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Safe and High-efficient Cultivation Technology for Facility Carrot Industrialization

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Abstract Based on the current problems in carrot production, Laixi City of Shandong Province adopted 5 m large arch shed double-layer plastic film to cultivate "Three Red" carrot, selected varieties suitable for export, ridging double-row mechanical drilling, integrated water and fertilizer management, carrot residue composting and returning to field, and finally realized safe and high efficient production of facility carrot industrialization.

Key words Facility carrot, Industrialization, Safe and high efficient technology

1 Introduction

Laixi City of Shandong Province started introducing carrots in 1995. The main carrot producing area is located in the southern low-lying land, where the soil is mainly Shajiang black soil with high viscosity, high water and fertility retention, but poor permeability. Due to such special soil, the carrots produced in Laixi City are well-known for "Three Red" features (red skin, red pulp, and red heart), and also characterized by good color, smoothness, bright appearance, and high sugar content, accordingly favored by consumers in local and other places. It has formed the famous local brand "Qingdao Dianbu Carrot". In 2010, "Dianbu Carrot" passed the Certification of Ministry of Agriculture for Agricultural Products Geographical Indications Protection; in 2013, Dianbu Town was determined as the national "one village one product" carrot demonstration town; in 2014, "Dianbu Carrot" was awarded by the Ministry of Agriculture as the national new, famous, and high quality agricultural products. At present, the carrot planting area in Laixi City has reached 4 333.3 ha, and the facility carrot planting area is up to 2 333.3 ha, in which 1 466.7 ha adopted 5 m large arch shed double-layer plastic film, accounting for 1/3 of the carrot planting area of the whole city. With the rapid development of large-scale and standardized facility carrot planting, continuous cropping, serious diseases and pests, excessive fertilizer and pesticide application have led to decline in the yield and commerciality of carrots, which restricts the improvement, transformation and upgrading of the carrot industry. At the same time, Laixi City has formed an industrial development model with "farmers + bases + leading enterprises (cooperatives)" as the main body, and also put forward higher requirements for the safe production of industrialized carrots.

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2 Existing problems and industrialization development mode of carrot production

Laixi City has more than 20 years of carrot cultivation. With the expansion of planting sale, more and more problems appear and lead to decline in both the yield and commerciality of carrot, which restricts the quality improvement, transformation and upgrading of the carrot industry.

(i) Continuous cropping, serious diseases and pests. Limited by land, carrots are seriously influenced by continuous cropping. Besides, the continuous cropping also aggravates the occurrence of the black rot and meloidogyne. (ii) Excessive application of fertilizer and pesticide. In order to pursue higher yields and benefits, carrot growers blindly increase the application of chemical fertilizers, leading to imbalance of acid and alkali in the soil and serious salinization; in order to pursue the effect of pest control, they increase the amount and frequency of chemical pesticides, leading to hidden danger of pesticide residues. (iii) Blind expansion of production scale. Most of the carrots produced in Laixi City are sold to Japan, South Korea, Southeast Asia, the Middle East and China's southern market. Due to the influence of the international market, the price difference between the years is significant. In addition, in order to obtain greater benefits, the carrot growers often blindly expand their production scale, leading to carrot overstock and price drop.

In recent years, Laixi City has formed an industrial model with "farmers + bases + leading enterprises (cooperatives)" as the main body for carrot cultivation. The total yield of facility carrots is 175 000 t, the output value is about 400 million yuan, and the export volume is 30 million US dollars. Now, there are more than 20 carrot processing enterprises, in which Qingdao Qianhoutun Carrot Specialized Cooperative, Qingdao Youtian Agricultural Development Co., Ltd., and Qingdao Lijun Food Co., Ltd. have annual sales of more than 20 000 t and annual sales amount of more than 40 million yuan. These promote sound and stable sustainable development of the carrot industry in Laixi City.

3 Key technologies for safe and industrialized carrot production

In view of existing problems in the traditional carrot production, Laixi Agriculture Bureau has developed a series of supporting measures in cooperation with local government, leading enterprises, specialized cooperatives, as well as related technical personnel.

3.1 Determining the cultivation varieties according to the market demands Through constant introduction, experiments and demonstration, it is recommended to select excellent carrot varieties which have good commerciality, and are suitable for Laixi City and favorable for export, such as Mendel series, Shinong series, and New Heitianwucun ginseng carrot, *etc*.

