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Agricultural, Ecological, and Social Insights: Residual Mulch Film Management Capacity and Policy Recommendations Based on Evidence in Yunnan Province, China

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Abstract: Mulch film contaminates the environment while increasing agricultural yield. As such, the factors that impact the residual film management capacity of farmers must be identified, which would also be helpful for the sustainable development and security of agriculture. We investigated 10 counties across nine cities (states) by surveying 1284 households. The improved entropy-weighted composite index and the grey correlation analysis model were employed to measure the residual film management capacity from five dimensions: human capital, use behavior, management skills, public policy, and willingness. The entropy-weighted composite index results showed that residual film being harmful to the environment had the highest overall rate of 0.0745, followed by the effectiveness of mulch film, which was 0.0715. The results of the grey correlation analysis model showed that willingness to use biodegradable mulch film had the highest correlation of 0.8960, followed by educational level of the laborers, which was 0.8824. We found that residual film being harmful to the environment, effectiveness of mulch film, willingness to use biodegradable mulch film, and educational level of the laborers were the major factors influencing the residual mulch film pollution knowledge of households. Based on this finding, the government should increase subsidies for promoting biodegradable mulch film and publicize the hazards of residual films using diversified means in multiple channels.

Keywords: mulch film; residual film recycling; agricultural ecological security; rural environment

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Citation: Chen, J.; Chen, X.; Guo, J.; Zhu, R.; Liu, M.; Kuang, X.; He, W.; Lu, Y. Agricultural, Ecological, and Social Insights: Residual Mulch Film Management Capacity and Policy Recommendations Based on Evidence in Yunnan Province, China. *Sustainability* **2021**, *13*, 1603. https://doi.org/10.3390/su13041603

Received: 10 December 2020
Accepted: 28 January 2021
Published: 3 February 2021

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1. Introduction

Individuals subjectively interpret the relationship between the social and physical environments based on their values and beliefs. When confronted with an environmental issue, individuals act on these interpretations [1]. Recently, the Chinese government increased their attention on environmental issues. The President of China, Xi Jinping, advocates for clear waters and lush mountains as invaluable assets, and the harmonious coexistence between humans and nature, striving for green and sustainable development [2].

Mulch film pollution is a major concern for the agricultural production environment. Identifying the social factors affecting mulch film use would be helpful for working toward agricultural sustainability.

Mulch film is commonly used in agricultural practice worldwide as it helps to improve agricultural productivity to meet the challenges posed by population growth, water shortages, and extreme weather conditions [3]. Globally, mulch film was first used in research in the 1950s, and has been commercially used since the early 1960s [4]. Global much film consumption increased 35% between 2006 to 2017, up to over $2Mt$, 80% of which acumulated in field or landfills [5]. Mulch film is used for weed and pest control, to avoid herbicide and pesticides use, as well as for improving water and heat retention in the soil, and it is cheaper compared to other mulch options (e.g., biodegradable film) [6]. However, residual film contaminates agricultural soil and has caused massive amounts of pollution, posing a major environmental threat.

Existing studies have reported that residual film may have adverse effects on agricultural production and the environment in a variety of ways: (1) Reducing nutrient availability, species numbers, and activities of microorganisms, which influence crop growth [7]; (2) damaging soil structure, which poses obstacles for nutrient movement and moisture penetration, consequently retarding root development and crop growth [8]; (3) indirectly affecting the soil microclimate and atmosphere, and directly adding carbon, microorganisms, and adherent chemicals into the soil [9] (the compounds used in the formulation of biodegradable film materials that may be released include adipic acid, 1,4-butanediol, lactic acid, glycerol, terephthalic acid, mono- and disaccharides, and fatty acids [10]); (4) residual film may also influence greenhouse gas emissions by changing the produced carbon strength [11]. Biodegradable film was developed as a substitution for plastic film to address these environmental concerns, and was designed to be tilled into soil after harvest. In recent years, a number of researchers have explored the impacts of biodegradable film, showing that there is no significant difference in temperature and humidity between plastic film and biodegradable film [12]. Previous studies have examined how mulch film helps agricultural production and impacts soil, water use efficiency, etc. However, few studies have explored how the mulch film use behavior of farmers impacts residual film pollution.

China is the largest mulch film user in the world [13] (Figure 1), where the overall agricultural film usage has increased to 2.47×10^6 t, covering 1.78×10^{10} ha, up to 2011 [14]. The accumulated residual film was 1.18×10^6 t in 2017 [15]. Research has shown that residual film poses the greatest challenge for the agricultural environment in China [16–19], threatening agricultural production and the sustainability of agriculture. Yunnan province is located on the southwest border of China, at 28°8′–29°15′ N and 97°31′–106°11′ E. The terrain is high in the northwest and low in the southeast, gradually descending from north to south. Of the terrain, 87.21% is in the mid-altitude range of 1000–3500 m. Yunnan is one of the largest producers of agricultural goods in southwest China, having a total arable land of 6.21×10^6 ha in 2017 and an average arable land area per household of 0.62 ha, which is typical for small household operations. In the same year, the irrigable area was 1.85×10^6 ha, accounting for 29.80% of the total arable land. The total area of crops planted was 6.79×10^6 ha, and the index of replanting was 1.09. The predominant crops in Yunnan are food crops, accounting for 61.39% of the total land planted for crops. In 2017, the grain production was 1.84×10^7 t; rice and maize accounted for the main planted area: 5.29×10^6 t and 9.13×10^6 t, respectively. In terms of economic income, gross products accounted for 1637.634 billion yuan, the value added of primary industries was 233.837 billion yuan, and the per capita disposable income of rural residents was 9862.17 yuan in 2017 [20]. From 1998 to 2017, the usage of mulch film increased from 3.47×10^4 to 9.64×10^4 t [20].

In this study, we aimed to comprehensively understand the social–economic factors of residual mulch film pollution to provide policy recommendations for improving mulch film management. The objectives of this research were to understand how:

- Human capital impacts mulch film application;
- The mulch film use behavior of farmers impacts residual film pollution;
- The farmers' agricultural management skills affect residual film pollution;
- Public policies influence mulch film application;
- The willingness and awareness of farmers impact residual film pollution.

Figure 1. Women constitute the main labor force in mulch film practice. Photo taken by Yao Lu in Qilin District of Qujing on 24 November 2018.

We built an indicator system to calculate the social–economic factors for mulch film pollution control, and adopted the improved entropy-weighted composite index and the grey correlation analysis model to quantitatively analyze the factors reflecting the mulch film use behavior of farmers. We analyzed 1284 questionnaires obtained from 10 counties across nine prefectures in Yunnan province to identify the factors that reflect the mulch film use behavior of farmers. The results of this study provide a reference for ensuring agricultural sustainability in the context of the rural revitalization strategy. We also propose policy recommendations to guide farmers to use mulch film properly and recycle residual film.

