water

Article

Identifying the Influencing Factors of Plastic Film Mulching on Improving the Yield and Water Use Efficiency of Potato in the Northwest China

Juzhen Xu [1,2], Yanbo Wang [2], Yuanquan Chen [2], Wenqing He [1], Xiaojie Li [1,*] and Jixiao Cui [1,*]

[1] Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences, Beijing 100081, China; xjz0068@cau.edu.cn
[2] College of Agronomy and Biotechnology, China Agricultural University, Beijing 100193, China; s20223010027@cau.edu.cn (Y.W.); chenyq@cau.edu.cn (Y.C.); hewenqing@caas.cn (W.H.)
* Correspondence: lixiaojie@igsnrr.ac.cn (X.L.); cuijixiao@caas.cn (J.C.)

Abstract: Potato is an important crop in the Northwest China, however, its production is constrained by water scarcity. Plastic mulching film is an efficient technical measure to alleviate potato production restrictions. Therefore, studying the response of potato yield and water use efficiency to plastic mulching film is of great significance. The study conducted a meta-analysis to quantify the effect of plastic film on potato yield and water use efficiency in the Northwest. The study then quantified the effects of different levels of natural conditions (mean annual precipitation, mean annual accumulated temperature $\geq$ 10 °C), fertilizer application (nitrogen fertilizer, phosphate fertilizer, potassium fertilizer), cultivation measures (planting density, cultivation method, mulching method), and mulching properties (mulching color, mulching thickness) through subgroups analysis. Finally, the random forest model was used to quantify the importance of factors. Plastic film mulching increased yield by 27.17% and water use efficiency by 27.16%, which had a better performance under relatively lower mean annual precipitation, low mean annual accumulated temperature $\geq$ 10 °C, relatively lower fertilizer application, planting density of 15,000–45,000 plants·ha^{-1}, ridge, and black mulching. Natural conditions, fertilization measures were vital to improve productivity. The research results can provide reference for agricultural management strategies of potato cultivation using plastic film in the Northwest China and other potato-producing areas.

Keywords: meta-analysis; random forest; importance; natural conditions; fertilization

Citation: Xu, J.; Wang, Y.; Chen, Y.; He, W.; Li, X.; Cui, J. Identifying the Influencing Factors of Plastic Film Mulching on Improving the Yield and Water Use Efficiency of Potato in the Northwest China. *Water* **2023**, *15*, 2279. https://doi.org/10.3390/w15122279

Academic Editor: Guido D'Urso

Received: 22 May 2023
Revised: 9 June 2023
Accepted: 14 June 2023
Published: 18 June 2023

1. Introduction

With the increase of global population, the demand for food demand is gradually increasing, and it is that the total demand for global food will increase by 56% by 2050 [1]. Potato (*Solanum tuberosum* L.) is an annual herb of Solanaceae, which is the world's fourth largest staple crop after rice, maize, and wheat. Nowadays, China has developed into the largest potato planting country in the world [2], with a yield of 94.36 million tons and a planting area of 5.78 million ha [3]. Potato production is concentrated in Northwest China [4]. In 2020, the potato planting area in the Northwest was 1.35 million ha, with a yield of 5.19 million tons, accounting for 28.97% and 28.88% of the national total, respectively[5]. However, the Northwest China is located in the inland and has a dry climate [6]. In the Northwest, evaporation exceeds precipitation, and precipitation is irregular, posing a challenge to water resources [7]. Potato is a shallow rooting crop, which is sensitive to water, while the water deficit seriously restricts the potato in the Northwest China [8,9]. Therefore, improving water use efficiency (WUE) is crucial for potato cultivation in the Northwest China.

Plastic film mulching (PM) is an important agricultural technology extensively used in China to prevent water evaporation, improve WUE, and crop yield. At present, China is the world's largest consumer of PM, with an annual amount of 1.36 million tons and covering an area of 17.39 million ha [10]. It is reported that PM increased the average of 51 crop yields and WUE by 45.5% and 58.0%, respectively [11]. PM increased yield and WUE by 24.3% and 28.7%, respectively, for potato cultivated in the Northwest [6]. Studies have shown that climate, soil properties, and field management measures have a significant impact on the effectiveness of PM [12]. Currently, numerous publications have used meta-analysis to comprehensively quantify the effect of PM on potato yield and WUE, in addition to the other factors. Ma et al. [13] found that PM was beneficial for the yield, WUE, and economic benefits of potato in the rainfed areas of the Northwest China. Gao et al. [14] compared the effects of PM on yield and WUE in different crops and regions, and the results showed that PM had the most significant effect on improving yield and WUE of potato, compared to other crops, and the effect of PM was the best in the Northwest among several regions. Gu et al. [15] observed that, compared with PM, degradable film insignificantly improved the yield and WUE of potato. Zhang et al. [16] noticed that ridge-furrow with PM had a better effect than only using PM; in addition, the yield and WUE increase of potato were the highest under the combination of ridge-furrow and PM. He et al. [17] compared the effects of white film and black film, and their study suggested that potato planting obtained higher economic benefits from black film, mostly because black mulching had the stronger effect of controlling weeds, which was beneficial in reducing the cost of herbicides. Overall, PM is of great significance for potato production. According to the major planting areas of potato, Li et al. [6] conducted a meta-analysis that divided China potato cultivation areas into seven major regions, and the results showed that PM performed the best on yield in the Northwest, which was consistent with Li et al. [18], and only increased WUE in the Northwest. Mo et al. [19] and Wang et al. [20] further divided the Northwest into irrigation areas and arid areas, and found that yield increase and WUE increase were both the highest in arid areas. Furthermore, the researchers introduced meta method to quantify the effects of different factors and levels of factors on PM, and the results found that climate, soil, and agricultural practices had significant impact on PM. However, although many publications studied on the response of potato yield and WUE to PM, few studies quantified the importance of influencing factors, which are an important guidance for the rational use of PM.

Meta-analysis is a method for combining the results of multiple independent studies on the same research topic for scientific statistical analysis, which can synthesize independent trial results for quantitative assessment at regional and global scales [21]. Meta-analysis is widely used in the medical field and was introduced into the ecological field at the end of the last century [22]. Researchers have also used this method to quantify the effect of PM on yield [14], WUE [23], greenhouse gas emissions [24], soil nutrients [13], root traits [25], and many other factors. In this context, random forest is a precise and powerful machine learning method for classification, which is able to quantify the importance of variables [26,27]. For example, Tseng et al. [28] adopted the method to study the factors influencing the yield gap in high-yield rice fields in Uruguay, which found that the sowing date and nitrogen application rate were the most main factors. Smidt et al. [29] reported that the elevation was the prominent factor for soybean yield. Philibert et al. [30] noticed nitrogen fertilizer and crops were the key factors in N_2O emission. Based on the advantages of both meta and random forest, the two methods can be combined. Currently, many studies introduced this method to deepen the analysis. Dang et al. [31] analyzed the importance of influence factors for soil inorganic carbon content. Liu et al. [32] determined that climatic factors were important drivers for the soil organic carbon content. Therefore, it is advantageous to adopt the combination of these two methods.