3.2 Promoting safe cultivation technologies for facility carrot

3.2.1 Fine soil preparation and formulated fertilization. It is recommended to select Shajiang black soil with high terrain, good drainage, deep soil layer, viscous texture, and high organic matter as the carrot cultivation area. The soil should be ploughed for more than 40 cm, and finely and deeply raked. Besides, it is necessary to remove weeds, eliminate pests and insects, store water and keep moisture, and resist drought and flood. Combined with deep tillage, for one hectare land, it is recommended to apply 1 500 – 3 000 kg of high-quality decomposed organic fertilizer, 1 500 kg of potassium sulfate compound fertilizer (N-P-K 15-15-15), and 600 – 750 kg of multi-element mineral fertilizer (Ca≥8%, Mg≥8%, S≥4%, Si≥4%, and trace elements≥2%).

3.2.2 Rotary tillage ridging. Mechanical rotary tillage should be carried out within 7 – 10 d before sowing at the tillage depth of 15 – 20 cm. After tillage, fine raking should be performed, to achieve no clod of earth at upper layer, no ridge lying at the lower layer, and rubbles and grass roots should be removed. Large arch shed double-layer plastic film is adopted, with arch span of 5 m and shed height of 1.4 – 1.5 m. Set five ridges, 1 m of ridge spacing, 70 cm of ridge bottom width, 25 – 30 cm of ridge surface width, 25 – 30 cm of ridge height, and 30 cm of furrow width. Large arch shed is set with three small sheds with height of 0.8 – 1.0 m. The two outer small sheds have span of 2 m, covering two ridges, and the middle small shed has span of 1 m, covering one ridge.

3.2.3 Sowing in proper period. (i) Sowing time. Using 5 m large arch shed, the suitable sowing time is January 10 to February 5. Carrots belong to long sunshine crops. At 4 – 5 leaves or even 2 – 3 leaves of the seedling stage, carrots can sense the low temperature and have the vernalization. When the temperature is lower than 10℃ and the accumulation time is more than 350 h, it is easy for bolting, and the lower the temperature, the longer the low temperature time, the higher the bolting rate. If the sowing is too late, the temperature in the late growth period will be too high, it will affect the carrot yield and quality. Therefore, the sowing time of carrot should not be too early or late. (ii) Sowing methods. The ridging double-row drill sowing method is used, because this method is easy for thinning out seedlings, convenient for field management, and carrots planted by this method are uniform in size without branching. The carrot seeds are first braided into seed strips and then sowing machine is adopted. Seed strips are generally braided as per the spacing of 3 cm – 3 cm – 6 cm. (iii) Sowing rate. Bare seeds: one seed for 3 cm, 2 025 – 3 000 per ha; pelletized seeds: one seed for 5 – 6 cm, 52.5 – 60.0 barrels per ha (10 000 seeds per barrel). Each ridge is sown with two rows, with row spacing of 11 – 13 cm, covering 1.5 – 2.0 cm deep soil. (iv) Sealed weeding. After sowing, use 250 g of 20% Pendimethalin + 3 750 g of 2.5% Lambda-cyhalothrin, and 600 – 750 kg of water, to evenly spray the ridge surface. The pesticide is prepared by two dilution methods. First, adjust the liquid to thick mother liquor with a small amount of water, and then dilute to the desired concentration, ensure the pesticide is evenly dispersed in the water, which is favorable for precisely applying pesticides and reducing pesticide residues.

3.2.4 Thinning out seedlings. Seedlings should be thinned out at the height of 5 – 8 cm, with seedling spacing of about 5 cm. The action of thinning out seedlings should be gentle, to prevent injury of root systems due to soil looseness, leading to dead seedlings and branching, influencing the yield and quality of carrots. At the same time of thinning out seedlings, it is necessary to perform weeding.

3.2.5 Integrated water and fertilizer management. The growth of carrots in the early stage is slow, and the amount of fertilizer needed is small. At the middle and late stages, the roots are rapidly expanding, and the amount of fertilizer needed is increased sharply. At the early stage, the topdressing was mainly based on nitrogen fertilizer; at the middle and late stages, the quick-acting fertilizer should not be applied within 20 d before harvesting.

Integrated water and fertilizer topdressing generally applies water-soluble fertilizer. Water-soluble fertilizers include solid and liquid forms. The micro-irrigation special-purpose liquid fertilizer is convenient for use, and the suitable fertilizer type and nutrient mixing ratio should be selected according to the soil nutrient, the carrot variety and the growth period, and it is feasible to adopt suitable soluble solid fertilizer suitable for the mixing ratio. When performing topdressing, first use clear water to drip for longer than 5 min, then open the control switch of the fertilizer mother liquor storage tank to make the fertilizer enter the irrigation system. Through adjusting the water and fertilizer mixing ratio of the fertilizing device or adjusting the valve flow of the fertilizer mother liquor flow, the fertilizer mother liquor is mixed with the irrigation water at certain ratio and then applied to the field. When adopting the integrated water and fertilizer drip irrigation, it is required to distinguish pellet seeds and bare seeds.

