

DESIGN AND EXPERIMENT OF POTATO PLANTER WITH ELECTRIC CHASSIS

/ 基于电动底盘的马铃薯播种机设计及试验

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Tel: +86-13086666798, E-mail: 179573388@qq.comDOI: <https://doi.org/10.35633/inmateh-78-120>**Keywords:** potato planter, hilly areas, electric chassis, field experiment**ABSTRACT**

To address the low mechanization level, poor adaptability, and insufficient sowing accuracy of potato planters in the hilly areas of Sichuan, a high-precision intelligent potato planter based on an electric chassis was developed. The integrated design ensures power matching between the electric chassis and the seeding system, while photoelectric and radar sensors enable real-time seed-metering monitoring and missing-seed compensation. A central composite design was used to optimize travel speed and seed-metering linear speed, with qualified spacing rate as the evaluation index. Results revealed a significant interaction between the two parameters. The optimal combination, determined via regression analysis, was 0.36 m/s (travel speed) and 0.23 m/s (seed-metering linear speed), yielding a qualified spacing rate of 98%. This study validates the feasibility and application potential of the electric chassis planter for hilly regions, offering a technical reference for the electrification and intelligent development of potato planting equipment.

摘要

本文针对四川丘陵山区马铃薯播种机械化程度低、现有播种机适应性差及播种精度不高等问题，研制了一款基于电动底盘的高精度智能化马铃薯播种机。通过一体化结构设计，实现了电动底盘与播种机的动力匹配，集成光电传感器与雷达传感器构建智能监控系统，实现了排种过程的实时监测与空穴补偿。采用中心复合设计试验，以行走速度和排种器线速度为因素优化作业参数，结果表明二者交互作用对合格率影响显著，最优参数组合为行走速度0.36 m/s、排种器线速度0.23 m/s，此时种薯间距合格率达98%。研究验证了电动底盘播种机在丘陵山区应用的可行性与优势，为马铃薯播种机的电动化、智能化发展提供了有效技术方案。

INTRODUCTION

As the world's fourth-largest food crop, the mechanization level of potato production is crucial for national food security and farmers' income (Zhang et al., 2017; Campos and Ortiz, 2020). However, in the hilly and mountainous areas of Sichuan, China, fragmented plots and significant slope variations pose challenges (Hong et al., 2025; Van Dijk et al., 2025). Traditional large fuel-powered planters suffer from poor flexibility and adaptability, while manual sowing is inefficient and struggles to ensure uniformity, severely restricting the local potato industry's development (Shi et al., 2025; Yadav et al., 2025; Yu et al., 2025).

Existing potato planters primarily rely on fuel-powered systems, which exhibit inherent operational limitations such as response delays and non-linear behavior when adjusting output speed and torque (Devaux et al., 2021; Zhou et al., 2022; Ahmad and Sharma, 2023). These characteristics impede precise dynamic control, thereby creating bottlenecks in achieving high sowing uniformity, particularly in terms of qualified spacing rate and hinder the effective implementation of real-time monitoring-based precision technologies, including missing-seed compensation and double-seeding detection (Zhang, 2015; Zhang et al., 2017; Qi et al., 2025). In contrast, electric agricultural machinery offers not only environmental benefits but also superior motion control capabilities (Jiang et al., 2025). Electric drives provide intrinsic advantages, including rapid response times and accurate speed and torque regulation, enabling seamless integration with sensors and control systems (Husain et al., 2021; Rihar et al., 2024; Li et al., 2025).

This establishes a robust foundation for demand-driven, variable-rate precision operations, offering revolutionary potential for advancing sowing accuracy and operational intelligence (Aijaz et al., 2025).

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Domestic and international scholars' research on the electrification and precision of planters has initially confirmed this development trend. In terms of electric agricultural equipment, Liu et al. systematically analyzed the key technical requirements of electric agricultural machinery in areas such as batteries, electric drive, control, and energy management, summarized the application characteristics of different new energy power forms, and envisioned their application prospects in facility agriculture, hilly and mountainous areas, etc. (Liu et al., 2024).

In terms of precise seed placement technology, domestic research mainly focuses on improving mechanical structures and introducing sensing technologies. For example, Lu et al. designed a potato pneumatic precise seed placer, which significantly improved the single-seed rate by optimizing the negative pressure system of the fan, but its power source still relied on the tractor PTO output and failed to break free from the dependence on traditional power sources (Lv et al., 2018). Xue et al. conducted in-depth research on the spoon chain seed distributor, optimizing the seed distribution chain speed, the inclination angle of the seed box bottom plate, and the inclination angle of the seed distributor through single-factor simulation and orthogonal experiments, but their research focused on mechanical optimization and did not integrate with advanced electronic control drive systems (Xue et al., 2024).

