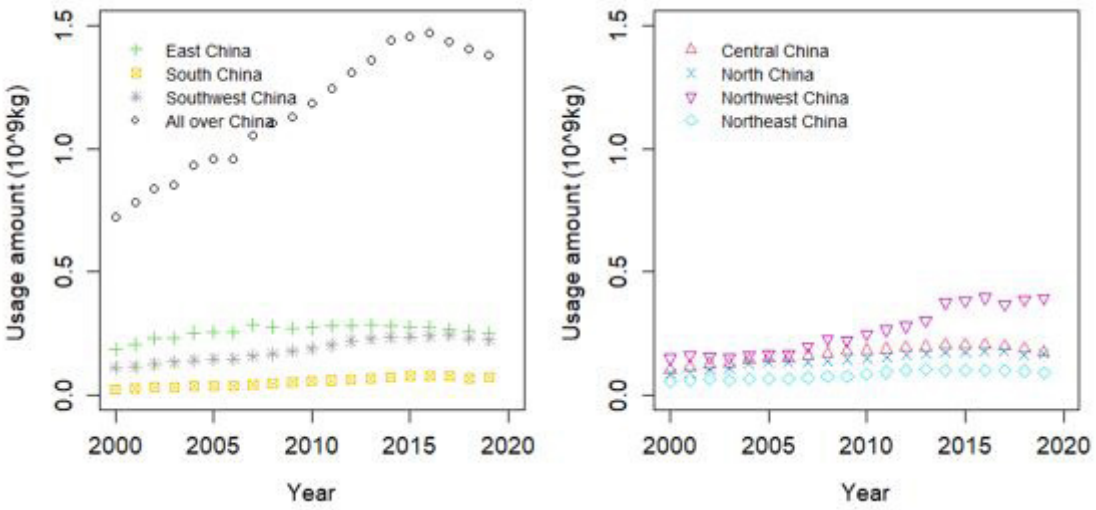

Figure 4: Change curves of mulch film consumption in China from Year 2000 to 2019

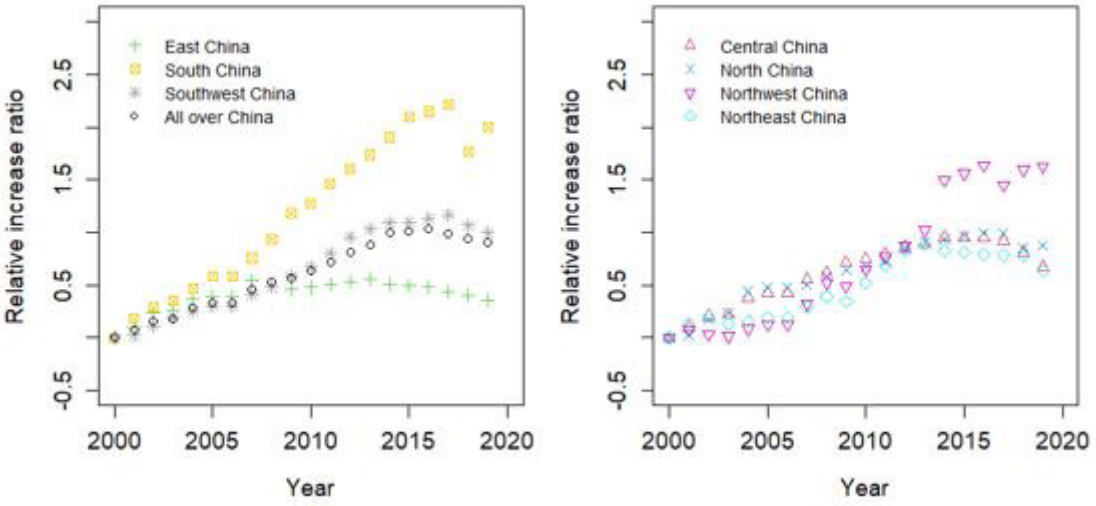

Figure 5: Change curves of relative growth rate of mulch film consumption in seven regions of China

Since the cultivated land area and film mulching rate are important factors determining mulch film consumption, we further analyzed the time–space changes in the film mulching rate (Figure 6). The results show that the temporal changes in film mulching rate were generally consistent with those of mulch film consumption, with a slow growth rate and a downward trend over the last two years. Specifically, the film mulching rate in China increased by 3.82% from 6.80% in Year 2000 to 10.62% in Year 2019. The film mulching rate in northwest China is the highest and far exceeds the state-wide overall level, followed by north China. The film mulching rate in northwest China grew quickly from Year 2007 to 2017. The film mulching rate was relatively low in south China, central China, and northeast China, and the relative amplitudes were small.

