

A Practical Field-Based Method for Improving Potato Yield and Tuber Uniformity through Optimized Planting Density

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Genomics and Applied Biology, 2026, Vol.17, No.1 doi: [10.5376/gab.2026.17.0005](https://doi.org/10.5376/gab.2026.17.0005)

Received: 28 Dec., 2026

Accepted: 02 Feb., 2026

Published: 19 Feb., 2026

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Preferred citation for this article:

Zhang J., 2026, A practical field-based method for improving potato yield and tuber uniformity through optimized planting density, Genomics and Applied Biology, 17(1): 51-60 (doi: [10.5376/gab.2026.17.0005](https://doi.org/10.5376/gab.2026.17.0005))

Abstract In many production areas, potatoes are not only a staple food but also an important source of income. Whether they are grown well or not directly affects the yield and stable production. However, in actual production, simply planting more does not necessarily lead to higher yields. Planting density often influences the field population structure, yield level, and uniformity of tubers. Appropriate density arrangement can often increase the yield per unit area without additional input and make the tubers more uniform in size. However, if planted too densely, competition for light, water, and nutrients becomes more intense, reducing the tuber-setting ability of individual plants, increasing the number of small and deformed tubers, and deteriorating the commercial quality. Based on these practical issues, comparing different densities through field experiments, summarizing the corresponding management experiences, and analyzing specific cases can provide more practical references for high-yield and high-quality potato cultivation under different ecological conditions.

Keywords Potato; Reasonable planting density; Yield increase; Tuber uniformity; Cultivation management

1 Introduction

In many regions of our country, potatoes not only play a role in food supply but also are related to planting benefits. Therefore, the yield per unit area and the quality of marketable potatoes have always been the subject of repeated discussions. In field production, planting density is often an unavoidable issue: if planted sparsely, individual plants produce larger tubers, but the land and light-heat conditions are not fully utilized, and the total yield is likely to be limited; conversely, if planted too densely, plants compete for water and nutrients, resulting in an increase in small tubers and uneven tuber sizes, thereby reducing marketability. It is precisely in this contradiction that reasonable planting density has gradually attracted attention. Some studies have found that density regulation can achieve a relatively balanced state between population structure and yield and quality (Zheng et al., 2016; Qi et al., 2025). Based on this, this study, in combination with field experiments, explores the changes in potato yield and tuber uniformity under dense planting conditions.

In actual production, the feasibility of many cultivation measures can only be clearly seen in the field. Compared with indoor reasoning or model analysis, field experiments are closer to the real situation. The differences in climate, soil and management methods among different regions often lead to different results. Take close planting as an example. In addition to changes in yield, whether the growth of plants is restricted, whether pests and diseases will increase, and whether mechanical operations are convenient all need to be observed one by one in the field. Some problems are not obvious in theory but will be exposed in production. Researchers and farmers can only continuously adjust and improve the technology by conducting joint experiments, making repeated comparisons, and summarizing gains and losses. This is also an indispensable part of the improvement of potato cultivation (Dhangra et al., 2024; Meng et al., 2025).

Regarding the long-standing issue of whether potatoes should be densely planted or not, there have always been many differences of opinion. Some people emphasize yield, while others are concerned about the unevenness of the potato tubers. This study did not rush to conduct field verification immediately. Instead, it first analyzed the

impact of planting density on the growth of the plant population and the formation of yield, serving as the basis for subsequent experiments. On this basis, different density treatments were arranged in the field, and the performance of individual plants, the yield per unit area, and the changes in the size of the potato tubers were compared one by one. An attempt was made to find a less extreme range of dense planting. At the same time, the practical difficulties in reality were not avoided, such as adjusting the row and plant spacing, coordinating water and fertilizer, and the problems of pests, diseases, and lodging that may occur after dense planting. Countermeasures were also considered for all of these. Finally, the approach was tested in typical production areas to see how the actual results were, and then it was judged whether this practice was worth promoting. A relatively feasible planting and cultivation approach was gradually sorted out (Zheng et al., 2016; Qi et al., 2025).