Drip irrigation for pellet seeds: water the first time within 2 – 3 d after sowing, generally at the rate of 60 – 90 m^3 water for one hectare land. Water the second time in 5 – 7 d after the first time, generally at the rate of 75 – 105 m^3 water for one hectare land. After the second watering and before the emergence of the seedlings, water one time every 6 – 8 d at the same rate as the second watering. Water one time within 7 – 10 d after emergence of seedlings at the rate of 105 – 135 m^3 water for one hectare land. Drip irrigation for bare seeds: water the first time within 2 – 3 d after sowing, generally at the rate of 45 – 75 m^3 water for one hectare land; 5 – 7 d later, water the second time at the rate of 60 – 90 m^3 water for one hectare land. After the second watering and before the emergence of the seedlings, water one time every 5 – 6 d at the same rate as the second watering. Water one time within 7 – 10 d after emergence of seedlings at the rate of 90 – 120 m^3 water for one hectare land.

For cultivation using large arch double-layer plastic film, water after covering the small arch plastic film, seedlings will emerge 20 – 25 d after watering, and seedlings become uniform after 45 d. After final seedlings, together with watering, apply one time of 37.5 – 75.0 kg of high-nitrogen water-soluble fertilizer (N-P-K is 30-10-10 + TE) for one hectare land. At the fleshy root expansion stage, apply 75 – 150 kg of high potassium water soluble fertilizer (N-P-K is 18-5-35 + TE), conduct topdressing one time every 5 – 7 d, and continuously apply 3 – 4 times.

3.2.6 Letting in fresh air. When the maximum temperature in the large arch shed reaches 10℃, open one air port with diameter of 10 cm at the top of inner film; when the maximum temperature reaches 13 – 14℃, uncover the inner film; when the maximum temperature reaches 15℃, uncover both sides of outer film to let in fresh air, and open one air port every 20 m; when the maximum temperature reaches 20℃, open one air port every 10 m in both sides of the outer film; when the minimum temperature within the arch shed remains 6℃ for 3 – 5 consecutive days, keep one meter of both sides of outer film, and uncover the rest film; when the temperature is below 0℃, close all air ports.

3.2.7 Prevention and control of diseases and pests. It is recommended to make proper crop rotation, for example, take the rotation between carrot and summer maize, and carrot and summer peanut. At the same time, green prevention and control technology is adopted to prevent pests and diseases.

(i) Prevention and control of soft rot. Use 72% agricultural streptomycin wettable powder (WP) 1 500 times, or 90% neomycin WP 1 000 times liquid to spray leaves, or use 50% chlorobromoisocyanuric acid WP 3 000 times solution to water roots.

(ii) Prevention and control of black rot. Before spwomg, apply 30% benzoyl propiconazol WP 22.5 – 30 kg per ha during ridging, or use 7.5 kg of stress-resistance inducer 20% hymexazol Isoprotholane (transplanting pesticide) emulsion oil to irrigate the carrot roots during the first time of watering; at the early stage of disease, spray 50% chlorobromoisocyanuric acid WP 2 000 times solution or 30% benzoyl propiconazol WP 2 000 times solution for prevention and control of black rot.

(iii) Prevention and control of root-knot nematode disease (meloidogyne). Because meloidogyne likes air, the soil should be ploughed for more than 25 cm deep. After harvesting carrots, completely remove the residual plants and burn them down. Alternatively, it is feasible to use summer hot temperature to disinfect the soil. Apply 1 500 kg of lime powder per ha on the ridge surface, plough and water one time, then cover with the plastic film, and use the high temperature above 50℃ under the film to effectively kill the root-knot nematode and soil-borne bacteria; or mix 30 – 45 kg/ha 10% thiazolidine granules with 750 kg of fine sand, apply them during ridging; or use 30 – 45 kg of 1.8% avermectin emulsion oil mixed with 1 500 – 3 000 kg of water to evenly spray the ridges for prevention and control of root-knot nematode disease.

3.2.8 Harvesting in proper time. The carrots planted with a 5 m large arch shed double-layer plastic film are generally harvested around May 20. During this period, the fleshy roots are 18 – 22 cm long, the single carrot weighs 150 – 200 g, and the yield is up to 60 000 – 75 000 kg/ha. The harvesting time can be adjusted according to market prices and market demands.

3.3 Benefit analysis According to the carrot planting with large arch shed double-layer plastic film in recent three years, there are great differences in the carrot income between years. Generally, the output value is 135 000 – 225 000 yuan/ha. Excluding the input cost of 45 000 – 52 500 yuan/ha (including large and small bamboo skin 15 000 – 18 000 yuan, plastic film 13 500 – 15 000 yuan, seed braiding, fertilizer, sowing, weeding, watering, labor, and machinery 16 500 – 19 500 yuan), the net income is about 90 000 – 172 500 yuan/ha, increasing by 25% and 118.8% compared with 2 m arch shed and open field planting.

