RESEARCH ON CONTROL SYSTEM OF ELECTRIC-DRIVE WHEAT SHALLOW-BURIED DRIP IRRIGATION AND WIDE-WIDTH PRECISION SEEDER
/
电驱式小麦浅埋滴灌-宽幅匀播机控制系统研究

Shenghe BAI[1,2], Yanwei YUAN[1,2], Liang WEI[2], Liming ZHOU[2], Kang NIU [2], Bo ZHAO[2], Jinhui ZHANG[3], Yuqi WANG[2], Wenyu TONG[2], Shuaiyang ZHANG[2], Lijing LIU[1,2], Zenglu SHI[4], Gang GUO [5]

[1] China Agricultural University, Beijing 100083, China
[2] Chinese Academy of Agricultural Mechanization Sciences Group Co., Ltd,
National Key Laboratory of Agricultural Equipment Technology, Beijing 100083, China
[3] Dongliao county mechanical technology promotion station, Jilin 136200, China
[4] College of Mechanical and Electrical Engineering, Xinjiang Agricultural University, Urumqi 830052, China
[5] Heilongjiang Province's Gengzheng Agricultural Machinery Manufacturing Co., Ltd., Nanyang 473000, China
Tel: +86-13815375524; E-mail: 13815375524@163.com
DOI: https://doi.org/10.35633/inmateh-74-07

Keywords: *Drip irrigation; Precision seeder; Electric-drive; Control system; Precision seeding and fertilization*

ABSTRACT

To achieve precise seeding and fertilization operations for wheat and improve the intelligent level of wheat shallow buried drip irrigation and wide-width precision seeder, this article proposes a fusion speed measurement method by integrating ground encoder and satellite positioning module, and designs a control system of electric-drive wheat shallow-buried drip irrigation and wide-width precision seeder. The system includes STM32 main controller, DC servo motor, servo motor reducer, wheel encoder, vehicle navigation positioning module, vehicle control terminal, attitude sensor, voltage conversion module, etc. Based on the VisualTFT platform and equipped with a multi-functional touch screen, by designing the overall functions of terminal including obtaining speed from ground wheel encoder, obtaining speed from vehicle navigation positioning module, automatic switching of seeding mode speed source, motor speed control model, and remote transmission of positioning information, the system achieves the precise seeding and fertilization by adjusting the seeding/fertilization speed according to the forward speed of the tractor. The experimental study investigated the working performance of the control system of electric-drive wheat shallow-buried drip irrigation and wide-width precision seeder. Calibration test results showed that the speed accuracy of the ground wheel encoder was above 97.00%, The average seeding rate and fertilizer application rate were 22.4 g/r and 157.4 g/r, the standard deviations were 1.1 and 3.3, respectively. Field trial results showed that the seeding rate control error ranged from 3.0% to 5.3%, and the fertilization amount control error ranged from 3.0% to 6.0%. It meets the requirements for precise seeding and fertilization operations of shallow-buried drip irrigation and wide-width precision wheat seeder.

摘 要

为实现小麦精量播种施肥作业过程，提高小麦浅埋滴灌-宽幅匀播机智能化水平，提出地轮编码器和卫星定位模块融合测速方法，设计了电驱式小麦浅埋滴灌-宽幅匀播机控制系统，包括 STM32 主控器、直流伺服电机、伺服电机减速器、地轮编码器、车载导航定位模块、车载控制终端、姿态传感器、变压模块等部分。基于 VisualTFT 平台，搭载多功能触摸屏，通过对地轮编码器速度获取、车载导航定位模块速度获取、播种模式速度源自动切换、电机调速控制模型、定位信息远程传输等终端功能整体设计，实现了随拖拉机前进速度调整排种/肥转速，达到精量播种施肥的目的。试验研究了电驱式小麦浅埋滴灌-宽幅匀播机控制系统工作性能，标定试验结果表明：地轮编码器测速精度都在 97.00%以上，平均排种/肥量分别为 22.4 g/r、和 157.4 g/r，标准差分别为 1.1 和 3.3；田间试验结果表明：播量控制误差范围为 3.0%~5.3%，施肥量控制误差范围为 3.0%~6.0%，符合实际小麦浅埋滴灌-宽幅匀播机精量播种施肥作业要求。

INTRODUCTION

Shenghe BAI, Ph.D. Stud. Eng.; Yanwei YUAN, Prof. Ph.D. Eng.; Liang WEI, M.S. Stud. Eng.; Liming ZHOU, Prof. Ph.D. Eng.; Kang NIU, Prof. Ph.D. Eng.; Bo ZHAO, Prof. Ph.D. Eng.; Jinhui ZHANG, M.S. Stud. Eng.; Yuqi WANG, M.S. Stud. Eng.; Wenyu TONG, Ph.D. Stud. Eng.; Shuaiyang ZHANG, Ph.D. Stud. Eng.; Lijing LIU, Prof. Ph.D. Eng.; Zenglu SHI, Prof. Ph.D. Eng. Gang GUO, Prof. Ph.D. Eng.*

Xinjiang is a typical arid and semi-arid region and water-saving high-yield is the inevitable direction for the sustainable development of wheat production in Xinjiang (*Wan, 2023*). Subsurface drip irrigation with wide-row planting is an efficient water-saving, and yield-increasing cultivation technique for wheat, promoting cost. Reduction and income increase, which has received significant attention and promotion in recent years (*Yu et al., 2023; Yao et al., 2021*). Precision seeding is to provide uniform seed flow according to agronomic requirements, that is, adjusting seeding density can effectively coordinate the relationship between the number of spikes per unit area and the number of grains per spike of wheat. It further increases production and becomes the development trend of shallow buried drip irrigation and wide-row uniform planting of wheat in Xinjiang (*Xue et al., 2023; Wang 2023*). Currently, traditional wheat seeders mostly use ground wheel-driven seeders, combined with manual gearbox to adjust seeding amount and grain spacing. However, due to the complexity of field conditions and the large vibration of the machinery during operation, it is prone to issues such as wheel slippage, hanging, and chain jumping when operating at high speeds. In addition, the uneven speed of the tractor often results in poor seeding uniformity, seriously affecting the quality of seeding (*Gui et al., 2024; Tang 2021*). In addition, adjusting the seeding volume manually through the gearbox can only adjust the seeding volume in a fixed gear, which makes it difficult to meet the precise control requirements of seeding volume under different planting agronomic requirements and operating speeds (*Liao et al., 2022; Sun et al., 2024*). Electric drive seeding technology, as an important means to achieve precise adjustment of seed spacing and seeding volume, has the advantages of saving seeds, labor, and increasing efficiency, and has always been a research focus at home and abroad. Therefore, studying a control system for an electric-drive wheat shallow-buried drip irrigation-wide-width precision seeder is of great significance for achieving precise seeding of wheat in Xinjiang.

