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Mulching-Induced Changes in Tuber Yield and Nitrogen Use Efficiency in Potato in China: A Meta-Analysis

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Received: 20 October 2019; Accepted: 20 November 2019; Published: 22 November 2019

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Abstract: In dry environments, potato (*Solanum tuberosum* L.) is grown under mulching for water conservation and improving tuber yield and nitrogen use efficiency (NUE). A meta-analysis was conducted to determine how mulching improved tuber yield and NUE in potato and how yield and NUE is influenced by fertilization, tillage practices, and growing environment in China. A search of peer-reviewed publications was performed to collect data on the effects of mulching on yield and NUE in potato grown in China. The data included were from field studies with a mulching and a no mulching treatment and data on tuber yield and NUE. A total of 169 publications (17 in English and 152 in Chinese) containing 1802 observations from 105 sites were compiled into the dataset. Mulching significantly increased both tuber yield and NUE by an average of 24% compared to no mulching, respectively. Plastic film mulching was more effective in improving yield and NUE than straw mulching. The yield and NUE increase were highest under plastic film mulching on ridge-furrow plots and straw mulching on flat plots. Mulching was more effective at improving yield and NUE in the Northwest dryland region at a plant density between 55,000 and 70,000 plants ha^{-1} and with application of synthetic N and P_2O_5 at rates of 100–200 kg ha^{-1}, K fertilization at 0–100 kg K_2O ha^{-1}, and without organic fertilization. Integrated use of organic fertilizer and mulching was found to reduce synthetic N and P fertilizer input by 50% and K fertilizer input by 100% for production without affecting yield and NUE. These results demonstrate that mulching increases yield and NUE in potato in China, but the benefits occur when the growing region, tillage, and fertilization practices are appropriately considered.

Keywords: potato; mulching; tillage; yield; nitrogen use efficiency

1. Introduction

Potato (*Solanum tuberosum* L.) is one of the most important staple foods; the annual fresh yield has reached 365 million tons, ranking it as the fourth staple food crop after maize (*Zea mays* L.), wheat (*Triticum aestivum* L.), and rice (*Oryza sativa* L.) [1,2]. China is the largest potato producer in the world—the planting area is 5.6 million hectares and the yield is more than 95 million tons per year [3], which accounts for 25% of the world's total planting area and yield, but the yield per unit area is only 83% of the world average [4]. Increasing demand for potatoes along with economic pressures have forced potato growers to move toward more intense cropping systems with extensive use of synthetic fertilizers and increased frequency of potato in crop rotations, which has raised environmental concerns and costs of production [1,5]. Therefore, alternative field management practices to reduce synthetic fertilizer use and improve yield of potato seem crucial for potato production, which will enhance farmers' profitability by enhancing yield [5–7].

Mulches include any material such as straw, leaves, or plastic film that is spread or formed upon the surface of the soil to protect the soil and/or plant roots from the effects of raindrops, soil crusting, freezing, evaporation, and so on [8]. Mulching has some important advantages regarding soil conservation and productivity. Mulching increases crop yield through reducing soil evaporation [7], maintaining soil moisture [9,10], restricting soil erosion [1], improving topsoil temperature [11], decreasing the leaching loss of nitrogen (N) fertilizer around the root zone [12], reducing the root-zone salinity [13], and increasing nutrient availability [14]. Mulching is widely used in potato production in China [9] as it greatly increases potato yield both quantitatively and qualitatively [7,11,15]. Northwest China is an important potato planting zone, but tuber yield was severely threatened by water shortage due to low seasonal precipitation [16]. Plastic film mulching has been used for harvesting rainwater, and it is now becoming a well-evolved technique for potato production in this region [17]. At the regional scale, plastic film mulching increased potato yield as a result of improved soil moisture and temperature conditions [7,9,15]. However, plastic film mulching has some disadvantages, such as the increase in soil temperature and CO_2 concentrations in the microclimate, which reduce yield [18,19], and the manual installation and removal of mulch materials, which is time-consuming and labor intensive [15]. In addition, large amounts of plastic film residue left in crop fields have resulted in negative effects on the environment, soil structure, and crop growth [20].

Synthetic fertilizers, particularly N, play a critical role in increasing crop yield and reducing food security risks [21]. However, excessive N fertilizer application has many adverse effects, such as soil acidification [22], water pollution [23], greenhouse gases emission [24], and low N fertilizer use efficiency (NUE) [25]. Thus, reducing synthetic N fertilizer inputs and enhancing fertilizer use efficiency in crops has become an important concern for both mitigating climate change and sustaining global food production. An improvement in NUE in China is urgently required. Most studies on improving NUE in crop production in China have focused on cereals, with limited information available for other crops such as potato [26].

Organic fertilizer (i.e., livestock manure) provides a slower release of nutrients, and improves soil organic matter, soil physical properties, and soil water holding capacity [27–29]. This enhances the synchrony between nutrient and water availability and crop nutrient uptake, and subsequently improves crop yield. For these reasons, organic fertilizer is widely used in potato production in China [15]. However, information on the interaction between applied organic fertilizer and mulching and the effects on yield and NUE in potato is limited. Information on the response of potato yield and NUE to mulching when organic fertilizer is applied is needed for developing field management practices such as synthetic fertilization rate, planting density, and tillage practices.

