



Article

Mechanized No-Tillage Planting with Maize Straw Mulching Improves Potato Yield and Water Use Efficiency in Arid Regions of Northwest China

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Abstract: To explore the yield-increasing mechanism of mechanized potato planting with corn straw mulching, a two-year (2021 and 2022) field experiment was conducted to study the effects of mechanized no-tillage with straw mulching on potato yield and water use efficiency. This experiment included mechanized no-tillage potato planting with corn straw mulch covering (JG), plastic film mulching (HM), and open flat planting (CK). The results showed that mechanical no-tillage with straw mulching significantly affected soil water content in the 0–100 cm soil layer, yield, and water use efficiency ($p < 0.05$). There was no significant difference in yield between JG and HM, but it was significantly higher than that of CK. The yield of JG was 3.09–12.27% higher than that of CK. The yield increase was mainly achieved by increasing the potato weight per plant (0.697–0.862 **) and the average single potato weight (0.048–0.631). The tuber weight per plant was positively correlated with the plant height at the seedling stage (0.03–0.92 **) and positively correlated with the dry weight of stems and leaves at the tuber expansion stage and starch accumulation stage (0.74 **–0.95 **). It was negatively correlated with the number of branches at the tuber formation stage (–0.33––0.88 **). Compared with CK, JG could significantly improve the water use efficiency of potatoes and reduce water consumption during the whole growth period of crops. In 2021, JG was 6.5% higher than CK, and HM was 6.88% lower than CK. In 2022, JG and HM increased water use efficiency by 26.17% and 14.50% compared with CK. When HM is applied in heavy soil areas, soil compaction can easily occur, which affects seedling emergence and reduces yield. At the same time, JG has strong adaptability to soil types and good yield stability. It can be seen that JG is a green and efficient mechanized potato cultivation technology suitable for dry farming areas.

Keywords: potato no-tillage sowing; soil moisture content; agronomic index; mechanism of production increase



Citation: Li, H.; Liu, P.; Sun, W.; Zhang, H.; Liu, X.; Li, P.; Zhang, F. Mechanized No-Tillage Planting with Maize Straw Mulching Improves Potato Yield and Water Use Efficiency in Arid Regions of Northwest China. *Agronomy* **2024**, *14*, 1711. <https://doi.org/10.3390/agronomy14081711>

Academic Editor: Masoud Hashemi

Received: 5 July 2024

Revised: 24 July 2024

Accepted: 1 August 2024

Published: 3 August 2024



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1. Introduction

Potatoes are one of the main staple crops in China [1] and one of the main staple crops in Gansu Province. The potato planting area in this area is large, with an annual planting area of about 680,000 hm² [2]. However, the yield of potatoes is 17.43 t/hm² [2], which is 1.58 t/hm² lower than the average yield of potatoes in the world [2]. The leading causes of low and unstable potato yields in the region are drought, water scarcity, and the uneven seasonality of precipitation. To improve water retention and crop irrigation conditions and enhance agricultural productivity, researchers have proposed a novel cultivation technique known as strip mulching with straw for potato cultivation [3].

This technique involves dividing the surface into planting strips and covering strips, each 60 cm wide, arranged alternately. Extensive research indicates that strip mulching with straw can regulate soil temperature [4], improve soil structure and fertility, and enhance potato yields [5]. However, the current technology involves manually removing the surface

corn straw, followed by farmland tillage and fertilization. Then, the straw is manually covered on the surface according to the arrangement of the 60 cm wide planting and covering belts. Finally, potato planting is completed by manual dibbling. This process is labor-intensive and inefficient, which seriously affects the large-scale promotion and application of the technology.

Mechanized seeding equipment is essential for promoting the widespread application of advanced technologies. In response, our project team, based on previous research on strip mulching with straw for potato cultivation, proposed a mechanized no-tillage planting mode for potatoes with year-round straw cover in the arid regions of northwest China. The research on the yield effect of potato no-tillage cultivation is mainly focused on the artificial cultivation of straw mulching [6,7]. The research on no-tillage machinery and equipment primarily focuses on small grain crops such as wheat and corn [8,9]. The agronomic requirements of potato planting require deep planting and a loose soil environment, which is quite different from the agronomic requirements of wheat and corn planting. It is not clear whether mechanized no-tillage potato planting with a straw mulch covering can improve the soil moisture environment and increase potato yield. At the same time, different soil environments and climatic conditions have an essential impact on potato growth.

Therefore, three treatments of mechanized no-tillage potato planting with a straw mulch covering (JG), plastic film mulching (HM), and traditional conventional planting (CK) were set up, and traditional conventional planting was used as a control. Field experiments were carried out in two different soil types and rainfall conditions in Lintao County and Tongwei County, Dingxi City, Gansu Province, to determine the soil moisture, agronomic indicators, and yield of different treatments during the critical growth period of potatoes. The effects of JG, HM, and CK on the soil moisture, yield, and yield water use efficiency of farmland were studied by statistical analysis. The yield-increasing mechanism and adaptability of mechanized no-tillage with straw mulching on potatoes in different ecological regions were explored, which provided theoretical guidance for the popularization and application of this technology.

2. Materials and Methods

2.1. General Situation of the Test Site

The experiments were conducted from June to October 2021 at the field trial base of Taoyang Town, Taohe Tractor Co., Ltd., Lintao County, Gansu Province, and from June to October 2022 at the dryland agricultural experimental base in Pingxiang Town, Tongwei County, Gansu Province. The Lintao trial base is located at 103°29' E, 35°03' N, with an elevation of 1890 m. It experiences a temperate continental climate, with an average annual temperature of 7 °C, a frost-free period of 150 days, and an average annual rainfall of 538.5 mm. Over 70% of the rainfall occurs during July, August, and September, with uneven distribution throughout the rainy season. In 2021, the total annual rainfall was 440.9 mm, with an effective rainfall during the potato growing season of 317.2 mm, accounting for 71.9% of the total annual rainfall. The soil in the experimental area is classified as clay, with an average bulk density of 1.68 g/cm³ in the 0–30 cm soil layer. The soil components (0–100 cm) at Lintao County are as follows: total N: 0.91 g/kg, available P: 15.36 mg/kg, available K: 220.21 mg/kg, soil organic matter: 12.53 g/kg, and pH: 8.12. The Tongwei trial base is located at 35°11' N, 105°19' E, with an elevation of 1760 m. It has a semi-arid climate with a temperate zone, an average annual temperature of 7.2 °C, and a frost-free period ranging from 120 to 170 days. The average annual rainfall is 390.7 mm, with uneven distribution throughout the rainy season. In 2022, the total annual rainfall was 309.22 mm, with an effective rainfall during the potato growing season of 211.45 mm, accounting for 68.4% of the total annual rainfall. The soil in the experimental area is classified as loess soil, with an average bulk density of 1.25 g/cm³ in the 0–30 cm soil layer. The soil components (0–100 cm) at Tongwei County are as follows: total N: 0.53 g/kg, available P: 4.91 mg/kg, available K: 183.46 mg/kg, soil organic matter: 8.50 g/kg, and pH: 8.73. The two test bases' monthly rainfall and average temperature during the test are shown in Figure 1. The

rainwater is naturally infiltrated, and the rainwater infiltration of the plastic film mulching treatment is realized by the dibbling hole and the uncovered strip between two ridges.

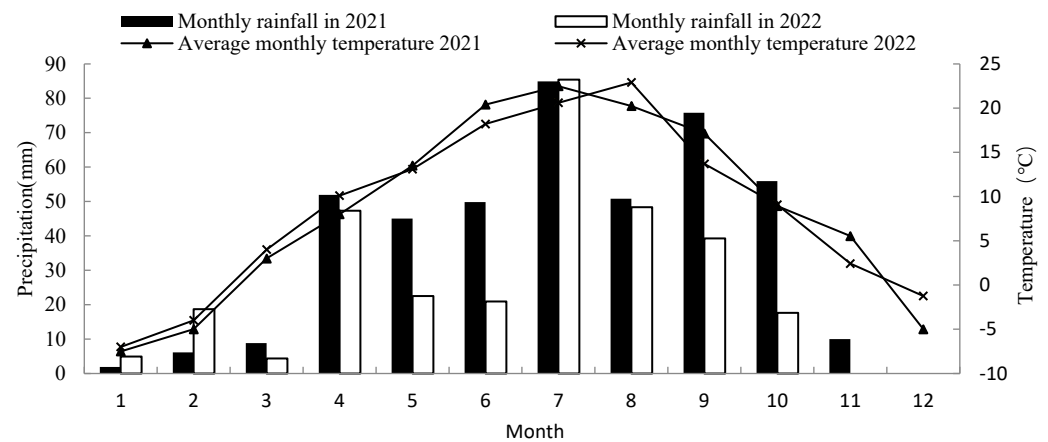


Figure 1. Precipitation and air temperature of the study area in 2021 and 2022.

