High-yield and High-efficiency Cultivation Techniques for Pepper-Maize Intercropping

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Abstract Pepper (*Capsicum annuum* L.) and maize (*Zea mays* L.) are important economic and grain crops in China. The pepper-maize intercropping model improves land use efficiency by optimizing resource allocation, delivering notable economic and ecological benefits. This article elaborates on high-yield and high-efficiency techniques for intercropping pepper with maize, including variety selection, land preparation and basal fertilization, field arrangement, sowing and transplanting, field management, and harvesting. It aims to provide technical support for standardized cultivation practices among farmers.

Key words Pepper; Maize; Intercropping; High-yield and high-efficiency; Technical specification

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Pepper (*Capsicum annuum* L.) and maize (*Zea mays* L.) are important economic and grain crops in China, holding a significant position in agricultural production. Pepper, with its rich nutritional value and strong market demand, is a key cash crop for farmers, while maize plays an irreplaceable role in ensuring food security as a high-yielding, stable-yielding grain crop. However, with the increasing scarcity of arable land and the demand for high-quality agricultural development, traditional monoculture models can no longer meet the needs of modern agricultural production. The intercropping of pepper and maize has been widely adopted and promoted by farmers due to its significant ecological and economic benefits.

Pepper-maize intercropping is a typical three-dimensional planting model. By rationally configuring the spatial arrangement and growth cycles of the two crops. The system can fully utilize natural resources such as light, heat, water, and soil. Research indicates that pepper-maize intercropping offers the following advantages: (1) Spatial complementarity. Tall maize plants can provide shade for pepper, reducing sunscald in peppers caused by intense summer light and high temperatures. Meanwhile, the low-growing characteristics of pepper reduce weed competition in maize fields. (2) Pest and disease control. Intercropping can effectively reduce the incidence of pepper blight and maize leaf spot diseases, decreasing pesticide usage and enhancing the safety of agricultural products. (3) Significant economic benefits. The intercropping model increases output per unit land area. For example, in Hunan, the total output value of intercropping can exceed 135 000 yuan/hm^2, representing income increases of 44% and 171% compared to monoculture maize or pepper, respectively. Additionally, intercropping improves soil microbial community structure and promotes nutrient cycling, achieving a balance between utilization and maintenance.

The high-yield and efficient cultivation techniques for pepper-maize intercropping have been promoted in regions such as Hubei, Hunan, Hebei, and Yunnan. However, their standardized application still faces challenges. On one hand, significant variations in soil and climatic conditions across different regions necessitate the localization of technical details such as variety selection, field configuration, and water and fertilizer management within the intercropping model. On the other hand, existing research mostly focuses on single technical aspects, lacking systematic technical specifications, making it difficult for farmers to fully realize the potential of intercropping in practice. Therefore, formulating a set of scientific, practical, and highly operable technical regulations for high-yield and efficient cultivation of pepper-maize intercropping is of great significance for promoting the standardized application of this model. The cultivation techniques for pepper-maize intercropping are now introduced as follows.

Variety Selection

Variety selection for pepper and maize is one of the key factors for the success of the intercropping model. For maize, varieties should be chosen with moderate growth periods, compact or semi-compact plant architecture, tolerance to dense planting, strong lodging resistance, high yield potential, and resistance to major diseases such as northern corn leaf blight, southern corn leaf blight, sheath blight, as well as pests including corn borer and fall armyworm. The growth period selection must align with local climatic conditions to ensure maize growth cycles matches those of pepper. For instance, in southern regions, early-to-medium maturing varieties like 'Zhengdan 958' or 'Xianyu 335' can be used, while in northern regions, medium-to-late maturing varieties such as 'Shendan 16' or 'Denghai 605' are suitable. Regarding plant architecture, compact or semi-compact types such as 'Longping 206' and 'Zhongdan 909' can reduce shading effects on pepper and improve field ventilation and light penetration.

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For pepper varieties, emphasis should be placed on disease resistance, plant architecture, and shade tolerance. Varieties with strong disease resistance, such as 'Xiangyan No. 19' and 'Zhongjiao No. 10', can effectively combat blight, anthracnose, and viral diseases. Varieties with compact architecture and fewer branches are preferable, such as the facing-heaven chili variety 'Tianyu No. 3' or the horn pepper variety 'Bulgarian'. These types reduce competition with maize and optimize spatial utilization in the field. Since peppers receive partial shade in the intercropping system, varieties tolerant to low light and less prone to excessive vegetative growth, such as spiral peppers or longhorn peppers, should be selected.