Meta-analysis provides a formal statistical method to compare and integrate the results of multiple studies and reveal underlying factors contributing to responses to make inferences on regional and global scales [30]. Previous meta-analyses on mulching have primarily focused on the effects of fertilizer application and individual practices on potato yield and water use efficiency [15], but an integrated assessment of mulching-induced changes in potato yield and NUE based on a synthesis of the literature has not been conducted. The understanding of potato yield and NUE in response to mulching practices with different tillage practices and fertilizer regimes is of paramount importance for sustainable intensification of potato production in China. Such information could serve as a basis for sustainable production of potato in other parts of the world. Therefore, this meta-analysis study of field trials on potato production in China aimed to determine how tuber yield and NUE respond to mulching and whether the response is influenced by growing region, synthetic fertilization rate, tillage practice, and planting density.

2. Materials and Methods

2.1. Data Search and Collection

A search of peer-reviewed publications was performed to collect data on the effects of mulching on yield and NUE (kilogram tuber yield per kilogram N fertilizer applied) of potato grown in China. Data published in English were collected from the ISI-Web of Science (http://apps.webofknowledge.com/) and Google Scholar (https://xs.glgoo.net/), and data published in Chinese were collected from the China National Knowledge Infrastructure (http://www.cnki.net/) and Baidu Scholar (http://xueshu.baidu.com/). The keywords used for the search were mulching, yield, NUE, and potato. The year of publication was not restricted, but publications after July 2019 were not included.

The data chosen for this study satisfied the following criteria: (1) field experimental studies must involve a mulching treatment and a no mulching control; and (2) yield, NUE, and the number of replicates of the treatments were directly acquired from the publication or calculated. On the basis of these criteria, 169 publications (17 in English and 152 in Chinese) from 1802 observations at 105 sites were compiled into the dataset. As not all studies reported NUE, the numbers of comparisons for NUE were 1571. The collected data for yield and NUE came from experiments located in the provinces of Liaoning, Xizang, Qinghai, Inner Mongolia, Xinjiang, Gansu, Shanxi, Ningxia, Shaanxi, Hebei, Shandong, Anhui, Guizhou, Guangxi, Yunnan, Jiangxi, Sichuan, Fujian, Hunan, Guangdong, Zhejiang, Jiangsu, and Hainan Island (Figure 1).

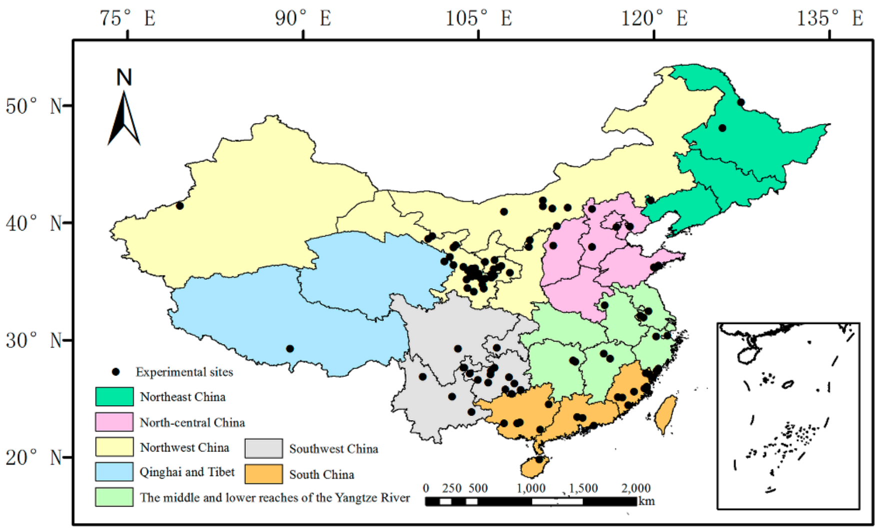

Figure 1. Location of field experiments included in this meta-analysis.

According to diverse geographic climatic conditions and natural cultivated regions of potato in China, the study areas were grouped into eight geographic regions: QT, Qinghai and Tibet; NE, Northeast China, NWI, Northwest irrigation region; NWD, Northwest dryland region; NC, North–Central China; MLYR, the middle and lower reaches of the Yangtze River; SW, Southwest China; S, South China [15,31,32]. The climate information of experimental sites in potato-cultivating regions were described in a previous study [15]. A previous study detailedly evaluated the NUE of potato in China, and the results showed that in NE and NC, in most cases, potato received eight topdressings; however, in NWI, NWD, MLYR, SW, and S, potato received less than three topdressings [33]. On average, the application rate of N fertilizer was 360 kg N ha^{-1} in China for eight geographic regions (NE, NC, NWI, NWD, QT, MLYR, SW, and S), and the application rate of N fertilizer was 228, 471, 330, 280, 300, 400, 300, and 390 kg N ha^{-1}, respectively [33].

On the basis of the classification of different mulching materials and the main mulching practices applied in China, the mulching methods were subject to three main categories: (1) PFM, plastic film mulching; (2) SM, straw mulching; and (3) PFSM, combination of plastic film and straw mulching. Plastic mulching materials included black plastic film and transparent plastic film. The straw materials in the literature comprised rice, wheat, and maize straw. On the basis of the classification of tillage practices in potato-cultivating in China, the tillage practices were subject to two main categories: (1) straw and/or plastic film mulch on FP, flat plots; (2) straw and/or plastic film mulch on RFP, ridge-furrow plots. Plant density was categorized as <40,000, 40,000–55,000, 55,000–70,000, 70,000–85,000, and >85,000. To study the effect of synthetic fertilizer application rate on potato yield and NUE, according to whether organic fertilizer is applied, the dataset was divided into two sub-datasets: (1) organic fertilization (O); (2) without organic fertilization (NO). Meanwhile, synthetic nitrogen (N) and phosphate (P_2O_5) fertilizer application rates were categorized as <100 kg ha^{-1}, 100–200 kg ha^{-1}, 200–300 kg ha^{-1}, and >300 kg ha^{-1}, whereas potash fertilizer (K_2O) rates were categorized as 0, 0–100, 100–200, and >200 kg ha^{-1}.