2 The Theoretical Basis of Reasonable Potato Planting Density

2.1 The mechanism of the impact of planting density on the population structure of potatoes

Under field conditions, whether potatoes are planted sparsely or densely is first reflected in the appearance of the population, such as the number of plants per unit area and the shape of the leaf layers. When the density is low, each plant has sufficient space, and the growth of the stems and leaves looks good, but the overall leaf area is not high, and much of the light is not utilized in the early stage. As the density increases, the rows are closed earlier, the leaf area accumulates rapidly, and the overall photosynthetic capacity increases accordingly. However, once the density is too high, the lower leaves are constantly shaded, and they tend to age and fall off prematurely, resulting in a decrease in the effective photosynthetic efficiency of the population.

At the same time, under high density, the plants often become slender and the leaves stand upright, although this is beneficial for competing for light in the upper layer, it makes the ventilation and light transmission conditions worse. Thus, it can be seen that dense planting continuously affects the population structure and light energy utilization of potatoes by changing the canopy formation and plant type characteristics (Wang et al., 2022; Derebe et al., 2023).

2.2 Characteristics of competition for light, heat, water and nutrients under dense planting conditions

Under field conditions, whether potatoes are planted sparsely or densely is first reflected in the appearance of the population, such as the number of plants per unit area and the shape of the leaf layers. When the density is low, each plant has sufficient space, and the growth of the stems and leaves looks good, but the overall leaf area is not high, and much of the light is not utilized in the early stage. As the density increases, the rows are closed earlier, the leaf area accumulates rapidly, and the overall photosynthetic capacity increases accordingly. However, once the density is too high, the lower leaves are constantly shaded, and they tend to age and fall off prematurely, resulting in a decrease in the effective photosynthetic efficiency of the population.

At the same time, under high density, the plants often become slender and the leaves stand upright, although this is beneficial for competing for light in the upper layer, it makes the ventilation and light transmission conditions worse. In terms of water and nutrients, increased density also exacerbates competition for soil moisture and nutrient uptake, affecting both photosynthesis and tuber formation (Wu et al., 2020; Meng et al., 2025). Thus, it can be seen that dense planting continuously affects the population structure and light energy utilization of potatoes by changing the canopy formation and plant type characteristics.

2.3 Relationship between rational plant density and yield components

When discussing potato yield, it is not advisable to focus solely on a single indicator. Both the number of plants per unit area, the number of tubers formed, and the size of the tubers all play a role. When the plants are planted sparsely in the field, each plant forms more tubers and they are larger in size, resulting in excellent performance per plant. However, due to the low number of plants, the overall yield is not high. As the density gradually increases, the number of tubers per plant and the average weight of the tubers will decrease. However, with more plants participating in tuber formation, the yield per unit area will increase.

At a certain density range, the increase in the number of plants and the reduction in the number of tubers per plant basically cancel each other out, and the total yield approaches its peak. If the density is further increased, the

number of tubers per plant and the average weight of the tubers decrease too rapidly, and the newly added plants are unable to make up for the loss. The yield then begins to decline. Therefore, only by controlling the density within an appropriate range can the various yield factors be relatively coordinated (Ierna et al., 2011; Meng et al., 2025).

3 Impact of Different Planting Densities on Potato Yield

3.1 Density gradient setup and field experiment design

Before discussing the potato yield, the factor of density is often repeatedly mentioned, but its specific impact is not always clear. In this experiment, the comparison was directly carried out in the field by setting multiple planting densities to directly observe the differences. All treatments used the same variety, only adjusting the plant spacing, and other management measures were kept as consistent as possible to avoid the results being influenced by other factors. In terms of density arrangement, both the conventional planting method as a control was retained, and situations of moderate density and sparse density were also included.

During the growth period, the growth of the plants was continuously monitored, and at the harvest stage, indicators such as the number of tubers formed, the weight of individual tubers, and the yield per unit area were concentratedly recorded. Through such an arrangement, the changes in yield under different densities can be presented more clearly, laying the foundation for subsequent analysis (Figure 1) (Ierna et al., 2011; Meng et al., 2025).