Land Preparation and Base Fertilizer Application

Land preparation should be conducted 15 – 20 d before sowing or transplanting, with a plowing depth of 25 – 35 cm. Ridge cultivation is generally adopted, with ridge widths of 80 – 100 cm, ridge heights of 30 – 35 cm, and furrow widths of 40 – 45 cm. For sloping land, ridges should be formed along contour lines to effectively prevent soil erosion. In fields prone to diseases, 900 – 1 125 kg of quicklime per hectare can be applied during land preparation to adjust soil pH, or soil fumigants such as dazomet can be used for soil disinfection to control soil-borne diseases.

Base fertilizer application is crucial for meeting the nutrient requirements of pepper and maize seedlings. The application rate can be determined based on soil fertility test results and target yield. For fields with medium fertility, it is recommended to apply 45 000 – 60 000 kg of well-decomposed farmyard manure, 750 – 900 kg of compound fertilizer (15-15-15), 450 – 600 kg of calcium superphosphate, and 225 – 300 kg of potassium sulfate per hectare. The well-decomposed farmyard manure should be evenly spread on the surface and then incorporated into the soil through deep plowing. Chemical fertilizers should be mixed and band-applied in the center of the ridge before ridging, at a depth of 15 – 20 cm. For fields deficient in boron or zinc, 15 – 23 kg of borax and 15 – 30 kg of zinc sulfate are supplemented per hectare.

Field Configuration

Scientific field configuration is key to the success of the pepper-maize intercropping model, directly affecting light utilization, ventilation conditions, and field management efficiency. The configuration must consider the growth characteristics, spatial requirements, and symbiotic relationship of the two crops to establish a reasonable planting structure. Strip intercropping is commonly used. Based on different production goals and regional characteristics, two main configuration schemes are recommended: the 2 ∶ 2 row ratio and the 2 ∶ 4 row ratio models.

The 2 ∶ 2 row ratio model is suitable for regions where maize production is prioritized. The total band width is 1. 9 m, with a maize row spacing of 70 cm, pepper row spacing of 40 cm, and a spacing of 40 cm between maize and pepper rows. In this configuration, maize planting density is controlled at 22 500 to 30 000 plants/hm^2, with a plant spacing of 35 – 46 cm. Pepper planting density is 18 000 to 30 000 plants, with a plant spacing of 35 – 58 cm. The advantage of this model is that maize obtains adequate growing space, while peppers are in a relatively shaded environment, suitable for planting pepper varieties with stronger shade tolerance.

The 2 ∶ 4 row ratio model is more suitable for regions where pepper production is prioritized. The total band width is 2. 5 m. Maize row spacing remains at 70 cm, pepper row spacing at 40 cm, but the spacing between maize and pepper rows is reduced to 30 cm. In this configuration, maize plant spacing is adjusted to 27 – 35 cm, and pepper plant spacing is 54 – 88 cm. This model increases the proportion of pepper plants, allowing peppers to receive more light resources, and is suitable for planting pepper varieties requiring stronger light. Meanwhile, reducing the row spacing between maize and pepper can enhance the ecological interaction between the two crops.

Fig. 1 Pepper-maize intercropping model

Sowing and Transplanting

Sowing and transplanting in the pepper-maize intercropping model require scientific scheduling based on the growth characteristics of both crops to ensure coordination during their co-growth period. Maize sowing time should be determined according to local climatic conditions. Generally, direct seeding is conducted from midMarch to early April. It can be slightly earlier in southern regions and appropriately later in northern regions. Before sowing, seeds should be carefully selected to remove damaged or moldy grains, and sun-drying treatment can be applied to improve germination rate. Sowing depth should be controlled at 3 – 5 cm, with 2 – 3 seeds per hill, covered with soil and compacted after sowing. After maize emergence, timely gap filling is carried out. Thinning is performed at the 3 – 4 leaf stage, and the final seedling stand is established at the 5 – 6 leaf stage, with vigorous single plants retained.

Pepper seedling raising is a critical step for successful

intercropping, usually conducted from late February to early March. Before raising seedlings, seeds should be disinfected by soaking in 55 ℃ warm water for 15 min or in a 10% trisodium phosphate solution for 20 min. The seedling substrate should use disease-free new soil, mixed with well-decomposed organic fertilizer at a 6∶4 ratio, and supplemented with an appropriate amount of compound fertilizer. After sowing, the seedbed temperature is maintained at 25 – 28 ℃, and then reduced to 20 – 25 ℃ after emergence. Seedlings are transplanted within the seedbed when they have reached the 2 – 3 leaf stage. Pepper seedlings are transplanted in mid-to-late May, when they have developed 8 – 10 true leaves and are 15 – 20 cm tall. Hardening off is carried out 7 – 10 d before transplanting by gradually lowering the temperature to enhance stress resistance.

