The effect of planting mode on the growth of pepper in a sunlight greenhouse

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Abstract. To adapt to the development of mechanization, a new mechanized planting mode is needed. Taking capsicum as the research object, a comparative test of mechanical east-west ridge planting mode and artificial north-south ridge planting mode was carried out in Hotan sunlight greenhouse with 2ZYZ-2 transplanter. The results showed that transplanting depth of 6 cm, row spacing of 30 cm and row spacing of 40 cm were the best working parameters of the transplanter. The plant height of artificial model pepper was 4.1% and 3.95% higher at 35 and 70 d, while the stem diameter of mechanized model pepper was 5.72% and 3.63% higher at 35 and 70 d. The difference was significant between them. However, the difference between the underground part of the two modes is small, while the accumulation of the mechanized part of the above ground is high and the characters are reasonable. The effective yield of mechanized mode is 2.38 t, which is 11.21% higher than that of manual mode. The two modes of pepper have the same nutritional composition. Therefore, the mechanized planting mode has certain advantages over the artificial planting mode and it can be used in Hotan sunlight greenhouse for pepper production.

1. Introduction

The term “solar greenhouse” is the short form of “energy-saving solar greenhouse”, which is mainly composed of gables on both sides, a back wall to facilitate maintenance, a supporting framework, and covering materials. It provides the advantages of low construction costs, good thermal insulation performance, reduced energy consumption, and easy maintenance. As the winter season in Hotan is characterized by a small solar zenith angle, with the sun rising in the southeast and setting in the southwest, solar greenhouses in the region are usually north-south oriented and extend in an east-west direction to maximize sunlight utilization in winter [1]. Traditional solar greenhouses usually adopt ridge cultivation in a north-south orientation for the better utilization of light energy. Such a layout is also simpler and more reasonable, with low operating requirements and a high space utilization rate. However, the large number of ridges with a short ridge length combined with the limited working space in greenhouses creates difficulties when maneuvering agricultural machinery, such as turning around, greenhouse entry, forward movement, and plowing at the edges. To cater for the development of mechanization, farmers in some areas have started to adopt ridge cultivation in an east-west orientation.
The effects of ridge orientation have been the subject of debate among researchers in recent years. Song contended that a change in the ridge orientation did not affect crops [2], and Feng et al. suggested that the east-west orientation provided more benefits [3]. However, the studies conducted by the aforementioned researchers mainly focused on field crop production rather than solar greenhouse cultivation. In addition, much of the research was centered on agronomy, whereas the influence of mechanized planting on crops in actual production has been largely neglected.

At present, there is a lack of systematic research on the mechanized planting of chili peppers, a major crop of Hotan, in solar greenhouses. In this study, a mechanized planting experiment was carried out with a chili pepper cultivar using the 2ZYZ-2 self-propelled transplanter in a solar greenhouse in Hotan. We aimed to determine the appropriate operating parameters for mechanized planting, investigate the differences between mechanized planting and conventional manual planting, and analyze the feasibility of mechanized planting in solar greenhouses in Hotan, to provide scientific support for agricultural development in Hotan.

2. Materials and methods

2.1. Experimental materials

The solar greenhouses used in the experiment were located in Jinye Village, Jiya Township, Hotan City (37.33°N, 79.72°E) at the southern fringe of Taklimakan Desert, which is characterized by high terrain in the south and low terrain in the north, an average altitude of approximately 1,300 m, an annual average temperature of 11.5°C, extreme maximum temperature and minimum temperatures of 41.9°C and -23.9°C, respectively, multi-year average precipitation of 35.1 mm, annual potential evapotranspiration of 2,595.3 mm, and a drought index of 20.8.