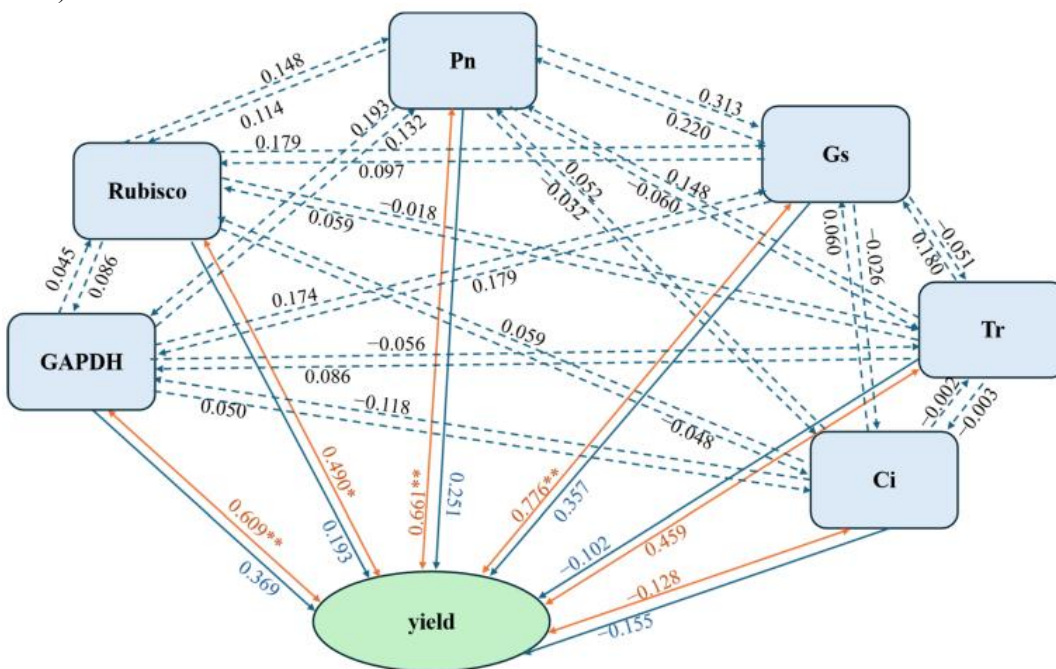


Figure 1 Correlation and Partial Least Squares Regression (PLS) analysis of photosynthetic rate (Pn), transpiration rate (Tr), stomatal conductance (Gs), intercellular CO₂ concentration (Ci), ribose-1,5-bisphosphate carboxylase oxygenase (Rubisco) activities, glyceraldehyde 3-phosphate dehydrogenase (GAPDH) activities, and potato tuber yield under the interaction of nitrogen and density. Solid lines of orange two-way arrows and orange numbers indicate the correlation and correlation coefficient between indicators; solid lines of blue one-way arrows indicate the direct relationship and direct regression coefficient between indicators; dotted lines of blue one-way arrows and black numbers indicate indirect relationship and indirect regression coefficient between indicators. * and ** indicate statistically significant p-values at less than 0.05 and 0.01, respectively (Adopted from Meng et al., 2025)

3.2 Changes in yield per plant and per unit area under different densities

Often, the growth of individual plants does not exactly match the final total yield. When the plants are planted relatively sparsely in the field, each plant does produce heavier tubers. However, with a smaller number of plants, the yield per unit area is not advantageous. When the density is increased, the yield per plant begins to decrease. But with a larger number of plants contributing to tuber formation, the yield per unit area actually increases. There was a turning point in the experiment, where the yield reached its peak within a moderate density range.

If the density is further increased, the situation changes. The yield per plant decreases more rapidly, and the newly added plants cannot make up for the losses. The overall yield growth slows down, and even declines. This shows that dense planting is not necessarily better when it goes too far; it can actually hinder the final yield (Ojala et al., 1990; Ierna et al., 2011).

3.3 Field verification and analysis of the optimal planting density range

When analyzing the yield data of various density treatments, the results are not simply a matter of which is higher or lower. What is interesting is that when the density roughly falls within the range of 50,000 to 60,000 plants per hectare, the yield per unit area has already reached the highest level, and there is no significant difference between different treatments. Regardless of whether the density is lower than this range or denser, the yield becomes less stable and the overall performance is slightly inferior. When this result is compared with existing research, it is found that this situation is not uncommon and similar performance is observed under different conditions. For actual production, controlling the planting density within this range makes it easier to achieve relatively ideal and stable yield increase effects (Zebarth et al., 2006; Ierna et al., 2011).