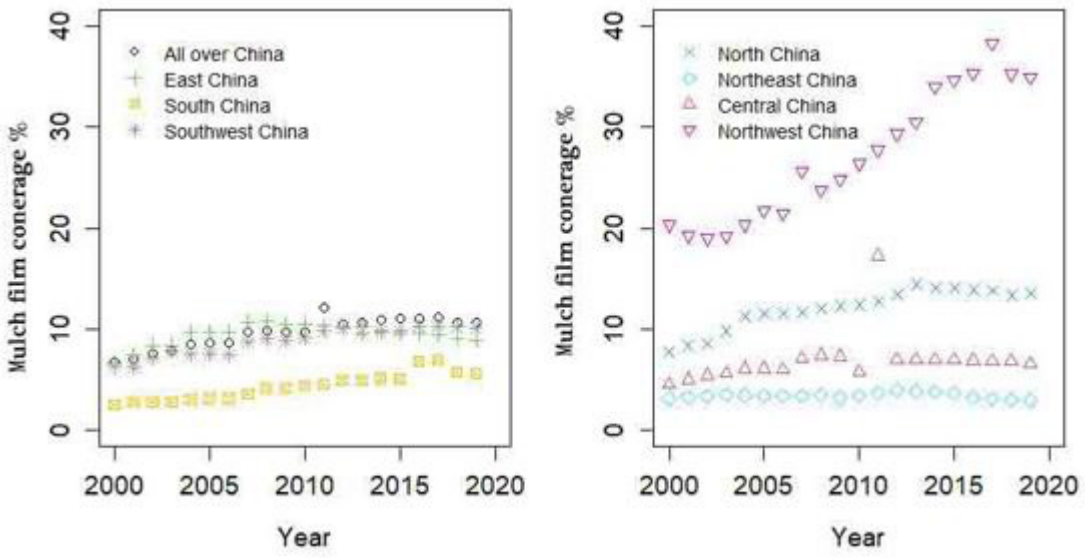

Figure 6: Change curves of film mulching rate in China from Year 2000 to 2019

Developing trend in mulch film consumption in China

The above analysis implies that mulch film consumption first increased and then declined, but the trend was obviously different between regions in terms of the peak time and change rate. To clarify the changing characteristics of mulch film consumption, we used quadratic polynomials from the R programming language to fit the peak time of mulch film consumption at national, regional, and provincial scales, and thereby fitted the variation rates before and after peaking by using linear models. The Law of Agriculture of the People's Republic of China, implemented in Year 2013, states that farmers and agricultural production and operation organizations should use mulch film appropriately so as to decrease the agricultural non-point-source pollution caused by mulch film[19] . This statement signifies that China started to stem mulch film development at the source, so we used the mulch film consumption data from Year 2013 to 2019 to estimate the peak time.