2.2. Experimental Design

The potato variety ‘Longshu 7’, commonly planted in dryland areas of Gansu Province (Tongwei County and Lintao County), was selected for the experiment. For the mulch covering, locally available black plastic mulch with a width of 120 cm and a thickness of 0.01 mm was utilized. Three treatments were established: plastic film mulching (HM), mechanized no-tillage potato planting with a straw mulch covering (JG), and traditional conventional planting (control, CK). Each treatment was replicated three times, resulting in nine experimental plots. The plots were arranged randomly in blocks, each covering an area of 100 m². The length and width of the plot was 16.67 m × 6 m.

The traditional conventional planting (CK) treatment mode was as follows: the straw was removed from the field when the corn was harvested, and the soil was prepared and fertilized by rotary tillage seven days before potato sowing in the spring of the following year. When sowing, the artificial hole sowing method was used in the field, flat planting with equal row spacing, and the row spacing was 60 cm. The planting pattern and actual growth diagram of the CK treatment test are shown in Figure 2a,d.

The mode of the mechanical no-tillage planting with straw mulching (JG) treatment was as follows: after the previous corn was harvested artificially, the total amount of straw was retained in the field without any treatment. The average weight of straw per square meter was 265.05 g (dry weight). The straw was chopped and returned to the field in the next potato planting season, and the average chopped length was 5 cm. Then, the self-developed dryland corn straw mulching potato no-till planter was used to complete the ditching, fertilization, sowing, and soil covering and pressing operations simultaneously, with a row spacing of 60 cm. The planting pattern and actual growth diagram of the JG treatment test are shown in Figure 2b,e.

The mode of the plastic film mulching treatment (HM) was as follows: the straw was removed from the field when the corn was harvested, and the soil was prepared by rotary tillage seven days before the potatoes were sown in the spring of the next year. When sowing, the ridge and film mulching machine was used to ridge and film in the field. The width of the ridge surface was 80 cm, the width of the furrow was 40 cm, and the gap between the inner membrane of the furrow was 5 cm wide as the seepage zone. The artificial hole-sowing method was used to plant on the ridge. Each ridge was planted with two rows, and the row spacing was 60 cm. The planting pattern and actual growth diagram of the HM treatment test are shown in Figure 2c,f.

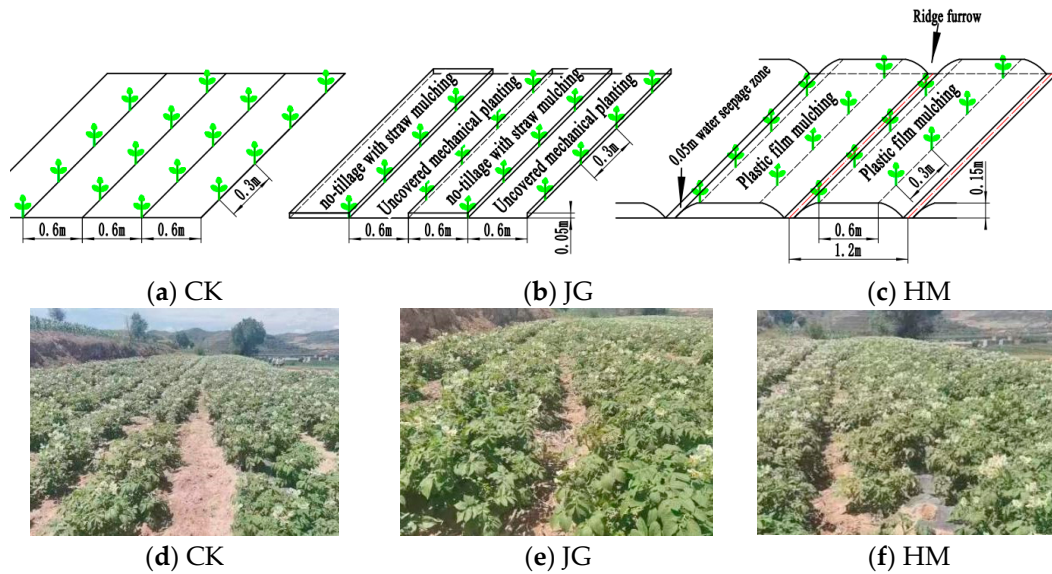


Figure 2. The planting pattern and realistic picture of each treatment on Longshu 7. They were: (a) the theoretical planting mode of traditional conventional planting without mulching (CK); (b) the theoretical planting mode of maize straw strip mulching on flat planting (JG); (c) the theoretical planting mode of plastic film mulching treatment (HM); (d) actual growth diagram of the CK treatment; (e) actual growth diagram of the JG treatment; (f) actual growth diagram of the HM treatment.

2.3. Field Management

The planting density for the three treatment modes was 55,500 plants/hm². The fertilizers were diammonium phosphate and urea, commonly used in potato planting. The amount of fertilizer was uniformly applied at 180 kg/hm² of nitrogen (N) and 150 kg/hm² of phosphorus pentoxide (P₂O₅), applied uniformly in one application (no additional fertilization later). After soil preparation, the HM treatment mode also adds ridging, film mulching, and manual dibbling operations. In addition to the timely release of seedlings under plastic film mulching, other production management methods were consistent with the production habits of local farmers. Sowing occurred on 3 June, with harvest on 17 October in 2021, and on 8 June, with harvest on 18 October in 2022.

2.4. Determination Items and Methods

2.4.1. Growth Index

In the five key growth stages of potatoes (seedling, tuber formation, tuber enlargement, starch accumulation, and harvest), five representative samples with basically the same growth vigor were randomly selected from each plot, and the plant height, branch number, stem leaf, and tuber weight of the potatoes were measured. The average value was recorded as the plant height, branch number, stem leaf, and potato tuber weight per plant. Plant height is measured as physiological height, the distance from the base of the aboveground stem to the growing point. The number of branches is the number of branches larger than 5 cm extracted from the main stem of the potato. The straw mass refers to the total mass of aboveground stems and leaves, while the tuber yield represents the total mass of tubers with a diameter greater than 1 cm. After the weight of straw and tubers were weighed, the straw and tubers were placed in an oven at 105 °C for 30 min according to the drying method in Reference [10] and then dried at 85 °C for 24 h to obtain the dry weight of the straw and tubers.

2.4.2. Soil Moisture

(1) Before sowing and the critical growth period of potatoes (seedling, tuber formation, tuber enlargement, starch accumulation, and harvest), each sampling interval is about

20 days. In the event of rainfall, the sampling starts when the surface is dry and white. Each time, a soil sample of 0~20 cm, 20~40 cm, 40~60 cm, 60~80 cm, and 80~100 cm was taken along the longitudinal direction of the planting line between the two plants with a soil drill in each plot. The soil sample was taken using a 50 mm diameter steel-core sampling drill, which was manually driven. The soil moisture content of each growth period was measured by the drying method (drying at 105 ± 2 °C for more than 24 h). The following formula calculates the soil moisture content:

$$\text{Soil water content (\%)} = (\text{Weight of wet soil and aluminum box} - \text{Weight of dry soil and aluminum box}) / (\text{Weight of dry soil and aluminum box} - \text{Weight of empty aluminum box}) \times 100\%.$$

(2) Calculation of soil water storage capacity

The selected experimental farmland had a smooth terrain, deep soil layers, a uniform soil texture, and a relatively deep groundwater level with no irrigation system. The water required for potato growth was entirely dependent on rainfall. The formula used to calculate the soil's water storage capacity is as follows:

$$W = h \times \rho \times \omega \times 10 \quad (1)$$

where: W is the soil's water storage capacity (mm); h is the depth of the soil layer (cm); ρ is the soil's bulk density (g/cm³); and ω is the soil's mass moisture content (%).

(3) Calculation of crop water consumption

Field experiments were conducted under dry and non-irrigated conditions during the growing season. The groundwater level in the test area is maintained at about 50 m below the surface, so the upward flow into the root system can be ignored. Because the test area is dry and flat terrain, surface runoff and drainage are not significant and drainage can be ignored; crop water consumption can be calculated according to the following formula:

$$ET = (W_1 - W_2) + P \quad (2)$$

where: ET is the water consumption during the growth period, including plant transpiration and surface evaporation (mm); W_1 and W_2 are the soil water storage capacity (mm) before sowing and after harvesting, respectively; P is the effective rainfall (mm) of the crop growth period ≥ 5 mm, and it is the effective rainfall (mm) recorded at the weather station near the experimental site.

2.4.3. Yield and Yield Water Use Efficiency

When the potatoes were harvested, 15 randomly selected plants were taken from each plot for tuber sampling. According to the literature [11], the weight was divided into three grades: >100 g for large potatoes, 50~100 g for medium potatoes, and <50 g for small potatoes. The number of tubers in each grade was recorded and weighed accordingly. These data are used to analyze yield composition and calculate the commercial potato rate.

$$\text{Commercial potato rate (\%)} = (\text{Yield of single potato above 50 g} / \text{Total potato yield}) \times 100\%$$

Average single potato weight (g) = Potato weight per plant at harvest / Number of tubers per plant

Potato excavation was completed manually at harvest, and the actual yield was measured separately for each plot. The average of three repeated measurements was taken and converted to hectare yield.

$$\text{Yield water use efficiency: } WUE = Y / ET$$

where WUE is the yield water use efficiency, kg/(mm·hm²); Y is the fresh yield of potato tubers, kg/hm².