4 Effects of planting density on the uniformity of tubers

4.1 Evaluation indicators and grading standards for tuber uniformity

When assessing the uniformity of potato growth, the research did not focus solely on the yield. Instead, it concentrated on the potato tubers themselves. After harvest, the tubers were first classified based on their weight or size. Those weighing over 150 grams were classified as large tubers, those ranging from 50 to 150 grams as medium tubers, and those less than 50 grams as small tubers. At the same time, abnormal malformed tubers with irregular shapes were also separately counted. Compared to simply looking at the weight in kilograms, the research paid more attention to the proportion of medium-sized tubers that met the commercial requirements.

This proportion is often used to reflect the degree of uniformity. Additionally, a supplementary judgment was made by calculating the dispersion of the tuber weights. The smaller the value, the more concentrated and uniform the size distribution (Love et al., 1998; Ierna et al., 2011). In the spring of 2025, we conducted a potato planting density experiment on the farm, and the results showed that under reasonable planting conditions, the yield of fresh potatoes increased by more than 30%, and the rate of large and medium-sized potatoes increased by more than 20% (Figure 2).



Figure 2 Spring potato planting base of Jinyun County Tongyuefang Family Farm (Left: Harvesting Potatoes; Right: Fresh Tubers) (Photographed by Jin Zhang)

4.2 Distribution characteristics of potato tubers under different density conditions

From the harvest results, it can be seen that the size distribution of potato tubers varies significantly under different densities. When the planting density is relatively sparse, the proportion of large tubers is higher, while small tubers are scarce. The individual tubers are large in size, but the difference in size is also quite obvious. When the density is too high, the situation is exactly the opposite. The number of small tubers increases

significantly, the number of medium-sized tubers decreases, and the average weight of a single tuber decreases accordingly.

In contrast, the treatment with an appropriate density is more stable. The proportion of medium-sized tubers is the highest, and both large and small tubers remain at a relatively reasonable level. The rate of marketable tubers also increases. Thus, it can be seen that whether the density is too sparse or too dense, it will affect the uniformity of the tuber size. A suitable density is more conducive to obtaining uniform tubers (Ierna et al., 2011; Zebarth et al., 2009).

4.3 The impact of high plant density on the incidence of abnormal tubers and small tubers

When harvesting, simply looking at the ridge surface can reveal that once the density becomes too high, the problem is not merely that the potato tubers become smaller. In the densest treatment, deformities such as twisting and branching occurred much more frequently, and some tubers failed to develop properly, resulting in an increase in the number of small tubers. When the density is appropriate, the situation is relatively stable, with a lower proportion of deformed and small tubers, and the commercial tubers appear more regular. It is not necessarily the case that the denser the better; if planted too sparsely, small tubers are hardly seen, but the tubers often grow too large, increasing the risk of hollow interiors and other problems. Considering all these phenomena, controlling the density within an appropriate range is more conducive to reducing deformities and small tubers, and improving the overall commercial quality (Love et al., 1994; Ierna et al., 2011).

5 Optimization of Cultivation Management Measures under Intensive Planting Conditions

5.1 Optimal configuration of row and plant spacing

In actual practice, if one wants to increase the density, merely increasing the number of plants is often ineffective. The ratio of row spacing and plant spacing is even more crucial. If the spacing is simply reduced, the field will soon become crowded and the growth conditions will deteriorate. The more common practice in production is to appropriately widen the row spacing, for example, from the original 60-70 cm to 80-90 cm. First, leave out the space for ventilation, light exposure and mechanical operations, and then reduce the plant spacing from 30 cm to 15-20 cm, increasing the number of plants within the row. After such adjustments, the plant distribution becomes more uniform and the land is used more efficiently. Some high-yield plots will further optimize the layout through methods such as double-row planting. In practice, as long as the row and plant spacing are arranged reasonably, dense planting and a favorable field environment are not contradictory (Li et al., 2019; Meng et al., 2025).

5.2 The regulatory effect of integrated water and fertilizer management on dense planting populations

Under dense planting conditions, whether water and fertilizer can be managed properly often directly affects the final outcome. As the number of plants increases, water consumption in the field significantly rises. If water supply is not timely, the tuber expansion stage is prone to be affected. Therefore, it is necessary to arrange watering reasonably according to the growth process, maintaining neither excessive dryness nor excessive wetness of the soil. The same applies to nutrients.