At present, there are numerous publications including field experiments and comprehensive studies exploring the impact of PM on potato production. Potato is important for food security in the Northwest China, however, there is no comprehensive analysis of potato cultivation with PM practice in the Northwest China, and the importance of influencing factors. Therefore, in this study, we utilized published literature to (a) quantify the impact of PM on potato yield and WUE in the Northwest China; (b) analyze the response of film effect to fertilization, cultivation measures, and film properties; and (c) adopt random forest model to quantify the relative importance of factors to the role of PM on potato yield and WUE. The results of this study will provide better guidance for the use of plastic film technology in potato cultivation in the Northwest China.

2. Materials and Methods

2.1. Data Collection

This study used meta-analysis to study the effect of PM on yield and WUE of potato. Using the theme of "plastic film Mulching/film Mulching & Potato", a literature search was conducted to collect field experimental research papers published domestically and internationally from 1981 to 2023 on the impact of PM on potato in China. Chinese literature mainly came from China National Knowledge Infrastructure (CNKI), while English literature mainly came from Web of Science (WOS). Excluding conference, review, macro, and model simulation literature, the first screening of the retrieved literature resulted in 189 publications.

In order to further eliminate literature that did not meet the standards and obtain more accurate data, the data screening criteria included the following: (1) The experimental site must be an outdoor field in China, and the location or longitude and latitude of the experimental site must be specified in detail in the article; (2) During the experiment, both covering and no covering treatments must be included, and other management measures, sampling and measurement time and methods must be consistent except for whether to cover the film; (3) The number of duplicates processed were known. For data presented in the form of images, we used the Get Data Graph Digitizer software to read it.

In order to explore the factors that affected the yield and WUE of potato under PM, the data were divided into different subgroups based on natural conditions, fertilizer applications, cultivation measures, and mulching properties. According to the study, the growth of crops heavily depends on climate; in the study, annual average precipitation (AP) (range of <200, 200–400, 400–600, and >600 mm) and ≥10 °C annual average accumulated temperature (AT) (range of 1500–3000, 3000–4500, and >4500 °C) are used as a part of subgroups, as shown in Table 1. Fertilizer is an indispensable agricultural resource for ensuring yield and quality in crop production. Nitrogen, phosphorus, and potassium fertilizers are important inorganic fertilizers, and the fertilizer gradients were divided into: 0–100, 100–200, and >200 kg·ha^{-1}. Planting density is another important influencing factor [20], so in this study it included 15,000–45,000, 45,000–75,000, and >75,000 plants·ha^{-1}. Agriculture in semi-arid areas heavily relies on precipitation, hence ridge and furrow cultivation is very beneficial for rainwater collection [33]. Cultivation method included ridge and flat. The mulching method of the PM included two common ones: full and partial (except full). The color and thickness of PM are important properties of PM, and important factors for the effect of PM, so white and black were chosen for color, and 0.008 and 0.01 mm were chosen for thickness.

Table 1. Gradient division of different subgroups.

Subgroup Classification	Classification Factors	Subgroups			
Natural condition	Mean annual precipitation (AP): mm	<200	200–400	400–600	>600
	≥10 °C mean annual accumulated temperature (AT): °C	1500–3000	3000–4500	>4500	
Fertilizer application	nitrogen fertilizer: kg·ha^{-1} phosphate fertilizer: kg·ha^{-1} potash fertilizer: kg·ha^{-1}	0–100	100–200	>200	
Cultivation measures	Planting density: plant ha^{-1}	15,000–45,000	45,000–75,000	>75,000	
	cultivation method	ridge	flat		
	mulching method	full	partial		
Mulching properties	mulching color	white	black		
	mulching thickness: mm	≤0.008	≥0.01		

2.2. Data Analysis

There is a hierarchical dependency between multiple observations in the study, and obtaining several effect quantities from the same publication violates the assumption that the effect quantities are independent [34]. Hierarchical meta-analysis model can be used to control the independence of data [35]. This study used "metafactor (rma.mv)" to control for the independence of different cases from a unified literature. The random effect model is used to analyze the effect of potato film mulching, and the natural logarithm of response ratio (R) is selected as the effect size [21]:

$$R = {}^{X_e}/_{X_c} \tag{1}$$

$$Ln({}^{X_e}/_{X_c}) = LnX_e - LnX_c \tag{2}$$

where, X_e represents the average yield or WUE under PM; and X_c represents the average yield or WUE under no PM. This study uses a 95% confidence interval to determine the significance of differences in yield effects. If the confidence interval includes a 0 value, the difference is not significant; if the confidence intervals are all to the right of 0, it is a significant positive effect; if the confidence intervals are all to the left of the 0 value, it is a significant negative effect. Due to the fact that many publications did not report standard deviations and include more studies, $weight = \frac{ne \times nc}{ne + nc}$ was chosen for this study, where ne and nc represent the numbers of replicates of the treatment and control experiments, respectively [36].

In the study, random forest was adopted to analyze the relative importance of AP, AT, nitrogen fertilizer, phosphate fertilizer, potash fertilizer, planting density, cultivation method, mulching method, mulching color and mulching thickness for potato yield and WUE increase under PM. Metafor package and metaforest package in R language were used for meta and random forest analysis [37], and GraphPad Prism was used for visual mapping.

3. Results

3.1. Overview of Meta Dataset and the Effects of PM on Potato Yield and WUE

The dataset for the study came from 189 references (168 in Chinese and 21 in English), with a total of 1028 pairs of data, including 748 pairs for yield and 280 pairs for WUE. The effect size of yield and WUE followed the Gaussian normal distribution (Figure 1a,b); the R square of yield was 0.93 ($p < 0.001$), and the R square of WUE was 0.71 ($p < 0.01$). Compared with no mulching, PM significantly improved potato yield and WUE in the Northwest (Figure 1c). PM improved potato yield by 27.17% and WUE by 27.16% on average, respectively.