2.4.4. Soil Nutrient Assay

The soil's pH value was determined by the pH test paper method, and the soil nutrients were determined by the TPY-16A soil nutrient rapid tester produced by Zhejiang Top Cloud Technology Co., Ltd. The company's production base is No.17 Guanzhuang Road, Taozhu Street, Zhuji City, Zhejiang Province. The soil samples were divided into three times for each measurement, and the average value of the three times was recorded as the index value.

2.5. Statistical Analysis

Excel 2007 software was used for data processing and mapping. SPSS 20.0 statistical analysis software was used to analyze variance and correlation. Analysis of variance was performed on all data collected each year. In addition, correlation analysis between potato yield and yield components, yield components and growth indicators, and growth indicators and soil moisture was also carried out. The mean values between treatments were compared by Fisher's least significant differences (LSD) at $p < 0.05$.

3. Results

3.1. Yield Effect of Mechanized No-Tillage with Straw Mulching

Table 1 shows potato yield and yield components under the three treatment modes. It can be observed that the effects of treatments on yield and yield components are significantly different ($p < 0.05$). Compared with CK, JG significantly increased potato yield by 3.09~12.27%. The yield increase of HM treatment was inconsistent with that of CK over two years. The yield of HM was 8.31% lower than that of CK in 2021 and 13.09% higher than that of CK in 2022. The main reason is that the test was conducted in Lintao, Gansu Province, in 2021. The soil is sticky and heavy (with a soil bulk density of 1432 kg/m^3), and there is more rainfall after sowing. The soil on the surface of the plastic film is hardened, which affects the emergence of potatoes. The emergence rate is 66%. The artificial transplanting method ensures that the test reaches the planting density, and the growth is slow after replanting, which affects the yield of potatoes. The yield difference between JG and HM was significant in 2021 ($p < 0.05$), and JG increased potato yield by 11.06% compared to HM. There was no significant difference between JG and HM in 2022 ($p > 0.05$).

Table 1. The effects of mulching treatment on yield and yield components.

Test Years	Treatments	Potato Weight per Plant (g)	Number of Tubers per Plant (Number)	Average Single Potato Weight (g)	Number of Large and Medium Potatoes (%)	Commodity Potato Rate (%)	Yield /kg hm ⁻²
2021	JG	1200.38 b	7.37 b	157.97 b	0.60 b	0.92 b	50,498.60 a
	HM	1497.14 a	7.67 a	204.53 a	0.68 a	0.94 a	44,914.16 b
	CK	1088.60 b	7.47 b	148.06 b	0.64 ab	0.91 c	48,987.01 a
	Mean	1262.04	7.50	170.18	0.64	0.92	48,133.26
	Range	408.54	0.30	56.47	0.08	0.03	5584.44
	CV (%)	16.73	2.04	17.72	6.34	1.43	6.00
2022	JG	447.93 b	2.53 b	118.76 a	0.50 a	0.87 a	18,946.99 a
	HM	507.28 a	3.33 b	104.45 ab	0.48 a	0.88 a	19,084.67 a
	CK	380.61 c	3.70 a	90.69 b	0.49 a	0.84 b	16,875.59 b
	Mean	445.27	3.19	104.63	0.49	0.86	18,302.42
	Range	126.67	1.17	28.07	0.02	0.04	2209.08
	CV (%)	14.23	18.71	13.41	2.42	2.08	6.76

Note: CV is the coefficient of variation; Different lower case letters in the same column mean significant differences between treatments at 0.05 level.

Based on the analysis of the components of yield, it can be observed that HM and JG significantly increased the individual tuber weight compared to CK. The number of

tubers per plant showed inconsistent results across the two years of experimentation. In 2021, HM significantly increased the average tuber weight compared to CK and JG. From the perspective of the coefficient of variation, each treatment had the greatest impact on the average tuber weight in 2021, followed by the tuber weight per plant. In 2022, each treatment had the greatest impact on the number of tubers per plant, followed by the weight of tubers per plant.

In 2021, compared to JG, HM significantly increased the number of large and medium-sized potatoes and the yield of commercial potatoes. In 2022, compared to CK, both HM and JG significantly increased the commercial potato rate. There was no significant difference in commercial potato rates between HM and JG. The commercial potato rates of HM and JG were 2.87~4.16% and 1.3~2.84% higher than that of CK, respectively.

3.2. Effect of Mechanized No-Tillage with Straw Mulching on Yield Water Use Efficiency

Water consumption and water use efficiency during the growth period under different cultivation methods are shown in Table 2. It can be seen that the water consumption and yield water use efficiency of the three treatments during the whole growth stage of potatoes were significantly different ($p < 0.05$). JG can significantly improve the water use efficiency of potatoes and reduce water consumption during the whole growth stage of crops. In 2021, JG significantly increased water use efficiency compared with HM and CK ($p < 0.05$). HM significantly reduced the water use efficiency of the yield; JG's was 6.5% higher than CK's, and HM's was 6.88% lower than CK's. In 2022, compared with HM and CK, JG significantly reduced crop water consumption during the whole growth period and increased yield water use efficiency. Compared with HM and CK, JG reduced water consumption during the whole growth period by 29.52 mm and 36.56 mm and increased water use efficiency by 26.17% and 14.50%, respectively. This indicates that JG can improve both the yield and water use efficiency of potatoes compared to HM and CK.

Table 2. The effects of mulching treatment on water use efficiency of potato yields.

Test Years	Treatments	Yield /kg hm ⁻²	Soil Water Storage before Seeding /mm	Soil Water Storage Harvest /mm	Amount of Rainfall in the Growth Period /mm	Crop Water Consumption /mm	WUE/ kg·(mm·hm ²) ⁻¹	Yield Is More than CK/%
2021	JG	50,498.55 a	240.62	214.98 a	317.20	342.83 b	147.30 a	6.50
	HM	44,914.2 b	240.62	209.08 b	317.20	348.74 ab	128.79 c	−6.88
	CK	48,987 a	240.62	203.64 c	317.20	354.18 a	138.31 b	
2022	JG	18,946.95 a	240.62	213.64 a	211.45	238.43 b	79.47 a	26.17
	HM	19,084.65 a	257.03	193.49 b	211.45	274.99 a	69.40 b	10.19
	CK	16,875.6 b	240.62	184.12 c	211.45	267.95 a	62.98 c	

Note: Different lower case letters in the same column mean significant differences between treatments at 0.05 level.

3.3. Effect of Mechanized No-Tillage with Straw Mulching on Soil Moisture Content

3.3.1. Average Soil Moisture Content in the 0~100 cm Soil Layer during the Whole Growth Period

The average soil moisture content in the 0~100 cm soil layer during the entire growth period is shown in Figure 3. It is evident that significant differences exist in soil moisture content among the different treatments throughout the entire growth period. In both experimental years, there was no significant difference between HM and JG ($p > 0.05$), but both were significantly higher than CK. In 2021, HM and JG were 0.51 and 0.41 percentage points higher than CK, respectively. In 2022, HM and JG were 0.91 and 1.30 percentage points higher than CK, respectively.

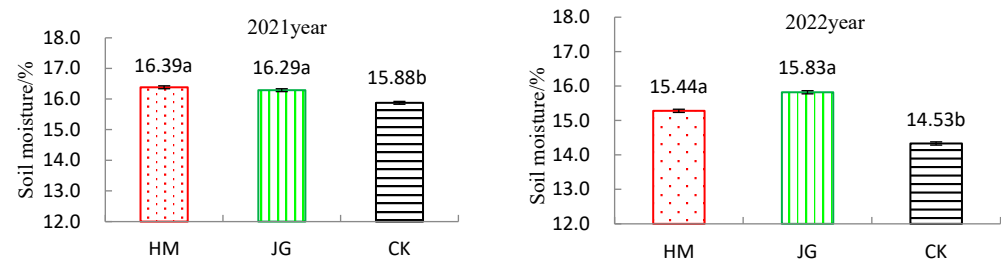


Figure 3. Mean soil water content in the 0~100 cm soil layer during the whole growth period. Data are means of three replicates. Different lower case letters in the same columnar section are significant differences at 0.05 level. Error bars are the standard deviation of means ($n = 3$).