2. Data and Methods

2.1. Data Sources

Based on planting species and historical mulch film use amount, national and provincial experts recommended the survey locations. We then administered one-to-one questionnaires in 10 counties of nine prefectures of Yunnan: Xiangyun county (Dali), Yanshan county (Wenshan), Mojiang county (city of Puer), Tengchong (Baoshang), Xuandian county (Kunming), Tonghai county (Yuxi), Zhaoyang and Qilin districts (Qujing), Jianshui county (Honghe), and Xuanwei (Zhaotong). Of the questionnaires, 97.87% were valid, resulting in a total of 1284 questionnaires. The others did not meet the prerequisites of the models.

The interviewed farmers were older, with the average age of the respondents in the 10 counties of the nine prefectures being between 40 and 50 years old. Among them, those aged 50 and above accounted for 42.76% of the total sample. The proportion of Han Chinese among the respondents was relatively low in the minority autonomous counties and higher in the other areas. The Han farmers interviewed accounted for less than 30% in Mojiang and Yanshan counties. These findings indicate that middle-aged and older populations are intensively involved in agricultural activities in rural areas in Yunnan, which could be explained by the aging phenomenon in rural areas. The minorities were distributed widely, whereas minority autonomous areas had a greater minority proportion in the population.

2.2. Indicators System

Based on local practice, focus group discussions, and experts' recommendations, we considered five dimensions as level 1 indicators: Human capital, use behavior, management skills, public policy, and willingness. These five dimensions cover the social and economic factors related to mulch film application in China. Under the first dimension, human capital, to find whether the education level of farmers affects their mulch film practice, we assumed that the more the formal education farmers received, the better their awareness of choosing and recycling residual film. Thus, the education level of the laborers was taken to be one of the level 2 indicators.

Not every single person in a rural area can work in the field: The more family members for whom a laborer is responsible, the fewer members the household can devote to farming practices, such as removing the residual film from fields. As such, population per laborer was selected as the second level 2 indicator in the system. Land size is another crucial factor that affects mulch film application behavior: If the farm land is sufficiently large and flat, machinery can be used; conversely, if the land is big but has a steep slope or Karst conditions, which are common in Yunnan, it could be challenging to remove the residual film from the field. The last level 2 indicator under human capital was per capita household annual income. From the field survey, we found that rural households under better economic conditions tended to choose thicker mulch film, which facilitates the removal of the residual from the field; consequently, these better-off households may reuse and recycle the mulch film more.

There were three indicators under the dimension of use behavior. The first level 2 indicator was the reuse behavior of farmers. In practice, farmers maximize the use of mulch film; the most common method of reusing mulch film is double use, which refers to using the same piece of mulch film to plant vegetables after harvesting maize. An agricultural technician said that reuse behavior is local wisdom and a cost-effective method, though it may deviate from scientific guidance. The second indicator was the change trend of mulch film use. We selected the pattern of mulch film usage quantity decreasing and maintaining as the advanced signal of farmers' environmental friendly awareness raising plus the efficiency from institutional intervention; and the pattern of mulch film usage quantity increasing as a warning of farmers' neglect of agricultural environment protection public advocacy. As per the national agricultural scientific guidance, uncovering mulch film before harvesting helps keep the shape of the film and is more efficient for recycling the film; this behavior was selected as the third indicator to evaluate mulch use behavior.

To comprehensively describe management skills, four indicators were combined. Farmers understanding that residual film is harmful for the farming environment is the motivation for actions such as removing the residual film from the field, washing the residual film for sale, bringing the residual film to recycling points, etc. If farmers do not think residual film is an issue, they might ignore the residual plastic in the earth. The second indicator was the residual film treatment behavior of farmers, which refers to whether farmers remove the residual film from the field, burn the residual film by the field, bury the residual film in the field, or wash the film and send it to the recycling points. The third indicator could partially explain the recycling behavior of farms if there is a professional recycling point or a station within a manageable distance, usually meaning within their village territory. In some cases, the recycling dealer may come to the village to purchase cleaned residual film. The price at which farmers sell residual film varies from 1.2 to 2.8 yuan per kilogram depending on the cleanliness and distance from primary plastic recycling facilities. The existence of a professional recycling business is crucial in famers' decisions regarding how to deal with residual film. The forth indicator was whether the farmers had received mulch film-related training. In the survey, we found that if agricultural technique training was held in the village, the farmers' awareness and behavior in terms of dealing with mulch film usually tended to be environmentally friendly.

Public policy and its mechanism are important; we selected two indicators to weigh this dimension. Farmers who had experienced residual film recycling-promoting activities from the agricultural technology extension department or state-owned companies tended to obey the guidance. Similarly, farmers who were included under the agro-tech extension program or were a member of a state-owned company business, such as a tobacco plantation, usually applied biodegradable film which is an advanced technology, or served with better recycling system.

The willingness to apply mulch film can be taken as a basis from which to improve environmentally friendly behavior. Farmers recognize the efficiency and importance of mulch film application; to ensure their livelihood, they have to use plastic film in reality, though they know the risks it poses to the environment. Farmers are eager to use a substitution for plastic film to prevent them from having to remove residual film, and to give them a chance to perform agricultural practices according to their conscience.

Of the 16 sub-indicators in the questionnaire on farmers' perceptions of mulch use and residual film pollution in Yunnan province, their internal relationships were analyzed using the improved entropy-weighted composite index and the grey correlation analysis model. The internal correlation of the system was measured based on the development trend of the factors' similarity and dissimilarity. The perceptions of mulch film and residual pollution were considered. The details of the index system are shown in Table 1.

Table 1. Indicators system of the social and economic measurement of mulch film pollution control.

	Tier 1 Indicators	Tier 2 Indicators	Explanation
Social–economic measurement for mulch film pollution control	Human capital	Educational level of the laborers (X_1)	0 year = 1; (0,6] years = 2; (6,9] years = 3; (9,12] years = 4; 12+ years = 5
		Population per laborer (X_2)	1 person = 1; (1,2] people = 2; (2,3] people = 3; (3,4] people = 4; 4+ people = 5
		Arable land per capita (X_3)	(0,5] mu = 1; (5,10] mu = 2; (10,15] mu = 3; (15,20] mu = 4; 20+ mu = 5
		Per capita household annual income (X_4)	(0,2500] yuan = 1; (2500,5000] yuan = 2; (5000,7500] yuan = 3; (7500,10,000] yuan = 4; 10,000+ yuan = 5
	Use behavior	Mulch film reuse (X_5)	No = 0; Yes = 1
		Change in mulch use over the last 5 years (X_6)	Decreased or remained flat year by year = 0; increased each year = 1
		Remove mulch before harvest (X_7)	No = 0; Yes = 1
	Management skills	Does residual film pose a hazard to the environment? (X_8)	No = 0; Yes = 1
		Rate of green treatment of residual film (X_9)	Burning or burying in a landfill = 0; recycled = 1
		Is there a local company that specializes in recycling? (X_{10})	No = 0; Yes = 1
		Attended training on the use of mulch (X_{11})	No = 0; Yes = 1
	Public policy	If government or enterprises provide mulch film recycling (X_{12})	No = 0; Yes = 1
		If government or enterprises provide biodegradable mulch film (X_{13})	No = 0; Yes = 1
	Willingness	Is mulch film helpful for agricultural production? (X_{14})	No = 1; general = 2; good = 3; better = 4; best = 5
		Effectiveness of using mulch (X_{15})	Not important = 1; general = 2; important = 3; comparatively important = 4; very important = 5
		Willing to use biodegradable mulch (X_{16})	No = 0; Yes = 1