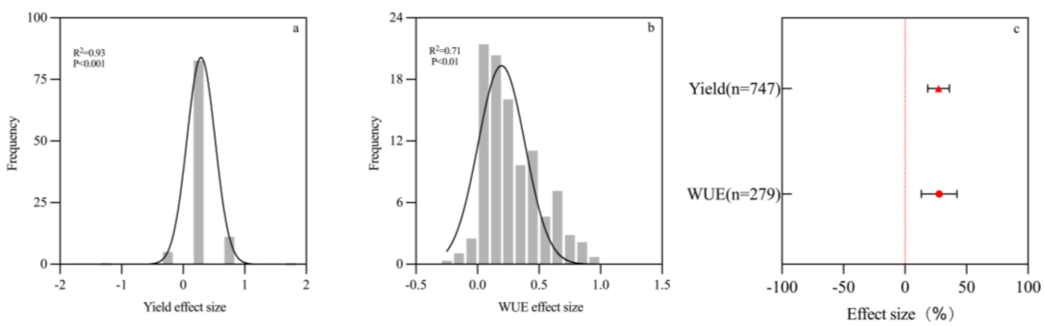

Figure 1. Frequency distribution of potato yield and water use efficiency; The curve represents a Gaussian fitting curve (**a**,**b**); Overall effect size in potato yield and WUE comparing plastic film mulching (PM) to no mulching in Northwest China (**c**). Error bars are the 95% confidence intervals (CIs). Number of samples indicated in parentheses.

3.2. Response of Potato Yield and WUE under PM to Natural Conditions

Natural conditions were the factors that affect the effectiveness of PM. As shown in Figure 2a,b, PM significantly increased yield when the AP was between 200–400 mm, 400–600 mm, but reached the highest at 200–400 mm, with yield of 30.41% and 24.8%, respectively. PM only significantly increased WUE between 200 mm and 400 mm, reaching 34.52%. PM significantly increases yield at 1500–3000 °C, 3000–4500 °C AT, but the best effect is at 1500–3000 °C, with 28.57% and 22.13%, respectively. For WUE, only the accumulated temperature between 1500 and 3000 °C significantly affected WUE, accounting for 32.53%. In general, PM performed greatly under the 200–400 mm AP and 1500–3000 °C AT.

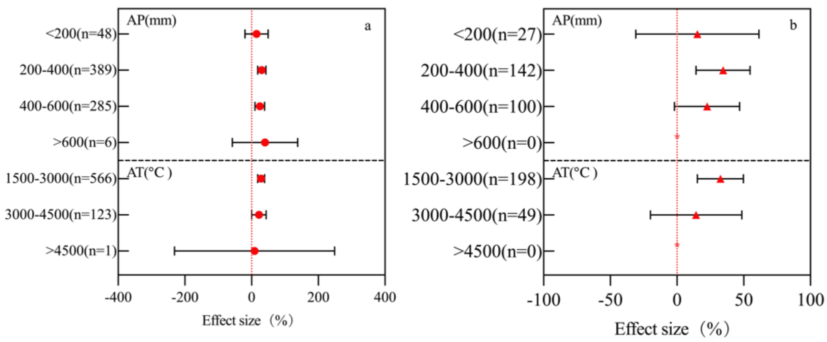

Figure 2. Effect of PM on potato yield (**a**) and WUE (**b**) comparing with no mulching in Northwest China at different AP (annual average precipitation) and AT (≥10 °C annual average accumulated temperature). Error bars are the 95% confidence intervals (CIs). Number of samples are indicated in parentheses.

3.3. Response of Potato Yield and WUE under PM to Fertilizer Application

Different fertilizer applications had different effects on improving potato yield and WUE under PM (Figure 3). Under nitrogen fertilizer, yield performed well under all three gradients of nitrogen application. As the application rate increased, the effect of yield increase became more effective. PM increased yield by 32.71% at >200 kg·ha^{-1} nitrogenous application. For phosphate and potassium, PM increased yield at 0–100, 100–200 kg·ha^{-1}, by 30.92% and 29.94%, respectively. For WUE, the effect of different fertilizers and their application rates on PM varied. PM only increased WUE by 32.43% at 100–200 kg·ha^{-1} nitrogenous application. For phosphate, PM was most effective at 0–100, 100–200 kg·ha^{-1}, and was the highest at 100–200 kg·ha^{-1} (30.88%). For potassium, PM only improved WUE at 100–200 kg·ha^{-1} by 24.54%.

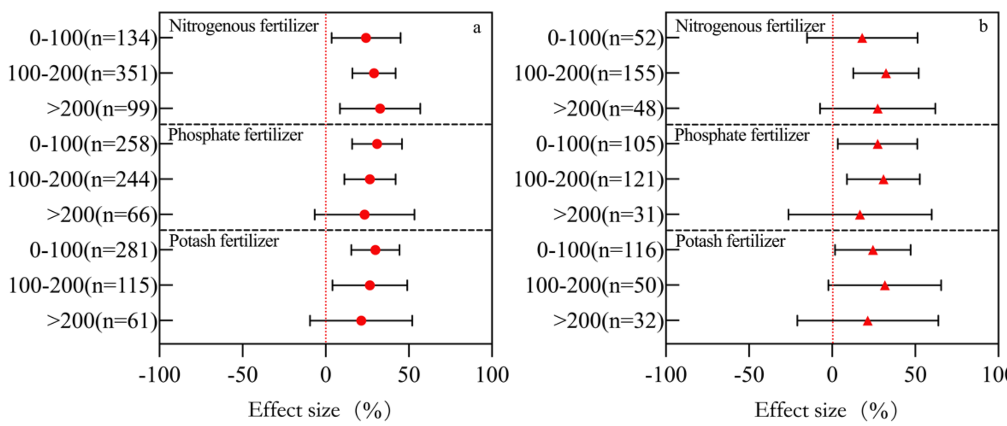

Figure 3. Effect of PM on potato yield (**a**) and WUE (**b**) comparing with no mulching in Northwest China at different nitrogenous fertilizer, phosphate fertilizer, and potash fertilizer applications. Error bars are the 95% confidence intervals (CIs). Number of samples are indicated in parentheses.

3.4. Response of Potato Yield and WUE under PM to Agriculture Practices

PM only increased yield and WUE at 45,000–75,000 plants ha^{-1}, by 30.34% and 32.42% respectively (Figure 4). The results showed that PM only increased yield and WUE at 29.57% and 32.17% respectively under ridge, a common cultivation practice in the Northwest China. The effect of PM on yield and WUE responded differently at different levels of cover, with PM increasing yield by 31.89% and 24.57% under both full and half mulching, respectively. Full mulching performed more effectively. In contrast, PM only increased WUE under full mulching by 34.44%.