Research on precision seeding technology at home and abroad mainly focuses on the structural design and parameter optimization of seeders. There are various seeders with stable performance and high seeding accuracy currently being applied in production practice (*Mudarisov et al., 2020; Nielsen et al., 2018; Zhang et al., 2024; Jiang et al., 2019*). To further achieve high-speed precision sowing and precise adjustment of sowing quantity, scholars have conducted extensive research on the driving and speed measurement methods of seeders (*Gui et al., 2024; Feng et al., 2020; Wang et al., 2022; He et al., 2017*). *Karimi et al., (2019),* developed a wheat seeder operation monitoring system, consisting of vehicle speed sensors, seed flow sensors, GPS, and electric drive modules. It achieves precise matching of seeding quantity and operation speed by controlling the electric drive module through the controller. Cay et al., (2018), designed a motor control system that integrates PWM and PID technologies, consisting of an encoder, a DC brushless motor, and its drive module. Inoti et al. (Ibrahim et al., 2018) developed a control system for pneumatic precision seeding, which features functions such as data collection, data processing, and seeding control. Domestically, *Liao et al., (2022), Wu (2022), Liao et al., (2017)*, designed a speed-controlled seeding system based on two speed measurement methods: wheel encoder and BeiDou signal receiver. *Zhang Zenghui, (2018),* designed a model for intelligent operation and precise control system of wheat seeder, solving the problems of unstable seeding quality and traditional backward seeding technology caused by the use of ground wheel drive in domestic wheat seeders. *Liu Wei, (2020),* studied the monitoring and control technology of wheat sowing amount based on seeding flow information, providing feedback control on the actual sowing amount. *Chen et al., (2022)*, designed a precision seeding control system based on BeiDou navigation, and the results showed that the system response time was ≤0.8 s. *Jiang Zhenhan et al., (2024)*, designed a control system for an electrically-driven high-speed intelligent corn planting machine, which achieves real-time matching of planting spacing and machine forward speed. In summary, the current electronic control seeding technology is based on measuring speed using wheel speed sensors, Doppler radar, satellites, etc., and controlling the speed of electric motors or hydraulic motors to dispense seeds or fertilizers as needed. The wheel speed sensor has low speed measurement accuracy, the Doppler radar is expensive and not easy to promote, and there is a delay when the satellite is in non-uniform motion on the carrier. The above speed measurement method is single and cannot guarantee the accuracy of speed measurement under different working conditions and speeds, affecting the uniformity of sowing and making precision sowing difficult to achieve.

To address the above issue, this article proposes a speed measurement method that integrates ground wheel encoders and satellite positioning modules based on a single-axis rotary tillage wheat shallow buried drip irrigation-wide width uniform sowing machine.

It uses the STM32 microcontroller to build and develop the control system for the electric drive wheat shallow buried drip irrigation - wide-width uniform broadcasting machine, and conducts parameter calibration and field performance verification tests in order to improve the quality of wheat shallow buried drip irrigation - wide-width uniform broadcasting operations.

MATERIALS AND METHODS

Overall design of wheat shallow-buried drip irrigation and wide-width precision seeder

The wheat shallow-buried drip irrigation and wide-width precision seeder is mainly composed of two parts: mechanical structure and control system.

- **Mechanical structure**

The mechanical structure of the single-axis rotary tillage wheat shallow-buried drip irrigation and wide-width precision seeder includes components such as the frame, reducer, rotary tillage device, tail seeding assembly, shallow-buried drip irrigation belt device, pressing device, side fertilization device, and fertilization box. It can complete operations such as leveling of 9 rows of wheat seedbeds, laying drip irrigation belts, precise seeding, variable fertilization, and covering soil in one go.

During operation, the machine is suspended on the tractor at three points, connected to the gearbox through the power output shaft, driving the rotary tillage device to crush and level the soil and throw it up. The motor drives the seeding/fertilizing shaft, and the seeds and fertilizers are transported through the seeding/fertilizing tube. And under the action of the harrow, the seeds are evenly distributed on the crushed and leveled seedbed. The overturned soil is smoothly and orderly covered on the surface of the organic fertilizer under the action of the retaining plate. The drip tape rotates on the drip tape rack and is laid shallowly along the front of the machine under the action of the shallow-buried drip tape device. The compaction device completes the post-seeding soil compaction and leveling process.

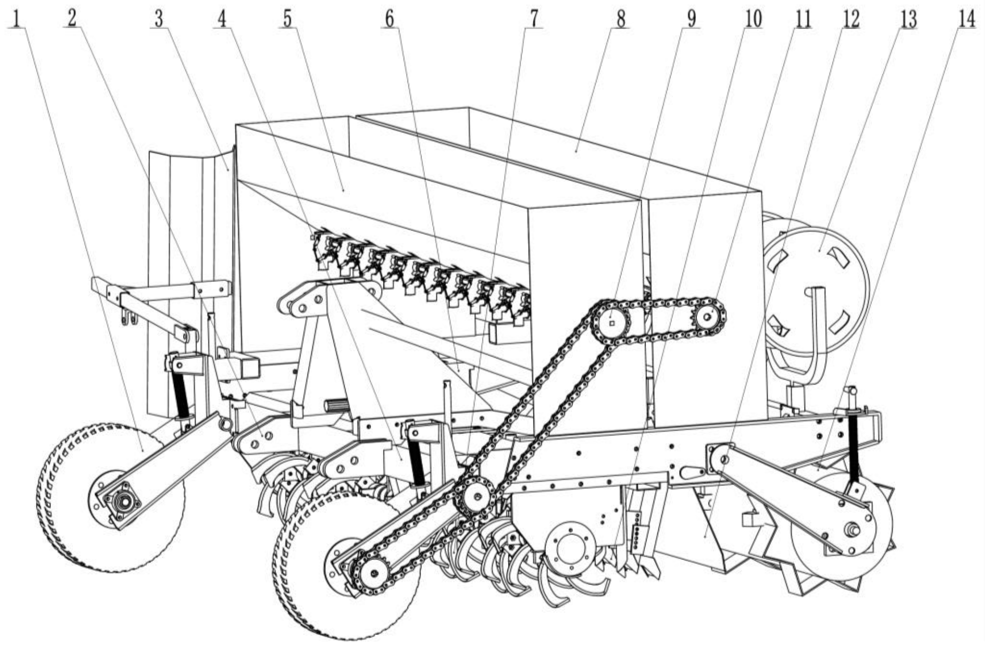

Fig. 1 - Mechanical structure diagram of Wheat Shallow-Buried Drip Irrigation and Wide-Width Precision Seeder
1. Ground wheel; 2. Three-point suspension; 3. Side fertilization device; 4. Frame; 5. Fertilizer box; 6. Reducer; 7. Rotary tillage device; 8. Seed box; 9. Fertilizer discharge shaft; 10. Swallowtail seeding assembly; 11. Seed discharge shaft; 12. Soil deflector; 13. Shallow buried drip irrigation tape device; 14. Pressing device.