3.3.2. Average Soil Moisture Content in the 0~100 cm Soil Layer at Different Growth Stages

Variations in the average soil moisture content of the 0~100 cm soil layer during different growth stages are depicted in Figure 4. It is evident that the trend of changes in the average soil moisture content in the 0~100 cm soil layer remains relatively consistent across all three treatments as growth progresses, with HM and JG generally being higher than CK. However, the water storage and moisture retention effects of HM and JG differ. In 2021, before the tuber formation stage, JG was higher than HM, but it was lower than CK during the tuber enlargement and starch accumulation stages. Significant differences between treatments were observed at the tuber formation stage (27 July) and tuber enlargement stage (29 August), with the maximum difference between treatments reaching 1.98 percentage points at the tuber formation stage (27 July). In 2022, both HM and JG had a higher soil moisture content than CK, with JG having the highest soil moisture content at the harvest stage, 2.27% higher than CK. JG's was significantly higher than CK's after the tuber enlargement stage, with the greatest difference observed at the harvest stage, being 1.55% higher than HM. Significant differences were observed between treatments at each growth stage, with the largest difference occurring at the harvest stage (17 October), reaching 2.27%.

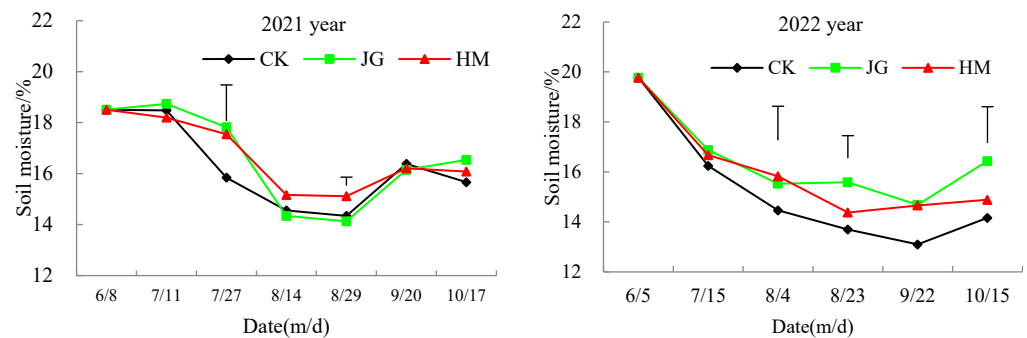


Figure 4. The change in average water content in the 0~100 cm soil layers at different growth stages. The error bar indicated that there were significant differences in soil moisture among treatments at different growth stages ($p < 0.05$). The length of error bar is LSD value.

The average soil moisture content in the 0~100 cm soil layer during different growth stages is summarized in Table 3. It can be observed that in both experimental years, the tuber formation stage had a significant impact on soil moisture content across treatments, with differences ranging from 1.98% to 3.36%. In 2021, the starch accumulation stage had minimal effect on soil moisture content across treatments, with a difference of 0.23%. In 2022, the seedling stage had a relatively small effect on soil moisture content across treatments, with a difference of 0.63 percentage points. In the growth stage, the variation coefficients of the HM, JG, and CK treatments in 2021 were 7.66%, 11.29%, and 9.42%, respectively, and the variation coefficients in 2022 were 6.20%, 5.40%, and 8.27%, respectively. The results showed that compared to plastic film mulching and open field conventional planting, straw mulching mechanized no-tillage planting increased the change in soil moisture content at

different growth stages in 2021 and inhibited the change in soil moisture content at different growth stages in 2022.

Table 3. Average soil water content in the 0–100 cm soil layer at different growth stages (%).

Years	Measuring Time	CK	JG	HM	Mean	Range	CV (%)
2021	6–8	18.51	18.51	18.51	18.51		
	7–11	18.48	18.74	18.20	18.47	0.54	1.47
	7–27	15.84	17.82	17.55	17.07	1.98	6.28
	8–14	14.56	14.34	15.16	14.69	0.82	2.90
	8–29	14.34	14.13	15.11	14.53	0.98	3.55
	9–20	16.38	16.15	16.21	16.25	0.23	0.75
	10–17	15.66	16.54	16.08	16.09	0.87	2.71
	Mean	15.88	16.29	16.39			
	Range	4.14	4.61	3.09			
	CV (%)	9.42	11.29	7.66			
2022	6–5	19.77	19.77	19.77	19.77	0.00	0.00
	7–15	16.24	16.88	16.67	16.60	0.63	1.95
	8–4	14.46	15.53	15.83	15.27	1.36	4.69
	8–23	13.70	15.59	14.38	14.55	1.89	6.58
	9–22	13.10	14.68	14.66	14.15	1.58	6.42
	10–15	14.16	16.43	14.88	15.16	2.27	7.65
	Mean	14.33	15.82	15.28			
	Range	3.14	2.19	2.29			
	CV (%)	8.27	5.40	6.20			

3.3.3. Average Soil Moisture Content in Different Soil Layers during the Whole Growth Period

The variation trend of average soil moisture content in soil layers, from shallow to deep, is shown in Figure 5. The impact of different treatments on the average soil moisture content during the entire growth period in different soil layers is significantly different ($p < 0.05$). The average soil moisture content trend in different soil layers during the entire growth period generally shows a decreasing trend followed by an increasing trend with increasing soil depth, except for HM in 2021. All treatments' average soil moisture content is lower in the 60 cm soil layer during the entire growth period. HM and JG increased the soil moisture content in each layer compared to CK (except for the 20 cm soil layer in 2021 for HM). In 2021, HM showed the most significant increase in soil moisture content in the 60 cm soil layer, reaching 2.08 percentage points. In 2022, JG significantly increased the average soil moisture content during the entire growth period in the 20 cm and 40 cm soil layers compared to HM, with the most significant increase observed in the 20 cm soil layer, reaching 1.51 percentage points.

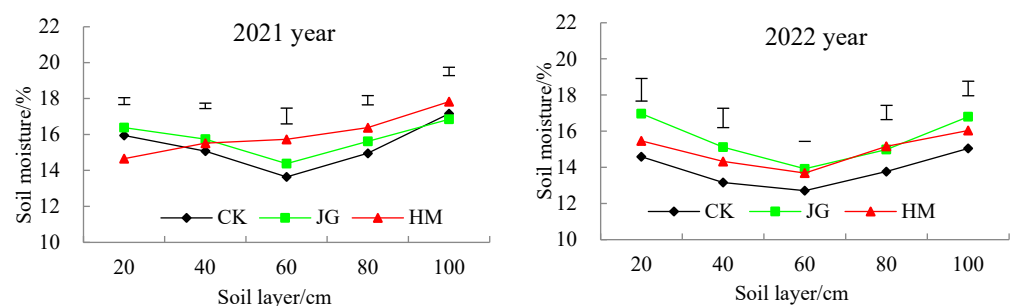


Figure 5. Variation trend of average soil moisture content in soil layers, from shallow to deep. The error bar indicated that there were significant differences in soil moisture among treatments at different growth stages ($p < 0.05$). The length of error bar is LSD value.

The average soil moisture content in different soil layers during the entire growth period of potatoes is presented in Table 4. It can be observed that the coefficients of variation for soil moisture content vary across different soil layers in both experimental years. In 2021, the largest variation in soil moisture content between soil layers during the entire growth period was observed in the 60 cm soil layer, with a difference of 2.08 percentage points. In 2022, the greatest variation occurred in the 20 cm soil layer, with a difference of 2.38 percentage points. Across soil layers, in 2021, the CK treatment exhibited the greatest variation in soil moisture content between layers during the entire growth period, with a difference of 3.52 percentage points. In contrast, in 2022, the JG treatment showed the greatest variation, with a difference of 3.05 percentage points.

Table 4. Average water content in the different soil layers during the whole growth period (%).

Years	Soil Layer/cm	CK	JG	HM	Mean	Range	CV (%)
2021	20	15.95	16.39	14.66	15.66	1.73	5.73
	40	15.08	15.74	15.52	15.45	0.67	2.20
	60	13.65	14.38	15.73	14.59	2.08	7.25
	80	14.96	15.62	16.38	15.65	1.42	4.55
	100	17.16	16.85	17.83	17.28	0.98	2.90
	Mean	15.36	15.80	16.02			
	Range	3.52	2.46	3.17			
	CV (%)	8.48	5.91	7.38			
2022	20	14.59	16.97	15.46	15.67	2.38	7.70
	40	13.16	15.12	14.33	14.20	1.95	6.93
	60	12.71	13.92	13.69	13.44	1.21	4.76
	80	13.77	14.99	15.16	14.64	1.39	5.18
	100	15.05	16.80	16.04	15.96	1.75	5.50
	Mean	13.86	15.56	14.94			
	Range	2.33	3.05	2.35			
	CV (%)	6.99	8.34	6.24			

3.3.4. Temporal and Spatial Variation of Soil Moisture Content

The vertical variation trend of soil moisture content in the 0~100 cm soil layer during different growth stages and treatments is illustrated in Figure 6. It can be observed that there were significant differences between different growth periods and different soil layers ($p < 0.05$). The difference between the treatments was the largest in the 80 cm soil layer at the harvest stage, with a difference of 4.08% in 2021 and 3.11% in 2022. Among the soil layers, JG had the most significant difference in the tuber formation period in 2021, with a difference of 9.01%, and CK had the most significant difference in the tuber formation period in 2022, with a difference of 6.30%. During the growth period, CK had the most significant difference in the 20 cm soil layer in 2021, with a difference of 9.26%, and CK had the most significant difference in the 80 cm soil layer in 2022, with a difference of 4.58%.