2.3. Methods

We used the improved entropy-weighted composite index model and the grey correlation analysis model. The improved entropy-weighted composite index can eliminate subjective human interference and can provide more reliable results [21]. The grey correlation theory works well for analyzing the degree of sensitivity of the factors and allows comparison with traditional methods. The results can be used to quantify the levels of the factors with higher reliability [22].

2.3.1. Improved Entropy-Weighted Composite Index

An evaluation index matrix X was constructed for the criterion layer, the weight of which was determined as the amount of information provided by that indictor:

$$X = (x_{ij})_{n*m}, (i = 1, 2, \ldots, n; j = 1, 2, \ldots, m), \tag{1}$$

where i is the sample, j is the indicator, n is the total sample size, m is the total number of indicators, and x_{ij} denotes the value of the jth indicator of variable i [23]. Standardization was used to eliminate the different scales of variation of the indicators and to reduce the errors:

$$x_{ij}^{*} = \frac{(x_{ij} - \overline{x_j})}{s_j + A}, (i = 1, 2, \ldots, n; j = 1, 2, \ldots, m), \quad (2)$$

where x_{ij}^{*} is the standardized sample, $\overline{x_j}$ is the mean of the sample under indicator j, and s_j is the standard deviation under the jth indicator.

To calculate the weight of the ith sample under j indicators:

$$y_{ij} = \frac{x_{ij}^{*}}{\sum_{j=1}^{n} x_{ij}^{*}}, (i = 1, 2, \ldots, n; i = 1, 2, \ldots, m). \quad (3)$$

To calculate the entropy of indicator j:

$$I_j = -\frac{1}{ln_n} \sum_{i=1}^{n} z_{ij} ln z_{ij}, \quad (4)$$

where $z_{ij} = \frac{y_{ij}}{\sum_{i=1}^{n} y_{ij}}$; y_{ij} denotes, in matrix x, the weight of the ith sample under the jth indicator.

The weight of indicator j is:

$$W_j = \frac{1 - I_j}{\sum_{i-1}^{m}}, w_j \in [0, 1], \sum_{i=1}^{m} w_j = 1. \quad (5)$$

Based on the weight of the indicators, the evaluation function was constructed as:

$$U_i = \sum_{j=1}^{m} w_{ij} y_{ij}. \quad (6)$$

2.3.2. Grey Correlation Analysis Model

The data reflecting the behavioral characteristics of the system were called the reference data, and the composite evaluation index for each farm household interviewed was used as the comparison data. The sequence of factors that influenced the behavior of a system was composed of a sequence of numbers, called comparison data, which were standardized to the original data using Equation (2):

Reference data were calculated as:

$$x_0(k) = (x_0(1), x_0(2), x_0(3). \ldots, x_0(k)), \quad (7)$$

and comparison data were calculated as:

$$x_i(k) = (x_i(1), x_i(2), x_i(3), \ldots, x_i(k)), \quad (8)$$

where k denotes each of the respondents and $i = 1, 2, 3, \ldots, 16$ denotes the 16 indicators.

The raw data were transformed, scale-free, and a new data series was obtained by averaging.

For initializing:

$$x_i(k) = \frac{x_i(k)}{x_i(1)}. \quad (9)$$

To calculate the difference sequence between reference sequence $x_i(k)$ and comparison sequence $y_i(k)$:

$$\triangle_{0i} = |x_0(k) - x_i(k)|. \quad (10)$$

We obtained the maximum and minimum values of the reference data and comparison data:

$$\triangle_{\max}(k) = \max\{\triangle_{0i}(k)\}, \tag{11}$$

$$\triangle_{\min}(k) = \min\{\triangle_{0i}(k)\}. \tag{12}$$

To calculate the correlation coefficient:

$$\zeta_{0i} = \frac{\triangle_{\min} + \rho\triangle_{\max}}{\triangle_{0i}(k) + \rho\triangle_{\max}}, \tag{13}$$

where ρ is the resolution, which increases the significance of the difference correlation coefficients; its typical value is 0.5 ($0 < \rho < 1$).

The many values of the correlations were not conducive to a comparison, so the correlations at each moment were pooled into a single value using each moment's mean to reflect the year of association for the whole process. The general expression for the degree of association is:

$$\nu_{0i} = \frac{1}{n}\sum_{k}^{n}\zeta_{0i}(k) = \frac{1}{16}[\zeta_{0i}(1) + \cdots + \zeta_{0i}(k)]. \tag{14}$$

3. Data Analysis and Results

3.1. Data Analysis

3.1.1. Ethnic Distribution

The ethnic distribution varied in the 10 investigated counties, involving 12 ethnic groups. The Han ethnic group accounted for a relatively small proportion in the minority autonomous counties and more in the other counties. The Han ethnic group in Mojiang and Yanshan counties was less than 30% of the respondents. Overall, the top four ethnic groups were Yi (n = 109), Zhuang (n = 47), Hani (n = 47), and Bai (n = 37). The Hui (n = 5), Blang (n = 3), Lahu (n = 1), and Kelao (n = 1) were the other four ethnic groups in smaller numbers. The details of ethnic distribution are shown in Figure 2.