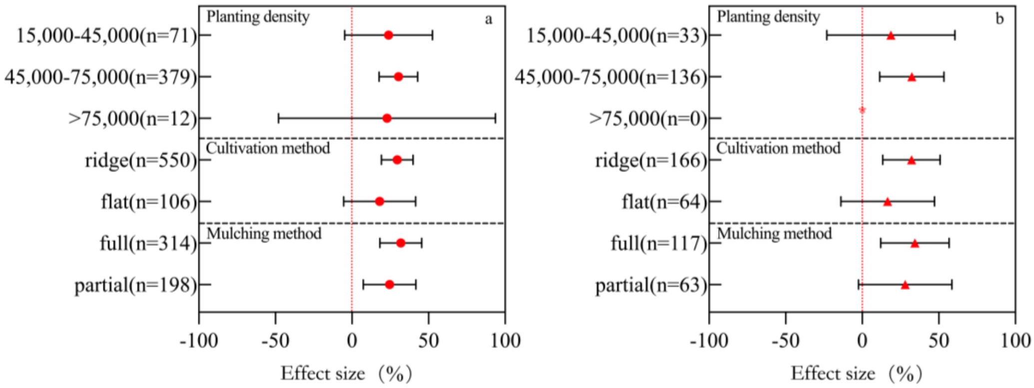

Figure 4. Effect of PM on potato yield (**a**) and WUE (**b**) comparing with no mulching in Northwest China at different planting density, cultivation method, and mulching method. Error bars are the 95% confidence intervals (CIs). Number of samples are indicated in parentheses.

3.5. Response of Potato Yield and WUE under PM to Mulching Properties

Both white and black mulching improved yield and the effect was not very different, 26.3% and 28.6% respectively, with black mulching slightly more effective (Figure 5a). Different mulching thicknesses improved yield, but ≥0.01 mm mulching increased yield by 30.44% and ≤0.008 mm mulching increased yield by 24.78%. The response of mulching color and mulching thickness to WUE differed from yield, improving WUE only with black mulching and ≥0.01 thickness, by 26.67% and 37.7%, respectively (Figure 5b).

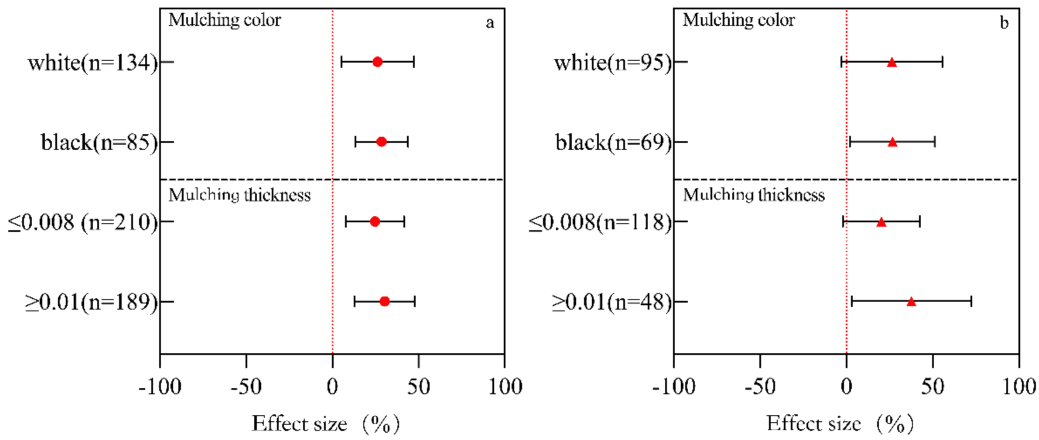

Figure 5. Effect of PM on potato yield (**a**) and WUE (**b**) comparing with no mulching in Northwest China at different mulching color, and mulching thickness (mm). Error bars are the 95% confidence intervals (CIs). Number of samples are indicated in parentheses.

3.6. The Importance of Natural Condition, Fertilizer Application, Agriculture Practice and Mulching Properties

As shown in the Figure 6a, AP was the most major influencing factor for yield increase, and the importance of mulching color was the least. The results of the random forest model showed that, for yield, the order of each factor was AP (100%), AT (56.4%), phosphate fertilizer (47.7%), potash fertilizer (47.4%), planting density (40.0%), nitrogen fertilizer (33.4%), mulching thickness (15.6%), mulching method (13.6%), cultivation method (7.3%), and mulching color (0%). For WUE (Figure 6b), AT was the most important factor, and, similar to the results for yield, the importance of mulching color was the least. The results showed that the order of each factor was AT (100%), AP (99.8%), planting density (76.9%), nitrogen fertilizer (76.3%), phosphate fertilizer (72.7%), mulching method (57.1%), mulching thickness (39.3%), potash fertilizer (34.5%), cultivation method (8.5%), and mulching color (0%). Overall, natural conditions had the most important influencing factor for the effect of PM, followed by fertilizer application and planting density. Except for the same non-importance of mulching color on yield and WUE increase, the importance of fertilizer application, cultivation measures, and mulching thickness on WUE improvement was higher than that on yield improvement.

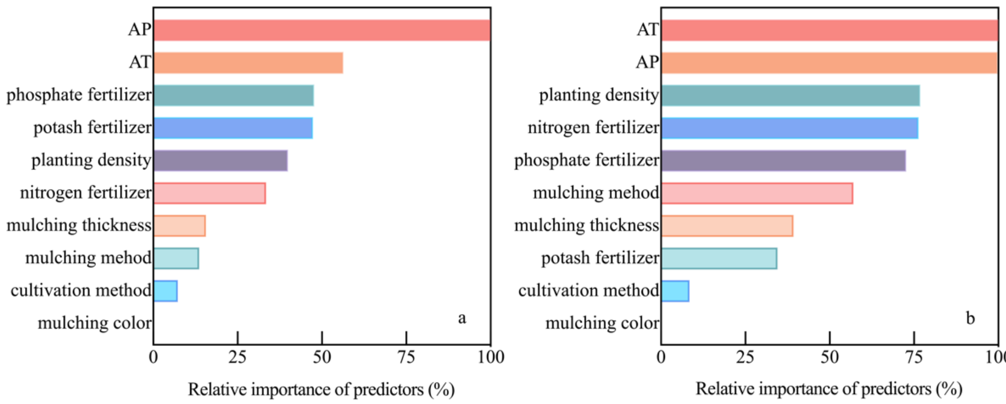

Figure 6. Relative importance of factors to the effect of PM on yield (**a**) and WUE (**b**) predicted by the random forest model. AP: annual average precipitation; and AT: $\geq$10 °C annual average accumulated temperature.