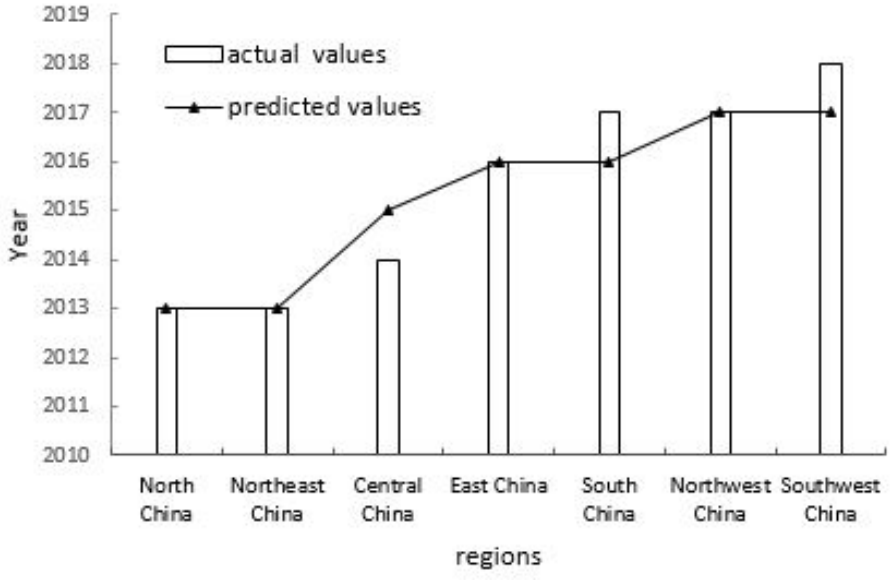

Figure 7: Fitted data and real data concerning the peak year of the relative mulch film consumption growth rate in seven regions of china

The regression trend curves of the relative increase in mulch film consumption in China from Year 2013 to 2019 ($R^2 = 0.97$) indicate that the relative increase was at a maximum in Year 2016, which is consistent with the actual situation. Fitting results for seven regions (Figure 7) show that mulch film consumption was mainly concentrated between Year 2013 and 2017, which is basically consistent with the real data, with a deviation of one year in some regions. Thus, both real-world comparison and equation fitting imply that all regions of China have passed the mulch film consumption peak time and slowly entered a downward trend. Kurtosis analysis of fitting models (Figure 8) suggests that the change trends in east and northeast China from Year 2013 to 2019 were gentle, but the increase and decrease rates for both south and northwest China were higher.

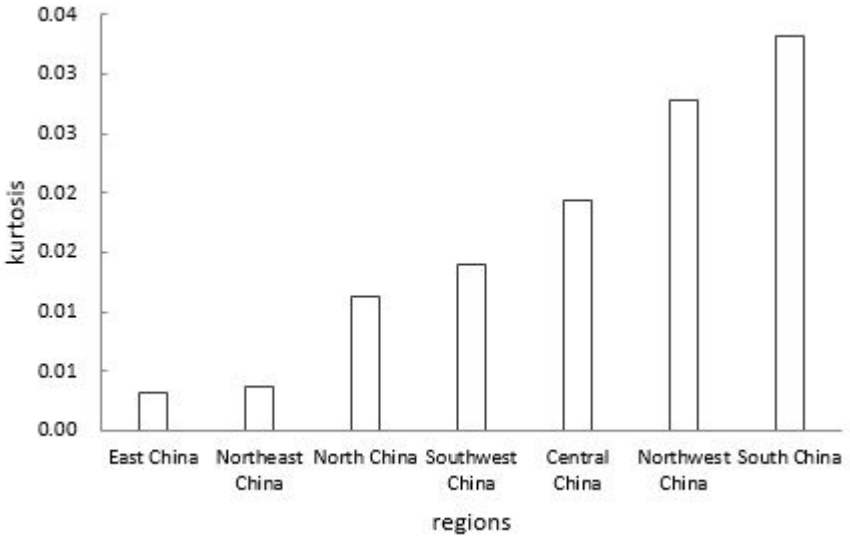

Figure 8: Kurtosis on quadratic fitted curves of the relative growth rate of mulch film consumption in seven regions of China

The data from before and after the mulch film consumption peak were further fitted linearly. The results show that the national mulch film consumption from 2000 to 2016 rose almost linearly, with an annual increase rate of 4.8 × 107 kg (R: lm(), $\beta = (4.84 \pm 0.11) \times 10^7\,\mathrm{kg/year}$). The mulch film consumption from 2016 to 2019 declined linearly, with an annual decrease rate of 3.05 × 107 kg (R: lm(),$\beta = (-3.05 \pm 0.15) \times 10^7\,\mathrm{kg/year}$). On this basis, it is predicted that by Year 2025 and 2030, the national mulch film consumption will drop to 1.19 × 109 and 1.04 × 109 kg, respectively, which are the usage levels of Year 2010 and 2017, respectively.