- **Control system**

The overall structure of the control system of the electric-drive wheat shallow buried drip irrigation-wide width precision seeder is shown in Figure 2, mainly composed of STM32 main controller, DC servo motor, servo motor reducer, ground wheel encoder, vehicle navigation positioning module, vehicle control terminal, attitude sensor, voltage conversion module, etc.

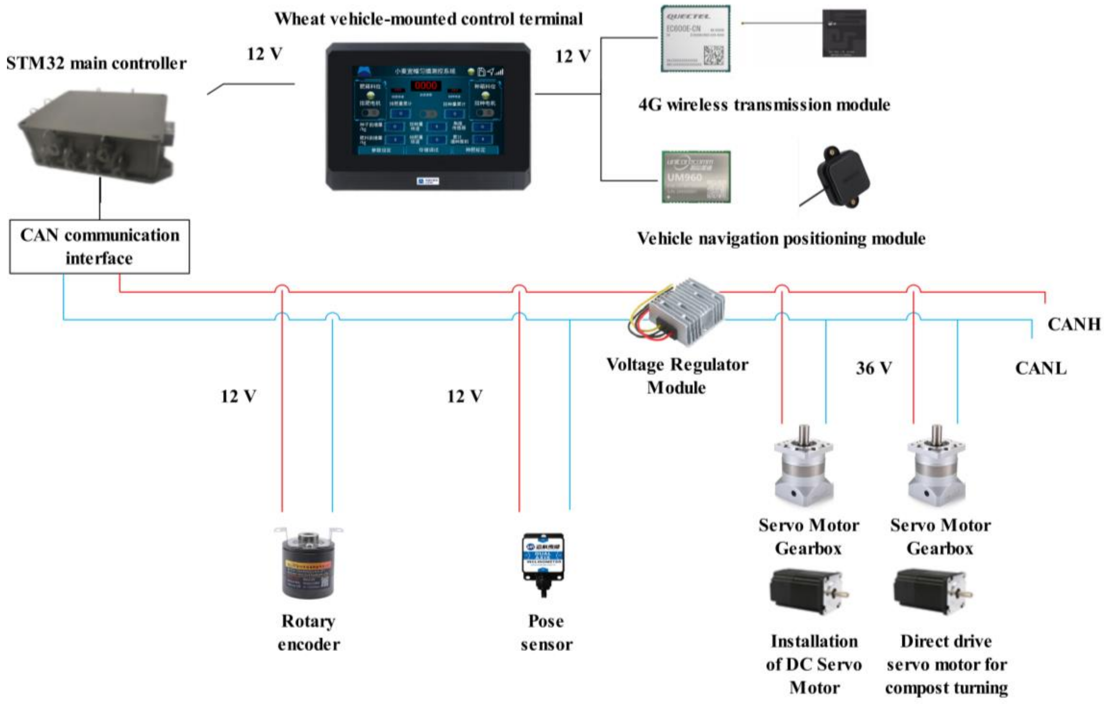

Fig. 2 - Overall control system composition diagram of electric-drive wheat shallow-buried drip irrigation and wide-width precision seeder

When the system starts working, it first installs the on-board control terminal in the tractor cab through operation. It sets parameters such as the number of planting/fertilizing units, working width, number of working rows, amount of planting/fertilizing per circle, amount of planting/fertilizing applied per mu (mu represents 666.7 square meters), angle threshold, etc., and sends them to the STM32 controller via the CAN bus. When the machine starts operating, the main controller first reads the angle value of the posture sensor to determine if the machine is on the ground. If it detects that the machine has landed, it will start the sowing and fertilizing operations, and turn on the motor enable switch. It reads the speed signals from the wheel encoder and the vehicle navigation positioning module, and generates motor control commands based on the speed signals and preset parameter information. It controls the servo motor to respond quickly, matching the planting/fertilizing rate with the forward speed of the tractor. The vehicle-mounted navigation positioning module obtains the seeding machine operation location information, uses a 4G wireless transmission module to remotely wirelessly transmit the positioning information to the cloud storage platform. When the tractor is working in variable speed mode, the main controller automatically selects the more accurate speed source between the wheel encoder and the vehicle navigation positioning module to drive the servo motor at the target speed for driving the planting/fertilizing shaft rotation. If the monitoring angle value is greater than the set threshold, the main controller stops sending motor drive pulses and stops reading speed signals. Continuously monitor and judge whether the tractor is landing, adjust the planting/fertilizer rotation speed according to the speed of the tractor to achieve precise seeding and fertilization.

System hardware design

- **Main Controller**

The main controller is the core of the control system, which needs to receive and process various sensor signals in real time, such as ground wheel encoders, vehicle navigation positioning modules, tilt sensors, and generates signals in real time to adjust the speed of the DC servo motor. This study used the STM32F407VET6 microcontroller produced by STMicroelectronics, which features a high-performance ARM Cortex-M4 core architecture. It has 32-bit arithmetic capability and interrupt masking function, with 100 external pins. The installation location is shown in Figure 3.