The chili pepper cultivar used in the experiment was Daguo 60, produced by Riyue Vegetable Seed Co., Ltd. Fifty-day-old seedlings were planted using a typical ridge-furrow pattern in the solar greenhouses. For each greenhouse, 10 m³ of cattle and sheep manure was prepared, fermentative bacteria were added to adjust the moisture content to approximately 60%, and the compost pile was turned every seven days. Before planting, the land was leveled and treated with the fermented manure and an appropriate amount of organic fertilizer (30 kg of calcium superphosphate and 30 kg of compound fertilizer). The base fertilizer was evenly mixed into the soil using a rotary tiller with a rotary tillage depth of 25 cm. After treatment, the soil had a pH of 7.7, organic matter content of 31.95 g·kg⁻¹, hydrolyzable nitrogen content of 105 mg·kg⁻¹, available phosphorus content of 193 mg·kg⁻¹, and rapidly available potassium content of 306 mg·kg⁻¹.

The equipment used were the 2ZYZ2 self-propelled transplanter (Kunming Shunji Technology Co., Ltd., China).

2.2. Experimental design

The experiment was conducted in greenhouses C006 and C007 in Jinye Village on July 10, 2019. A north-south ridge orientation was adopted for the greenhouse designated for the manual planting while an east-west ridge orientation was adopted for the greenhouse designated for mechanized planting. To ensure the ease of operations, the planting parameters were rounded off as follows: transplanting depth, 6 cm; row spacing, 30 cm; plant spacing, 40 cm; ridge height, 20 cm; ridge width, 60 cm; and aisle length, 35 cm. Transplanting along the east-west and north-south orientations were carried out using the 2ZYZ-2 self-propelled transplanter and manual planting, respectively. The effective yields, plant growth status and fruit quality of the two greenhouses were recorded.

Measurements of plant height and stem diameter: In each greenhouse, the planting area was divided into 10 plots using the diagonal method, and 10 sample plants were selected from each plot for data collection. For the 100 sample plants, plant height and stem diameter were measured at 5 d (seedling stage), 35 d (flowering and fruit setting period), and 70 d (mature stage).

Measurement of plant material accumulation: After the harvest period, five sample plants were selected from each plot. The 50 sample plants from each greenhouse were subjected to cleaning followed
by separation of the aboveground and underground plant parts. After the measurement of the fresh weight, the plant parts were dried to a constant weight at 105°C in a forced convection drying oven. The root-shoot ratio was calculated after the measurement of the dry weight.

Measurement of effective yield and fruit quality: Harvesting was performed 75–80 days after planting, and screening was performed using the same method adopted in the planting parameter selection experiment. One hundred fruits were randomly selected from each greenhouse for the measurement of fruit type parameters and nutrient contents, with the measurement of nutrient contents conducted in the Urumqi laboratory of Pony Testing Group Co., Ltd. The capsaicin content was measured according to the relevant Chinese national standard (GB / T 21266-2007, GB / T 5009.86-2003, GB / T 5009.10-2003, GB 5009.124-2016).

3. Results and analysis

3.1. Comparison of mechanization and manual planting

Compared with manual transplanting, mechanized transplanting had lower coefficients of variation for plant spacing and row spacing, and a higher qualified rate of planting depth, which indicated that the 2ZYZ-2 transplanter achieved higher planting accuracy than manual transplanting. During the measurement process, it was found that missed planting and seedling damage, which occurred during mechanized operations, were rare with manual operations. This represents an advantage of manual transplanting as well as a key area of improvement for transplanters.

3.2. Comparison of plant growth during different periods

Table 1 shows the growth parameters of the chili pepper plants. When the external appearance of the plants was compared, it was found that plant height for the manual planting mode exceeded that of the mechanized planting mode at 35 d and 70 d, with growth rates for the two modes being 4.1% and 3.95%, respectively. By contrast, the stem diameter for the mechanized planting mode exceeded that of the manual planting mode, with the growth rates being 5.72% and 3.63%, respectively. At a significance level of 0.05, the differences in plant height and stem diameter between the two planting modes were significant. Measurements of bioaccumulation revealed no significant differences in the underground plant parts and significantly higher bioaccumulation in the aboveground parts for the mechanized planting mode compared with the manual planting mode. The root-shoot ratio for the

| Direction | Plant height [mm] | Stem diameter [mm] | Fresh weight [g] | Root shoot ratio |
|-----------|------------------|-------------------|-----------------|----------------|
|           | 35d | 70d | 35d | 70d | Above ground | Underground |               |
| NS        | 392.3±49.1a | 666.0±82.8a | 6.1±0.7b | 9.2±0.8b | 191.0±21.2b | 45.7±5.7a | 0.24 |
| EW        | 376.8±52.9b | 640.7±70.7b | 6.7±0.8a | 9.6±0.8a | 204.0±26.5a | 45.9±6.3a | 0.24 |