The variation coefficient and range of soil moisture content in the different growth stages of each treatment are summarized in Table 5. The coefficient of variation between soil layers was highest for JG during the tuber formation stage (CV = 23.24%) and lowest for CK during the starch accumulation stage (CV = 6.25%) in 2021. The results showed that JG exacerbated the variation in soil moisture content between soil layers during the tuber formation stage compared to HM and CK. At the same time, CK suppressed the variation in soil moisture content between soil layers during the starch accumulation stage compared to HM and JG. In 2022, the coefficient of variation was highest for CK during the tuber formation stage (CV = 16.32%) and lowest for HM during the seedling stage (CV = 4.39%). The results showed that CK exacerbated the variation in soil moisture content between soil layers during the tuber formation stage compared to HM and JG. At the same time, HM

suppressed the variation in soil moisture content between soil layers during the seedling stage compared to JG and CK.

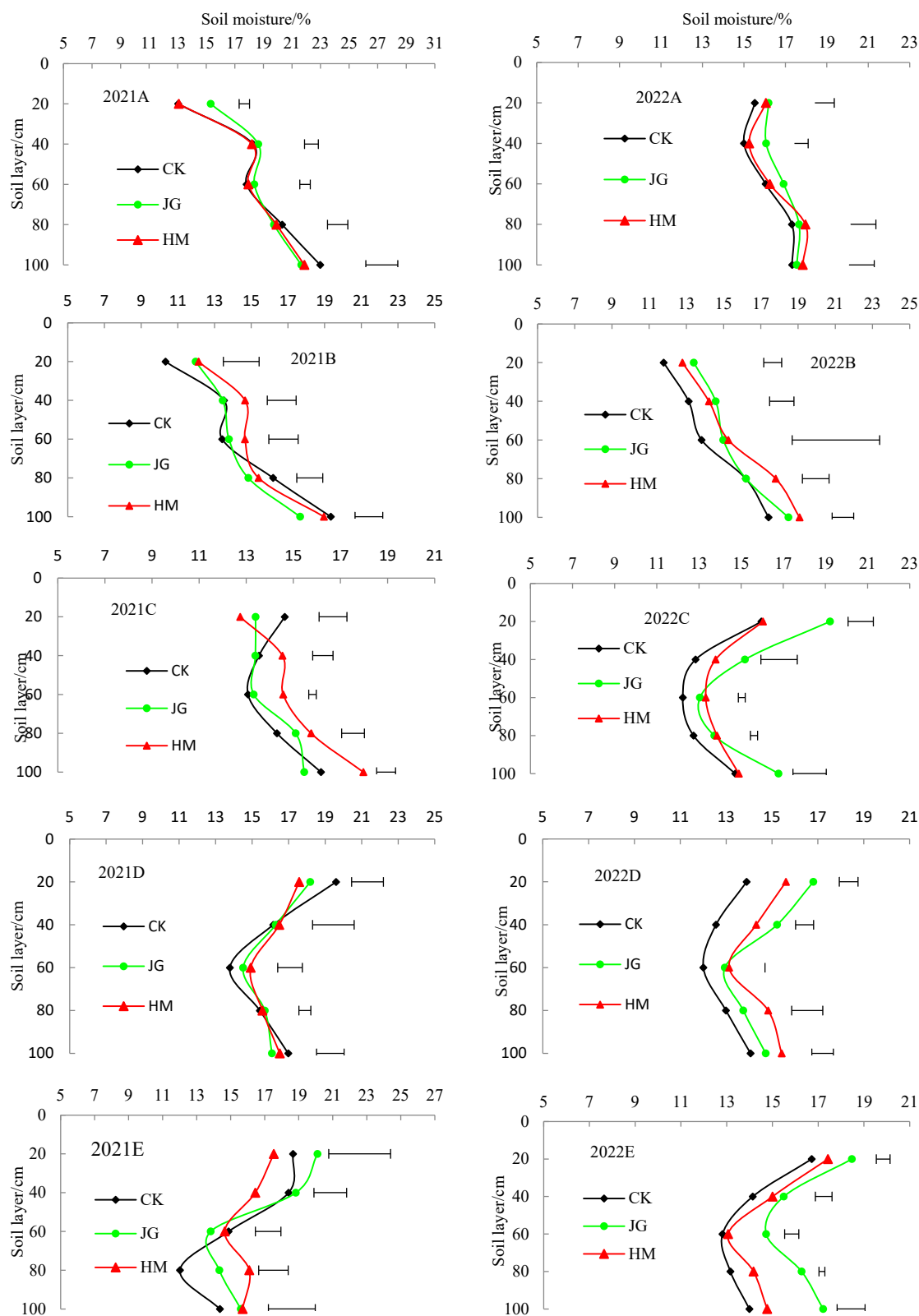


Figure 6. The spatial and temporal changes of soil water content at different growth stages in 2021 and 2022. Note: A: Seedling stage; B: Tuber formation period; C: Tuber enlargement stage; D: Starch accumulation period; E: Harvest.

Table 5. The variation coefficient and range of water content between soil layers.

Years	Measuring Time	JG		HM		CK	
		Range	CV (%)	Range	CV (%)	Range	CV (%)
2021	7–11	9.94	19.83	6.34	12.33	8.80	17.96
	7–27	5.88	15.17	2.94	6.73	6.69	17.11
	8–14	9.01	23.24	5.70	14.81	6.84	16.23
	8–29	3.10	8.32	2.15	7.48	5.23	12.73
	9–20	5.82	13.11	3.68	8.23	2.65	6.25
	10–17	6.65	18.10	6.28	16.86	2.89	6.56
2022	7–15	2.32	6.48	1.59	4.39	2.71	7.10
	8–4	5.64	15.90	5.09	12.44	6.30	16.32
	8–23	3.73	11.54	6.18	15.95	2.71	7.58
	9–22	2.06	6.69	3.86	10.04	2.48	6.81
	10–15	3.90	10.81	3.75	8.92	4.36	10.79

3.3.5. Effect of Mechanized No-Tillage Planting with Straw Mulching on the Water Consumption of Potatoes

Each stage's water consumption and its proportion to the total water consumption for different treatments in the two experimental years are shown in Table 6. It can be observed that there are significant differences in water consumption between the three treatments at each growth stage ($p < 0.05$). The influence of each treatment on water consumption at different growth stages varies between the two experimental years. In 2021, JG had the highest proportion of water consumption from the seedling stage to the tuber formation stage, reaching 36.47%, while HM had the lowest proportion of water consumption from the tuber formation stage to the tuber enlargement stage, accounting for only 7.46% of the total. In 2022, HM had the highest proportion of water consumption from the sowing stage to the seedling stage, reaching 37.15%, while JG had the lowest proportion of water consumption from the starch accumulation stage to the harvest stage, accounting for only 2.23% of the total.

Table 6. Water consumption and ratios in different potato growth periods.

Test Years	Treatments	Sowing to A		A to B		B to C		C to D		D to E		Sowing to E
		Quantity (mm)	Proportion (%)	Quantity (mm)	Proportion (%)	Quantity (mm)	Proportion (%)	Quantity (mm)	Proportion (%)	Quantity (mm)	Proportion (%)	Quantity (mm)
2021	HM	96.28 a	27.60 a	107.35 c	30.79 c	26.01 b	7.46 b	61.57 a	17.65 a	57.54 b	16.50 b	348.74 ab
	JG	89.21 ab	26.03 b	125.08 a	36.47 a	28.09 a	8.19 a	49.59 b	14.48 b	50.86 c	14.83 c	342.83 b
	CK	92.60 b	26.16 b	118.88 b	33.60 b	28.17 a	7.93 ab	49.28 b	13.94 b	65.24 a	18.38 a	354.18 a
2022	HM	101.81 a	37.15 a	55.79 c	20.10 b	50.65 a	18.56 a	52.08 c	19.03 c	14.66 a	5.16 a	274.99 a
	JG	82.74 c	34.67 b	62.33 b	26.21 a	31.03 c	13.04 c	67.48 a	28.32 a	−5.14 c	−2.23 c	238.43 c
	CK	90.97 b	33.85 b	67.93 a	25.55 a	41.76 b	15.65 b	63.51 b	24.08 b	3.77 b	0.87 b	267.95 b

Note: Different lower case letters in the same column mean significant differences between treatments at 0.05 level.

Throughout both growing seasons, JG had lower total water consumption than CK, averaging 20.43 mm lower than CK. HM showed inconsistent performance in the two experimental years, being 5.44 mm lower than CK in 2021 and 7.04 mm higher than CK in 2022.