In summary, existing research either places emphasis on the green transition of power platforms or centers on the mechanical optimization and intelligent monitoring of the seed metering device itself. Nevertheless, the integrated design and coordinated control of a high - precision electric chassis along with a sowing execution system equipped with intelligent feedback have been inadequately explored. Especially in light of the specific agronomic requirements of China's hilly and mountainous areas, further investigation is needed in the area of achieving the adaptive precision operation of electric planters under complex working conditions.

Addressing the above issues, this paper aims to develop a potato planter with electric chassis suitable for Sichuan's hilly areas. Leveraging the high precision and fast response control characteristics of the electric chassis, an intelligent seeding system integrating speed encoding and real-time feedback control is constructed. This research focuses on: (1) High-precision power matching and transmission design between the electric chassis and the planter, (2) An adaptive control strategy for seeding speed based on the motor's rapid response characteristics, (3) Validation through field experiments of the sowing qualification rate and stability of this electric planter under complex conditions. This study aims to provide a new technical pathway and practical solution for developing high-precision, intelligent modern agricultural equipment.

MATERIALS AND METHODS

Overall Structure

Potato planter with electric chassis mainly consists of two parts. An electric chassis utilizing a diesel range extender, responsible for machine travel, traction, and power supply. The overall structure is shown in Figure 1, primarily comprising a PTO output device, crawler traveling device, hitch lift device, DC output device, controller, diesel range extender, and battery.

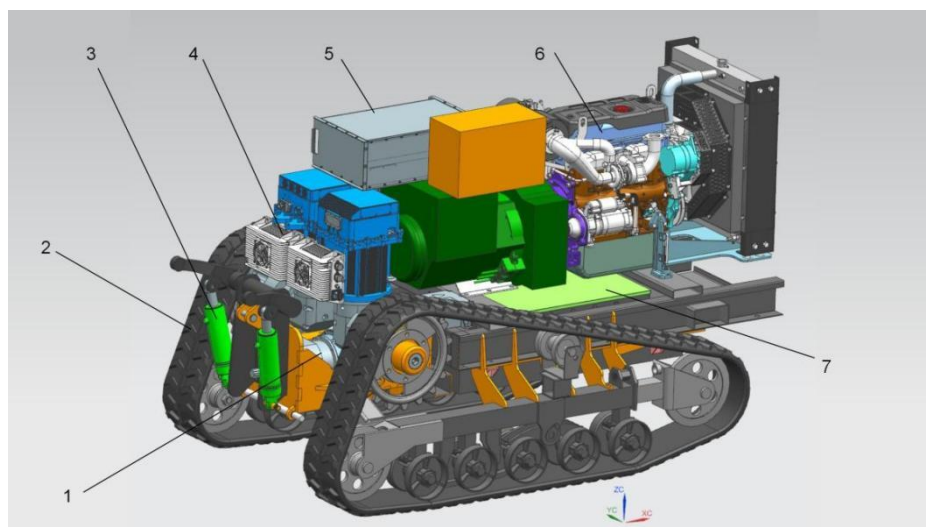


Fig. 1 - Schematic diagram of the electric chassis structure
 1. PTO output device, 2. Crawler traveling device, 3. Hitch lift device, 4. DC output device,
 5. Controller, 6. Diesel range extender, 7. Battery

The second part is the potato seeding system, divided into mechanical and electronic control components. The mechanical components mainly include the seed metering system, seed hopper, ridging mechanism, film mulching mechanism, ground wheel, hitch, and frame. as shown in Figure 2. The seed metering system consists of a seed box, seed metering chain, seed-filling monitoring sensor, housing, driving sprocket for seed metering, seed cups, driven sprocket, and seed-discharging monitoring sensor, as shown in Figure 3. The driving sprocket is driven by an independent motor, replacing the traditional ground-wheel chain drive system. This design fundamentally eliminates the impact of ground-wheel slip rate variations on transmission ratio stability, thus solving the problem of fluctuating qualified spacing rate caused by unstable slip rate in traditional planters. The planter connects to the electric chassis via a three-point hitch and performs furrowing, fertilizing, seeding, covering, ridging, and film mulching during operation.