2.2. Statistical Analysis

Nitrogen use efficiency (NUE) was defined by as the tuber yield divided by the synthetic N fertilizer application:

$$NUE = \frac{Y}{FN} \quad (1)$$

where Y is the tuber yield (kg ha^{-1}) and FN is the quantity of synthetic N fertilizer application (kg N ha^{-1}).

Data were analyzed using the methods of meta-analysis described in previous studies [30,34–37]. The weighted means of the logarithmic response ratios was calculated for all independent studies as individual experiments often differ in their statistical precision. The homogeneity statistic Q was used to test whether variances were significantly different [34,35]. A mixed or random effects model was employed to determine whether mulching significantly affected each dependent variable using the statistical software MetaWin 2.1 (Systat Software, Inc, San Jose, CA, USA) with a resampling of 9999 iterations [35–37]. A random effect model was adopted in cases of high heterogeneity (a chi-square p-value < 0.05). The Kolmogorov–Smirnov test indicated that the distribution of yield and NUE was not normal. We used the bootstrapping test (sampling with replacement of the size equal to the initial size of the subset repeated n = 9999 times) to generate means and 95% confidence intervals (CIs) for yield and NUE in the study, as well as subgroups of yield and NUE [35,37]. A negative change indicated a decrease in the respective variable with mulching relative to no mulching, whereas a positive value indicated an increase. Means of the different categorical variables were considered significantly different from one another if their 95% bootstrapping CIs did not overlap [35,36]. The frequency distribution of effect size was plotted and the frequency of effect size was fit to a Gaussian distribution function using SigmaPlot v. 12.5 software (Jandel Scientific, Corte Maders, CA, USA).

3. Results

3.1. Overview of the Dataset

Our dataset consisted of 1802 observations from 105 sites. There were 1232 observations for plastic film mulching (PFM), 464 for straw mulching (SM), and 106 for combination of plastic film and straw mulching (PFSM). The frequency distribution of effect size was fit to a Gaussian distribution function for yield and NUE of potato. The Kolmogorov–Smirnov test indicated that the distribution of yield and NUE was not normal ($p < 0.001$) (Figure 2).

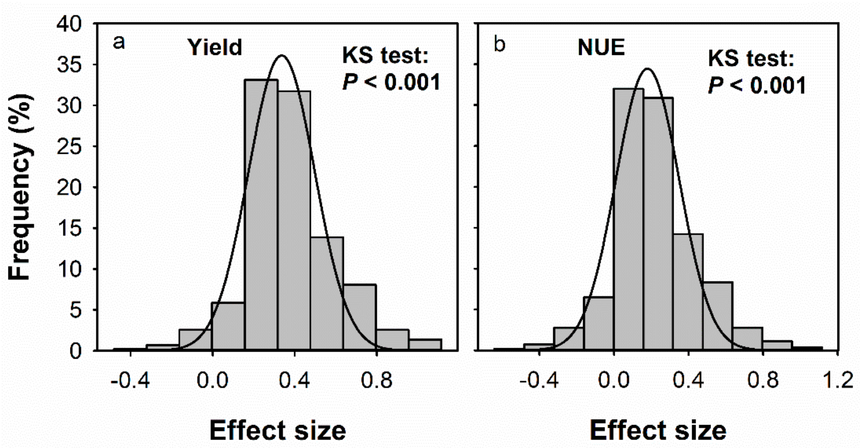

Figure 2. Frequency distribution of effect size for potato yield (**a**) and nitrogen use efficiency (NUE) (**b**) response to mulching compared to without mulching. Solid lines are fitted to a Gaussian distribution function. The Kolmogorov–Smirnov (KS) test indicated that the distribution of yield and NUE was not normal ($p < 0.001$).

3.2. Overall Response of Potato Yield and NUE to Mulching

Yield and NUE of potato were significantly increased by mulching compared to no mulching. These significant increases in potato yield and NUE with mulching were both 24% when compared to no mulching (Figure 3). On average, yield was 26.2 and 22.6 Mg ha^{-1} under mulching and no mulching, respectively; NUE was 187.5 and 151.9 kg tuber yield kg^{-1} N, respectively (Figure S1).

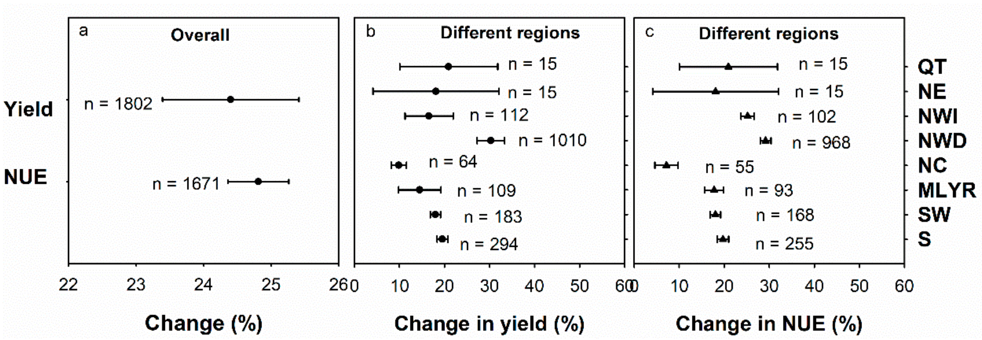

Figure 3. The response of change in potato yield and NUE to mulching compared to no mulching average for China (**a**), for the eight regions for potato yield (**b**), and for NUE (**c**). Abbreviations: NC, North–Central China; QT, Qinghai and Tibet; NE, Northeast China; NWI, Northwest irrigation region; NWD, Northwest dryland region; MLYR, the middle and lower reaches of the Yangtze River; SW, Southwest China; and S, South China). Error bars represent 95% confidence intervals. The values for *n* represent the corresponding number of observations.