With increased density, the demand for nitrogen, phosphorus, and potassium increases accordingly. Fertilizing only once is often insufficient. In production, a sufficient amount of base fertilizer is usually applied first, followed by a small amount of multiple top-dressing fertilization during the middle growth stage, with a focus on supplementing nitrogen and potassium fertilizers. Integrating irrigation and fertilization can help improve utilization efficiency and make the growth of dense planting populations more balanced (Zebarth et al., 2018; Meng et al., 2025).

5.3 Risk management of pests, diseases and stubble flooding under dense planting conditions

Under dense planting conditions, field management is often more meticulous than in conventional planting. With more plants, ventilation and light transmission conditions deteriorate, and the humidity increases. Late blight, early blight and other diseases are more likely to occur. Therefore, in production, it is usually necessary to take preventive measures in advance, such as selecting disease-resistant varieties, implementing reasonable rotation, and taking protective measures during the prone periods. Sometimes, pest problems can be more concealed.

Aphids, beetles, etc. spread faster, so it is necessary to strengthen field inspections and deal with them as early as possible. On the other hand, after dense planting, the stems of the plants become thinner, and they are prone to collapse in the face of wind and rain.

At this time, attention should be paid to controlling the amount of nitrogen fertilizer, avoiding excessive growth, and applying soil covering in the middle and later stages to stabilize the plants. In necessary cases, measures to control the plant growth should be taken to reduce losses caused by collapse and pest damage (Figure 3) (Fry et al., 2015; Rens et al., 2021).

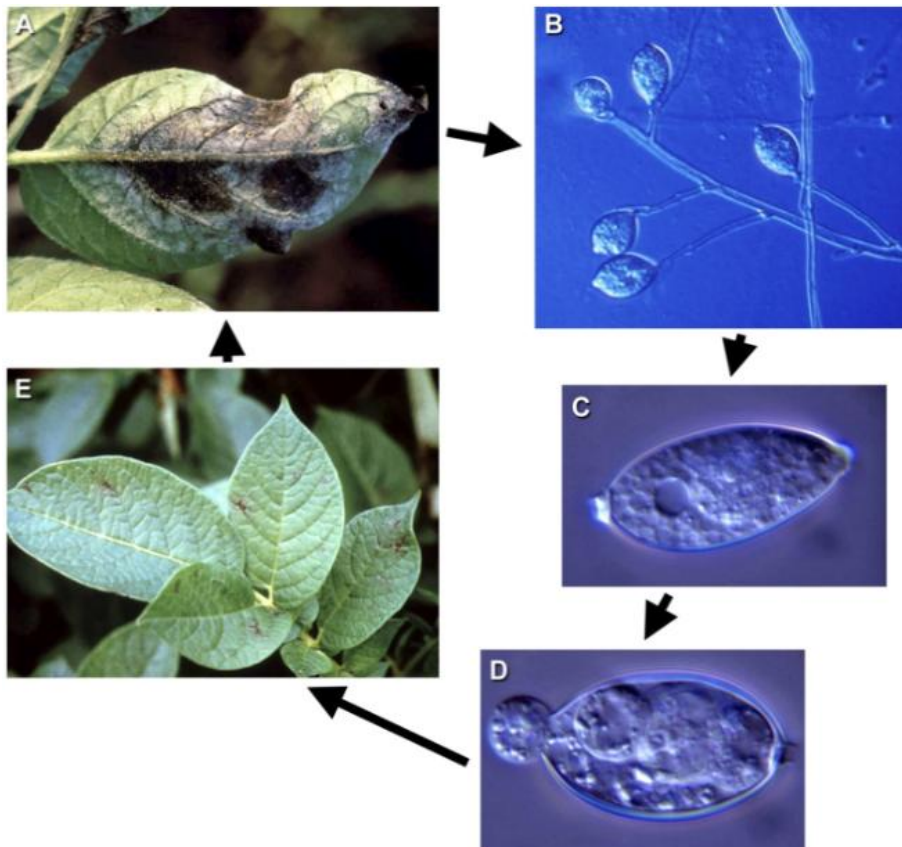


Figure 3 Asexual life cycle of *Phytophthora infestans* on potato tissue (Adopted from Fry et al., 2015)

Image caption: A, After moist conditions for several hours (at least 6 to 8 h) at moderate temperatures (15 to 22°C), the pathogen sporulates from lesions. B, Sporangia are borne on sporangiophores and C, sporangia are dehiscent (readily removed from sporangiophores) and are aerially dispersed. D, Sporangia can germinate directly (via a germ tube at warmer temperatures [$>18^{\circ}\text{C}$]) or at lower temperatures ($<18^{\circ}\text{C}$) via zoospores. E, Within 3 to 6 days, young lesions appear on after infection on host tissue (Adopted from Fry et al., 2015)