3.4. Potato Growth Index

The effect of mechanized no-tillage sowing of straw-covered potatoes on growth indicators is shown in Table 7. Each treatment significantly affected plant height, branch number, and the dry weight of stems and leaves in the 2 experimental years ($p < 0.05$). Compared with HM and CK, JG significantly increased plant height by 4~7.2 cm and 2.8~8.9 cm at the tuber formation stage and decreased branch number by 2.5~3.9 and 1.3~5.9. There was no significant difference in the dry weight of stems and leaves between JG and HM at the late growth stage, but it was significantly higher than that of CK. In 2021,

the dry weight of stems and leaves had the most significant difference at the harvest stage, and JG's was 1.69 g and 15.72 g higher than HM's and CK's. In 2022, the dry weight of stems and leaves had the most significant difference at the starch accumulation stage, and JG's was 34.5 g and 0.1 g higher than HM's and CK's. It can be seen from the coefficient of variation that each treatment had the most significant influence on the number of branches and the most negligible impact on plant height.

Table 7. Effects of different mulching methods on potato growth index.

Years	Treatments	A			B			C			D			E		
		ZG	FZ	JY	ZG	FZ	JY	ZG	FZ	JY	ZG	FZ	JY	ZG	FZ	JY
2021	CK	32.6	0.0	11.0 b	48.0	1.3	23.2 b	82.0 a	4.0 a	26.1 b	103.5 c	19.3 a	98.0 c	133.0 a	12.5 a	105.8 b
	JG	32.0	0.0	10.8 b	50.8	0.0	33.2 a	85.0 a	3.8 a	31.5 c	113.5 b	14.3 ab	103.0 b	120.5 b	9.5 b	121.6 a
	HM	31.3	2.5 a	16.4 a	46.8	2.5	23.1 b	86.5 a	5.3 a	64.9 a	135.0 a	7.3 b	121.4 a	127.5 ab	11.0 ab	119.9 a
	Mean	32.0	0.8	12.7	48.5	1.3	26.5	84.5	4.3	40.8	117.3	13.6	107.5	127.0	11.0	115.8
	Range	1.4	2.5	5.7	4.0	2.5	10.1	4.5	1.5	38.8	31.5	12.0	23.4	12.5	3.0	15.7
2022	CK	23.5 b	5.5 a	10.4 ab	52.1 b	15.8 a	46.8 a	68.8 b	32.5 a	74.5 b	75.5 ab	28.8 b	94.5 a	131.3 a	12.5 a	105.8 b
	JG	27.4 a	2.8 b	11.0 a	61.0 a	9.9 c	39.1 b	66.8 c	24.5 c	78.9 b	69.8 b	31.3 a	94.6 a	120.5 b	9.5 b	121.6 a
	HM	28.1 a	5.0 a	10.2 b	53.8 b	13.8 b	48.0 a	72.5 a	26.5 b	89.3 a	80.5 a	14.3 c	57.1 b	127.5 ab	11.0 ab	119.9 a
	Mean	26.3	4.4	10.5	55.6	13.1	44.6	69.4	27.8	80.9	75.3	24.8	82.1	127.0	11.0	115.8
	Range	4.7	2.8	0.8	9.0	5.9	8.9	5.8	8.0	14.8	10.6	17.0	37.5	12.5	3.0	15.7
	CV (%)	9.5	33.2	3.6	8.5	22.8	10.8	4.2	15.0	9.4	7.1	37.1	26.3	4.9	13.6	7.5

Note A: Seedling stage; B: Tuber formation period; C: Tuber enlargement stage; D: Starch accumulation period; E: Harvest; ZG was Plant height/cm, FZ was branch number/number, and JY was stem leaf dry weight/g; Different lower case letters in the same column mean significant differences between treatments at 0.05 level.

3.5. Formation Mechanism of Yield Difference

3.5.1. The Relationship between Yield and Its Components

It can be seen from Table 8 that the yield was significantly positively correlated with the tuber weight per plant (0.697 to 0.862 **), positively correlated with the average single tuber weight (0.048~0.631), significantly negatively correlated with the number of tubers per plant (−0.865 to −0.877 **), and negatively correlated with the number of large and medium tubers (in 2021: −0.772 *, in 2022: −0.327). The results showed that under different mulching treatments, increasing yield was achieved by increasing tuber weight per plant and average tuber weight and reducing the number of tubers per plant and the number of large and medium tubers.

Table 8. Correlation analysis table of potato yield and components.

Test Years		Yield	Potato Weight per Plant	Number of Tubers per Plant	Average Single Potato Weight	Number of Large and Medium Potatoes
2021	Yield	1				
	Potato weight per plant	0.697 *	1			
	Number of tubers per plant	−0.865 **	0.868 **	1		
	Average single potato weight	0.048	0.182	−0.071	1	
	Number of large and medium potatoes	−0.772 *	0.551	0.607	−0.094	1
2022	Yield	1				
	Potato weight per plant	0.862 **	1			
	Number of tubers per plant	−0.877 **	−0.751 *	1		
	Average single potato weight	0.631	0.541	−0.878 **	1	
	Number of large and medium potatoes	−0.327	−0.414	−0.125	0.275	1

Note: * and ** represent significantly different at $p < 0.05$ and $p < 0.01$, $n = 9$.

3.5.2. Relationship between Yield Components and the Growth Index

The correlation analysis between the yield components of potatoes and the growth index at the growth stage is shown in Table 9. It can be observed that individual tuber weight is positively correlated with plant height during the seedling stage (0.03 to 0.92 **). However, its correlation with other indicators shows inconsistent patterns across the two experimental years. In 2021, individual tuber weight was significantly positively correlated with stem and leaf dry weight during the tuber enlargement and starch accumulation

stages (0.74 ** to 0.95 **); however, this correlation was not significant in 2022. It negatively correlates with the number of branches during the tuber formation stage (−0.33 to −0.88 **). Average tuber weight is positively correlated with the number of branches (0.74 * to 0.95 **), stem dry weight (0.30 to 0.88 **), and leaf dry weight (0.10 to 0.75 **) during the seedling stage, while negatively correlated with plant height during the seedling stage (−0.18 to −0.90 **) and the tuber formation stage (−0.08 to −0.43). The number of tubers per plant is positively correlated with plant height during the tuber formation stage (0.30 to 0.84 **) while negatively correlated with plant height during the tuber enlargement stage (−0.27 to −0.48) and starch accumulation stage (−0.06 to −0.66), number of branches during the tuber formation stage (−0.09 to −0.56), and tuber weight during the tuber enlargement stage (−0.23 to −0.94). The proportion of large and medium-sized tubers is positively correlated with leaf dry weight during the seedling stage (0.05 to 0.68 *) but negatively correlated with plant height during the seedling stage (−0.08 to 0.19).

Table 9. Correlation analysis table of yield components and the growth index.

Test Years	Index	Measuring Time	Potato Weight per Plant	Average Single Potato Weight	Number of Tubers per Plant	Number of Large and Medium Potatoes	Index	Measuring Time	Potato Weight per Plant	Average Single Potato Weight	Number of Tubers per Plant	Number of Large and Medium Potatoes
2021	Plant height	7–11	0.033	−0.18	−0.421	−0.082	Stem dry weight	7–11	0.806 **	0.882 **	−0.296	0.795 *
		8–14	−0.608	−0.434	0.3	−0.12		8–14	−0.875 **	−0.689 *	−0.277	−0.164
		8–29	0.021	0.243	−0.48	0.691 *		8–29	0.922 **	0.950 **	0.096	0.668 *
		9–20	0.498	0.593	−0.058	0.853 **		9–20	0.785 *	0.869 **	0.023	0.659
		10–17	0.063	0.097	0.525	−0.474		10–17	0.795 *	0.771 *	−0.191	0.266
	Branch number	7–11	0.883 **	0.945 **	−0.032	0.767 *	Leaf dry weight	7–11	0.790 *	0.745 *	−0.334	0.679 *
		8–14	−0.88 **	−0.925 **	−0.087	−0.43		8–14	−0.729 *	−0.556	−0.32	0.051
		8–29	0.297	0.629	−0.232	0.304		8–29	0.938 **	0.963 **	0.048	0.642
		9–20	−0.392	−0.688 *	0.397	−0.781 *		9–20	0.885 **	0.786 *	0.405	0.52
		10–17	0.231	0.093	0.368	−0.582		10–17	−0.33	−0.219	0.064	0.262
2022	Plant height	7–16	0.919 **	−0.902 **	0.644	−0.194	Stem dry weight	7–16	−0.191	0.304	−0.572	−0.172
		8–4	0.237	−0.763 *	0.835 **	0.57		8–4	0.362	0.116	−0.189	−0.203
		8–23	0.569	0.088	−0.268	−0.602		8–23	0.284	−0.09	−0.232	0.186
		9–19	0.141	0.368	−0.661	−0.314		9–19	−0.575	0.33	−0.287	0.024
	Branch number	7–16	−0.233	0.743 *	−0.837 **	−0.539	Leaf dry weight	7–16	−0.185	0.096	−0.337	0.045
		8–4	−0.332	0.634	−0.556	0.114		8–4	−0.153	0.432	−0.408	−0.195
		8–23	−0.752 *	0.963 **	−0.938 **	−0.025		8–23	0.006	−0.006	−0.199	0.486
		9–19	−0.667 *	0.105	0.199	0.646		9–19	−0.613	0.187	−0.069	0.262

Note: * and ** represent significantly different at $p < 0.05$ and $p < 0.01$, $n = 9$.