4. Discussion

4.1. The Effects of PM on Potato Yield and WUE

The study adopted meta-analysis to comprehensively quantify the effect of PM on potato yield and WUE in Northwest China, which showed that PM was beneficial for increasing yield by an overall average of 27.17% and increasing WUE by an overall average of 27.16%. The results were close to the findings of Li et al. [6] (Figure 1), who reported an increase of potato yield and WUE by 24.3% and 28.7%, respectively. Natural conditions were the primary factors of the effect of PM on the yield and WUE improvement (Figure 6). The results showed that PM had a greater potential to improve yield and WUE under 200–400 mm AP and 1500–3000 °C AT. The reasons mainly are that PM turns into a physical barrier on the soil surface, thereby increasing soil water and temperature, reducing soil evaporation [38], and accelerating the speed of soil drying and wetting alternation [39]. PM significantly raised soil water storage at surface by 8.4% in rainfed semi-arid areas, moreover, the effect was most significant when the AP was lower [40]. PM can reduce fluctuations in soil surface temperature and regulate temperature for crop growth [41]. Wang et al. [42] conducted a long-term positioning experiment on the Loess Plateau, which found that PM increased the average effective accumulated temperature of the 0–50 cm soil profile. Climate conditions in the Northwest are very suitable for cultivation, and the application of PM has great potential in the area [14]. Compared to the Northwest, PM performed relatively poorer in the South [16,20]; in addition, PM had inconspicuously promoted yield and WUE in the Southwest. In addition to increased WUE, PM is favorable to nitrogen use efficiency [43], and thermal use efficiency [44], both of which contribute to yield and quality promotion. However, PM increases agricultural inputs and labor costs, but ultimately significantly increases profits due to increased production [17,45]. A study in India discovered that straw mulching combined with irrigation significantly increased water productivity [46]. According to Xing et al. [47], organic mulching increased soil organic matter and potato tuber yield. This study concentrated solely on the Northwest China, and those areas with similar climatic and geographical characteristics can serve as a point of comparison.

4.2. The Influencing Factors of PM on Improving Potato Yield and WUE

The effects of PM on potato yield and WUE were significantly influenced by the application rate of synthetic fertilizer. The results showed that the yield and WUE of potato performed better under the application rate of 0–100 and 100–200 kg·ha^{-1}, which was consistent with Li et al. [6]. Wang et al. [20] studied the impact of synthetic fertilizers on the effectiveness of PM in the presence and absence of organic fertilizer application, and the results emphasized that organic and potassium fertilizers were not suitable for simultaneous use, as potassium fertilizer reduced yield at the same time, while potassium is the most needed nutrient element for potato growth. Zhang et al. [48] applied a meta-analysis to explore the effect of agricultural measures on WUE of potato cultivation in the Loess Plateau, which observed that increasing nitrogen fertilizer measures had a better effect on improving WUE than PM, possibly due to the significant effect of nitrogen fertilizer on increasing yield. Nitrogen fertilizer is an important source of greenhouse gases, although a study suggested that high nitrogen application rate combined with PM and irrigation reduced the carbon footprint [49]. However, when the amount of nitrogen fertilizer increased, the effect is weakened due to the consumption of more water to promote crop growth. Furthermore, PM increased the effectiveness of soil nutrients and improved the fertilizer use efficiency [12], which possibly occurred because that PM increased soil microbial activity, thereby increasing the decomposition and turnover of soil nutrients by microorganisms [50]. Ding et al. [51] reported that PM reduced nitrogen leaching and loss in a 28-year study. Therefore, the rational application of synthetic fertilizers is an important way to promote greater interaction between fertilizers and PM.

Because of higher WUE, the use of PM provides the possibility of increasing potato yield by higher planting density. Hou et al. conducted a field trial about the impact of planting density on yield and WUE in the Loess Plateau of China, and the results showed yield and WUE performed best in 52,500 plants ha^{-1} when considering profits [52]. Wang et al. divided the Northwest into irrigated and arid areas, and the best fertilization gradients for improving yield were 40,000–55,000 and 55,000–70,000 plants ha^{-1}, respectively [20]. In this study, the most effective planting density for yield and WUE was 45,000–75,000 plants ha^{-1}, which approached to the results. There was no linear relationship between yield and planting density, indicating that higher density did not necessarily mean higher yield, which is mainly due to the fact that, as planting density increases, the competition for resources between inter species increases, leading to a decrease in yield; in addition, the impact of planting density on WUE was closely related to rainfall [52].

Research has shown that the increase of crop yield and WUE indicates that PM can improve resource utilization efficiency through ridges and furrows [53]. The results of the present study agreed with this, which showed that ridges significantly improved yield and WUE, however, flat conditions had insignificant effects on yield and WUE. Ridge and furrow with mulching improves rainwater collection efficiency and ensures the water supply required for the entire growth period of potato [54], which is the best farming method in the Northwest China [16]. Full mulching had a more significant improvement in yield and WUE than partial mulching, which was consistent with Gao et al. [55], a study that analyzed the effect of PM on maize production. In another study, full mulching enhanced emergence rate and more stems, and at the same time increased cost investment, but finally it increased economic benefits due to increased production [45].

Studies have shown that different mulching colors of PM also affect its use in field production. Black and white mulching are currently the most widely used mulching color in agricultural production. Zhang et al. [56] found that white film had a better water-saving effect than black mulching, while black mulching was more suitable for the production of large stems like potato, which was mostly because black mulching covered the plant canopy, receiving more longwave radiation from the surface, causing the plant to grow vigorously, but at the same time increasing the water consumption. White film had a higher transmittance than black mulching, which increases soil temperature more effectively [2]. A possible factor in in this type of case is that potato tubers are sensitive to soil temperature in soil. Another advantage of application of the black mulching was that it had better weed control effects than white mulching, which meant that it reduced overall herbicide and labor investment cost [57]. Li et al. [18] compared the effects of film thickness less than 0.008 mm, equal to 0.008 mm, and greater than 0.008 mm on the increase of potato yield with PM, and found that the thicker the mulching, the higher the yield increase. In this study, the results also showed that increasing the mulching thickness was favorable for increasing yield and WUE. However, using a thicker mulching would increase costs, so farmers often choose to use thinner mulching in production, resulting in serious pollution problems.

4.3. Uncertainty and Limitations

This study used the method of meta and random forest to study the effect of PM on potato yield and WUE in Northwest China, including natural conditions, fertilization application, cultivation measures, and mulching properties as influencing factors. Using random forest, the importance of factors was further quantified. However, there are still limitations to the study. Firstly, factors affecting the effect of PM include altitude, soil properties, irrigation, degradable film, variety, and so on [15,18,58]. However, due to factors such as data acquisition, they were not included in this study. Secondly, there is interaction between factors, and only the importance has been evaluated. Moreover, quantifying the degree of interaction between factors is also an important issue [6,32]. Finally, while considering the impact of PM on yield and WUE, due to PM being an important source of plastic pollution in farmland [59], and the residue of PM increases the potential pathogens [60,61], the ecological effects of PM should also be considered. Moreover, it has been reported that PM increases the risk of increasing phthalate esters in the soil, which can be absorbed by plant roots and are toxic to humans and crops [62]. In order to achieve sustainable development, it is necessary to balance the improvement of human life and the protection of the ecological environment by PM. Therefore, future research can incorporate more factors and consider issues such as film pollution, which is beneficial to produce a more comprehensive understanding of PM and provide guidance for other agricultural measures.