3.4 Treatment of carrot residues About 180 000 t of carrot residues is generated from the cultivation of facility carrot in Laixi City. In the past, carrot growers treat carrot residues mainly through discard (to ponds, ditches, rivers), burial or burning, which easily lead to widespread of diseases and pests caused by carrot residues, and lead to pollution to air and water resources, consequently affecting people's living environment and physical and mental health. Through study and discussion, we summarized a simple harmless treatment method, namely, carrot residue composting and returning to field. The specific procedures are as follows.

(i) Composting site should be an open place with well ventilation, good sunshine, and high terrain. (ii) Cut the carrot residues into 3 – 5 cm small pieces, and remove plastic film, strings, and pesticide bags. (iii) Weigh 10 kg of urea and mix it with 25 kg of water to prepare a liquid for use; use RW rot-promoting agent (produced by Hebi City Renyuan Biotechnology Development Co., Ltd., viable bacteria count ≥ 5.0×10^9 cfu/g) 250 g, add 7.5 – 10.0 kg of wheat bran, mix well for use. (iv) Evenly place the small pieces of carrot residues at thickness of 20 – 25 cm, spray the prepared urea liquid evenly to the residues,

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tion, the pepper plants were short and thin. This was because that the lower root activity of pepper under continuous cropping conditions weakened the nutrient absorption capacity of pepper, and the decrease of chlorophyll content affected the photosynthesis of the pepper. This in turn affected the growth of shoots and underground part of the plants, which eventually led to disorders in the growth and development of the pepper. Among the continuous cropping treatment groups, the leaf area, average plant weight and yield of pepper growing in the soil that had been planted with pepper for three consecutive years were the highest. With the extension of continuous cropping duration, they tended to decline, indicating that long-term continuous cropping had a great influence on the growth traits and yield of pepper.

Continuous cropping significantly reduced the mass fraction of chlorophyll a in pepper. This might be because that environmental stress increased chlorophyllase activity and promoted chlorophyll degradation[11]. At the same time, the total chlorophyll content under continuous cropping conditions was significantly lower than that of the control. Continuous cropping resulted in a decrease in the photosynthetic pigment content of the leaves, which reduced the ability of the blade to capture and use light energy and affected the distribution of light energy in the chloroplast. This might be because that the deterioration of soil physical and chemical properties caused by continuous cropping caused malabsorption in plant roots and reduced the nutrient level in plant, so that the leaf chlorophyll content was reduced.

This study found that the soluble solids, soluble protein and total soluble sugar of the pepper fruit decreased to varying degrees. This was because continuous cropping significantly reduced the chlorophyll content of pepper leaves and affected their photosynthetic performance, thus affecting the quality of pepper fruit. Some scholars believe that when the duration of continuous cropping is longer, the yield, Vc content and soluble solids content will decline significantly[12].

The occurrence of continuous cropping obstacles involves many complex biological and non-biological factors such as crops, soil and the environment. Long-term continuous cropping results in soil salinization and acidification, structural changes, reduced activity of beneficial microorganisms[13], and serious incidence of soil-borne diseases, eventually resulting in reduced crop yield and decreased quality[14]. The mutual interaction between these factors makes this problem more complex, and it is difficult to receive ideal results from any single measure or through a combination a few measures. Because of different crop varieties and different cultivation conditions, the man reasons for continuous cropping obstacles are also different. So far, the research on continuous cropping obstacles has mostly stayed on the single factor level and is lack of in-depth understanding of the intrinsic interrelationships and interactions. Therefore, research in this area requires to be strengthened.

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and place the 1/4 fermented wheat bran to carrot residues, continue to add one layer of carrot residues at the same thickness, then spray urea and place 1/4 fermented wheat bran, and continue to operate in similar manner. (v) Stack fermented carrot residues in a trapezoid shape, generally 3–4 layers, 1.2 m stack height. After completion of stack, cover with plastic film, keep moisture and increase temperature to facilitate fermentation. The stack volume of carrot residues depends on the output of carrot residues, generally taking 1 500–2 000 kg as the unit, with the spacing of 1.5–2.0 m between stacks for the convenience of mechanical or manual operation. (vi) When the temperature within the stack is higher than 50℃, uncover the plastic film to lower the temperature; when the temperature drops to 25–30℃, turn over the stack fully to mix well, then stack the residues into trapezoid shape again, cover with the plastic film to continue fermentation, till the central stack becomes black or dark brown, and there is white or white hyphae, showing water retention and permeability, then it can be deemed that the composting is successful.