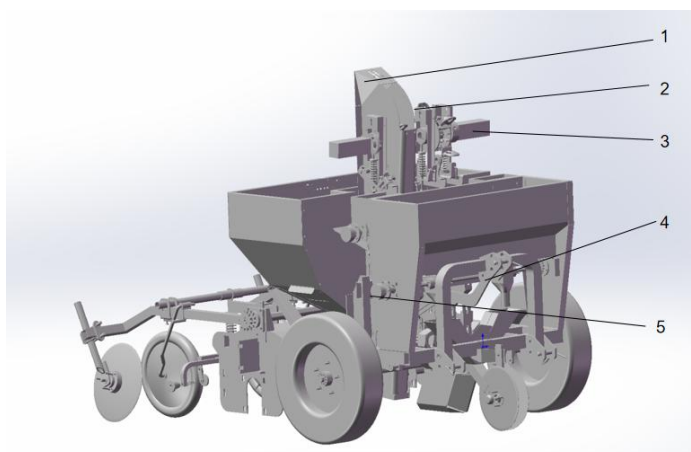


Fig. 2 - View of the potato seeding system

1. Seed meter, 2. Photoelectric sensor, 3. Seeding motor, 4. Three-point hitch, 5. Radar sensor

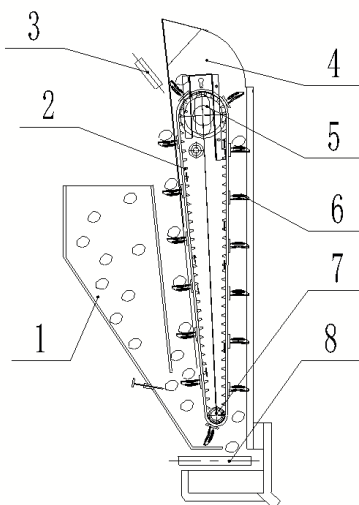


Fig. 3 - Schematic diagram of the seed meter

1. Seed box, 2. Seed metering chain, 3. Seed-filling monitoring sensor, 4. Housing, 5. Driving sprocket for seed metering; 6. Seed cups; 7. Driven sprocket; 8. Seed-discharging monitoring sensor

Working Principle

The potato planter unit is constructed on the electric chassis and consists of the electric chassis and the seeding system. During operation, the electric chassis is responsible for the machine's movement, traction, and power supply. The planter, connected through the three - point hitch, sequentially carries out furrowing, fertilizing, seeding, covering, ridging, and film mulching.

The electronic control components of the seeding system are powered by the built-in battery of the electric chassis. During the operation, the radar sensor detects the working speed of the machinery in real time. According to the set sowing plant spacing and the characteristic parameters of the seed dispenser, the processor in the control box controls the running speed of the seed dispenser motor in real time.

During the seed filling stage, the seed potatoes enter the seed spoon from the bottom of the seed box. In the seed cleaning stage, the amplitude of the spoon chain is changed by adjusting the speed of the vibrating motor to shake off the excess seed potatoes. In the seed arrangement stage, the remaining seed potatoes are lifted to the top of the seed arrangement device by the spoon chain and then run to the bottom of the seed arrangement device to fall into the seed groove. To ensure the quality of sowing, the system is equipped with a multi-level monitoring and control mechanism: a photoelectric sensor is installed above the seed arranger (after seed cleaning). The time it takes for the seed spoon to pass through the photoelectric sensor at the current speed is used to determine whether there are seed potatoes in the seed spoon. If an empty spoon is identified, the system will promptly increase the speed of the seed discharge motor when the spoon reaches the previous station before seed drop, accelerating the spoon chain and allowing the empty spoon to pass through quickly. The seed potatoes from the subsequent seed spoons will then be used for replanting to achieve void compensation. In addition, a capacitive sensor is added at the seed discharge port as a second monitoring point to conduct real-time detection and feedback on the seed discharge results. Once any abnormality is detected, the control system can alert the operator of the working status of the seed discharge device. If there is continuous missed or repeated sowing, the machine will be stopped in time for maintenance to ensure the quality of sowing.

Main Technical Parameters

Based on the agronomic requirements of the main potato production areas in Sichuan's hilly regions, the main technical parameters of the potato planter are determined, as shown in Table 1.