5. Conclusions

Based on the current impact of PM on potato yield and WUE in Northwest China, the results showed that PM increased yield by 27.17% and WUE by 27.16%, respectively. AP, AT, nitrogen fertilizer, phosphate fertilizer, potassium fertilizer, planting density, cultivation method, mulching method, mulching color, and mulching thickness were the influencing factors that affect the effectiveness of PM. PM had the best yield improvement and WUE effect between 200–400 mm and 1500–3000 °C. Under nitrogen fertilizer application >200 kg·ha^{-1}, phosphate fertilizer and potato fertilizer 0–100 kg·ha^{-1}, PM had the best performance on yield increase. Nitrogen, phosphate, and potassium fertilizers application had the best effect on improving WUE under 100–200 kg·ha^{-1}. With 15,000–45,000 plants·ha^{-1}, ridge, full mulching, black mulching, and $\geq$0.01 mm, PM had the best performance in promoting yield and WUE. The results of random forest model showed that AP and AT had high scores among the above factors, in addition, fertilizer application and planting density were also of importance. Through comprehensive agricultural management, PM can better play its role and achieve sustainable development.

Author Contributions: Writing—original draft, J.X.; Writing—review & editing, Y.W. and J.C.; Supervision, Y.C., W.H. and X.L. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the National Key Research and Development Program of China (Grant number: 2021YFD1700700).

Data Availability Statement: Data can be obtained at the request of the corresponding authors.

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

References

1. Van Dijk, M.; Morley, T.; Rau, M.L.; Saghai, Y. A meta-analysis of projected global food demand and population at risk of hunger for the period 2010–2050. *Nat. Food* **2021**, *2*, 494–501. [CrossRef] [PubMed]
2. Zhang, Y.L.; Feng, R.; Nie, W.; Wang, F.X.; Feng, S.Y. Plastic Film Mulch Performed Better in Improving Heat Conditions and Drip Irrigated Potato Growth in Northwest China than in Eastern China. *Water* **2020**, *12*, 2906. [CrossRef]
3. FAO. *Crops and Livestock Products*; FAO: Rome, Italy, 2021.
4. Chang, L.; Han, F.X.; Chai, S.X.; Cheng, H.B.; Yang, D.L.; Chen, Y.Z. Straw strip mulching affects soil moisture and temperature for potato yield in semiarid regions. *Agron. J.* **2020**, *112*, 1126–1139. [CrossRef]
5. *China Rural Statistical Yearbook*; China Statistics Press: Beijing, China, 2021. (In Chinese)
6. Li, Q.; Li, H.B.; Zhang, L.; Zhang, S.Q.; Chen, Y.L. Mulching improves yield and water-use efficiency of potato cropping in China: A meta-analysis. *Field Crop. Res.* **2018**, *221*, 50–60. [CrossRef]
7. Wu, Y.; Huang, F.Y.; Jia, Z.K.; Ren, X.L.; Cai, T. Response of soil water, temperature, and maize (*Zea may* L.) production to different plastic film mulching patterns in semi-arid areas of northwest China. *Soil Till. Res.* **2017**, *166*, 113–121. [CrossRef]
8. Liang, S.M.; Ren, C.; Wang, P.J.; Wang, X.T.; Li, Y.S.; Xu, F.H.; Wang, Y.; Dai, Y.Q.; Zhang, L.; Li, X.P.; et al. Improvements of emergence and tuber yield of potato in a seasonal spring region using plastic film mulching only on the ridge. *Field Crop. Res.* **2018**, *223*, 57–65. [CrossRef]
9. Djaman, K.; Irmak, S.; Koudahe, K.; Allen, S. Irrigation Management in Potato (*Solanum tuberosum* L.) Production: A Review. *Sustainability* **2021**, *13*, 1504. [CrossRef]
10. Li, N.Y.; Qu, J.H.; Yang, J.Y. Microplastics distribution and microbial community characteristics of farmland soil under different mulch methods. *J. Hazard. Mater.* **2023**, *445*, 130408. [CrossRef]
11. Sun, D.B.; Li, H.G.; Wang, E.L.; He, W.Q.; Hao, W.P.; Yan, C.R.; Li, Y.Z.; Mei, X.R.; Zhang, Y.Q.; Sun, Z.X.; et al. An overview of the use of plastic-film mulching in China to increase crop yield and water-use efficiency. *Natl. Sci. Rev.* **2020**, *7*, 1523–1526. [CrossRef]
12. Wang, N.J.; Ding, D.Y.; Malone, R.W.; Chen, H.X.; Wei, Y.S.; Zhang, T.B.; Luo, X.Q.; Li, C.; Chu, X.S.; Feng, H. When does plastic-film mulching yield more for dryland maize in the Loess Plateau of China? A meta-analysis. *Agric. Water Manag.* **2020**, *240*, 106290. [CrossRef]
13. Ma, D.D.; Chen, L.; Qu, H.C.; Wang, Y.L.; Misselbrook, T.; Jiang, R. Impacts of plastic film mulching on crop yields, soil water, nitrate, and organic carbon in Northwestern China: A meta-analysis. *Agric. Water Manag.* **2018**, *202*, 166–173. [CrossRef]
14. Gao, H.H.; Yan, C.R.; Liu, Q.; Ding, W.L.; Chen, B.Q.; Li, Z. Effects of plasticmulching and plastic residue on agricultural production: A meta-analysis. *Sci. Total Environ.* **2019**, *651*, 484–492. [CrossRef] [PubMed]
15. Gu, X.B.; Cai, H.J.; Fang, H.; Li, Y.P.; Chen, P.P.; Li, Y.N. Effects of degradable film mulching on crop yield and water use efficiency in China: A meta-analysis. *Soil Till. Res.* **2020**, *202*, 104676. [CrossRef]
16. Zhang, S.H.; Wang, H.D.; Sun, X.; Fan, J.L.; Zhang, F.C.; Zheng, J.; Li, Y.P. Effects of farming practices on yield and crop water productivity of wheat, maize and potato in China: A meta-analysis. *Agric. Water Manag.* **2021**, *243*, 106444. [CrossRef]
17. He, G.; Wang, Z.H.; Hui, X.L.; Huang, T.M.; Luo, L.C. Black film mulching can replace transparent film mulching in crop production. *Field Crop. Res.* **2021**, *261*, 108026. [CrossRef]
18. Li, H.; Chang, W.Y. Exploring optimal film mulching to enhance potato yield in China: A meta-analysis. *Agron. J.* **2021**, *113*, 4099–4115. [CrossRef]
19. Mo, F.; Yu, K.L.; Crowther, T.W.; Wang, J.Y.; Zhao, H.; Xiong, Y.C.; Liao, Y.C. How plastic mulching affects net primary productivity, soil C fluxes and organic carbon balance in dry agroecosystems in China. *J. Clean. Prod.* **2020**, *263*, 121470. [CrossRef]
20. Wang, L.L.; Coulter, J.A.; Palta, J.A.; Xie, J.H.; Luo, Z.Z.; Li, L.L.; Carberry, P.; Li, Q.; Deng, X.P. Mulching-Induced Changes in Tuber Yield and Nitrogen Use Efficiency in Potato in China: A Meta-Analysis. *Agronomy* **2019**, *9*, 793. [CrossRef]
21. Hedges, L.V.; Gurevitch, J.; Curtis, P.S. The meta-analysis of response ratios in experimental ecology. *Ecology* **1999**, *80*, 1150–1156. [CrossRef]
22. Gurevitch, J.; Hedges, L.V. Statistical issues in ecological meta-analyses. *Ecology* **1999**, *80*, 1142–1149. [CrossRef]
23. Yu, Y.Y.; Turner, N.C.; Gong, Y.H.; Li, F.M.; Fang, C.; Ge, L.J.; Ye, J.S. Benefits and limitations to straw- and plastic-film mulch on maize yield and water use efficiency: A meta-analysis across hydrothermal gradients. *Eur. J. Agron.* **2018**, *99*, 138–147. [CrossRef]
24. He, G.; Wang, Z.H.; Li, S.X.; Malhi, S.S. Plastic mulch: Tradeoffs between productivity and greenhouse gas emissions. *J. Clean. Prod.* **2018**, *172*, 1311–1318. [CrossRef]
25. Li, Y.Z.; Yang, J.B.; Shi, Z.; Pan, W.H.; Liao, Y.C.; Li, T.; Qin, X.L. Response of root traits to plastic film mulch and its effects on yield. *Soil Till. Res.* **2021**, *209*, 104930. [CrossRef]
26. Cutler, D.R.; Edwards, T.C.; Beard, K.H.; Cutler, A.; Hess, K.T. Random forests for classification in ecology. *Ecology* **2007**, *88*, 2783–2792. [CrossRef] [PubMed]