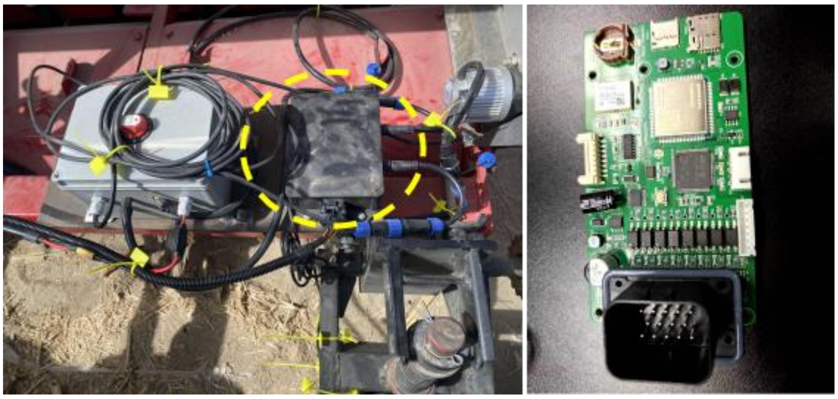

Fig. 3 - Installation diagram of main controller

- **Drive module**

The drive module consists of a DC servo motor, servo motor reducer, planting/fertilizing actuator, etc. The design of the single-axis rotary wheat shallow buried drip irrigation-wide width uniform sowing machine includes a seed sowing amount of 30 kg per mu, a fertilizer application amount of 10 kg per mu, a working width of 2850 cm, a sowing width of 30 cm, and a row spacing of 60 cm. To meet the requirements of machine operation speed and precise sowing, the transmission ratio for the planting reducer is selected as 20, and the transmission ratio for the fertilization reducer is 10. The driving torque of the servo motor is (*Liao et al., 2022*):

$$N = \frac{KM}{\alpha\beta} \tag{1}$$

where:

N - motor drive torque, Nm;

K - the safety factor of the motor, which is set to 2;

M - the maximum load on the planting axis during operation, Nm;

α - the sprocket transmission ratio;

β - the gear ratio of the reducer.

The starting torque of the planting shaft measured by the digital torque wrench ATRITERBME-006 of Wuhu Aritter Mechanical and Electrical Equipment Co., Ltd. is 9.8 Nm, and the steady rotation torque is 7.4 Nm. The torque of the motor drive is calculated as 1.48 Nm according to formula (1). The 60AIM40 integrated torque servo motor produced by Hangzhou Yizhi Technology Co., Ltd. with a torque of 3 Nm is selected, which meets the operational requirements. It uses PF-60 servo motor with two-stage reducer to meet the transmission requirements. The installation location is shown in Figure 4.

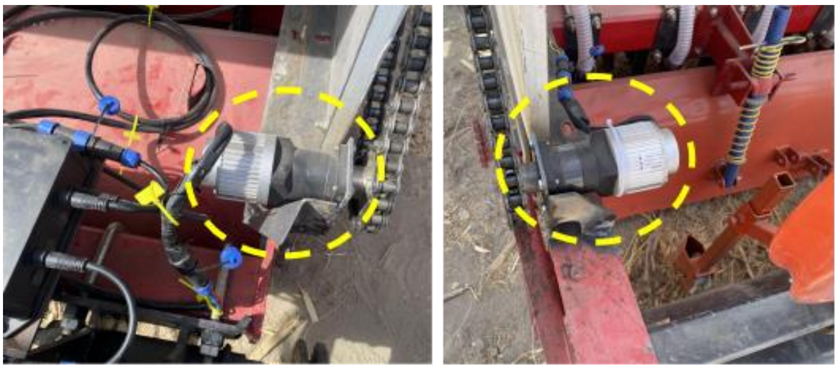

Fig. 4 - Installation diagram of drive module

- **Rotary encoder**

Forward speed is an important measurement parameter for precision planting. This article features the IP68 single-turn waterproof and explosion-proof absolute value encoder produced by Brite Electronic, which has strong anti-interference capability and high-cost performance. The installation location is shown in Fig. 5.

Fig. 5 - Installation diagram of rotary encoder

- **Vehicle navigation positioning module**

The vehicle navigation positioning module uses the GPS/BeiDou dual-mode positioning module produced by Redcore IoT Technology to real-time obtain the positioning location of the seeder in the field operation (communicate with the control platform through the 4G CAT module to upload the machine operation position in real time). It sets the signal update frequency to calculate the forward speed and seeding area of the machine, with characteristics such as high gain, low standing wave ratio, and stable signal. The installation location is shown in Figure 6.

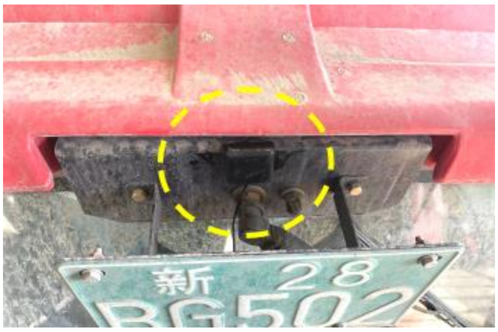

Fig. 6 - Installation diagram of vehicle navigation positioning module

- **Attitude sensor and pressure module**

The posture sensor uses the LVT425T-90 dual-axis tilt sensor produced by Microsensor, which real-time acquires the tilt angle value of the machine, and determines whether it exceeds the set angle threshold, that is, whether the machine is grounded. It features simplicity of use, reliable performance, and good scalability. The voltage booster module uses a non-isolated boost converter produced by Enpu Technology to convert the tractor voltage of 12 V to the operating voltage of the servo motor of 36 V, providing continuous and stable power for the drive module. The installation location is shown in Figure 1.

- **Vehicle control terminal**

The vehicle control terminal uses the DC80480KM070 model serial display night vision screen produced by Guangzhou Dacai. It is based on the VisualTFT platform to process, display, control, and store data. It has the advantages of good handling of workpiece movement and vibration, meeting the actual requirements of the electric drive wheat shallow buried drip irrigation-wide width seeder control system.

System Software Design

- **Overall design of terminal functions**

Based on the functional requirements of the precision seeding/fertilization control system, this article designs the system implementation process. The implementation process is shown in Figure 7. Initialize configuration before system startup, set system parameters, and obtain parameter values through corresponding protocol parsing. Start the system and cyclically check the working status of each sensor. After the control system is started, input the equipment parameters of the wheat shallow buried drip irrigation-wide width seeder through the touch screen (machine operation width, number of sowing and fertilizing rows, etc.), single circle sowing/fertilizer amount, target fertilizer application amount, target sowing amount of wheat, angle threshold, etc.

Establish the serial connection relationship between the main controller and the driver module, wheel encoder, onboard navigation positioning module, attitude sensor, etc. The embedded controller determines the target speed for planting/fertilizing by obtaining the operating posture and working speed of the machine, combined with the input parameters.