3.3. Yield and NUE of Potato in Response to Mulching in Different Regions

The effect of mulching on yield and NUE of potato varied with regions in China (Figure 3). The highest increase in potato yield was found in the Northwest dryland region (30%), followed by Qinghai and Tibet, South China, Northeast China, Southwest China, Northwest irrigation region, and the middle and lower reaches of Yangtze River (14–20%), and North–Central China (10%). Similarly, the positive effect of mulching on NUE was parallel to yield except for the Northwest irrigation region. The positive effect of mulching on NUE was greatest in the Northwest dryland region (29%), followed by the Northwest irrigation region (25%), Qinghai and Tibet, South China, Northeast China, Southwest China, the middle and lower reaches of the Yangtze River (18–21%), and North China Plain (7%).

3.4. Yield and NUE of Potato in Response to Mulching with Different Tillage and Mulching Practices

Tillage practices (ridge-furrow and flat plots) and mulching practices (PFM and SM) significantly affected potato yield and NUE (Figure 4). The positive effect of mulching on yield and NUE was highest under PFM, followed by PFSM and SM. On average, PFM, PFSM, and SM increased potato yield by 25%, 23%, and 21%, respectively, compared to no mulching. Similarly, PFM, PFSM, and SM increased NUE by 25%, 23%, and 22% compared to no mulching, respectively. Ridge-furrow system was more advantageous with plastic film mulching rather than straw mulching. With plastic film mulching, ridge-furrow system significantly increased yield and NUE by 29%, whereas flat plots planting significantly increased yield and NUE by 20%. With straw mulching, ridge-furrow system significantly increased yield and NUE by 13%; however, flat plots planting significantly increased yield and NUE by 27% and 29%, respectively.

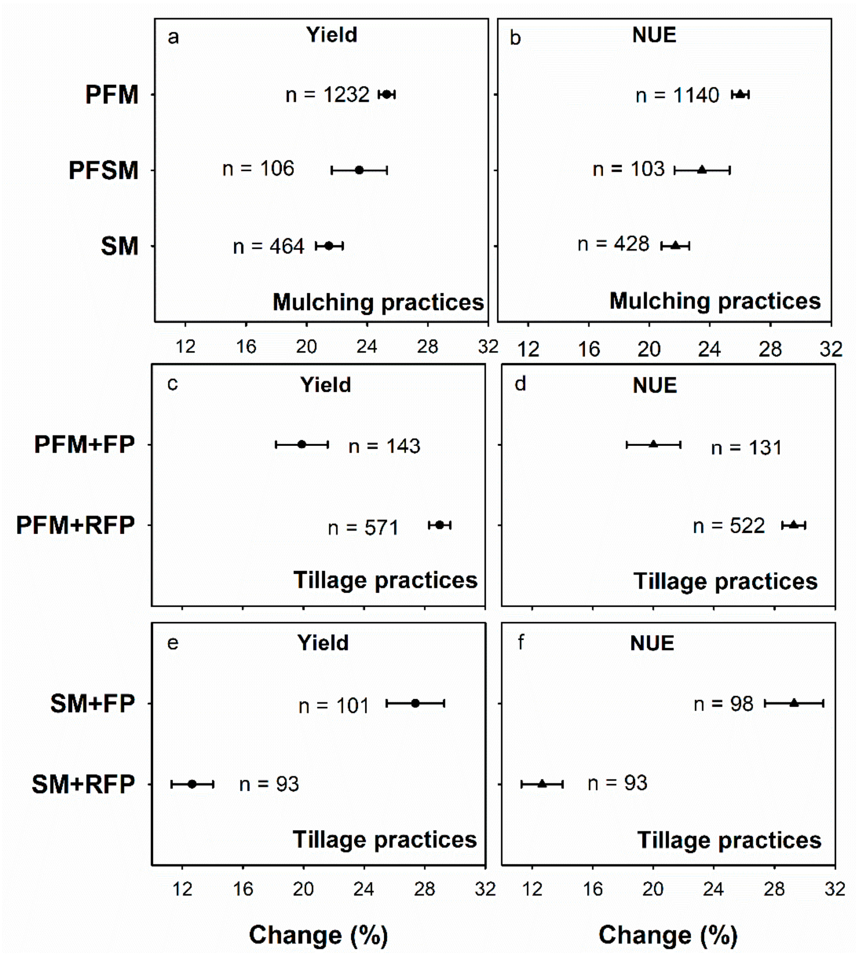

Figure 4. Response of change in potato yield (**a**,**c**,**e**) and NUE (**b**,**d**,**f**) to mulching compared to no mulching with different mulching and tillage practices. Error bars represent 95% confidence intervals. The values for *n* represent the corresponding number of observations. PFM, plastic film mulching; SM, straw mulching; PFSM, combination of plastic film and straw mulching; FP, flat plots; RFP, ridge-furrow plots.