27. Grömping, U. Variable Importance Assessment in Regression: Linear Regression versus Random Forest. *Am. Stat.* **2009**, *63*, 308–319. [CrossRef]
28. Tseng, M.-C.; Roel, A.; Macedo, I.; Marella, M.; Terra, J.; Zorrilla, G.; Pittelkow, C.M. Field-level factors for closing yield gaps in high-yielding rice systems of Uruguay. *Field Crop. Res.* **2021**, *264*, 108097. [CrossRef]
29. Smidt, E.R.; Conley, S.P.; Zhu, J.; Arriaga, F.J. Identifying Field Attributes that Predict Soybean Yield Using Random Forest Analysis. *Agron. J.* **2016**, *108*, 637–646. [CrossRef]
30. Philibert, A.; Loyce, C.; Makowski, D. Prediction of N2O emission from local information with Random Forest. *Environ. Pollut.* **2013**, *177*, 156–163. [CrossRef]
31. Dang, C.R.; Kong, F.L.; Li, Y.; Jiang, Z.X.; Xi, M. Soil inorganic carbon dynamic change mediated by anthropogenic activities: An integrated study using meta-analysis and random forest model. *Sci. Total Environ.* **2022**, *835*, 155463. [CrossRef]
32. Liu, X.T.; Tan, S.W.; Song, X.J.; Wu, X.P.; Zhao, G.; Li, S.P.; Liang, G.P. Response of soil organic carbon content to crop rotation and its controls: A global synthesis. *Agric. Ecosyst. Environ.* **2022**, *335*, 108017. [CrossRef]
33. Munyasya, A.N.; Koskei, K.; Zhou, R.; Liu, S.T.; Indoshi, S.N.; Wang, W.; Zhang, X.C.; Cheruiyot, W.K.; Mburu, D.M.; Nyende, A.B.; et al. Integrated on-site & off-site rainwater-harvesting system boosts rainfed maize production for better adaptation to climate change. *Agric. Water Manag.* **2022**, *269*, 107672.
34. Tuck, S.L.; Winqvist, C.; Mota, F.; Ahnström, J.; Turnbull, L.A.; Bengtsson, J. Land-use intensity and the effects of organic farming on biodiversity: A hierarchical meta-analysis. *J. Appl. Ecol.* **2014**, *51*, 746–755. [CrossRef] [PubMed]
35. Rossetti, M.R.; Tscharntke, T.; Aguilar, R.; Batáry, P. Responses of insect herbivores and herbivory to habitat fragmentation: A hierarchical meta-analysis. *Ecol. Lett.* **2017**, *20*, 264–272. [CrossRef] [PubMed]
36. Pittelkow, C.M.; Liang, X.Q.; Linquist, B.A.; van Groenigen, K.J.; Lee, J.; Lundy, M.E.; van Gestel, N.; Six, J.; Venterea, R.T.; van Kessel, C. Productivity limits and potentials of the principles of conservation agriculture. *Nature* **2015**, *517*, 365–368. [CrossRef]
37. Terrer, C.; Phillips, R.P.; Hungate, B.A.; Rosende, J.; Pett-Ridge, J.; Craig, M.E.; van Groenigen, K.J.; Keenan, T.F.; Sulman, B.N.; Stocker, B.D.; et al. A trade-off between plant and soil carbon storage under elevated CO_2. *Nature* **2021**, *591*, 599–603. [CrossRef]
38. Hou, X.Y.; Wang, F.X.; Han, J.J.; Kang, S.Z.; Feng, S.Y. Duration of plastic mulch for potato growth under drip irrigation in an arid region of Northwest China. *Agric. For. Meteorol.* **2010**, *150*, 115–121. [CrossRef]
39. Zhang, X.D.; Yang, L.C.; Xue, X.K.; Kamran, M.; Ahmad, I.; Dong, Z.Y.; Liu, T.N.; Jia, Z.K.; Zhang, P.; Han, Q.F. Plastic film mulching stimulates soil wet-dry alternation and stomatal behavior to improve maize yield and resource use efficiency in a semi-arid region. *Field Crop. Res.* **2019**, *233*, 101–113. [CrossRef]
40. Ren, A.T.; Zhou, R.; Mo, F.; Liu, S.T.; Li, J.Y.; Chen, Y.L.; Zhao, L.; Xiong, Y.C. Soil water balance dynamics under plastic mulching in dryland rainfed agroecosystem across the Loess Plateau. *Agric. Ecosyst. Environ.* **2021**, *312*, 107354. [CrossRef]
41. Chen, N.; Li, X.Y.; Simunek, J.; Shi, H.B.; Hu, Q.; Zhang, Y.H. Evaluating the effects of biodegradable and plastic film mulching on soil temperature in a drip-irrigated field. *Soil Till. Res.* **2021**, *213*, 105116. [CrossRef]
42. Wang, H.; Fan, J.; Fu, W.; Du, M.G.; Zhou, G.; Zhou, M.X.; Hao, M.D.; Shao, M.A. Good harvests of winter wheat from stored soil water and improved temperature during fallow period by plastic film mulching. *Agric. Water Manag.* **2022**, *274*, 107910. [CrossRef]
43. Wang, X.K.; Xing, Y.Y. Effects of Mulching and Nitrogen on Soil Nitrate-N Distribution, Leaching and Nitrogen Use Efficiency of Maize (*Zea mays* L.). *PLoS ONE* **2016**, *11*, e0161612. [CrossRef] [PubMed]
44. Zheng, J.; Fan, J.L.; Zhou, M.H.; Zhang, F.C.; Liao, Z.Q.; Lai, Z.L.; Yan, S.C.; Guo, J.J.; Li, Z.J.; Xiang, Y.Z. Ridge-furrow plastic film mulching enhances grain yield and yield stability of rainfed maize by improving resources capture and use efficiency in a semi-humid drought-prone region. *Agric. Water Manag.* **2022**, *269*, 107654. [CrossRef]
45. Zhao, H.; Wang, R.Y.; Ma, B.L.; Xiong, Y.C.; Qiang, S.C.; Wang, C.L.; Liu, C.A.; Li, F.M. Ridge-furrow with full plastic film mulching improves water use efficiency and tuber yields of potato in a semiarid rainfed ecosystem. *Field Crop. Res.* **2014**, *161*, 137–148. [CrossRef]
46. Biswal, P.; Swain, D.K.; Jha, M.K. Straw mulch with limited drip irrigation influenced soil microclimate in improving tuber yield and water productivity of potato in subtropical India. *Soil Till. Res.* **2022**, *223*, 105484. [CrossRef]
47. Xing, Z.S.; Toner, P.; Chow, L.; Rees, H.W.; Li, S.; Meng, F.R. Effects of Hay Mulch on Soil Properties and Potato Tuber Yield under Irrigation and Nonirrigation in New Brunswick, Canada. *J. Irrig. Drain. Eng.* **2012**, *138*, 703–714. [CrossRef]
48. Zhang, G.X.; Zhang, Y.; Zhao, D.H.; Liu, S.J.; Wen, X.X.; Han, J.; Liao, Y.C. Quantifying the impacts of agricultural management practices on the water use efficiency for sustainable production in the Loess Plateau region: A meta-analysis. *Field Crop. Res.* **2023**, *291*, 108787. [CrossRef]
49. Xiong, L.; Liang, C.; Ma, B.L.; Shah, F.; Wu, W. Carbon footprint and yield performance assessment under plastic film mulching for winter wheat production. *J. Clean. Prod.* **2020**, *270*, 122468. [CrossRef]
50. Li, Y.Z.; Xie, H.X.; Ren, Z.H.; Ding, Y.P.; Long, M.; Zhang, G.X.; Qin, X.L.; Siddique, K.H.M.; Liao, Y.C. Response of soil microbial community parameters to plastic film mulch: A meta-analysis. *Geoderma* **2022**, *418*, 115851. [CrossRef]
51. Ding, F.; Ji, D.C.; Yan, K.; Dijkstra, F.A.; Bao, X.L.; Li, S.Y.; Kuzyakov, Y.; Wang, J.K. Increased soil organic matter after 28 years of nitrogen fertilization only with plastic film mulching is controlled by maize root biomass. *Sci. Total Environ.* **2022**, *810*, 152244. [CrossRef]
52. Hou, X.Q.; Li, R.; He, W.S.; Ma, K. Effects of planting density on potato growth, yield, and water use efficiency during years with variable rainfall on the Loess Plateau, China. *Agric. Water Manag.* **2020**, *230*, 105982. [CrossRef]