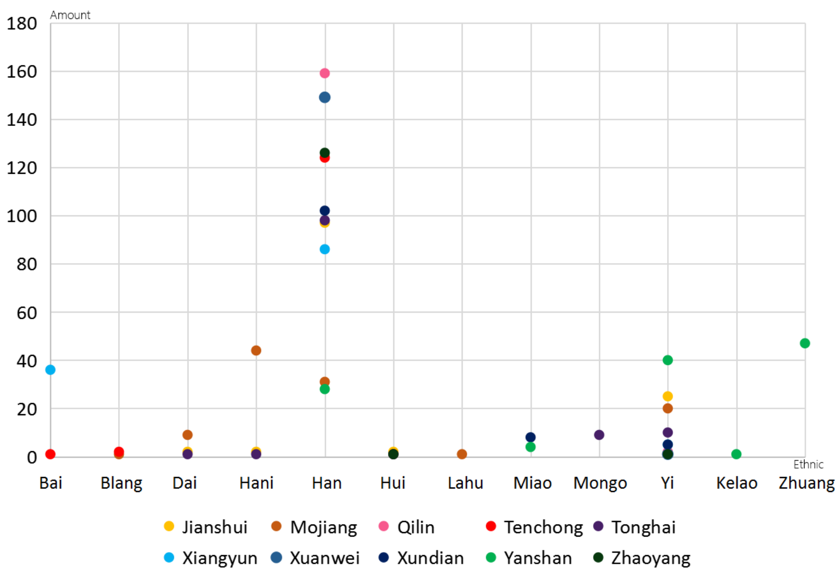
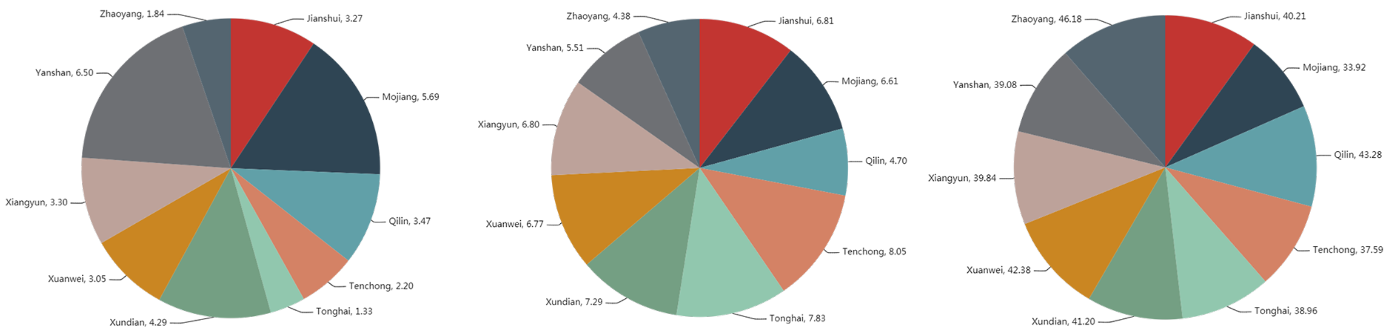


Figure 2. Ethnic distribution of the survey population.

3.1.2. Age and Education

The surveyed farmers in the 10 counties in the nine states (cities) were generally older, with people aged 50 and above accounting for 42.76% of the total sample. The average age of the men was distributed in the range of 35.66–46.08 years. The average age of the male respondents in Mojiang county, Tengchong, Xiangyun county, and Yanshan county was less than 40 years. The average age of the women was distributed in the range of

32.18–46.27 years. The average age of the female respondents in Jianshui county, Mojiang county, Tengchong city, Tonghai county, Xundian county, and Yanshan county was less than 40 years. The highest average age was found in Zhaoyang district, and the lowest in Mojiang county, indicating that the majority of agricultural production in rural Yunnan is provided by middle-aged and elderly people. This is consistent with the aging in rural areas. The average education level of the respondents was between five and eight years, with the average education level of the men being generally higher than that of the women. The largest disparity in average eduction years between the women and men was recorded in Qilin district, at 3.45 years, with highest being 6.97 years and the lowest being 2.97 years. The disparity in average education years between the women and men was less than one year in Jianshui, Xundian, and Tonghai counties. We also found that that the education level of the respondents was mainly primary and junior high school, which is consistent with the current education in rural Yunnan (Figure 3).



(a). Gender ratio (b). Average education years (c). Average age

Figure 3. Overall statistics of the respondents.

3.1.3. Human Capital

The details of human capital are shown in Figure 4. The average number of people per laborer household in the 10 counties of the nine states (cities) was two, indicating that the investigated farm households have a heavy human capital burden in agricultural production activities. Most of the per capita arable land area of the farming households interviewed was 2–4 mu, while that in Mojiang and Yanshan counties was up to 6 mu. The per capita arable land area was higher in Mojiang and Yanshan counties due to the emergence of a large number of large growers; they contracted a large amount of land through land transfer for agricultural production. The per capita arable land of 60 households was more than 5 mu, accounting for 56.61% of the sample in Mojiang. Meanwhile, the per capita arable land of 68 households was more than 5 mu in Yanshan, accounting for 56.67% of the sample. A slight difference was found between the agricultural production income and the per capita annual income of the households: They fluctuated between 10,000 and 20,000 yuan. Generally, the per capita annual income of the households was more than the agricultural production income. Notably, the per capita family income was as high as as 36,700 yuan in Jianshui county, with a per capita agricultural production income of up to 35,500 yuan; due to a large grower transfer of 305 acres of land for agricultural production, the annual income reached 8 million yuan, resulting in a high average income in Jianshui.

3.1.4. Use Behavior

The details of mulch film use behavior are shown in Figure 5. In the 10 counties of the nine states (cities) surveyed, the proportion of households paying for the removal of mulch film varied, ranging from 7.56% to 88.19%. A high proportion of the households paid for removing mulch film due to tobacco companies requiring farmers to collect used mulch film 45 days after harvest to maintain soil health and to ensure the quality of the next year's tobacco. The amount of mulch use increased over the last five years for 14.84–44.71% of the respondents because the size of the family arable land remained constant. The increase in Jianshui, and Yanshan counties was over 40% due to the households contracting more land under the land transfer policy. The reuse of mulch film was rarely reported. The thickness of the mulch film used in 10 counties was 0.008 and 0.005 mm, which are thin and fragile and cannot be reused.