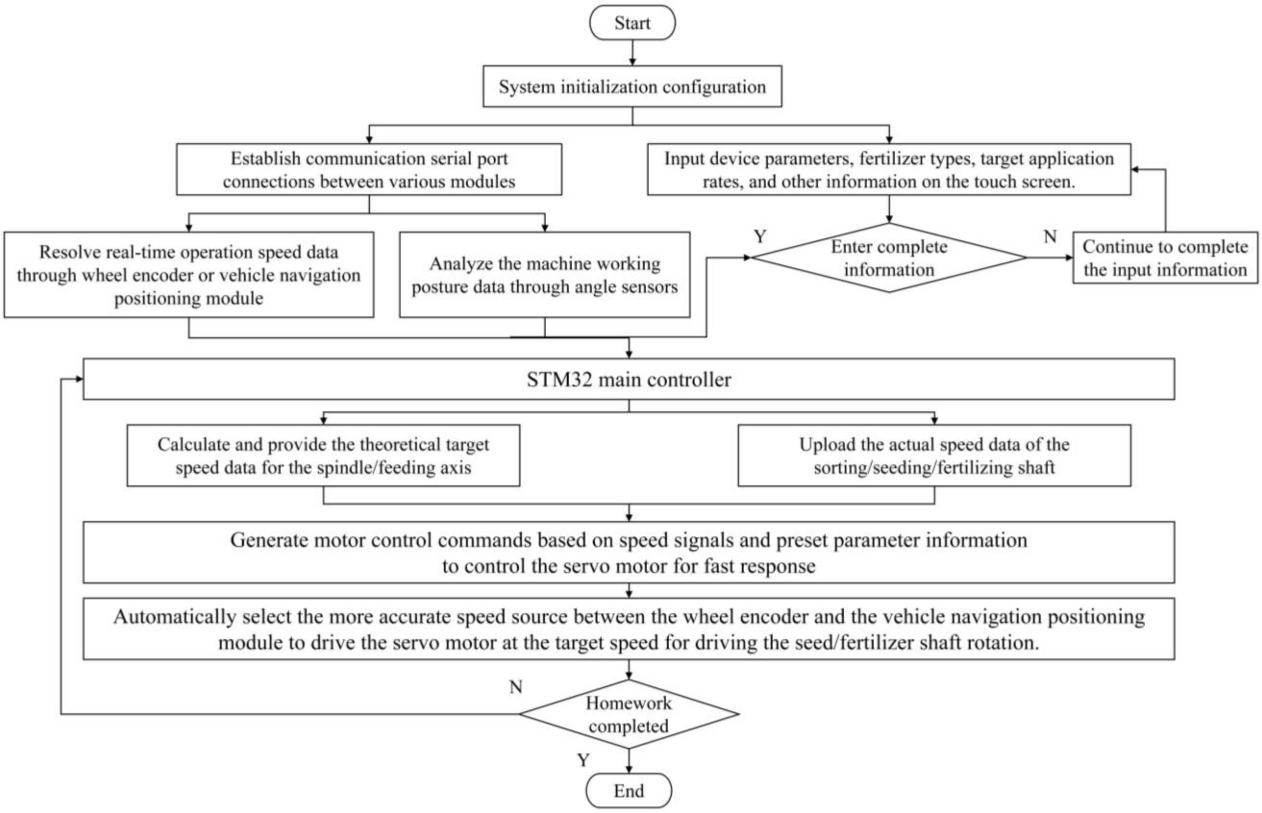

Fig. 7 - Control system implementation flowchart

(1) Rotary encoder speed acquisition

By using a precision rotary grating disk and optocoupler to generate count pulses that can be recognized for direction, the count pulses are transmitted to the STM32 controller to calculate the ground wheel rotation speed (i.e. implement forward speed), allowing real-time acquisition of implement movement data information. However, due to the phenomenon of wheel slippage, the wheel slippage coefficient must be considered. The formula for calculating the actual wheel speed (i.e. implement forward speed) is:

$$\begin{cases} v = \dfrac{\pi d(1+\varepsilon)N}{tn} \\ v = \dfrac{33\pi(1+\varepsilon)N}{25600t} \end{cases} \tag{2}$$

where:

v - the speed of the machine, m/s;

n - the number of speed pulse signals per revolution of the encoder, which is 1024;

d — the diameter of the speed measuring wheel, which is 1.32 m;

ε — the slip rate, generally taken as 0.05 to 0.12 (*Zhang et al., 2021*).

(2) Vehicle navigation positioning module speed acquisition

The UM220-IV outputs location information in the communication standard format of NMEA-0183 and accepts data input in ASCII format. It sets the output frequency of the module to 5 Hz through the MCU, and obtains valid information such as latitude, longitude, UTC time, and ground speed by parsing the mixed positioning data RMC frame of GPS and BeiDou. The basic format of RMC frame is as follows:

$GNRMC, time, status, Lat, N, Lon, E, spd, cog, date, mv, mvE, mode*cs

Where spd is the ground speed, obtaining spd data can obtain the real-time speed v of the planter. The speed resolution process diagram is shown in Figure 8.

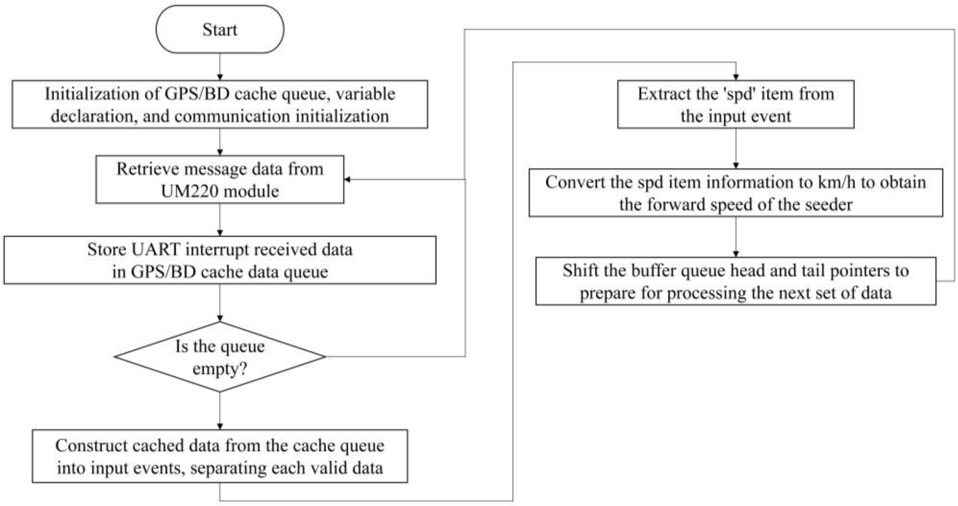

Fig. 8 - Flowchart of speed acquisition process for vehicle navigation positioning module

(3) The speed of sowing mode comes from automatic switching

When the tractor is working in variable speed mode, the main controller automatically selects the more accurate speed source between the wheel encoder and the vehicle navigation positioning module to drive the servo motor. The speed measured by the vehicle navigation positioning module is v1, the speed measured by the wheel encoder is v2, and the critical speed for switching speed measurement methods is v3. The speed source V selection mode is as shown in Table 1.