53. Xiong, L.; Wu, W. Can additional agricultural resource inputs improve maize yield, resource use efficiencies and emergy based system efficiency under ridge-furrow with plastic film mulching? *J. Clean. Prod.* **2022**, *379*, 134711. [CrossRef]
54. Zhao, H.; Xiong, Y.C.; Li, F.M.; Wang, R.Y.; Qiang, S.C.; Yao, T.F.; Mo, F. Plastic film mulch for half growing-season maximized WUE and yield of potato via moisture-temperature improvement in a semi-arid agroecosystem. *Agric. Water Manag.* **2012**, *104*, 68–78. [CrossRef]
55. Gao, H.H.; Yan, C.R.; Liu, Q.; Li, Z.; Yang, X.; Qi, R.M. Exploring optimal soil mulching to enhance yield and water use efficiency in maize cropping in China: A meta-analysis. *Agric. Water Manag.* **2019**, *225*, 105741. [CrossRef]
56. Zhang, Y.L.; Wang, F.X.; Shock, C.C.; Yang, K.J.; Kang, S.Z.; Qin, J.T.; Li, S.E. Effects of plastic mulch on the radiative and thermal conditions and potato growth under drip irrigation in arid Northwest China. *Soil Till. Res.* **2017**, *172*, 1–11. [CrossRef]
57. Qin, X.L.; Li, Y.Z.; Han, Y.L.; Hu, Y.C.; Li, Y.J.; Wen, X.X.; Liao, Y.C.; Siddique, K.H.M. Ridge-furrow mulching with black plastic film improves maize yield more than white plastic film in dry areas with adequate accumulated temperature. *Agric. For. Meteorol.* **2018**, *262*, 206–214. [CrossRef]
58. Ma, J.T.; Cheng, H.B.; Chai, S.X.; Wang, S.E.; Gao, T.T.; Chang, L.; Ding, W. Influence of different mulching patterns on soil moisture and yield of potato cultivars with different maturities in dryland farming. *J. Gansu Agric. Univ.* **2019**, *54*, 55–64.
59. Zhang, Q.Q.; Ma, Z.R.; Cai, Y.Y.; Li, H.R.; Ying, G.G. Agricultural Plastic Pollution in China: Generation of Plastic Debris and Emission of Phthalic Acid Esters from Agricultural Films. *Environ. Sci. Technol.* **2021**, *55*, 12459–12470. [CrossRef]
60. Zhu, D.; Ma, J.; Li, G.; Rillig, M.C.; Zhu, Y.G. Soil plastispheres as hotpots of antibiotic resistance genes and potential pathogens (Aug, 10.1038/s41396-021-01137-z, 2021). *ISME J.* **2022**, *16*, 615. [CrossRef]
61. Qi, Y.; Ossowicki, A.; Yergeau, É.; Vigani, G.; Geissen, V.; Garbeva, P. Plastic mulch film residues in agriculture: Impact on soil suppressiveness, plant growth, and microbial communities. *FEMS Microbiol. Ecol.* **2022**, *98*, fiac017. [CrossRef]
62. Wang, D.; Xi, Y.; Shi, X.Y.; Zhong, Y.J.; Guo, C.L.; Han, Y.N.; Li, F.M. Effect of plastic film mulching and film residues on phthalate esters concentrations in soil and plants, and its risk assessment. *Environ. Pollut.* **2021**, *286*, 117546. [CrossRef]