Table 1

Main technical parameters of the potato planter unit	
Parameter	Value
Chassis Power [kW]	40
Number of Rows [rows]	2
Qualified Spacing Rate [%]	≥85
Multiple Index [%]	≤20
Miss Index [%]	≤10
Working Width [cm]	90 ~ 105
Productivity [m^2/h]	≥0.12

KEY COMPONENT DESIGN

Electric Chassis Control Design

The power chassis in this study uses an SPC-STW-2612CMS motion controller, chosen for its high protection rating, compact size, high integration, and fast response. The 2612CMS utilizes a 3-CAN bus architecture to create a layered structure: Display/Remote Control Layer, Energy Management Layer (battery, charge/discharge), and Power Execution Layer (motors). The upper layer (CAN1) handles human-machine interaction and remote-control input. The middle layer (CAN2) focuses on battery status monitoring and management. The lower layer (CAN3) manages charging, power conversion, and motor drives, supporting vehicle power and peripheral functions. This design leverages the high reliability and multi-node communication capability of the CAN bus to ensure module coordination, simplify wiring, and enhance system scalability.

The control system communication schematic is shown in the figure. The 2612CMS controller acts as the central node, integrating 3 CAN interfaces to coordinate communication and control logic for all sub-modules. CAN1 serves as the upstream communication interface, connecting a 7-inch display and the remote control receiver for data exchange, HMI display (e.g., vehicle status, parameters), and receiving remote commands (e.g., start, speed adjustment) for processing by the controller. CAN2 handles battery communication, connecting the Battery Management System (BMS). The BMS communicates its own CAN1 with the controller's CAN2, transmitting real-time battery status (voltage, current, SOC, faults) for controller decision-making (e.g., charge/discharge control). CAN3 connects to the power and energy subsystems: The On-Board Charger (OBC), responsible for converting external AC to DC for battery charging, reports charging status via its own CAN1, The DC/DC converter, performing high-to-low voltage conversion (e.g., for lights, instruments), reports status via CAN1, The PTO motor controller receives speed/torque commands from the controller via CAN1, The integrated motor and controller (motor-drive unit), responsible for vehicle propulsion, exchanges speed/fault information with the controller via CAN1.

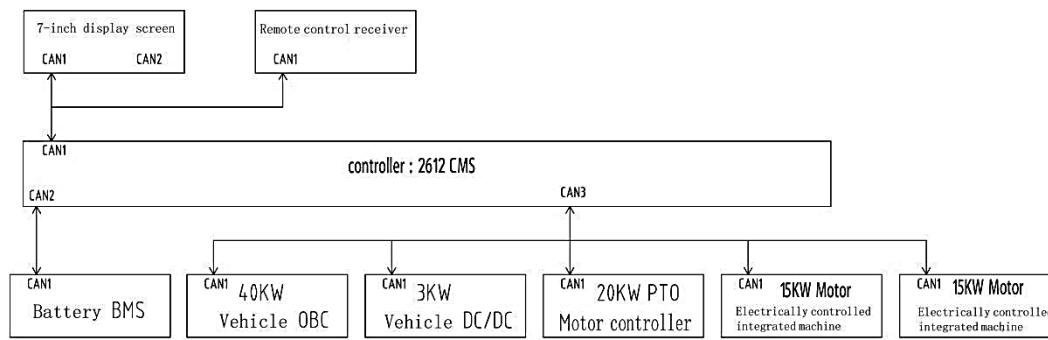


Fig. 3 - Electrical schematic diagram

Seeding Speed Control Design

The miss-seeding compensation method in this study is based on a speed control strategy, dynamically adjusting the speed of the seed cup-chain. To ensure the reliability of this control method, analyzing the dynamic characteristics of the seeding system is essential, focusing on determining the maximum critical speed of the seeding shaft.

When the seed meter operates at excessively high speeds, the centrifugal force acting on the potato piece inside the seed cup, as it rotates to the top of the seed wheel, may exceed the component of its gravity acting radially outward. This can cause premature ejection of the seed potato, preventing it from properly entering the seed drop channel and resulting in a miss. To avoid this, it is necessary to analyze the maximum critical angular velocity of the seed discharge wheel.

To determine this critical state, a force analysis is performed on a seed potato located at the top of the seed wheel. At this point, the seed potato is primarily subjected to gravity (mg) and the normal force (F_N) from the seed cup. The required centripetal force is provided by the resultant of gravity and the normal force, satisfying:

$$mg - F_N = m \omega^2 r \tag{1}$$

where: m - mass of the seed potato,
 g - acceleration due to gravity,
 ω - angular velocity of the seed wheel,
 r - radius of the seed wheel.