It can be seen that improving the plant height and dry weight of stems and leaves at the seedling stage is beneficial for increasing the potato weight per plant and the rate of large and medium potatoes.

3.5.3. Relationship between the Growth Index and Soil Moisture

The correlation analysis of soil moisture content and the growth index in different soil layers at different growth stages is shown in Table 10. It can be seen that 51 of the 90 points in the determination of soil moisture content were positively correlated with plant height (36 points were significant), 74 points were negatively correlated with branch number (48 points were significant), and 50 points were positively correlated with stem and leaf dry weight (21 points were significant). The soil moisture content in the 40~100 cm soil layer during the seedling stage is significantly positively correlated with plant height during the seedling stage, tuber enlargement stage, and starch accumulation stage (0.66 ** to 0.92 **). It also positively correlates with stem and leaf dry weight during the seedling and starch accumulation stages (0.35 to 0.64 **).

Table 10. Correlation analysis table of the growth index with soil water in different periods of potato growth.

Growth Stage	Soil Layer	A			B			C			D			E		
		ZG	FZ	JY	ZG	FZ	JY	ZG	FZ	JY	ZG	FZ	JY	ZG	FZ	JY
A	20	−0.55 *	0.53 *	−0.51 *	0.72 **	0.66 **	0.86 **	−0.56 *	0.72 **	0.51 *	−0.70 **	0.45	−0.58 *	−0.88 **	−0.79 *	0.55
	40	0.69 **	−0.71 **	0.39	−0.50 *	−0.84 **	−0.80 **	0.70 **	−0.86 **	−0.71 **	0.78 **	−0.45	0.64 **	−0.32	−0.53	0.10
	60	0.66 **	−0.75 **	0.39	−0.39	−0.86 **	−0.78 **	0.80 **	−0.87 **	−0.72 **	0.79 **	−0.51 *	0.64 **	−0.86 **	−0.92 **	0.43
	80	0.68 **	−0.72 **	0.40	−0.58 *	−0.83 **	−0.84 **	0.92 **	−0.90 **	−0.72 **	0.84 **	−0.70 **	0.50 *	−0.13	−0.18	−0.34
	100	0.74 **	−0.76 **	0.41	−0.65 **	−0.85 **	−0.86 **	0.86 **	−0.93 **	−0.78 **	0.84 **	−0.57 *	0.55 *	0.17	0.01	−0.61
	0–100	0.70 **	−0.74 **	0.35	−0.48 *	−0.84 **	−0.76 **	0.83 **	−0.88 **	−0.75 **	0.79 **	−0.55 *	0.54 *	−0.56	−0.65	−0.03
B	20				−0.26	−0.82 **	−0.53 *	0.55 *	−0.78 **	−0.92 **	0.44	−0.28	0.24	−0.35	−0.23	−0.07
	40				−0.07	−0.59 **	−0.33	0.54 *	−0.58 *	−0.43	0.51 *	−0.52 *	0.28	−0.92 **	−0.83 **	0.93 **
	60				−0.21	−0.39	−0.34	0.15	−0.35	0.04	0.54 *	−0.41	0.43	−0.08	0.01	0.65
	80				−0.39	−0.52 *	−0.42	0.46	−0.54 *	−0.17	0.71 **	−0.73 **	0.26	−0.20	−0.04	0.69 *
	100				−0.33	−0.69 **	−0.56 *	0.44	−0.67 **	−0.31	0.64 **	−0.61 **	0.25	0.01	0.21	0.48
	0–100				−0.19	−0.67 **	−0.59 *	0.69 **	−0.72 **	−0.48 *	0.53 *	−0.61 **	0.10	−0.23	−0.24	−0.30
C	20							−0.70 **	0.71 **	0.56 *	−0.86 **	0.70 **	−0.47 *	0.22	0.18	−0.71 *
	40							−0.02	−0.06	0.30	0.08	−0.01	0.17	−0.05	0.08	0.19
	60							0.56 *	−0.61 **	−0.06	0.77 **	−0.72 **	0.41	−0.01	−0.11	0.52
	80							0.74 **	−0.83 **	−0.44	0.85 **	−0.74 **	0.53 *	−0.26	−0.49	0.73 *
	100							0.33	−0.48 *	−0.05	0.52 *	−0.28	0.62 **	0.35	0.19	0.18
	0–100							0.71 **	−0.87 **	−0.64 **	0.68 **	−0.44	0.55 *	−0.23	−0.24	−0.30
D	20										0.53 *	−0.39	0.33	0.19	0.29	−0.64
	40										0.62 **	−0.57 *	0.37	−0.36	−0.41	0.23
	60										0.76 **	−0.58 *	0.40	−0.47	−0.54	0.47
	80										0.74 **	−0.69 **	0.20	−0.32	−0.17	0.20
	100										0.66 **	−0.55 *	0.24	0.23	0.16	−0.58
	0–100										0.72 **	−0.60 **	0.36	−0.23	−0.24	−0.30
E	20													−0.01	−0.17	0.06
	40													0.06	0.04	−0.26
	60													0.81 **	0.65	−0.50
	80													−0.39	−0.30	0.82 **
	100													−0.51	−0.69 *	0.58
	0–100													−0.24	−0.42	0.57

Note A: Seedling stage; B: Tuber formation period; C: Tuber enlargement stage; D: Starch accumulation period; E: Harvest; ZG was Plant height/cm, FZ was branch number/number, and JY was stem leaf dry weight/g; * and ** represent significantly different at $p < 0.05$ and $p < 0.01$, $n = 9$.

In general, in certain varieties, increasing the soil moisture content in each soil layer at each growth stage is beneficial for increasing plant height and the dry weight of stems and leaves, as well as reducing the number of plant branches. The soil moisture content below 40 cm in the seedling stage greatly influenced the potato growth index.

3.6. Benefit Analysis of Different Treatments

The effect of straw mulching mechanized no-tillage planting on potato production had higher economic benefits and a better output/input ratio than CK (Table 11). Compared with CK, HM and JG increased cladding material but greatly reduced labor input and improved operation efficiency. JG had the highest economic benefits and output/input ratio compared with other treatments in both years. JG increased net income and output/input ratio by 10.64% and 12.68% compared to CK. The net income of HM is slightly lower than that of CK, but the ratio of output to input is slightly higher than that of CK.

Table 11. Economic benefits of straw mulching mechanized no-tillage planting on potato production based on data from experimental field plots in Tongwei and Lintao, Gansu Province, China, in 2021 and 2022.

Treatment	Mean Yield (kg/hm ²)	Value of Output (CNY/hm ²)	Input (CNY/hm ²)				Net Income (CNY/hm ²)	Output/Input Ratio
			Cladding Material	Labor	Others (Fertilizers, Seeds, Pesticides, etc.)	Total Investment		
JG	34,722.75	24,305.93	2160.00	3600.00	4500.00	10,260.00	14,045.93	1.37
HM	31,999.43	22,399.60	1650.00	4000.00	4500.00	10,150.00	12,249.60	1.21
CK	32,931.30	23,051.91	0.00	6000.00	4500.00	10,500.00	12,551.91	1.20

Note: The output value is 1.4 CNY/kg according to the unified price of fresh potato, and the manual and other calculations are based on the actual occurrence of the test site.

4. Discussion

4.1. Effect of Mechanized No-Tillage Planting with Straw Mulching on Soil Moisture in Farmland

Different tillage methods can improve soil moisture conditions in farmland, enhance precipitation use efficiency, and promote crop growth [12–14]. This experimental study demonstrates no significant difference in soil moisture content between plastic film mulching and mechanized no-tillage planting with straw mulching ($p > 0.05$). However, both are significantly higher than traditional conventional planting (CK) ($p < 0.05$) (Figure 3). This finding is consistent with the conclusions of previous studies by Hou Xianqing [15,16], Zhang Long [17], and others. The water retention and moisture conservation effects of plastic film mulching and mechanized no-tillage planting with straw mulch cover varied over the two experimental years. Before the tuber formation period in 2021, JG was higher than HM, while during the tuber swelling and starch accumulation period, it was lower than CK. In 2022, the soil moisture content of HM and JG during each growth period was higher than CK, with JG being significantly higher than HM after the tuber swelling period, and the difference was most significant at the harvest stage, being 1.55% higher than HM (Figure 6). The main reason for the analysis is that the amount of rainfall in the two experimental years was quite different (317.2 mm in 2021 and 211.45 mm in 2022). The effects of mulching and tillage methods on rainfall infiltration are different. HM can easily stagnate in the low-lying part of the film under heavy rain and less than 5 mm of precipitation, which hinders water infiltration. At the same time, it increases soil temperature during the growth period and increases evaporation loss [18]. JG is easy to infiltrate under heavy rain [19], affecting water storage and soil moisture conservation.