Table 1

Speed source switch logic

Real-time speed	Measured speed	Speed Source
＞ v	$v_1 > v_2$	v_1
	$v_1 \le v_2$	v_2
≤ v	/	v_1

(4) Motor Speed Control Model

To achieve precise planting control, the motor needs to dynamically match the forward speed of the tractor. The demand weight per unit time in the field is equal to the sowing quantity per unit time required by the sowing machine, and the calculation formula is:

$$\begin{cases} N_T = BS = XH\dfrac{1000v}{60}\cdot\dfrac{1.5}{1000} \\ N_B = \dfrac{V_s \rho n X}{1000} \end{cases} \tag{3}$$

Simplifying formula (3), the theoretical speed calculation formula of the seed meter (motor scheduling control model) can be obtained:

$$n = \frac{25BLv}{V_s \rho} \tag{4}$$

where: S - the planting area per unit time of the planter in the field, acres/min;

X - the number of rows planted by the seeder;

H - the row spacing of the planter, m;

v - the operating speed of the seeder, km/h;

N_T - the demand weight per unit time in the field, kg/min;

B - the seeding rate per acre, kg/acre;

N_B - the seeding amount per unit time of the seeder, kg/min;

V_S - the calculated volume of the seeding rotor, cm^3;

ρ - the bulk density of wheat seeds, g/cm^3;

n - the theoretical working speed of the planter, r/min.

(5) Remote transmission of location information

When transmitting positioning information of the seeder, the 4G wireless transmission module needs to be configured. The STM32F407 microcontroller configures the 4G wireless transmission module using AT commands, setting the data communication baud rate between the 4G wireless transmission module and the STM32F407 microcontroller USART1 (TXD_1) to 9600. 4G wireless transmission module connects to Alibaba Cloud server, port is 8090, connection type is long connection, and working mode is network transparent transmission mode. After the above configuration, the 4G module can transmit the positioning information of the planter through the network to the specified server port after receiving the positioning data packet sent by the STM32F407 microcontroller, realizing the remote transmission of the planter's positioning information.

- **Display Interface**

Based on the precision seeding/fertilization control algorithm and flow chart, the display interface of the electric-drive wheat shallow buried drip irrigation-wide width precision seeder control system is planned and designed on the VisualTFT platform. It is mainly divided into four major functional interfaces: main interface, parameter setting interface, storage debugging interface, and fertilizer calibration interface.

The main interface sets the switch for sowing, fertilizing, and motor control, displaying parameters such as amount of sowing applied per mu, amount of fertilizer applied per mu, sowing speed, fertilizing speed, machine forward speed, angle sensor, sowing area, etc., and provides alarm prompts for the material level in the seed and fertilizer boxes. The parameter setting interface mainly sets the number of seeders, the number of fertilizers, working width, angle threshold, number of working rows, wheel rotation radius, single circle seeding amount, single circle fertilization amount, amount of sowing applied per mu, amount of fertilizer applied per mu, etc., and can adjust the rotation direction of the motor. Debug the stored content of the prototype positioning status, operation information, etc. in the storage debugging interface. The fertilizer calibration interface is mainly used to calibrate the single circle seeding amount and single circle fertilization amount, as shown in Figure 9.

Fig. 9 - Display Interface

Performance test design of monitoring system

- **Parameter calibration**

(1) Wheel Encoder Speed Measurement

Accurate measurement of the forward speed of the machine is related to the control system for seeding/fertilizer rate calculation and control accuracy, and speed testing work is required. The wheat shallow buried drip irrigation-wide width precision seeder maintains a constant speed of 3-6 km/h and records the time it takes to pass through the calibration interval (100m*5m).

By transforming formula (2), the calculation formula for slip ratio is obtained:

$$\varepsilon = \frac{25600tv}{33\pi N} - 1 \tag{5}$$

The study selected 6% as the slip rate of the wheat shallow buried drip irrigation-wide width precision seeder. To verify the accuracy of the speed measurement, repeat the experiment 3 times and take the average value. Calculate the actual speed by dividing the distance traveled by the time taken.

(2) Seed planting/fertilizer measurement

To achieve precise seeding and fertilization, it is necessary to determine the seeding/fertilizer discharge rates of different planters/fertilizer applicators. The experimental materials selected were commonly used granular compound fertilizer and Xin Chun 6 wheat seeds. Before the experiment, the seeds/fertilizer are loaded into the seed/fertilizer box separately.

The servo motor is controlled by the controller to drive the slot wheel type seed/fertilizer dispenser to rotate at a certain speed. Place the feeding container at the discharge port, and the amount of seeds/fertilizer for sowing/fertilizing can be obtained by weighing the seeds/fertilizer in the feeding container. Then use a stopwatch to time the sowing/fertilizing, repeating the experiment three times at each speed.

- **Field performance test**

To verify the operation effect of the control system of the electric-drive wheat shallow-buried drip irrigation-wide-width precision seeder, a field test of precision seeding of wheat was conducted on March 30, 2024 in Yuli County, Bayingolin Mongol Autonomous Prefecture, Xinjiang Uygur Autonomous Region. The supporting power is John Deere 1204 tractor, the wheat variety is Xinchun 6, the compound fertilizer variety is Guizhuhua 27-17-7, and the seeding and fertilization experiment is conducted using the wheat shallow-buried drip irrigation-wide-width uniform sowing machine equipped with this system.

According to the national standards GB/T9478-2005 "Test methods for grain drill" (China Agricultural Machinery Standardization Technical Committee 2005) and GB/T35487-2017 "Variable rate fertilizer seeder control system" (China Agricultural Machinery Standardization Technical Committee 2017), the test process starts by powering on the system and resetting the data. Then start the machine moving forward by adjusting the throttle and shifting gears to control the forward speed of the machine. In this experiment, the machine was set to move at speeds of 1.0, 2.0, 3.0, 4.0, 5.0, and 6.0 km/h, with a seeding rate of 30.0 kg per mu and a fertilizer application rate of 10.0 kg per mu. At each speed, the machine operates on an area of 1 mu. The actual seeding and fertilization amounts are recorded in the experimental table.

RESULTS AND ANALYSIS

- **Parameter calibration**

(1) Wheel Encoder Speed Measurement

The test site is shown in Figure 10. The detection speed was calculated using formula (2), and the test results are shown in Table 2. The speed measurement accuracy during the test was above 97.00%, meeting the requirements for accurate speed measurement in seed/fertilizer testing work.