At the critical state where the seed potato is about to lose contact, the normal force $F_N = 0$. Substituting into the equation above gives the formula for the maximum critical angular velocity ω_{max} :

$$mg = m\omega_{max}^2 r \tag{2}$$

Simplifying yields:

$$\omega_{max} = \sqrt{\frac{g}{r}} \tag{3}$$

Based on this, the maximum critical linear velocity v_{max} of the seed belt can be calculated:

$$v_{max} = \omega_{max} \cdot r = \sqrt{gr} \tag{4}$$

According to this analysis, this critical speed is the theoretical upper limit ensuring reliable seed release at high operating speeds. With a seed wheel radius $r = 0.125$ m, calculation using the formula (taking $g \approx 9.8\text{m/s}^2$) gives the maximum critical linear velocity.

In practical control, the system uses the machine's forward speed detected by the radar sensor as the control signal, calculating the required seeding motor speed in real-time based on the preset plant spacing. During empty-cup compensation, the acceleration command issued by the system must ensure that the instantaneous speed of the seeding motor corresponds to a cup-chain linear velocity not exceeding the maximum critical speed of 1.107 m/s. This fundamentally prevents seed potatoes from being ejected due to excessive centrifugal force while achieving rapid compensation, ensuring the effectiveness and accuracy of the seeding operation.

FIELD EXPERIMENT

Experimental Conditions

The experiment was conducted on May 19, 2024, at the potato planting base of the Agricultural Science Institute in Mianyang City. Before sowing, the experimental area was prepared by using a rotary tiller to break up the soil and level it, removing weeds and stones. The potato seeds used were cut-segmented seeds with an average mass of 38.5 grams. Before the experiment, the soil covering device was removed. After the sowing operation was completed, one row was randomly selected from each plot for inspection, and 20 seed potatoes were continuously inspected in each row.

The field experiment process is shown in the figures below.



Fig. 4 - Field experiment

Experimental Method

The experiment was conducted according to the methods specified in the "Agricultural Machinery Promotion Appraisal Outline" (DG/T 098-2019). Therefore, the qualified seed spacing rate was used as the performance evaluation indicator. According to local agronomic requirements, the standard seed spacing is 22 cm, with an allowable error of ±1 cm. Thus, spacing between 21-23 cm was considered qualified in this experiment.

Experimental Results

To scientifically evaluate the sowing performance of the electric chassis potato planter, particularly the impact of travel speed and seed meter speed on sowing quality, a Central Composite Design was used for multivariate regression fitting and ANOVA of the experimental data.

A mathematical model was established relating machine travel speed, seed meter linear speed, and the qualified seed spacing rate. Interaction effects on the response surface were analyzed. All experimental factors were represented using three coded levels: -1 (low), 0 (medium), and +1 (high). The experimental factors, levels, and results are shown in Table 2 and Table 3.

Table 2

Experimental Factor Coding Table			
Coding	Factor		Metering Line Speed X2 [m/s]
	Machine Forward Speed X1 [m/s]		
-1.414	0.1172		0.1337
-1	0.20		0.20
0	0.40		0.36
1	0.60		0.52
1.414	0.6828		0.5863

Table 3

Experimental Protocol and Results			
Experimental No.	Machine Forward Speed X1 [m/s]	Metering Line Speed X2 [m/s]	Acceptable Potato Spacing Index Y [%]
1	0	0	98.23
2	-1	1	97.53
3	0	0	99.36
4	0	1.414	98.01
5	1.414	0	97.98
6	-1	-1	95.35
7	0	0	98.77
8	1	1	95.32
9	-1.414	0	95.53
10	0	0	98.56
11	0	0	99.13
12	0	-1.414	95.88
13	1	-1	98.22

Based on the data in the table above, regression analysis of variance for the qualified spacing rate Y was performed using Design-Expert 12 software, yielding a regression model describing the relationship between Y and the experimental factors, as shown below.

$$Y=98.81+0.5156X_1+0.2865X_2-1.27X_1X_2-1.09X_1^2-0.9937X_2^2 \quad (5)$$

Variance Analysis

Based on the experimental data, ANOVA was performed, and non-significant terms were removed. The results are shown in Table 4.