3.5. Yield and NUE of Potato in Response to Mulching at Different Planting Densities

Planting density under mulching significantly affected potato yield and NUE (Figure 5). In the Northwest irrigation region, mulching significantly increased yield by 12%, 17%, and 25% when plant density was <40,000 plants ha^{-1}, 40,000–55,000, and 55,000–70,000, respectively (Figure 5). In the Northwest dryland region, the highest increase in potato yield under mulching (38%) occurred at a plant density of 55,000–70,000 plants ha^{-1}, followed by a plant density of <55,000 and 70,000–85,000 plants ha^{-1} (19–26%). In North–Central China, mulching significantly increased yield by 15% when plant density was 55,000–70,000 plants ha^{-1}, but mulching did not affect yield when plant density was >70,000 plants ha^{-1}. In the middle and lower reaches of the Yangtze River, mulching significantly increased yield by 33% when planting density was 70,000–85,000 plants ha^{-1}, by 22% when planting density was >85,000 plants ha^{-1}, and by 8% when planting density was <55,000–70,000 plants ha^{-1}. In Southwest China, mulching significantly increased yield by 39% when planting density was 70,000–85,000 plants ha^{-1} and by 7–10% when planting density was <70,000 plants ha^{-1}. In South China, the highest increase in potato yield with mulching was found when planting density was 55,000–70,000 plants ha^{-1} (23%), followed by when planting density was >70,000 plants ha^{-1} (8–13%).

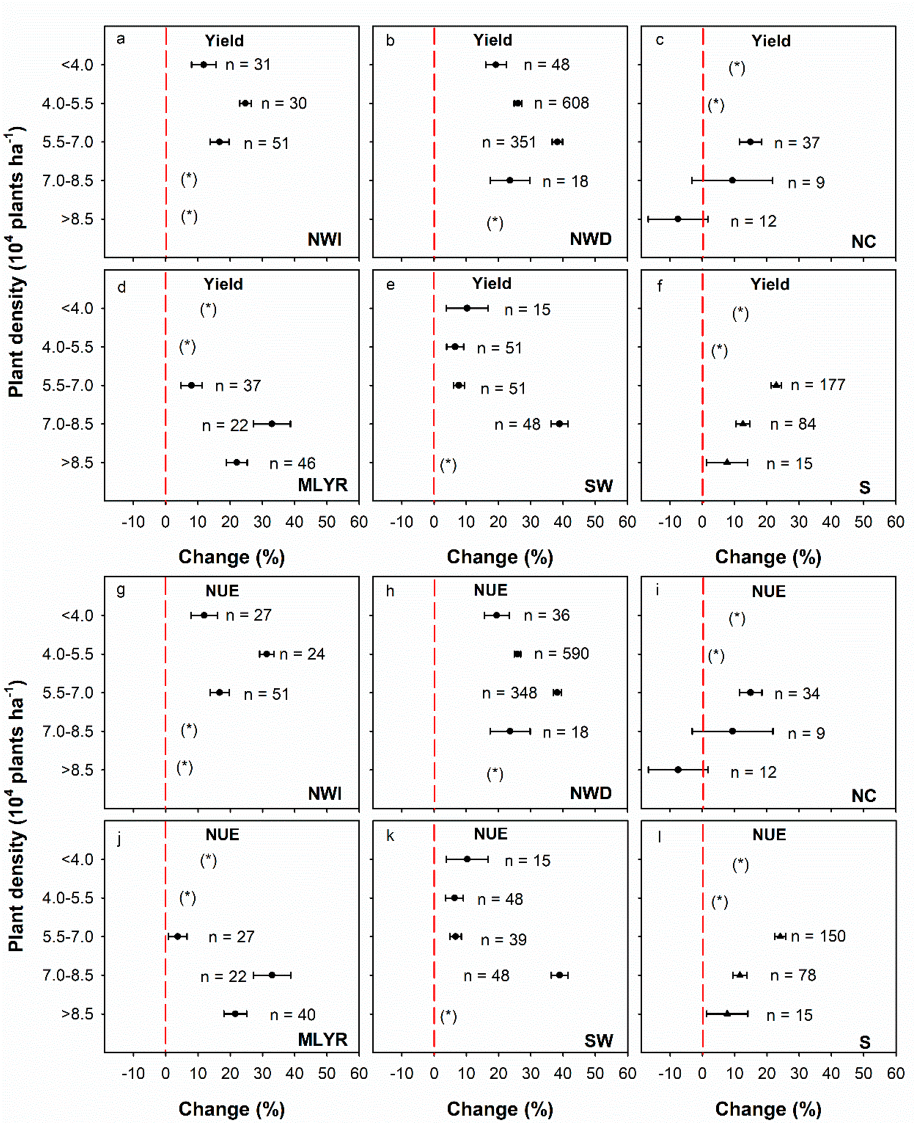

Figure 5. Response of change in potato yield (**a**–**f**) and NUE (**g**–**l**) to mulching compared to no mulching at different levels of plant density in different regions of China. The values for *n* represent the corresponding number of observations. Asterisks (*) represent fewer than two valid comparisons for a subgroup. NC, North–Central China; QT, Qinghai and Tibet; NE, Northeast China; NWI, Northwest irrigation region; NWD, Northwest dryland region; MLYR, the middle and lower reaches of the Yangtze River; SW, Southwest China; and S, South China. Error bars represent 95% confidence intervals.