Our conclusions on the trend analysis and prediction are inconsistent with some previous studies that suggested that mulch film consumption in China will continue to increase. Such differences may be attributed to the different data used by our study and other studies. Liu et al[20]used mulch film consumption data from Year 1991–2011, respectively, in which the mulch film consumption characteristics in China did not change obviously . Recently, the "white pollution" caused by mulch film was recognized by Chinese researchers, and relevant policies at national and local scales were issued to decrease mulch film pollution from the source[8, 21] . As a result, the rates of mulch film consumption slowed down and became a decreasing trend. Hence, our conclusions are more consistent with the actual situation in China. Conclusions from analyses at national, regional, and provincial scales are relatively consistent. Analysis at the provincial scale shows that the relative increase in mulch film consumption started to decline after it reached its maximum in 20 provinces. Although mulch film consumption is still on the rise in other provinces, the increase rates have slowed down. This conclusion well reflects the year in which mulch film consumption trends in different areas started to change. Mulch film consumption is clearly different between regions. The mulch film consumption and mulching rate of northwest China are both the highest, and the increase rates are far higher than in other regions. The mulch film consumption in Xinjiang and Gansu is far larger than in other provinces, which is consistent with the conclusions of Other scholars[4, 22] . The major natural characteristic of northwest China is drought, so soil moisture sufficiency is a key factor influencing crop growth. Film mulching can

significantly increase the water use efficiency in semiarid areas of northwest China[5], and efficiently improves the natural situation of rainfall deficiency and large evaporation, which accounts for the high mulch film consumption in northwest China . The mulch film consumption and film mulching rate in northeast China are the lowest and increase at the slowest rates.

Influence Factors of Mulch Film Consumption in China

A descriptive analysis of relevant data is given in Table 2. Due to a lack of data on the per capita net income of rural residents in some provinces after Year 2014, the per capita disposable income of rural residents was used instead, according to a reported method [23].

Variables	Mean	Maximum	Minimum
Mulch film consumption	3.71	24.27	0.004
Mulching film area	50.05	379.59	0.01
Proportion of economic crops	0.34	0.67	0.03
Agricultural technical personnel	21,646.75	56,991.00	1447.00
Agricultural total output	1180.89	5408.60	25.30
Per capita net income of rural residents	7471.79	33,195.20	1330.81
working population in the primary industry	984.19	4235.00	37.10

Table 2: Descriptive analysis of dependent variables and independent variables

For the quantitative investigation into the influence degrees of different factors on mulch film consumption, a multiple linear regression analysis was conducted in the R programming language (Table 3). The model has $P = 0.00 < 0.001$, F = 894.57 (F test), indicating that this model is significant at the test level of 0.05, and the multiple regression model of mulch film consumption in China generally fits well (R^2 = 89.7%). Except for agricultural total output, all the tested factors were significant at the level of 1% (including mulch film area, per capita net income of rural residents, working population in the primary industry, number of agricultural technical staff, and proportion of economic crops). Regression coefficients showed that all influence factors promote mulch film consumption, except for working population in the primary industry, which significantly negatively affects mulch film consumption, and the most influential factor is the mulch film area.

Factors	Regression coefficient	Standard deviation	Sig.
(constant)	–0.057	0.009	0.000
Mulch film area	0.731	0.018	0.000
Per capita net income of rural residents	0.056	0.015	0.000
working population in the primary industry	–0.045	0.013	0.000
Agricultural total output	0.022	0.012	0.062
Agricultural technical personnel	0.175	0.016	0.000
Proportion of economic crops	0.13	0.018	0.000

Table 3: Regression analysis of mulch film consumption

Based on the above results of the multiple regression, the influence factors on mulch film consumption are analyzed below.