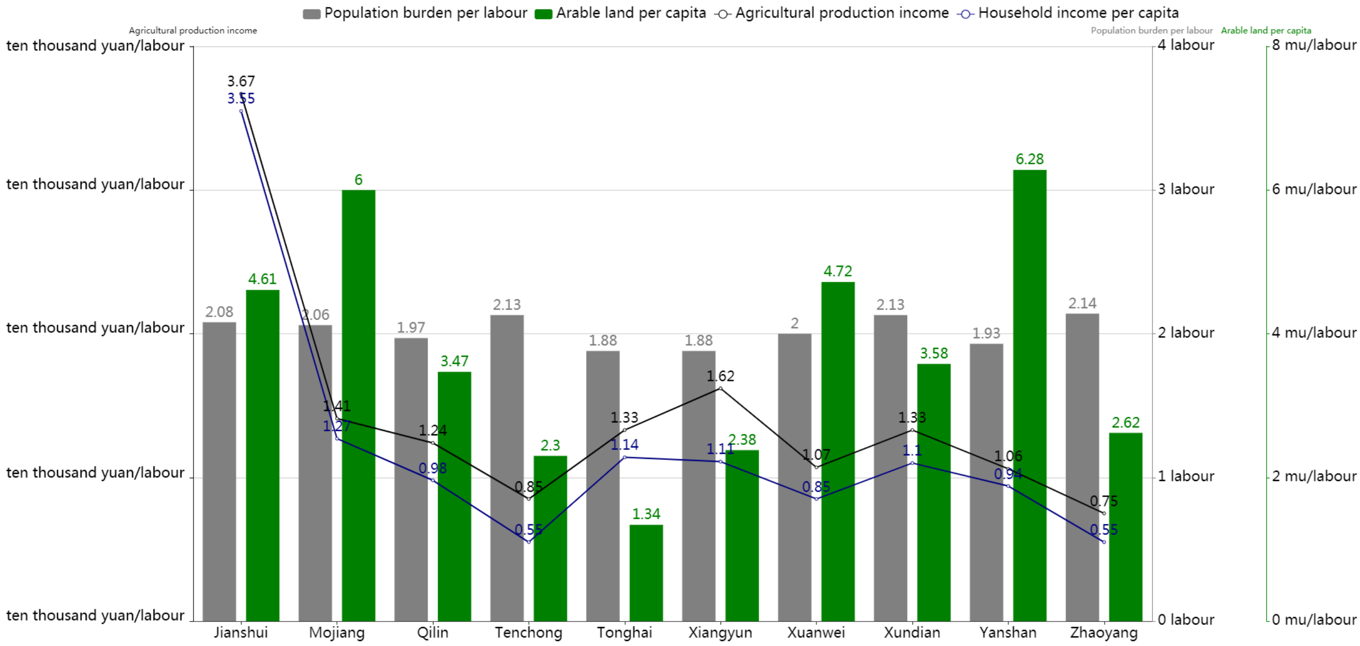


Figure 4. The primary indicators of human capital.

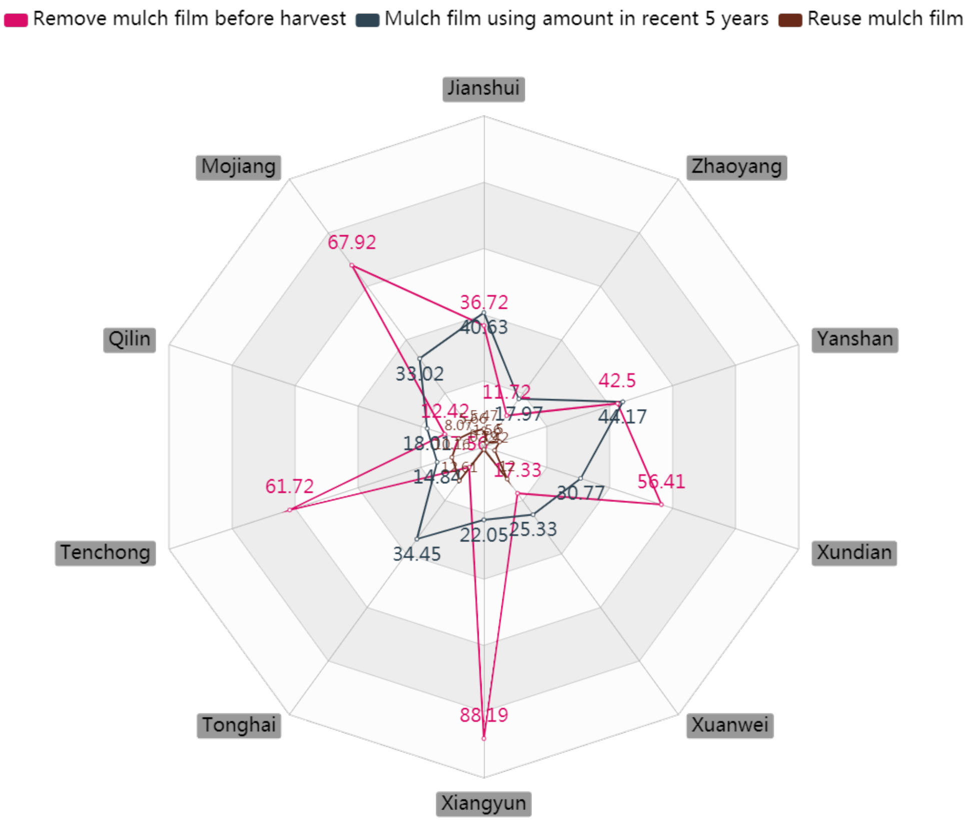


Figure 5. The primary indicators of use behavior.

3.1.5. Management Skills

The details of the management skills are shown in Figure 6. The proportion of respondents who knew that there were local mulch film recycling companies in Xiangyun, Qilin, and Xundian counties were 80.31%, 72.67%, and 70.94%, respectively. The difference between the mulch film recycling rate and the proportion of respondents who knew that there were local mulch film recycling companies was small in these three counties. Moreover, the difference in Tonghai county was significant, where only 7.56% of the respondents knew that there were local mulch film recycling companies; however, the mulch film recycle rate was 34.45%. Following this was Zhaoyang district, where only 10.16% of the respondents knew that there were local recycling companies, and the mulch film recycle rate was 28.91%. Of the respondents, 67.97–96.58% believed that residual film would cause environment contamination and would have negative effects on soil health. This indicates that the respondents were aware of the hazards of residual film. Furthermore, most of them recycled residual film in practice.

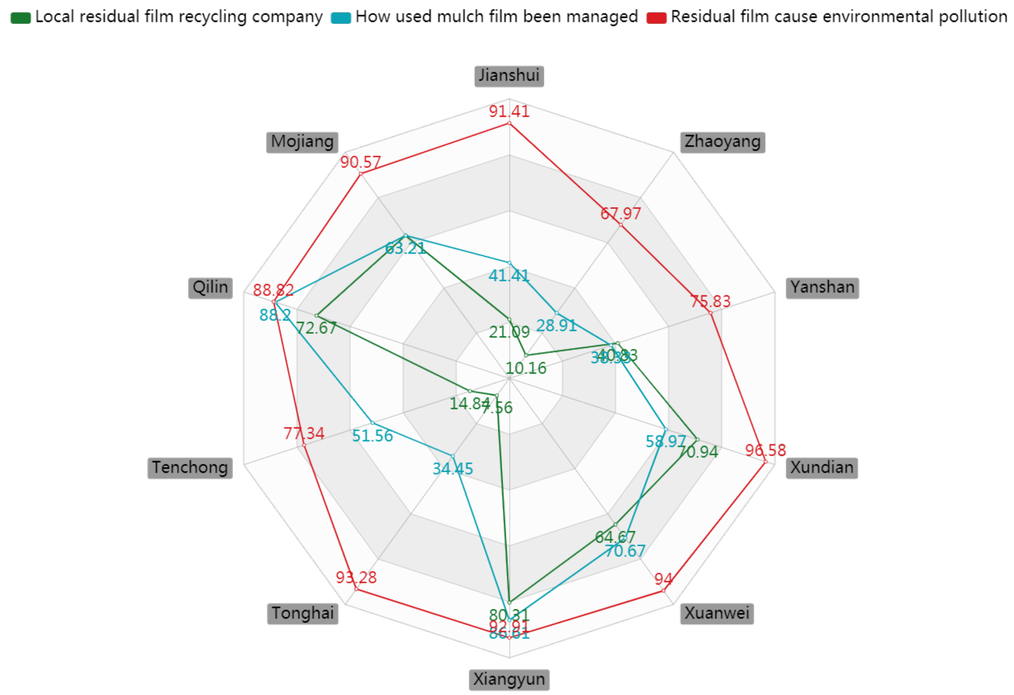


Figure 6. The primary indicators of management skills.