Table 4

Variance Analysis Table of Seed Potato Spacing Qualification Rate					
Source	Sum of Squares	Degrees of Freedom	Mean Square	F Value	P Value
Model	22.62	5	4.52	8.67	0.0065
X ₁	2.13	1	2.13	4.08	0.0832
X ₂	0.6568	1	0.6568	1.26	0.2987
X ₁ X ₂	6.45	1	6.45	12.37	0.0098
X ₁ ²	8.25	1	8.25	15.82	0.0053
X ₂ ²	6.87	1	6.87	13.17	0.0084
Residual	3.65	7	0.5214		
Lack of Fit	2.84	3	0.9482	4.71	0.0843
Error	0.8054	4	0.2014		
R ²	0.8610				
Total	26.27	12			

According to the analysis of variance for the qualified spacing rate among varieties presented in Table 4, the order of influence of the interaction effects of the factors on the impurity content rate was X₁², X₂², X₁X₂, X₁, X₂. Among them, X₁², X₂² and X₁X₂ exhibited extremely significant effects (P < 0.01), whereas X₁ and X₂ showed relatively significant effects (0.05 ≤ P < 0.1). The effects of the remaining factors were not significant (P > 0.1). The residual term was also not significant P = 0.0843 (P > 0.1), indicating that no other major factors significantly affected the experimental indicators.

Response Surface Analysis

The ANOVA indicates that machine travel speed X1, seed meter linear speed X2, and their interaction significantly affect the qualified spacing rate Y. Using Design-Expert 12, the response surface illustrating the effects of these factors and their interaction on Y was obtained, as shown in Figure 5.

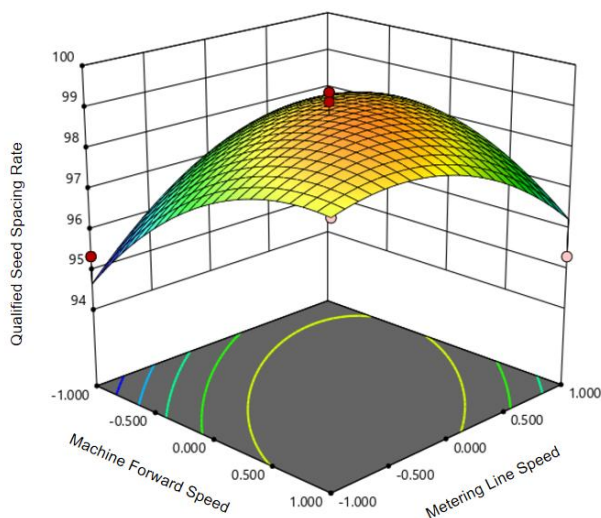


Fig. 5 - Variance analysis table containing impurity rate

The interaction between travel speed and seed meter linear speed has a considerable impact on the qualified spacing rate. When both factors are at their lowest levels, Y reaches a minimum within the plotted range. When travel speed is at its highest level, Y generally remains in a higher range. Similarly, when seed meter linear speed is at its highest level, Y is generally high.

RESULTS

To achieve the planter's optimal working state with a high qualified spacing rate, a constraint was set ($Y > 98\%$). The optimization function in Design-Expert 12 was used to solve the regression model. To validate the findings, multiple verification experiments were conducted under the identified optimal conditions. The results are shown in Table X. The small experimental error is acceptable, indicating good agreement between the regression equation and reality, confirming model reliability.

Table 5

Prediction and Verification Results			
Parameters	Machine Forward Speed X1 [m/s]	Metering Line Speed X2 [m/s]	Acceptable Potato Spacing Index Y [%]
Predicted Values			98.76
Experimental Values	0.36	0.23	98.43

CONCLUSIONS

This study combined the adaptive characteristics of the electric chassis in adjusting the set speed, reducing the fluctuation of operation speed, with the electrically controlled precision planting technology for potatoes. It developed an intelligent electric control planting system based on radar speed measurement for the operation requirements in the hilly areas of Sichuan. Through experimental design, a precise quantitative model was established for the operation parameters of this type of electric planting machine (machine forward speed and metering line speed) and the qualified rate of seed spacing. It revealed the significant nonlinear interaction rules between the two. Creatively, the optimal operation parameter combination (machine forward speed of 0.36 m/s, metering line speed of 0.23 m/s) was obtained through model optimization, and the qualified rate of plant spacing reached 98% in the verification experiment, significantly improving the uniformity of planting. This research not only provides a reliable theoretical basis and practical parameter optimization methods for the precise operation of electric planting equipment, but also has important practical guiding value for promoting the mechanization, intelligence and standardization development of potato production in hilly areas.

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