In relation to the agricultural practice, both mulch film area and proportion of economic crops are significant at the 1% level and have positive regression coefficients, indicating that the province with larger mulch film area and a higher proportion of economic crops consumes more mulch film. This conclusion is consistent with two previous studies; during the planting of economic crops, the investments in mulch film and other agricultural production materials are generally higher than for grain crops. Mulch film were

first introduced in China for the planting of crops with higher economic benefit[4]. Farmers planting economic crops are willing to invest more in mulch film, aiming to increase economic benefits and production value.

In respect of science and technology, the number of agricultural technical staff members is significant at the level of 1% and has a positive regression coefficient, suggesting that a province with more agricultural technical staff consumes more mulch film. One major function of agricultural technical staff is to popularize and guide modern agricultural technologies. Hence, a larger number of agricultural technical staff corresponds to the wider use of mulch film and a greater understanding of local farmers about mulch film, which promote the application of mulch film. However, the number of agricultural technical staff is only one measure of technological factors, which affect mulch film consumption by changing agricultural production methods (e.g., changing the application of mulch film coverage), by developing new production materials to substitute for mulch film[24, 25] (e.g., degradable mulch film or straw mulching techniques), or by providing techniques to decrease pollution[11] (e.g., the "one mulch film and multiple uses" technique or a mulch film recovery machine). On the one hand, technological progress brings farmers benefits directly through technological innovation, and promotes increases in agricultural yield. For farmers, this means greater production value with a smaller labor force and less working time. On the other hand, the optimization of mulch film products and the development of relevant mulch film recovery techniques will bring indirect benefits in terms of the environment. Since the efficiency of mechanized residual mulch film recovery is far higher than that of manual recovery, mechanized recovery can save a lot of time and labor during manual recovery and improve the recovery rates[26]. Hence, the effects of technological factors on mulch film consumption are promoting effects.

For the socioeconomic factors, the per capita net income of rural residents is significant at the level of 1% and has a positive regression coefficient, but agricultural total output is not significant, indicating that a province with higher per capita net income of rural residents consumes more mulch film. Mulch film are key agricultural production materials, and the income of farmers affects their willingness to purchase production materials, which is consistent with the results from field surveys in Yunnan province. A study of the relationship between mulch film investment and agricultural growth in Chongqing showed that mulch film consumption linearly increases with the rise in the per capita net income of rural residents. An analysis of agricultural data between 1995 and 2010 in Henan Province demonstrates that GDP per capita and mulch film consumption are related in an inverted "U" shape[27] . Hence, economic factors also promote mulch film application.

As for labors contribution, working population in the primary industry is significant at the level of 1% and has a negative regression coefficient, suggesting that a province with a greater labor force investment consumes less mulch film. This can be explained by two factors. (1) Among the first industry workers, the majority of agricultural workers are involved in other fields than planting that provide greater economic benefits, and the economic value of labor investment is relatively low. (2) The phenomenon of farmers taking on multiple jobs will increase family income and enhance awareness about the safety of agricultural products and environmental safety, thereby decreasing the consumption of mulch film. Reportedly, an analysis based on the "one family and two systems" theory holds that farmers will choose to preserve one part of their farmland for planting self-supporting crops, and for pursuit of food safety, farmers will decrease their investment in mulch film, fertilizers, and other agricultural materials, leading to an overall negative effect on the investment in agricultural materials[8] .

Conclusion

The national mulch film consumption in China from Year 2000 to 2019 first rose and then declined, with a peak in Year 2016, and has gradually decreased linearly since year 2016, with an annual decrease rate of 3.05×10^7 kg. It is predicted that mulch film consumption will further drop to 1.19×10^9 kg by Year 2025. The mulch film consumption of the seven regions hit a maximum either early or late and then all regions entered a stage of continual decline. The order of peak value of relative growth of mulch film use in different regions is: North China > Northeast China > Central China > East China > South China > Northwest > southwest China. The mulch film consumption and change characteristics of China are obviously different between regions, as the mulch film consumption and mulching rate are both the highest in northwest China, and rapidly rose after Year 2010.