4.2. Effect of Straw Mulching Mechanized No-Tillage Planting on Potato Growth Index

Covering and tillage methods [20,21] have a significant impact on the growth indicators of potatoes. For instance, plastic film mulching can promote the nutritional growth of potatoes [22], and no-tillage with straw mulch combined with plastic film mulching significantly increases the height of potato plants [23]. Both plastic film and straw mulch cover effectively increase plant height and biomass accumulation [24]. This study showed that the increase in rainfall was beneficial to increases in plant height, but it was not conducive to increases in branch number. Compared with CK, JG was helpful in increasing the plant height at the tuber formation stage, increasing the dry weight of stems and leaves at the late growth stage, the number of tubers per plant and the dry weight of tubers per plant, and reducing the number of branches. HM was beneficial for increasing the dry weight of stems and leaves at the early growth stage. This finding is broadly consistent with the experimental conclusions of Hou Xianqing et al. on no-tillage and mulch-covered potato planting in the Ningnan Mountainous Area [22].

4.3. Effect of Mechanized No-Tillage Planting with Straw Mulching on Yield and Water Use Efficiency

Existing studies have shown that mechanized no-tillage planting with straw mulching can improve the soil environment of farmland, increase crop yields, and enhance water use efficiency [25–27]. For instance, Zhao Hong et al. found that the ridge furrow cultivation of potatoes could increase yield and water use efficiency compared to traditional flat planting, with a yield increase of up to 78.2% with a double ridge furrow covering [10]. Zhang Pingliang's research on different covering planting methods in the arid areas of northwest China revealed that compared with open field planting, whole film mulching ridge planting could increase potato yield (43.4~60.7%) and yield water use efficiency (59.4~79.6%) [28]. Wu Chunhua et al. showed that ridge furrow rainwater harvesting combined with mulching could significantly increase potato yield (44.8%) and the commodity potato rate (8.1%) compared with open field planting [29]. Zhang Long et al., through research on no-tillage and deep loosening combined with straw mulching, found that different tillage measures combined with straw mulching could further increase water storage in the 0 to 100 cm soil layer, which is beneficial for stable and high potato yields [17]. However, some studies have found that covering plants leads to yield reduction. For example, Zhang Long et al. found that no-tillage planting increased soil bulk density, affecting crop root growth and hindering the crop's absorption of deep soil nutrients, thus affecting crop yield [30]. Li Fengmin et al. found that the warming effect of plastic film coverings led to premature senescence of wheat in the later stages of growth, resulting in reduced wheat yields [31]. Gao Chuang et al. showed that moderate covering in rainfed areas is conducive to increasing wheat yields, while excessive covering reduces yield [32].

The effects of mulching and tillage methods on yield and yield water use efficiency were significantly different. ($p < 0.05$). In the two experimental years, the yield increase of JG was significantly different from that of CK, being 3.09% in 2021 and 12.27% in 2022. The main reason is that the test site was located in Lintao in 2021, where the effective rainfall in the potato growing season was 317.2 mm, indicating a wet year. This amount of rainfall can meet the needs of potato growth, and the effect of water storage and the soil moisture conservation of mulching treatment is not significant. In 2022, the test site was located in Tongwei County, and the effective rainfall in the potato growing season was only 211.45 mm, indicating a dry year. JG reduces water consumption during the potato growth period and improves water use efficiency. The results show that the straw mulching mechanized no-tillage planting of potatoes is more suitable for dry farming areas with less rainfall.

The yield water use efficiency of HM was 8.31% and 6.88% lower than that of CK in 2021, respectively. In 2022, it was 13.09% and 10.19% higher than that of CK, respectively, reaching a significant level ($p < 0.05$). The main reason is that the experiment was set in Lintao, Gansu Province, in 2021. The soil is sticky and heavy. If there is rainfall after sowing, the precipitation accumulates at the seedling hole. After rain, irradiation from the sun makes the soil harden at the seedling hole on the film surface, which seriously affects potato emergence. The natural emergence rate in 2021 was only 66%. Due to the high temperature of soil compaction and plastic film mulching, the growth of potatoes was seriously affected. At the same time, to ensure that the HM reached the density set in the experiment, the experiment ensured the planting density of potatoes by artificial seedling replenishment, which seriously affected the yield and yield water use efficiency of potatoes. In 2022, the experiment was conducted in Tongwei, Gansu Province, where there was relatively less rainfall and loose soil. The emergence under plastic film coverings was better, and the difference in yield between JG and HM was not significant but significantly higher than the yield of CK ($p < 0.05$). HM and JG significantly increased the tuber weight per plant compared to CK.

In general, the yield of JG in the two soil types was relatively stable and higher than that of CK. HM in areas with sticky soil would seriously affect the emergence and yield of potatoes.

4.4. Application Value of Different Treatments

HM could improve soil water content and increase potato yield. The average ratio of output to input in the two experimental years was slightly higher than that of CK. Tongwei's dry land had a good yield effect, but under the condition of Lintao's clay soil, potato seedling emergence was seriously affected due to soil compaction. HM can be popularized and applied in dry loessial soil or areas with sandy loam. However, the long-term use of PE film mulching to increase the pollution of residual film mulching in farmland can promote the application of biodegradable film in dryland areas.

Compared with CK, JG increased soil water content, reduced soil water consumption, and increased potato yield and water use efficiency. The average output/input ratio in the two experimental years was higher than that of CK. The yield in the two experimental areas was relatively stable. In 2022, the yield and water use efficiency were similar to HM. At the same time, straw mulching planting has the following advantages. First, JG completes the no-tillage planting of straw-covered potatoes through seeding machines, which can significantly reduce labor intensity compared with traditional manual mulching. Second, JG provides a resource utilization for idle corn straw in dry farming areas, which can prevent haze pollution caused by the burning of straw. Third, JG planting is conducive to reducing the use of polyethylene plastic films and soil pollution caused by residual films. Fourth, JG mulching improves soil structure and increases soil organic matter. In summary, JG is a simple, economical, green, and sustainable potato mulching planting technology that is suitable for application in the production of arid rain-fed agricultural areas in northwest China.

4.5. Research Prospects

This study was conducted in Tongwei County and Lintao County, Dingxi City, China. The two experimental areas had different rainfall and soil types. At the same time, only the soil moisture and growth index of the critical growth period were measured, and the data of the two test points were used for statistical analysis. The reliability of the conclusion needs to be further investigated. In order to fully reflect the production effect of JG, continuous monitoring of soil moisture and soil temperature should be carried out in the future. At the same time, covering no-tillage also affects soil respiration, nutrient absorption and loss [33], the individual density of farmland soil macrofauna [34], and soil microbial diversity [35]. It can be seen that there may be complex interactions between these soil indicators. Therefore, it is necessary to conduct a comparative study of JG on the above soil indexes in the future.

5. Conclusions

Compared with traditional film mulching and conventional planting, there was no significant difference in yield between JG and HM in the two test years, but it was significantly higher than CK. The yield of JG was 3.09~12.27% higher than that of CK. This increase in yield was mainly achieved by increasing the potato weight per plant (0.697~0.862 **) and the average single potato weight (0.048~0.631). JG could significantly increase potato yield water use efficiency by 6.5~26.17% compared to CK, and reduce the water consumption of crops during the whole growth period by 11.35~29.52 mm. When HM is applied in areas with heavy soil and relatively heavy rainfall, soil compaction will seriously affect seedling emergence, thereby increasing labor input and reducing potato yield. JG had better water conservation and yield effects than CK in both test areas and was strongly adaptable to soil types. At the same time, JG could reduce the amount of plastic film, the cost of land preparation, and the production cost. It is a green and efficient potato mechanized cultivation technology suitable for dry farming areas (maize and potato rotation cultivation). This study studied soil moisture, agronomic indicators, and yield. In the follow-up study, straw-covered potato no-tillage yield-increasing mechanisms could be examined to improve soil temperature, structure, and physical and chemical properties.

Author Contributions: Conceptualization, H.L.; methodology, P.L. (Pengxia Liu) and H.Z.; software, H.L.; validation, P.L. (Peiwen Li) and F.Z.; formal analysis, P.L. (Peiwen Li), W.S., X.L. and H.L.; investigation, P.L. (Pengxia Liu), H.L. and X.L.; resources, H.L. and F.Z.; data curation, H.L.; writing—original draft preparation, P.L. (Peiwen Li); writing—review and editing, H.L.; visualization, H.L.; supervision, H.L.; project administration, H.L.; funding acquisition, H.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was financially supported by the Public Recruitment Doctoral Research Initiative of Gansu Agricultural University in China (GAU-KYQD-2021-33), and the Research and Development of Agricultural Machinery and Equipment of Agricultural and Rural Department of Gansu Province Project (njyf2024-04-1), and the Gansu province agricultural machinery R & D and manufacturing application integration (2-2), and the Gansu Provincial University Industry Support Plan (2024CYZC-32), and Northwest Chinese herbal medicine full mechanization scientific research base construction project (2109-000000-20-01-199092).

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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

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