NS: North-south; EW: East-west

As the aboveground plant parts are primarily harvested for chili pepper plants, this result indicates that the chili pepper traits obtained with the mechanized planting mode were more desirable. Such an outcome may be attributed to better daylight conditions in the east-west ridge orientation compared with the north-south orientation, which had a stronger inhibitory effect on auxin in the plants. Consequently, stem elongation was inhibited, resulting in shorter plants. Moreover, better daylight conditions also enhanced plant photosynthesis, which contributed to thicker stems and greater dry matter accumulation [4].

3.3. Comparison of yield and fruit quality

Harvesting was performed in the two greenhouses in September 2019. The effective yields for the mechanized and manual planting modes were 2.38 t and 2.14 t, respectively. The difference between the
actual and predicted yields for the mechanized planting mode was 8.82%, which indicated adequate reliability of the model. The yield achieved with the mechanized planting mode was 11.21% higher than that of the manual planting mode, suggesting that mechanized planting was superior to conventional manual planting in terms of yield.

Table 2 show the measurement results of fruit appearance, dimensions and nutrient contents. The fruit appearance measurements revealed no significant difference in the appearance of the chili pepper fruit between the two modes, with the harvested fruits having the same level of appearance quality [5].

| Direction | fruit weight/g | thickness/mm | Fruit shape index | capsaicin/g·kg⁻¹ | Vitamin C/mg·100g⁻¹ | Total soluble sugar/% | Crude fiber/% |
|-----------|----------------|--------------|-------------------|------------------|---------------------|----------------------|--------------|
| NS        | 60.1±8.9a      | 2.6±0.3a     | 4.5±0.2a          | 0.009            | 133                 | 4.36                 | 1.1          |
| EW        | 60.8±6.4a      | 2.5±0.2a     | 4.5±0.2a          | 0.007            | 94.2                | 4.22                 | 1.0          |

The nutrient content measurements revealed that chili pepper fruits harvested from manually transplanted plants contained 28.57% more capsaicin, 41.19% more vitamin C, 3.31% more soluble sugars, and 10% more crude fiber than those obtained from mechanically transplanted plants. There was no significant difference in the amino acid composition of the harvested fruits between the two planting modes, with aspartic acid and glutamic acid having the highest contents and accounting for approximately 40% of the total amino acid content. The total amino acid content of fruit obtained from mechanized planting was 20.73% higher than that of fruit obtained from manual planting, with the essential and non-essential amino acid contents being 10.63% and 25.6% higher, respectively.

In view of the fact that the flavors of the chili peppers are determined by their nutrient contents [6], it was deduced that differences existed in the flavors of the chili pepper fruit obtained from the two planting modes. To elucidate the influence of such flavor differences on the economic value of the chili pepper fruit, 50 local workers were tasked to perform a sensory evaluation of the various fruits. The sensory score of artificial and mechanical was 13.3 and 14.1. The evaluation results suggest that there was no significant difference in the sensory scores of the fruit obtained from the two planting modes. Therefore, it can be deduced that the differences in flavor had no influence on economic value of the fruit.

4. Conclusion
The results of existing research, including in this study, have shown that the adoption of an east-west ridge orientation in solar greenhouses does not reduce the economic value of crops. Mechanized planting significantly enhances the operating efficiency of solar greenhouse and reduces labor wastage without influencing the economic value of the agricultural product. Our results fully demonstrate the feasibility of mechanized transplanting in solar greenhouses in Hotan, and the planting modes derived from this study can serve as theoretical and practical bases for agricultural production in Hotan.

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