Fig. 10 - Wheel encoder speed test

Table 2

Test measurement results of wheel encoder speed calibration

Number	Actual Speed (km/h)	Detection speed (km/h)	Accuracy (%)
1	3.00	2.93	97.67
2	3.50	3.45	98.57
3	4.00	4.07	98.25
4	4.50	4.60	97.78
5	5.00	4.88	97.60
6	5.50	5.59	98.36
7	6.00	6.14	97.67

(2) Seed planting/fertilizer measurement

The test site is shown in Figure 11, and the test results are shown in Table 3. The average seeding/fertilizer application rates were 22.4 g/plant and 157.4 g/plant, with standard deviations of 1.1 and 3.3 respectively. It can be seen that the slot wheel type seed/fertilizer planter dispenses a larger amount of seeds/fertilizer per revolution at low speed and a smaller amount at high speed, which is mainly related to the weight of seeds/fertilizer carried out between the slot wheel outer side and the shell.

Fig. 11 - Seed planting/fertilizer application test

Table 3

Test measurement results of seeding/fertilizer dispenser capacity

Category	Number of trials	Manure spreader speed / (r/min)		
		10	30	50
Sowing quantity (g/r)	1	25.6	21.6	20.6
	2	24.8	21.6	19.6
	3	24.4	23.8	19.6
	Average	22.4		
	Standard Deviation	2.2		
Manure application (g/r)	1	163.4	148.6	148.8
	2	162.0	159.0	151.4
	3	165.6	164.8	153.0
	Average	157.4		
	Standard Deviation	6.6		

- **Field performance test**

The test site is shown in Figure 12, and the test results are shown in Table 4. Field trial results showed that the seeding rate control error ranged from 3.0% to 5.3%, and the fertilization amount control error ranged from 3.0% to 6.0%, meeting the requirements for practical operation of electrically driven wheat shallow buried drip irrigation-wide width precision seeder. However, there is still room for optimization in the accuracy of the prototype control. In the future, in-depth research on the working principle, key components, and control modules of the prototype is needed to improve its control accuracy.

Fig. 12 - Field test site

Table 4

System field monitoring test results

Forward speed (km/h)	Theoretical audience reach (kg)	Actual playback volume (kg)	Control Error (%)	Theoretical fertilization amount (kg)	Actual amount of fertilizer (kg)	Control Error (%)
1	30.0	31.5	5.0	10.0	10.5	5.0
2		31.3	4.3		10.3	3.0
3		28.9	3.7		9.4	6.0
4		29.1	3.0		9.5	5.0
5		28.4	5.3		9.4	6.0
6		28.6	4.7		9.6	4.0

CONCLUSIONS

In this paper an electrically driven control system for wheat shallow buried drip irrigation-wide width precision seeder was designed, parameter calibration tests were conducted, and field tests were carried out to verify the reliability of the system operation.

1) This article proposed a fusion speed measurement method integrating the ground wheel encoder and satellite positioning module. The control system was designed with a single-chip STM32 controller as the core, consisting of STM32 main controller, DC servo motor, servo motor reducer, ground wheel encoder, vehicle navigation positioning module, vehicle control terminal, attitude sensor, voltage conversion module, etc., to achieve precise wheat sowing and fertilization for an electric-drive shallow-buried drip irrigation and wide-width precision seeder.

2) Based on the VisualTFT platform, the software system developed for the electric drive control system can calibrate the single-circle seeding amount, single-circle fertilization amount, set the number of seed/fertilizer dispensers, working width, angle threshold, working rows, wheel rotation radius, seed amount of sowing applied per mu, amount of fertilizer applied per mu, etc. It can display real-time parameters such as seeding amount rotation speed, fertilization amount rotation speed, machine forward speed, machine posture status, seeding area, and has fault alarm and storage functions.

3) Calibration tests and field trials of the control system for an electric-drive wheat shallow-buried drip irrigation and wide-width uniform seeding machine showed that the system operated stably and reliably. In the parameter calibration test, the speed accuracy of the ground wheel encoder was above 97.00%, with average seeding/fertilizer amounts of 22.4g/r and 157.4g/r respectively, and standard deviations of 1.1 and 3.3. In field experiments, the seeding rate control error ranged from 3.0% to 5.3%, and the fertilization amount control error ranged from 3.0% to 6.0%, meeting the operational requirements of the actual electric-drive wheat shallow-buried drip irrigation and wide-width precision seeder.

Subsequent research will add fertilization prescription charts, flow monitoring sensors, and consider introducing other programming languages to take into account the development characteristics of other high-level programming languages, enhancing the monitoring performance of the system. Further research will collect more diverse data to enhance the robustness and adaptability of the model, ensuring greater stability, reducing control accuracy errors, improving the system's environmental adaptability and operational reliability, making the system functions more in line with actual production conditions, and adaptable to different operational scenarios.

ACKNOWLEDGEMENT

This work was supported by the Xinjiang Uygur Autonomous Region Major Science and Technology Special Projects (2022A02003-3).

REFERENCES

[1] Cay A., Kocabiyik H., May S., (2018), Development of an electro-mechanic control system for seed-metering unit of single seed corn planters-Part I: design and laboratory simulation [J]. *Computers and Electronics in Agriculture*, 144: 71-79, London / UK.;

[2] Cay A., Kocabiyik H., May S., (2018), Development of an electro-mechanic control system for seed-metering unit of single seed corn planters-Part II: field performance[J]. *Computers and Electronics in Agriculture*, 145:11-17, London / UK.;

[3] Chen S.F., Yu C., Sun Q.X., Yang, J., Lu X.C., Li X.H., Liu, X., (2020), Research on Control System of Precision Seeder Based on Beidou Navigation [J]. *Journal of Agricultural Mechanization Research*, 44(08): 114-118, Heilongjiang / P.R.C.;

[4] Feng Y.G., Jin C.Q., Yuan W.S., Chen M., Xu J.S., Liu Z., (2020), Research on precision electric seeding control system based on satellite velocity measurement for wheat [J]. *Journal of Chinese Agricultural Mechanization*, 41(12): 124-130, Jiangsu / P.R.C.;

[5] Gui Z.L., Gu Y.Q., Xu L.X., He X., Zhu Y.H., Wang B.S., Wang W.Z., (2024), Design and experiment of electronic control system of wheat planter based on GNSS velocity measurement [J]. *Journal of Henan Agricultural University*, 58(03): 1-14, Zhengzhou / P.R.C.;

[6] He X., Zhang D., Wei J., Wang M., Yu Y., Liu Q., Yan B., Zhao D., Yang L., (2017), Development of an electric-driven control system for a precision planter based on a closed-loop PID algorithm [J]. *Computers and Electronics in Agriculture*, 136(C): 184-192, London / UK.;

[7] Ibrahim E.J., Liao Q., Wang L., (2018), Design and experiment of multirow pneumatic precision metering device for rapeseed [J]. *International Journal of Agricultural and Biological Engineering*, 11(05): 116-123, Beijing / P.R.C.