Similarly, in the Northwest irrigation region, the increase in NUE with mulching was highest when planting density was 40,000–55,000 plants ha^{-1} (31%), followed by when planting density was 55,000–70,000 plants ha^{-1} (17%) and <40,000 plants ha^{-1} (12%) (Figure 5). In the Northwest dryland region, the highest increase in potato NUE with mulching was found when planting density was 55,000–70,000 plants ha^{-1} (38%), followed by when planting density was <55,000 and 70,000–85,000 plants ha^{-1} (19–26%). In North–Central China, mulching increased NUE by 15% when planting density was 55,000–70,000 plants ha^{-1}, but mulching did not affect yield when planting density was >70,000 plants ha^{-1}. A negative effect of mulching on NUE was found when plant density was >85,000 plants ha^{-1}. In the middle and lower reaches of the Yangtze River, mulching significantly increased NUE by 33%, 22%, and 4% when plant density was 70,000–85,000, >85,000, and <55,000–70,000 plants ha^{-1}, respectively. In Southwest China, mulching significantly increased NUE by 39% when plant density was 70,000–85,000 plants ha^{-1} and by 6–10% when plant density was <70,000 plants ha^{-1}. In South China, the greatest increase in potato NUE with mulching was found when plant density was 55,000–70,000 plants ha^{-1} (24%), followed by when plant density was >70,000 plants ha^{-1} (8–13%).

3.6. Yield and NUE of Potato under Mulching with Different Fertilizer Combination Types and Fertilization Rate

The effect of mulching on yield and NUE in potato varied with the rate of N, P, and K supplied (Figures 6–8). According to the results of a literature report, the organic fertilizer application rate was about 10−75 Mg ha^{-1} for potato production in China [data not shown]. Without organic fertilization, mulching significantly increased potato yield by 26%, 21%, and 15% when synthetic N fertilizer was applied at 100−300, >300, and <100 kg N ha^{-1}, respectively (Figure 6a). Similarly, the increase in NUE with mulching was 26%, 20%, and 15%, when synthetic N fertilizer was applied at 100−300, >300, and <100 kg N ha^{-1}, respectively (Figure 6b). With organic fertilizer supplied, mulching significantly increased both yield and NUE of potato by 34%, 24%, 20%, and 13% when synthetic N fertilizer was applied at <100, 100−200, 200−300, and >300 kg N ha^{-1}, respectively (Figure 6c,d).

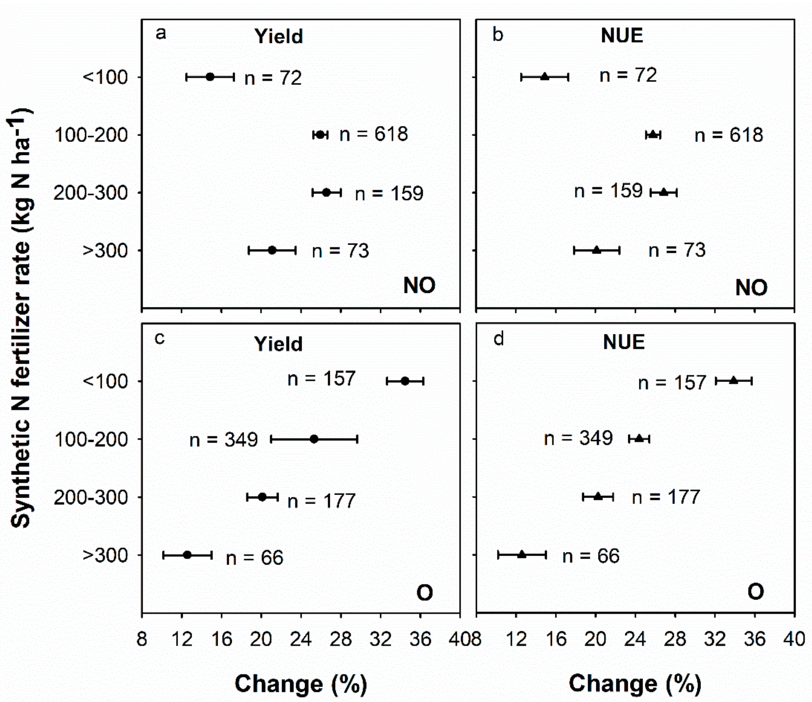

Figure 6. Response of change in potato yield (**a**,**c**) and NUE (**b**,**d**) to mulching compared to no-mulching control at different levels of synthetic nitrogen (N) fertilizer rates. Error bars represent 95% confidence intervals. The values for *n* represent the corresponding number of observations. NO, without organic fertilization; O, with organic fertilization.