6 Case Study Based on Field Practice

6.1 Overview and natural conditions of the typical production area test site

To test the actual effect of the dense planting yield-increasing measures, the test site was selected in a major potato-producing area of Dingxi, Gansu Province. The altitude here is around 2,000 meters, and rainfall is not abundant, but it mostly occurs during the crop growth period. Combined with sufficient sunlight and a large diurnal temperature difference, it has always been an advantageous condition for the development of potatoes in this area. The soil is loam, with a deep plough layer, and the foundation for tuber growth is good.

However, affected by the semi-arid climate, local farmers have long adopted a lower planting density of approximately 2,000 plants per mu to avoid the risk of water shortage. This region has a long history of potato cultivation, with stable average yields per mu, and is an important economic source. Conducting the experiment in this context is more conducive to judging the applicability and yield-increasing potential of the dense planting technology under rain-fed conditions (Zhang et al., 2018; Li et al., 2020).

6.2 Comparative analysis of yield and uniformity before and after intensive planting technology application

During the field trials in typical production areas, the first thing encountered was a very realistic situation: Many farmers had always been accustomed to planting at a relatively low density and their management methods were rather casual. Against this backdrop, the experiment compared conventional planting with the adjusted dense planting. Under normal conditions, the individual tubers were indeed larger, but there was a significant difference in size, and the yield was mostly around 2 000 kilograms per mu. After changing to a reasonable planting density and synchronizing water and fertilizer management, the performance in the fields was noticeably different.

The yield increased to around 2 600 kilograms per mu, an increase of nearly 30%. More intuitively, the size of the tubers was more concentrated. The rate of marketable tubers rose from about 85% to 92%, while small tubers and deformed tubers decreased significantly. From this, it is easy to see that dense planting not only brings about an increase in yield, but also improves the appearance (Li et al., 2019; Meng et al., 2025).

6.3 Summary of case experience and replicability evaluation

Before discussing the promotion, it is necessary to re-examine the results in the specific conditions. The results in Dingxi did show significant changes. Intensive planting led to a nearly 30% increase in yield, but this was not simply achieved by simply increasing the density. One important prerequisite for such an effect in this area is that irrigation is in place and fertilization is also well done. On this basis, the rate of commercial potatoes increased simultaneously, and both yield and quality benefited. However, this situation is not suitable for all places.

In contrast, in areas with better water and fertilizer conditions, there is still more room for improvement after intensive planting; while in regions with high humidity or heavy disease pressure, the density needs to be appropriately reduced and management needs to be strengthened. Overall, this case indicates that, under the premise of similar ecological conditions and complete supporting measures, reasonable intensive planting has the potential for promotion in similar areas in the northwest, but specific approaches still need to be determined based on local conditions (Li et al., 2020; Meng et al., 2025).

7 Application Prospects and Promotion Value of Rational Plant Spacing Technology

7.1 Adaptability of potato planting spacing patterns in different ecological zones

When it comes to dense planting in production, it is difficult to find a set of standards that are applicable everywhere. In many cases, it still depends on how local conditions restrict things. For example, in areas like the northwest plateau with low precipitation, without stable irrigation, even if the density is increased, it is hard to achieve good results; conversely, in regions with abundant rainfall in the south, if the density is too high, diseases tend to concentrate more easily, and in such cases, it is necessary to reduce the planting quantity and improve ventilation conditions.

In short-growing cool regions with short growing periods, it is common to appropriately densify to speed up the process; while in fields with long growing periods and good soil quality, it is even more necessary to prevent premature closure. Considering the differences in varieties, some plant types have a compact structure and are more tolerant of dense planting, while others with vigorous branches and leaves are not suitable for being crowded together. In general, the idea of dense planting is the same, but the methods must be adjusted flexibly according to local conditions and varieties (Li et al., 2020; Rens et al., 2021).