[8] Jiang M., Liu C.L., Wei D., Du X., Cai P.Y., Song J.N., (2019), Design and Test of Wide Seedling Strip Wheat Precision Planter [J]. *Transactions of the Chinese Society for Agricultural Machinery (Transactions of the CSAM)*, 50(11): 53-62, Beijing / P.R.C.;

[9] Jiang Z.H., Jiang Z.H., Wang Y.X., Wei Y.F., Yu Y., Sun Y.J., Sun Y.T., (2024), Design and experiment of control system of electric drive corn high speed operation seeder [J]. *Journal of Chinese Agricultural Mechanization*, 45(03): 24-30,57, Jiangsu / P.R.C.;

[10] Karimi H., Navid H., Besharati B., Eskandari I., (2019), Assessing an infrared-based seed drill monitoring system under field operating conditions [J]. *Computers and Electronics in Agriculture*, 162: 543-551, London / UK.;

[11] Liao Q.X., Lei X.L., Liao Y.T., Ding Y.C., Zhang Q.S., Wang L., (2017), Research progress of precision seeding for rapeseed [J]. *Transactions of the Chinese Society for Agricultural Machinery (Transactions of the CSAM)*, 48(09): 1-16, Beijing / P.R.C.;

[12] Liao Q.X., Wu C., Zhang Q.S., Wang B.S., Du W.B., Wang L., (2022), Design and Experiment of Speed-dependent Seeding Control System of Rapeseed Precision Combined Seeding Machine [J]. *Transactions of the Chinese Society for Agricultural Machinery (Transactions of the CSAM)*, 53(12): 49-58+159, Beijing / P.R.C.;

[13] Liu W., (2020), *Research on Seeding Rate Monitoring and Controlling Technology Based on Information of Seed Flow Rate for Wheat Drill* [D]. *Jiangsu University*, Zhenjiang / P.R.C.;

[14] *National Agricultural Machinery Standardization Technical Committee*., (2005), GB/T 9478-2005 Test method of grain strip machine [S]. China Agriculture Press, Beijing / P.R.C.;

[15] *National Agricultural Machinery Standardization Technical Committee*., (2017), GB/T 35487-2017 Variable fertilization planter control system [S]. China Agriculture Press, Beijing / P.R.C.

[16] Nielsen S.K., Munkholm L.J., Lamandé M., Nørremark M., Edwards G.T.C., Green O., (2018), Seed drill depth control system for precision seeding [J]. *Computers and Electronics in Agriculture*, 144: 174-180, London / UK.;

[17] Salavat M., Ildar B., Zinnur R., Ramil L., Elmas N., (2020), Numerical simulation of two-phase “air-seed” flow in the distribution system of the grain seeder [J], *Computers and Electronics in Agriculture*, 168: 105151, London / UK.;

[18] Sun X.W., Xi X.B., Chen M., Huang S.J., Jin Y.F., Zhang R.H., (2024), Design and experiment of control system of wheat mechanized uniform sowing [J]. *Journal of Chinese Agricultural Mechanization*, 45(02): 27-32, Jiangsu / P.R.C.;

[19] Tang W.B., (2021), *Design and research of vertical rotary tillage electric drive wide narrow row sowing compound machine* [D]. Henan Agricultural University, Zhengzhou / P.R.C.;

[20] Wang W.L., (2023), *Effect of Optimizing Large Tube to Row Ratio Drip Irrigation Patterns on Yield and Water Use Efficiency of Spring Wheat and Its Physiological Mechanism* [D]. Shihezi University, Xinjiang / P.R.C.;

[21] Wang W.W., Wu K.P., Zhang Y., Wang M.X., Zhang C.L., Chen L.Q., (2022), The development of an electric-driven control system for a high-speed precision planter based on the double closed-loop fuzzy PID algorithm [J]. *Agronomy*, 12(04): 945, Madison Wisconsin / USA.;

[22] Wang Y.L., (2023), *Design and Research of Electric Control Wheat Precision Seeder* [D]. Henan Agricultural University, Zhengzhou / P.R.C.;

[23] Wu C., (2022), *Design and Experiment of Speed-dependent Seeding Control System of Rapeseed Precision Combined Seeding Machine* [D]. Huazhong Agricultural University, Wuhan / P.R.C.;

[24] Xue B., Zhou L.M., Niu K., Zheng Y.K., Bai S.H., Wei L.A., (2023), Sowing Depth Control System of Wheat Planter Based on Adaptive Fuzzy PID [J]. *Transactions of the Chinese Society for Agricultural Machinery (Transactions of the CSAM)*, 54(S1): 93-102, Beijing / P.R.C.;

[25] Yao J.W., Qi Y.Q., Li H.H., Shen Y.J., (2021), Water saving potential and mechanisms of subsurface drip irrigation: a review [J]. *Chinese Journal of Eco-Agriculture*, 29(06): 1076-1084, Beijing / P.R.C.;

[26] Yu H.L., Kan M.X., Xu Z.L., Ma R.Q., Liu A.K., Wang D.M., Wang Y.J., Yang Y.S., Zhao G.C., Chang X.H., (2023), Yield and dry matter accumulation of wheat in response to spring irrigation water in uniform sowing and strip sowing [J]. *Acta Agronomica Sinica*, 49(10): 2833-2844, Beijing / P.R.C.;

[27] Zhang C.L., Liu T., Zheng Z.H., Fang J., Xie X.D., Chen L.Q., (2024), Design and test of the precision seeding dispenser with the staggered convex teeth for wheat sowing with wide seedling belt [J]. *Transactions of the Chinese Society of Agricultural Engineering (Transactions of the CSAE)*, 40(05): 47-59, Beijing / P.R.C.;

[28] Zhang J.C., Yan S.C., Ji W.Y., Zhu B.G., Zheng P., (2021), Precision Fertilization Control System Research for Solid Fertilizers Based on Incremental PID Control Algorithm [J]. *Transactions of the Chinese Society for Agricultural Machinery (Transactions of the CSAM)*, 52(03): 99-106, Beijing / P.R.C.;

[29] Zhang Z.H., (2018), *Research and Design of Control System for Wide Wheat Multifunction Precision Seeder* [D]. Shandong Agricultural University, Taian / P.R.C.