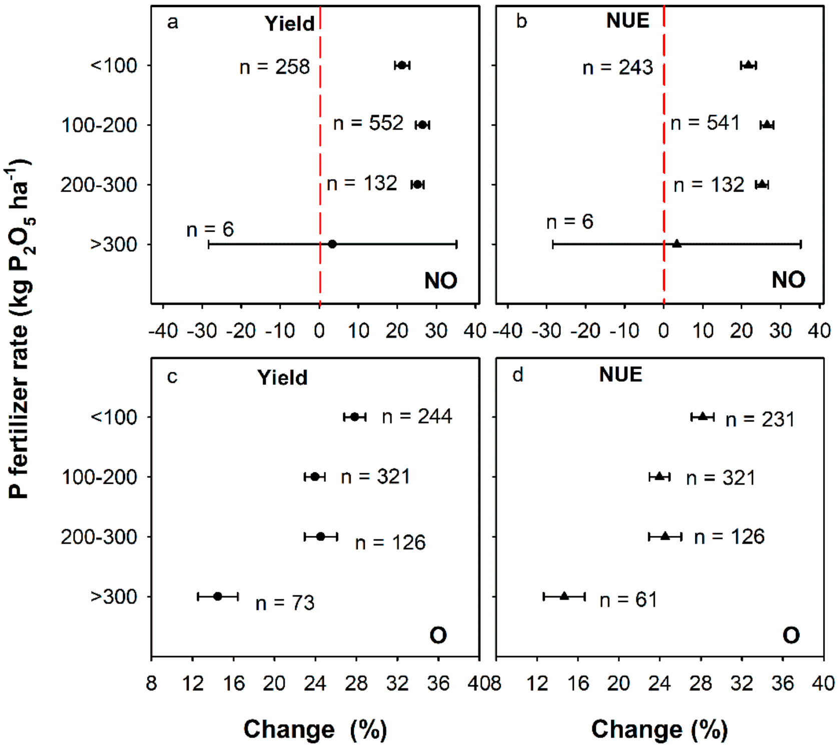

Figure 7. Response of change in potato yield (**a**,**c**) and NUE (**b**,**d**) to mulching compared to no mulching at different levels of phosphorus (P) fertilization. Error bars represent 95% confidence intervals. The values for *n* represent the corresponding number of observations. NO, without organic fertilization; O, with organic fertilization.

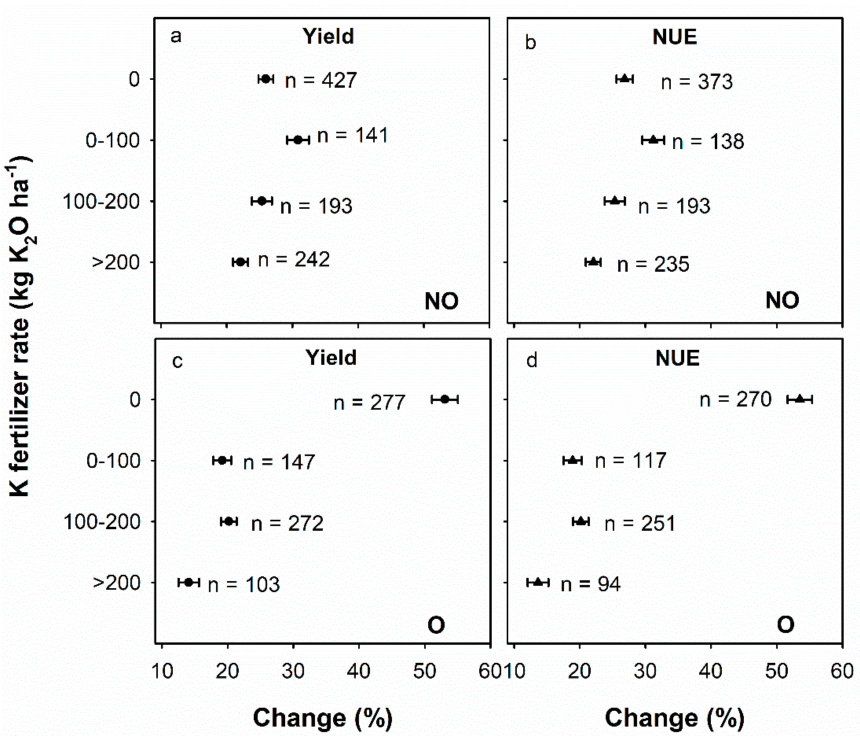

Figure 8. Response of change in potato yield (**a**,**c**) and NUE (**b**,**d**) to mulching compared to no-mulching control at different levels of potassium (K) fertilization. Error bars represent 95% confidence intervals. The values for *n* represent the corresponding number of observations. NO, without organic fertilization; O, with organic fertilization.

Without organic fertilization, mulching significantly increased yield and NUE of potato by 25%–26% when P fertilizer was applied at 100–300 kg P_2O_5 ha^{-1} and by 21% when P fertilizer was applied at <100 kg P_2O_5 ha^{-1}. Mulching did not affect yield and NUE when the P fertilizer rate exceeded 300 kg P_2O_5 ha^{-1} (Figure 7a,b). With organic fertilization, the positive effect of mulching on yield and NUE was highest when P fertilizer was applied at <100 kg P_2O_5 ha^{-1} (28%), followed by when P was applied at 100–300 kg P_2O_5 ha^{-1} (25%) and >300 kg P_2O_5 ha^{-1} (14%) (Figure 7c,d).

Without organic fertilization, mulching increased yield and NUE of potato by 31% when K fertilizer was applied at 0–100 kg K_2O ha^{-1}, by 25%–26% in the absence of synthetic K fertilizer and when K fertilizer was applied at 100–200 kg K_2O ha^{-1}, and by 22% when the K fertilizer rate exceeded 200 kg K_2O ha^{-1} (Figure 8a,b). With organic fertilization, mulching increased yield and NUE of potato by 53% in the absence of synthetic K fertilizer, by 19%–20% when K fertilizer was applied at 0–200 kg K_2O ha^{-1}, and by 14% when K fertilizer rate exceeded 200 kg K_2O ha^{-1} (Figure 8c,d).