3.1.6. Public Policy

The public policy details are shown in Figure 7. We found less of a difference in the proportion of respondents who extend biodegradable mulch film in the 10 counties (cities), ranging from 12.5% to 33.02%, Xundian county and Xuanwei city recorded higher proportions—40.14% and 44%, respectively. The proportion of farmers who recycle residual varied widely in the different regions: Jianshui county and Zhaoyang district had the lowest proportions—16.41% and 26.56%, respectively. In Xiangyun county, 91.34% of farmers were aware, which was the highest proportion. Additionally, The proportion of farmers who had attended training on mulch film varied greatly: Jianshui county, Tonghai county, and Zhaoyang district had the lowest proportions—10.16%, 13.45%, and 15.63%, respectively; Mojiang and Xiangyun counties had the highest proportions—72.64% and 72.44%, respectively.Notably, the main crop of the counties where the above indicators were high was tobacco. Tobacco companies provide mandatory training sessions and residual film recycling. Furthermore, tobacco companies recycle residual film to ensure sustainable soil development.

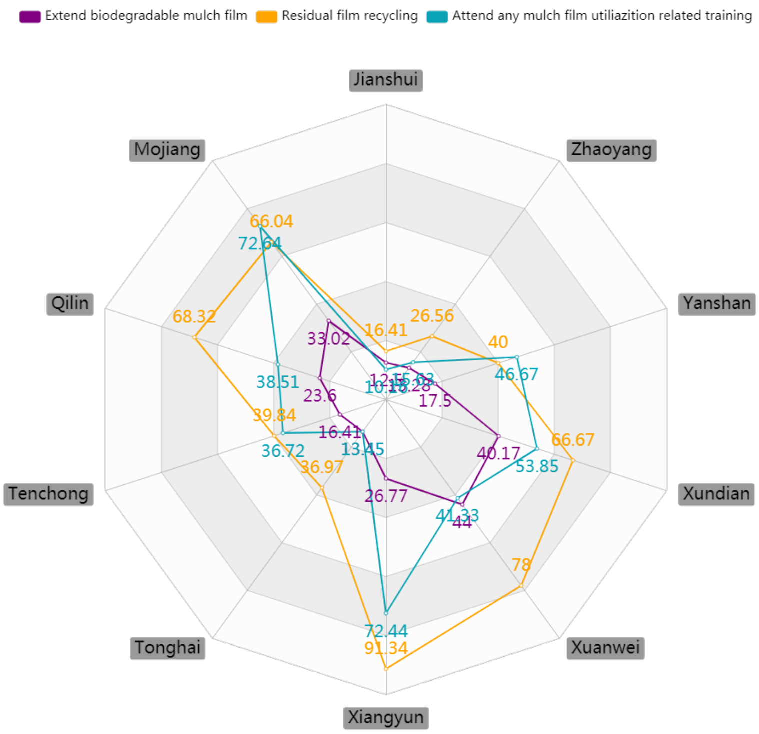


Figure 7. The primary indicators of public policy.

3.1.7. Willingness

The willingness details are shown in Figure 8. The majority of the surveyed farmers in the 10 counties of the nine states (cities) responded that mulch is very important for agricultural production, and that the use of mulch is very helpful for agricultural cultivation. Minor differences were detected in the above two indicators. The proportion of farmers who were willing to use biodegradable mulch film in most of the investigated regions ranged from 78.33% to 91.6%, except for Mojiang county, where the proportion was 3.02%. Therefore, farmers' environmental protection awareness is gradually increasing.

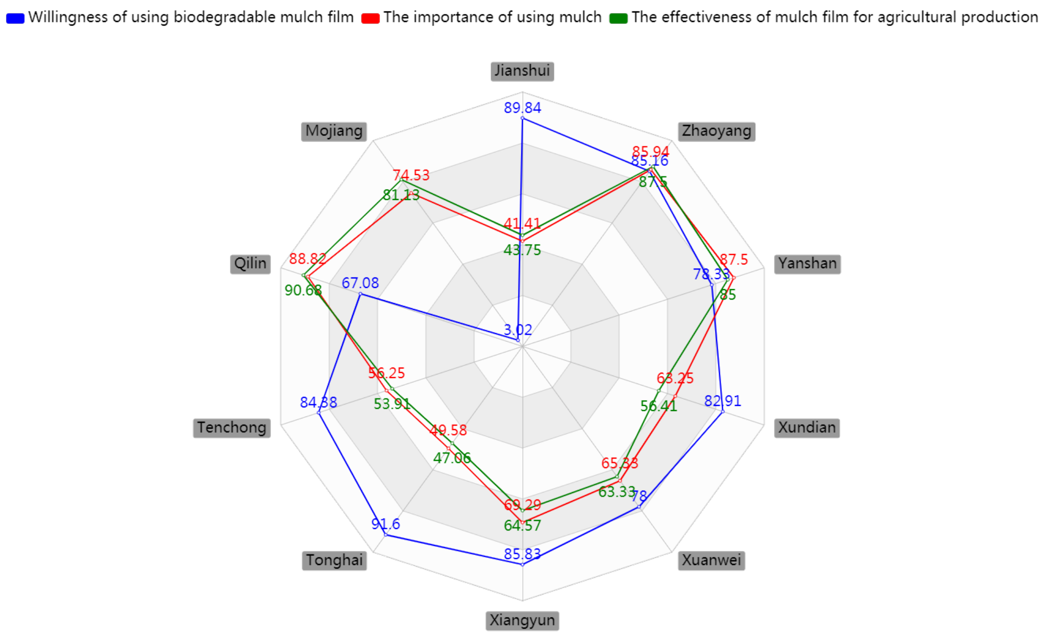


Figure 8. The primary indicators of willingness.

3.2. Results

The results calculated by the improved entropy-weighted composite index and the grey correlation analysis model are described below and are shown in Table 2.

Table 2. Results of social–economic measurement for mulch film pollution control.