Transplanting should be done on cloudy days or in the afternoon on sunny days to avoid seedling wilting caused by high temperature and strong light. Before transplanting, holes are made on the ridge surface according to the predetermined plant spacing. For pepper, the transplanting depth should be such that the cotyledonary node is level with the ground. For maize, an appropriate depth is maintained. Immediate and thorough watering is carried out after transplanting. Seedling survival is closely observed for 3 – 5 d after transplanting, and dead seedlings are promptly replaced. During the pepper recovery period, a 0.3% urea solution or amino acid foliar fertilizer can be sprayed to promote rapid seedling recovery.

To ensure coordinated growth of both crops, the time interval between maize sowing and pepper transplanting should be reasonable, generally controlled at 30 – 40 d, so that maize can provide moderate shade during the vigorous growth period of pepper. Excessive density that leads to poor ventilation should be avoided. During the recovery period, the soil is kept moist, but excessive irrigation that causes soil compaction should be avoided.

Field Management

Scientific field management is the key to ensuring high yield and efficiency in the pepper-maize intercropping model. Differentiated management measures need to be taken according to the growth characteristics of the two crops. During the co-growth period, management strategies should be adjusted timely based on crop growth, focusing on water and fertilizer regulation, plant adjustment, and pest and disease control.

Water and fertilizer management

The principle of "base fertilizer as the main, topdressing as the supplement" should be followed for water and fertilizer management. For maize, topdressing of urea is applied at a rate of 150 – 225 kg/hm^2 during the jointing stage (7 – 9 leaves) and the bell stage (12 – 14 leaves), respectively, to promote sturdy stalk and grain development. For pepper, the first topdressing is applied about 15 d after transplanting and at the initial fruit-setting stage, with 75 – 150 kg of 45% (15-15-15) ternary compound fertilizer per hectare dissolved in water. Subsequently, 37.5 – 45.0 kg of 45% (15-15-15) ternary compound fertilizer per hectare is applied after every 2 – 3 harvests of pepper. Alternatively, foliar fertilization can be performed using a 0.5% potassium dihydrogen phosphate plus 0.3% urea solution. For irrigation, the principle of "small amounts, multiple times" is followed, to maintain the soil moisture content at around 60% – 70%. During the rainy season, ditches are cleared promptly to prevent waterlogging.

Plant pruning and training

Plant adjustment is an important means to coordinate the growing space of the two crops. For maize, the lower 3 – 4 old leaves are removed at the 9 – 10 leaf stage to improve ventilation and light penetration. Leaves below the ears are promptly removed after pollination to reduce nutrient consumption. For pepper, lateral buds below the first flower (king flower) are promptly removed, while 3 – 4 main branches are retained. Lower old and diseased leaves are removed during the mid-to-late growth stage to enhance field ventilation. In fields with high lodging risk, support ropes can be set up on both sides of the pepper rows to secure plants.

Pest and disease control

Pest and disease control should adhere to the principle of "prevention first, integrated control". For maize, the focus is put on controlling leaf spot diseases and corn borer. For pepper, attention should be paid to the control of blight, anthracnose, and aphids. Integrated methods combining agricultural control (crop rotation, field sanitation), physical control (yellow sticky traps, insecticidal lamps), and biological control (release of natural enemies, application of biopesticides) can be adopted. For chemical control, highly effective and low-toxicity pesticides are selected, and attention is paid to alternating their use.

For cutworm control, 0.1% diazinon granules are applied at a rate of 600 – 750 kg/hm^2 for broadcasting. For aphid control, 0.2% monosultap · thiamethoxam granules are applied at a rate of 750 – 900 kg/hm^2 for broadcasting. For corn borer control, *Beauveria bassiana* wettable powder (300 billion spores/g) is sprayed at 1 500 – 1 800 g/hm^2. Alternatively, 5% phoxim granules are broadcast at 3 000 – 3 600 g/hm^2, or 5% emamectin benzoate soluble powder is sprayed at 150 – 225 g/hm^2. For fall armyworm control, *B. bassiana* wettable powder (300 billion spores/g) is sprayed at 675 – 900 g/hm^2. Alternatively, *Bacillus thuringiensis* G033A wettable powder (32 000 IU/mg) is sprayed at 2 250 – 4 500 g/hm^2. For leaf spot diseases, 18.7% propiconazole · azoxystrobin suspension concentrate is sprayed at 750 – 1 050 ml/hm^2, or 30% pyraclostrobin · tebuconazole suspension concentrate is sprayed at 300 – 600 ml/hm^2. For stalk rot, seed coating is adopted. Seeds are coated with 9% pyraclostrobin · fludioxonil · thiamethoxam suspension concentrate at 2 – 3 kg per 100 kg of seeds, or coated with 35 g/L fludioxonil · metalaxyl-M suspension concentrate at 150 – 200 ml per 100 kg of seeds. For rust, 25% triadimefon wettable powder is sprayed at 450 – 525 g/hm^2. For sheath blight, seeds are treated with 28% thiamethoxam · thifluzamide

seed treatment suspension concentrate at 570 – 850 ml per 100 kg of seeds for seed dressing, or 24% jinggangmycin aqueous solution is sprayed at 450 – 600 ml/hm^2.