7.2 The significance of reasonable plant spacing for large-scale and mechanized production

During the process of promoting large-scale planting, dense planting is often regarded as a "cost issue" at first, as the amount of seeds used and the investment will increase. However, when viewed from the perspective of mechanization, this concern may change. When planting over a large area in contiguous rows, reasonable increase in density can fully utilize the land potential, resulting in higher output per unit area, and the total cost can be more easily spread out. At the same time, mechanical operations have clear requirements for row spacing and plant spacing, and the dense planting plan precisely provides a unified standard.

Sowing and harvesting are more smooth. For example, precision sowing machines can plant seeds at the set intervals, and the plant spacing is more uniform; during harvesting, the size of the tubers is relatively consistent, and the loss and damage will also be reduced. After the field population becomes orderly, subsequent management and monitoring will also be more standardized. In summary, combining reasonable plant spacing with mechanization is more conducive to improving the efficiency and income of large-scale potato production (He et al., 2018; Li et al., 2021).

7.3 Problems and countermeasures in technology promotion

During the actual promotion process, dense planting did not go as smoothly as expected. Some concerns were raised at the outset. Many farmers were worried that if the planting density was increased, they might end up using more seeds but not necessarily increase their income. Therefore, they preferred to wait and see. In response to this situation, demonstration fields and on-site observations often carry more persuasive power. Combined with training on water, fertilizer, and pest control management, the risks of trial planting can be reduced. On the other hand, the investment in seed potatoes and fertilizers brought by dense planting is indeed relatively high, and it will compress profits in the short term. This requires subsidy support or through methods such as whole-seed sowing or cut-seed sowing to reduce costs.

At the same time, in areas with insufficient machinery conditions, manual dense planting is time-consuming and labor-intensive, which also affects enthusiasm. Introducing suitable agricultural machinery or providing unified operation services would be more realistic. Gradually resolving these problems will enable the technology to be truly accepted and applied (Zhang et al., 2019; Spielman et al., 2020).

8 Conclusion and Outlook

When all the observations made during the field trials are combined, it is actually not difficult to determine the effect of dense planting. Compared with the planting methods commonly used by farmers, when the density is around 50 000 to 60 000 plants per hectare, the yield per unit area usually increases, with an increase rate generally above 20%. At the same time, the size distribution of the tubers has also changed, with medium-sized tubers becoming more concentrated, and small tubers and deformed tubers significantly reduced. It seems more orderly. However, simply increasing the density is not enough. After the density is increased, if the water and fertilizer supply is insufficient and the disease and pest control is not in place, the competition among the plants will actually intensify. The demonstration results in typical production areas show that as long as the conditions are suitable and the management measures are in place, reasonable dense planting is completely feasible in production and can indeed bring relatively stable increases in yield and improvement in benefits (Li et al., 2020; Meng et al., 2025).

In previous discussions on dense planting, the focus was mainly on "whether more yield could be achieved", with little attention paid to quality. This study, however, took a different approach, examining the changes in yield and the commercial quality of tubers together, with particular attention paid to more sensitive indicators such as uniformity in actual production. Based on this, we combined density adjustment with row and plant spacing, water and fertilizer management, and pest and disease control to form a relatively complete cultivation concept. The field application results showed that this approach not only could stabilize the yield but also could simultaneously improve the quality. The relevant conclusions have reference value for the production department in formulating high-yield and high-quality plans, provide a basis for flexible application of dense planting technology under different ecological conditions, and have practical significance for improving the overall efficiency of the potato industry (Zebarth et al., 2018; Rens et al., 2021).

Based on the current results, there are still many aspects of the dense planting method that warrant further exploration. Different varieties have varying responses to density. If the relationship between varieties and appropriate densities can be clearly identified through experiments, it will provide more confidence when promoting this method. Additionally, the data from one location per year is inherently limited. Multi-location and continuous-year verification is necessary to determine the stability of the effects and to identify potential problems such as soil nutrient depletion or disease accumulation in advance. The understanding of changes within the dense

planting population is also insufficient. For instance, how light is utilized and how nutrients are distributed among plants. Incorporating sensor monitoring, precise water and fertilizer management, and compatible agricultural machinery will enhance the management accuracy and operational efficiency, thereby making the practicality and promotion foundation of the dense planting technology more solid (Rens et al., 2021; Li et al., 2022).

Acknowledgments

I would like to thank the anonymous reviewers for their detailed review of the draft. Their specific feedback helped us correct the logical loopholes in our arguments.

Conflict of Interest Disclosure

The author affirms that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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