	Level 1 Indicators	Level 2 Indicators	Overall Valuation	Grey Correlation
Social–economic measurement of mulch film pollution control	Human capital	Educational level of the laborers (X_1)	0.0613	0.8824
		Population per labor force burden (X_2)	0.0597	0.7871
		Arable land per capita (X_3)	0.0528	0.7889
		Per capita household annual income (X_4)	0.0642	0.8162
	Use behavior	Mulch film reuse (X_5)	0.0512	0.8421
		Change in mulch use over the last 5 years (X_6)	0.0584	0.7727
		Remove mulch before harvest (X_7)	0.0603	0.7406
	Management skills	Does residual film pose a hazard to the environment? (X_8)	0.0745	0.8448
		Rate of green treatment of residual film (X_9)	0.0635	0.8081
		Is there a local company that specializes in recycling? (X_{10})	0.0614	0.7890
	Public policy	Attended training on the use of mulch (X_{11})	0.0605	0.7918
		If government or enterprises provide mulch film recycling (X_{12})	0.0629	0.8125
		If government or enterprises provide biodegradable mulch film (X_{13})	0.0577	0.7873
	Willingness	Is mulch film helpful for agricultural production? (X_{14})	0.0693	0.8170
		Effectiveness of using mulch (X_{15})	0.0715	0.8185
		Willingness to use biodegradable mulch (X_{16})	0.0708	0.8960

3.2.1. Analysis of the Improved Entropy-Weighted Composite Index Model Results

Under the primary indicator of human capital, the secondary indicator of per capita household annual income had the highest overall rating of 0.0642, followed by educational level of the labor force at 0.0613, population burden per laborer at 0.0597, and arable land per capita at 0.0528. The results showed that the human capital stock of the households was low. Human resource capacity was weak and arable land was insufficient.

Under the primary indicator of use behavior, the secondary indicator of remove mulch film before harvest had the highest overall rating of 0.0603, followed by change in mulch film use amount over the last five years at 0.0584 and reuse mulch film at 0.0512. The results showed that removing mulch film before harvest was a better indicator of whether the farmer was using mulch film properly.

Under the primary indicator of management skills, the secondary indicator of whether residual films poses a hazard to the environment had the highest overall rating of 0.0745 followed by the recycle rate of residual films at 0.0635. If local mulch film recycling is available was the lowest, at 0.0614. The results showed that the respondents were aware that residual film is harmful to the environment.

Under the primary indicator of public policy, the secondary indicator of whether the government or a company provided residual film recycling had the highest overall rate of 0.0629, followed by if respondents attended mulch film-related training at 0.0605 and if the government or enterprise promoted biodegradable mulch film at 0.0577. The results showed that respondents were more reliant on extension and promotion from the government. Furthermore, the respondents were increasingly concerned about the security of agri-ecology.

Under the primary indicator of willingness, the secondary indicator effectiveness of mulch film had the highest overall rating of 0.0715, followed by willingness to adopt biodegradable mulch film at 0.0708 and if mulch film is helpful for agricultural production, which was the lowest, at 0.0693. The results showed that the effectiveness of mulch film was the major determinant for using it.

3.2.2. Analysis of the Grey Correlation Analysis Model Results

Under the primary indicator of human capital, the secondary indicator of the educational level of the laborers had the highest correlation of 0.8824, followed by per capita household annual income at 0.8162, arable land per capita at 0.7889, and population burden per laborer, which was the lowest, at 0.7871. The results showed that education impacted the human capital of the investigated households.

Under the primary indicator of use behavior, the secondary indicator of reusing mulch film had the highest correlation of 0.8421, followed by change in mulch film use amount over the last five years at 0.7727 and removing mulch film before harvest, which was the lowest, at 0.7406. The results showed that removing mulch film before harvest could indicate if the farmer properly uses mulch film, and reusing mulch film is reflected in mulch film recycling practices.

Under the primary indicator of management capacity, the secondary indicator of whether residual films pose a hazard to the environment had the highest correlation of 0.8448, followed by the recycling rate of mulch film at 0.8081 and if local mulch film recycling company is available, which was the lowest, at 0.7890. The results showed that the respondents were aware that residual film may impact the environment. This awareness had a strong impact on residual film management.

Under the primary indicator of public policy, the secondary indicator of whether the government or enterprises provide mulch film recycling had the highest correlation of 0.8125, followed by attending mulch film-related training at 0.7918 and if the government or enterprises provide biodegradable mulch film, which was the lowest, at 0.7873. The results showed that the provision of training by the government or enterprises was the major determinant of farms properly using mulch film and recycling film.

Under the primary indicator of willingness, the secondary indicator of willingness to use biodegradable mulch film had the highest correlation of 0.8960, followed by the effectiveness of mulch film at 0.8185 and if mulch film is helpful for agricultural production, which was the lowest, at 0.8170. The results showed that respondents were willing to adopt biodegradable mulch film if its price is reasonable.

4. Discussion

The mulch film was applied across the world and cover major crops. A large number of previous researches clarified the impacts of residual mulch film on production and soil, as well as proposed recommendations for reducing negative effects of residual. There are ways to reduce the negative effects of residual mulch film. Substitute materials is an option, such as starch polymer comosite plastic film, photodegradable plastic film and biodegradable film [24], but these substitutions were not extended to large-scale application due to the high cost, insufficient water and wind resistance [25]. Our research found that effectiveness of mulch film and willingness to use biodegradable mulch film are major factors influencing residual mulch film pollution knowledge of households. Therefore, the poor performance of substitutive mulch film reduces willingness to use of households, further, obstacles the mulch film substitutions application. Additionally, the impacts of substitutions on crops and soil remain unclear. The government should improve standard of substitutive mulch film production to promote application. Developing light-weight machinery for mulch film recycling is also proposed to mitigate negative impacts of residual mulch film [8]. Furthermore, policy has been applied as a solution, which was tested in some countries [26]. In Sweden, the upstream mulch film manufactures have to finance downstream recycling [27]. Our research found similar policy in Mojiang county, main crop of where is tobacco, tobacco companies provide residual film recycling.