For pepper damping-off, 722 g/L propamocarb hydrochloride aqueous solution is sprayed at 1 080 – 1 605 ml/hm^2. Alternatively, 30% metalaxyl-M · hymexazol soluble concentrate is applied for seedbed treatment at 450 – 675 ml/hm^2, or 0.8% metalaxyl-M · azoxystrobin granules are broadcast at 3 – 5 g/m^2. For pepper *Rhizoctonia* rot, 13% jinggangmycin aqueous solution is applied by drenching at 0.8 – 1.0 ml/m^2, or 0.4% pyraclostrobin granules are broadcast at 10 – 12 g/m^2. For pepper gray mold, 50% procymidone wettable powder is sprayed at 1 125 – 1 500 g/hm^2, or 50% prochloraz manganese chloride complex wettable powder is sprayed at 450 – 600 g/hm^2. For pepper *Phytophthora* blight, 440 g/L metalaxyl-M · chlorothalonil suspension concentrate is sprayed at 1 125 – 2 475 ml/hm^2, or 51.9% dimethomorph · metalaxyl-M soluble concentrate is sprayed at 900 – 1 200 ml/hm^2. For pepper viral diseases, 5% oligosaccharins aqueous solution is sprayed at 525 – 750 ml/hm^2, or 2% ningnanmycin aqueous solution is sprayed at 4 500 – 6 255 ml/hm^2. For pepper powdery mildew, 30% picoxystrobin · tebuconazole suspension concentrate is sprayed at 360 – 540 ml/hm^2, or 25% prochloraz emulsifiable concentrate is sprayed at 750 – 938 g/hm^2. For aphids on pepper, 14% chlorantraniliprole · lambda-cyhalothrin microcapsule suspension-suspension concentrate is sprayed at 225 – 300 ml/hm^2, or 1.5% matrine soluble concentrate is sprayed at 450 – 600 ml/hm^2.

Intertillage and weeding

Intertillage and weeding are important aspects of field management. Intertillage is conducted 2 – 4 times during the early growth stage of the crops. The first shallow hoeing should be done 10 – 15 d after transplanting, gradually deepening in later stages. Weeding can be combined with intertillage, or mulch film or herbicides can be used. When using herbicides, special attention must be paid to selecting varieties safe for both crops to avoid phytotoxicity.

Additionally, field growth conditions are regularly inspected, with problems promptly identified and remedial measures taken. During hot and dry seasons, sprinkler irrigation can be used for cooling and humidification. During continuous rainy weather, disease monitoring and control are strengthened. Through meticulous field management, the advantages of intercropping can be maximized to achieve stable and high yields.

Harvesting

Scientific and reasonable harvesting management is an important part of achieving optimal economic benefits in the pepper-maize intercropping model. Differentiated harvesting strategies should be adopted based on the maturity characteristics of the two crops and market demand.

For pepper, the optimal harvest time should be determined based on variety characteristics and intended use. Generally, fresh peppers are harvested when fruits are fully enlarged with smooth, shiny skin, while peppers for processing are harvested after fruits have completely changed color. For continuously fruiting pepper varieties, harvesting is carried out in stages. The first fruit (king flower fruit) and the pair of fruits on the first node are harvested early to prevent overbearing. During the peak fruiting period, harvesting is conducted every 3 – 5 d. The fruit stalk is retained during harvest, and gentle handling is applied to avoid mechanical damage. Harvesting is best performed on sunny days after dew has dried. Harvesting immediately after rain or on rainy days is avoided to prevent disease spread.

For maize, the harvest period should be flexibly determined based on use. Fresh maize is harvested during the milk stage, 20 – 25 d after pollination, when kernels are plump, juicy, and taste best. Grain maize should be harvested at the full maturity stage when kernel moisture content drops below 25%. Changes in husk leaves are observed during harvest. A suitable harvest time is indicated when husk leaves turn yellow and loose, and a black abscission layer appears at the base of the kernels. After maize harvest, husk leaves are promptly removed, and the ears are sun-dried to below 14% moisture content before storage to prevent mold.

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