The influence factors of mulch film area, proportion of economic crops, number of agricultural technical staff, agricultural total output, per capita net income of rural residents, and number of first industry workers were chosen to study the changing characteristics of mulch film application in China. The main conclusions are listed below. Except for agricultural total output, all tested factors are significant at the level of 1% (including mulch film area, per capita net income of rural residents, number of agricultural technical staff, and proportion of economic crops). working population in the primary industry significantly negatively affects mulch film consumption, while mulch film area is the most influential factor on mulch film consumption. These results indicate that the agricultural practice, technological factors, socioeconomic factors, and labor force investment factors all cause changes in mulch film consumption in China. the agricultural practice, technological factors, and socioeconomic factors all significantly promote mulch film consumption, but labor force investment factors significantly negatively affect mulch film consumption.

Based on the above conclusions, we present four suggestions. (1) Increasing the use of technological products in agricultural production activities, and developing and promoting small-scale machinery in accordance with local actual production characteristics will improve farmer incomes and residual mulch film recovering efficiency, and decrease the environmental pollution caused by mulch film, which all contribute to the green and sustainable development of agriculture.

(2) During the popularization of mulch film use, agricultural technical staff should also disseminate information about the scientific use of mulch film and mulch film recovery, e.g., greater use of mulch film is certainly not better; timely and appropriate use of mulch film is favorable for improving agricultural production values; and lifting mulch film at the appropriate time will decrease plant diseases and insect pests and increase residual mulch film recovery rate[28] . Agricultural technical staff should also help farmers to understand the environmental damage caused by mulch film pollution, and improve their willingness to decrease mulch film use from the source and to scientifically recover mulch film during use. Farmers should be taught some mulch film recovery skills, which will help to prevent and control agricultural non-point-source pollution[29] .

(3) The popularization and application of degradable mulch film should be strengthened. Degradable mulch film are an important way to substitute common polyethylene mulch film and efficiently relieve mulch film pollution. At present, the application of degradable mulch film is still at the small-scale experimental stage. Hence, relevant measures should be proposed to improve the performance of degradable mulch film, decrease prices, increase governmental subsidies for the purchase of degradable mulch film, and guide farmers to select more degradable mulch film or new national standard mulch film[30].

(4) The social responsibility of enterprises should be strengthened. The Measures for the Administration of Agricultural Film implemented in 1 September 2020 indicated the main responsibilities of the relevant bodies. Mulch film production enterprises should strictly abide by the mandatory national standards for mulch film in China, and manufacture mulch film with a thickness of no less than 0.010 mm. They should ensure the quality of their products, and not produce substandard mulch film. Enterprises selling mulch film should inspect the thickness, quality test certificates, and other relevant materials of mulch film, and should never allow substandard mulch film products to enter the market or farmland. Mulch film recycling enterprises should raise the prices of residual mulch film recycling, innovate recycling mechanisms (e.g., "old-for-new services," "specialized recycling," "replacing subsidies with rewards", and encourage enthusiasm among farmers about residual mulch film recovery, which together will reduce residual mulch film pollution.

Declarations

Conflicts of Interest: The authors declare no conflicts of interest.

Author Contributions: Conceptualization, Lu Yao and Li Wenfeng; methodology, Li Wenfeng; software, Chang Xinxia; validation, Lu Yao and Li Wenfeng; formal analysis, Chen Rong; investigation, He Wenqing and Guo Jin; resources, Lu Yao; data curation, Li Wenfeng; writing—original draft preparation, Chang Xinxia and Chen Rong; writing—review and editing, Li Wenfeng; visualization, Li Wenfeng; supervision, Lu Yao; project administration, Lu Yao; funding acquisition, Lu Yao and Li Wenfeng. All authors have read and agreed to the published version of the manuscript.

Funding: "A Study on Potential Productivity Prediction and Suitability Evaluation for Winter Maize Plants in Yunnan," National Natural Science Foundation of China (No. 3186033); General Survey and Sampling Survey of Mulch for Agricultural Pollution Sources, Department of Agriculture and Rural Affairs of Yunnan Province, grant number 4530000HT201903385; a doctoral research seed fund was provided by Yunnan Agricultural University, grant number A2032002546.

Consent for publication: All the authors consent to publish this research paper.

Data availability: Not applicable.

Ethical approval and consent: **Not** applicable.

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