However, a few previous researches explored the social factors of residual film pollution. Globally, food demand keeps increasing, food security received intensive concerns. Mulch film is a effective way for keeping food security. At present, the advantages of mulch film are overweigh disadvantages. Degradable mulch film will not completely replace plastic film in a short term. It is important to explore how to control and mitigate mulch film pollution in practice. Our research explored the social factors from the perspective of farmers, by using improved entropy-weighted composite index and the grey correlation analysis model to decrypt residual mulch film management capacity of households and presented policy initiatives. Libin Xiang found subsidies threshold for much film recycling is 1500 yuan/t, in Shanxi province by using grey correlation model GM (1,1) [28]. The government should provide subsidies for farmers, residual recycling enterprise and residual reusing enterprise. In our research, the results of indicators "is there a local company that specializes in recycling" and "if government or enterprises provide mulch film recycling" showed that farmers completely agree with "farmer-government-enterprise"cooperation mode. Taixiang Wang quantitively analyzed factors of residual film recycling from the perspective of farmer, enterprise and government, by using fuzzy set theory and DEMATEL method. The result showed that the more government technically support residual recycling, the higher recycling effectiveness, and the higher willingness of the farmer and enterprise to be involved [29]. Further, farmers are rational economic workers, and the economic benefit is the direct driver for farmers involved in residual recycling. Similarly, we found that the high residual film recycling rate in Mojiang county, due to local state-owned enterprises, provides mandatory training for using and recycling mulch film, distributes unified standard mulch film, and recycles residual quickly. We also found that the effectiveness of residual recycling is good in the county where subsidies are available residual recycling. Additionally, as rational economic workers, the farmers prefer plastic film due to the high cost of degradable film.

A comprehensive understanding of residual film control from perspective of agriculture, ecological and social remains vague. This is a further research direction.

5. Conclusions and Policy Implications

5.1. Conclusions

As a result of long-term production goals, a large amount of mulch remains in the soil, thereby polluting it, as it is discarded in the fields. Pollution has visibly formed in rivers and other water bodies; in addition, direct incineration causes air pollution. Therefore, farmers must use mulch reasonably, increase the recycling of residual film, and reduce white soil pollution, and the knowledge of rural households on the use of mulch must be increased. Analysis of the factors influencing the recycling of residual film will help guide farmers to use mulch scientifically and rationally in the agricultural production process, as well as to actively conduct residual mulch recycling. Therefore, we focused on farmers' perceptions of mulch use and residual film recycling, as well as their influencing factors. The main conclusions are as follows.

5.1.1. Higher Education vs. Better Awareness

The use of mulch and the recycling of residual film was more likely to be influenced by the education level of the laborers and the per capita annual income of the household: The higher the level of education, the more likely the laborers were to have a higher income. Farmers who are more inclined to rationally use mulch are more willing to pick up residual mulch. The households with higher income were more likely to protect the environment.

5.1.2. Willingness vs. Reality

Although farmers reported a strong willingness to reuse mulch film, the agricultural terrain of Yunnan province is diverse; the thickness of the mulch film used in practice was 0.006 or 0.008 mm, which does not meet the national criterion of 0.010 mm and is not reusable. During the interviews, the manufacturers of mulch film said that thin much film is in stock. This implies that its product does not meet the national regulation.

5.1.3. Personal Skills vs. Professional Cooperation

Most farmers reported an awareness that residual film may cause environmental pollution, yet that local professional cooperations do not provide professional recycling services. Professional farmer organizations play an active role in residual recycling. For example, in Mojiang county, professional farm organizations provide an on-site mulch film recycling service for a comparatively good price.

5.1.4. Public Policy vs. Personal Experience

The promotion by the government and their related cooperation are crucial for managing residual film pollution. Reasonable mulch film use was shown to depend greatly on training. However, only occasional sessions and commercial promotion were available for farmer training; therefore, public education should be a priority for the government.

5.1.5. Current vs. Future

The knowledge that the use of mulch film could increase agricultural production was common amongst farmers. They were willing to use biodegradable film as a substitution to ensure sustainable agricultural development. However, biodegradable film breaks down earlier than expected and cannot fulfill the practical requirements; therefore, a more mature technology is in needed in the near future.

In general, this research revealed that "whether residual film is harmful for the environment", "effectiveness of mulch film", "whether willing to use biodegradable mulch film" and "educational level of the labours" were the major factors that influencing residual mulch film pollution cognition of households.

5.2. Policy Implications

From the perspective of policy-makers, in the future, governments at all levels should conduct special research on agricultural resources and the environment, track farmers' demand for mulch, implement new standards for agricultural films, strengthen polluter responsibility constraints, increase subsidies, and improve support policies for recycling and processing enterprises, as well as improve the recycling rate of residual films, the penetration rate of biodegradable mulches, multi-channel and multi-dimensional means to publicize the hazards of residual films, and how to use them appropriately to raise the awareness of farmers in rural areas on environmental protection and ensure the sustainable green development of the agricultural production process.

From the perspective of enterprises and professional cooperatives, enterprises, as mulch producers, as well as the main body performing film recycling, should increase funding to research new mulch and degradable mulch, improve the rate of residual film recovery, and provide biodegradable mulch to make sustained efforts to increase agricultural production.

From the perspective of the frontline of agricultural technology organizations, grassroots agricultural extension services will be used to actively provide training on the use of mulch and promote the use of biodegradable mulch. Apart from biodegradable mulch film and small-scale machines, the efficiency of sustainable methods is the same as that of mulch film. Plants with ecological and economic value can be used to replace weeds. For example, *Setaria anceps* has been used to replace and control *Ageratina adenophora* in Lincang and Yuxi cities in Yunnan Province [30]. After risk assessment, natural enemies could be released to control plant diseases and pests, such as fungal agents, parasitic flies or wasps, to prevent the larvae of Scarabaeoidea from harming crops roots.

6. Limitations and Future Work

The social factors for mulch film pollution are complex and may vary with location, culture, ethnicity, etc. Thus, a single study is unable to cover all factors. Future work may explore social and economic factors affecting mulch film pollution in different geographical conditions, cultural backgrounds, economic conditions, and ethnicities.

Author Contributions: Conceptualization, Y.L. and W.H.; methodology, J.C. and X.C.; software, X.C. and J.C.; validation, J.G., R.Z., and M.L.; formal analysis, X.C. and J.C.; investigation, Y.L.; resources, X.K.; data curation, J.G.; writing—original draft preparation, X.C. and J.C.; writing—review and editing, J.C.; visualization, X.C. and J.C.; supervision, Y.L.; project administration, Y.L.; funding acquisition, X.C. and Y.L. All authors read and agreed to the published version of the manuscript.

Funding: This research was funded by the Project of General Survey and Sampling Survey of Mulch Film for Agricultural Pollution Sources, Department of Agriculture and Rural Affairs of Yunnan Province, grant number 4530000HT201903385; the Project of Individual Cognition under Farming Environment—The Establishment of Multi-Dimensional Mulch Film Pollution Level System, Yunnan Provincial Department of Education, grant number 2019J0124; the Project of Evaluation of Residual Pollution Status of Agricultural Mulch Film Based on Microscopic, Yunnan Agricultural University, grant number HT2019ZK20180401. Doctoral research start-up fees were provided by Yunnan Agricultural University, grant number A2032002502.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: This research was kindly supported by the Yunnan Agricultural Environmental Protection and Monitoring Station and Yunnan Agricultural Technology Extension Station. The Editor's help in improving the quality of this manuscript is also greatly appreciated.

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

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