4. Discussion

Mulching greatly increased potato yield and NUE, which is in agreement with the results from other studies [15–18]. NUE of potato was less in China than in other countries in the world (160–240 kg tuber yield kg^{-1} N) [38–47]. This discrepancy may be associated with differences in the application rate of N, as some studies in other countries have been conducted at a low N rate (i.e., medium N rate, 100–200 kg N ha^{-1}) [38–47]. Mulching has been more effective at increasing potato yield and NUE in rainfed systems than in irrigated systems in Northwest China. This is likely because crops often experience water stress in rainfed farming systems and because mulching has greater advantages in increasing soil water storage and alleviating water stress under rainfed conditions. The advantage of mulching on potato yield and NUE was less in the wet regions of middle and lower reaches of the Yangtze River, Southwest China, and South China than in the northwest dryland region. Potato is rarely grown in North–Central China because the local climate, such as summer high temperature, is not suitable for potato cultivation [15]. Compared to other regions, the increase in potato yield and NUE with mulching was less in North–Central China, mainly because fertilization is done several times in this region, but the period of fertilization did not closely match potato nutrient uptake [33].

Both straw and plastic film mulching significantly increased potato yield and NUE, in agreement with previous studies of potato [15] and maize [36]. This was likely because mulching protects soil from water erosion and thus reduces soil and water loss [36,48], suppresses weed growth, and reduces competition with weeds for water and nutrients [49]. The increases in yield and NUE were greater with plastic film mulching than straw mulching [15], mainly because plastic film mulching was more effective in reducing water loss from soil than straw mulching.

The increases in yield and NUE of potato with plastic film mulching on ridge-furrow plots were significantly larger than those of flat plots. This was likely because plastic film mulching in a ridge-furrow system is more effective at water harvesting and improving yield [10,50,51]. Conversely, straw mulching on flat plots resulted in greater yield and NUE than that of ridge-furrow plots. This was likely because the ridge-furrow system has higher surface area of soil available for water evaporation when compared to flat plots, and because loose soil and large porosity in ridge-furrow plots accelerated water loss from soil, and thus both these conditions limited yield and NUE of potato.

The optimum plant density of potato under mulching varied among regions in China. It was lower in the northwest irrigation region than in the Northwest dryland region, mainly because at a plant density of 5,000–70,000 plants ha^{-1}, water supply under irrigation enhanced plant canopy development, inducing aboveground competition for space and light and shading, leading to reduction in the positive effect of mulching on yield and NUE. At the same plant density level, potato crops growing in the dry environment of the Northwest dryland region, grew slow and had small aboveground biomass, resulting in a higher optimum plant density compared to the Northwest irrigation region. In the middle and lower regions of the Yangtze River, Southwest China, and South China, potato is usually planted in late autumn and the use of straw mulching is more prevalent in the winter [52]. Because of the high relatively humidity and low air temperature [15], plant density was higher than in the Northwest irrigation region, Northwest dryland region, and North–Central region.

Fertilization significantly influenced the effect of mulching on yield and NUE of potato. Without organic fertilization, mulching was most effective at improving yield and NUE at application of synthetic N and P_2O_5 at rates of 100−200 kg ha^{-1} and K fertilization at 0−100 kg K_2O ha^{-1}, demonstrating that the right combination of N, P, and K fertilization rate is an effective means to increase tuber yield and NUE, in agreement with previous studies [15,33,38–47]. When organic fertilizer was applied, application of K fertilizer significantly reduced the benefit of mulching on yield and NUE, indicating that K and organic fertilizers should not be applied simultaneously when mulching is used. This is likely because a large amount of K is brought into the soil from organic fertilizer and under these conditions; thus, excessive K fertilization, when organic fertilizer was applied, reduced the effect of mulching on yield and NUE as a result of high K input. Under organic fertilization, mulching could save synthetic N and P fertilizer by 50%, and K fertilizer by 100% in potato production without affecting yield and NUE. The benefit of mulching and organic fertilization on yield and NUE was reduced under high application rates of N, P, and K, mainly because both mulching and organic fertilizer can improve the availability of these nutrients to plants [53–55]. Under these conditions, high application rates of N, P, and K limited the effect of mulching on yield and NUE of potato, in agreement with previous studies [15,56].

5. Conclusions

Mulching significantly increased potato yield and NUE and the highest increase occurred under plastic film mulching on ridge-furrow plots. On flat plots, straw mulching produced the highest increase in yield and NUE. Mulching was more effective at improving yield and NUE in the Northwest dryland region at a plant density between 55,000 and 70,000 plants ha^{-1} and with application of synthetic N and P_2O_5 at rates of 100−200 kg ha^{-1}, K fertilization at 0−100 kg K_2O ha^{-1}, and without organic fertilization. Integrated use of organic fertilizer and mulching has the potential to reduce N and P fertilizer input by 50% and K fertilizer input by 100% for potato production without affecting yield and NUE. These results highlight the potential of mulching to facilitate optimal fertilizer input for potato production while producing high yield and enhancing the efficiency of N resources.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4395/9/12/793/s1, Figure S1: Response of change in potato yield and nitrogen use efficiency to mulching compared to no mulching in China.

Author Contributions: L.W. and L.L. conceived the idea and designed the conceptualization; L.W. and Q.L. performed the data collection and analysis; L.W. wrote the draft of the manuscript guided by L.L.; and J.X., J.A.C., J.A.P., Z.L., P.C. and X.D. contributed to the manuscript enhancement.

Funding: This work was supported by the Gansu Provincial Key Laboratory of Aridland Crop Science, Gansu Agricultural University (GSCS-2019-09, GSCS-2017-4, and GSCS-2019-Z04), the scientific research start-up funds for openly-recruited doctors of Gansu Agricultural University (GAU-KYQD-2018-20), the National Natural Science Foundation of China (No. 31761143004, 31660373, and 31460337), the National Science and Technology Supporting Program (2015BAD22B04-03), and the Department of Education of Gansu Province (2017C-12).

Acknowledgments: We would like to extend special thanks to Zhengkai Peng for critical reading of the manuscript.

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

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