Effects of seed furrow liquid spraying device on sowing quality and seedling growth of maize

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Abstract: The two cultivation patterns, no-tillage and ridge cultivation, are widely used in maize planting in Northeast China. However, the seed bounce in the falling process and drought seriously at the seedling stage often occur to affect the sowing quality, mean emergence time, percentage of emergence, root biomass, aboveground biomass and root shoot ratio of maize, and eventually reduces the grain yield. To solve the problems, a seed furrow liquid spraying device was designed and thereby the effects of spraying water volumes [0 L/m (V0), 0.6 L/m (V1), 1.2 L/m (V2) and 1.8 L/m (V3)] and nozzle types [conical nozzle (N1) and sectorial nozzle (N2)] on the sowing quality and seedling growth of maize were studied. The water volume and nozzle type had significant effects on the sowing quality (QR, CV, LD), not seedling growth (MET, PE, RB, AB, RSR) (p<0.05). Spraying water into seed furrow further humidified the soils around the maize seeds, effectively suppressing the bounce and rolling of seed and significantly promoting the growth and development of seeds. The sowing quality in the N2 treatment was significantly better than that in the N1 treatment. The qualified rate of seed spacing was increased with the increase of the water volume (V3>V2>V1>V0). However, the variability coefficient of seed spacing and lateral deviation of seed position were the opposite. The larger spraying water volume led to shorter mean emergence time (V0>V1>V2>V3) and higher percentage of emergence (V3>V2>V1>V0). The root biomass and aboveground biomass increased significantly with the enlargement of spraying water volume. Under different water volumes, the root shoot ratio differed significantly. The plants in the V1, V2 and V3 treatments had lower root shoot ratios compared with the V0 treatment. The increase of spraying water volume significantly reduced the root shoot ratio. The seed furrow liquid spraying device provides a reference for improving sowing quality and promoting seedling growth.

Keywords: seed bounce, drought, spraying water volume, nozzle type, seed spacing uniformity, root shoot ratio
DOI: 10.25165/j.ijabe.20191202.3799

Citation: Wang W J, Wang W P, Jia H L, Zhuang J, Wang Q. Effects of seed furrow liquid spraying device on sowing quality and seedling growth of maize. Int J Agric & Biol Eng, 2019; 12(2): 68–74.

1 Introduction

The Northeast China farming region is the most important commodity grain base of China. Maize is one of the three main crops there (the other two are rice and soybean) and holds a particularly prominent position. The planting area of maize is about 8.9×10^6 hm^2, accounting for more than 50% of the planting areas of grain crops in this region and 29% of maize acreage in China[1]. The maize yield in this region accounts for 30% of total maize yields in China[2]. Therefore, maize production in Northeast China significantly guarantees food security in China.

On the one hand, the seeds will bounce and roll when they fall into the seed furrow, resulting in a big seed spacing variation. The seed spacing variability during the sowing operation makes the distribution of environmental resources uneven, which leads to the fierce competition of the adjacent plants, where the weak plants are at a disadvantage, eventually resulting in the decline of the yield[3]. On the other hand, due to the unreasonable utilization of water resources in recent years, drought frequently attacked the Northeast China farming region, especially in spring[4]. In this region, 27% of the maize planting areas are highly drought-sensitive[5-7]. However, only 15% of the maize planting areas were equipped with irrigation conditions, and the frequent occurrence of drought had adversely affected the maize growth[8,9]. Although the planting patterns of no-tillage and ridge cultivation eased the problem, the situation has not been improved significantly. Thus, the urgent problems in the Northeast China farming region are how to improve the seed or plant spacing variability and deal with the adverse effects of drought.

Seed or plant spacing variability affects maize grain yield. As reported, the more uniform plant spacing and line spacing, the higher the crop yields[10,11]. The planting precision could increase yields 200-1200 kg/hm^2 without changing planting rates[12]. The uneven plant spacing within rows decreased corn grain yield at rates up to 2 bushels per acre for every inch increase in standard deviation of plant-to-plant spacing within a range of plant spacing variability from 2 to 8 inches[13]. The seed or plant spacing uniformity provides the largest growth space for each crop, increasing the size of the roots and reducing the competition between the strains, thereby increasing the yield[14].

Drought at the seedling stage affects maize emergence time. As reported, drought occurring at the trefoil-shooting stage of

Received date: 2017-09-11 **Accepted date:** 2018-05-17
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maize led to 13-day delay of whole growth period, 29.8% decrease of plant height and 41.2% reduction of leaf area[15]. Drought stress of seedling stage would postpone the growth and maturation period of maize[16,17]. The emergence time of the crop would be shortened when the seedbed was maintained at higher soil moisture[18]. The beet emergence time was significantly shortened under proper compaction and higher initial soil moisture[19].

Drought at the seedling stage affects percentage of emergence and grain yield of maize. Under the condition of less than 19% soil moisture content, every 1% decrease led to 6% reduction of percentage of emergence and 7% decrease of maize yield[20]. The increase of one dry day at the seedling, flowering and maturing stages led to reductions of 56.1 kg/hm^2, 58.7 kg/hm^2 and 21.2 kg/hm^2 of maize yields respectively[21]. Drought at the maize seedling stage often resulted in poor emergence quality, 25%-30% reduction in maize yield, and even maize failure[22]. Drought significantly affected maize emergence, plant growth and finally maize yields[23]. Under the relatively arid condition, maize yield was positively correlated with soil moisture content at the seedling stage[24].

Drought at the seedling stage also affects maize plant biomass. Maize could consume much water at the seedling stage and was sensitive to water deficit[25]. The maize seedling stage is the important period of root and leaf growth, when the root growth is the center and the occurrence of drought would cause the reduction of root dry weight[26]. The changing trends in the crop water stress index are consistent with the reduction of soil moisture contents induced by deficit irrigation. Both the dry matter and grain yields would decrease with the increase of soil water deficit[27]. The biomass of maize is improved linearly with the increase of soil moisture content in arid conditions[28]. Drought stress decreases leaf growth speed and plant height, reduces biomass, and severely inhibits seedling growth[29]. Drought could delay the grain-filling period, decelerate the relative grain growth and the maximum grain-filling speed, and shorten dry matter accumulation and stable growth periods[30].

In summary, compared with the variable plant spacing, the uniform plant spacing and line spacing could significantly increase the crop yields. In addition, the drought of seedling stage affected adversely maize mean emergence time, percentage of emergence, grain yield and plant biomass.

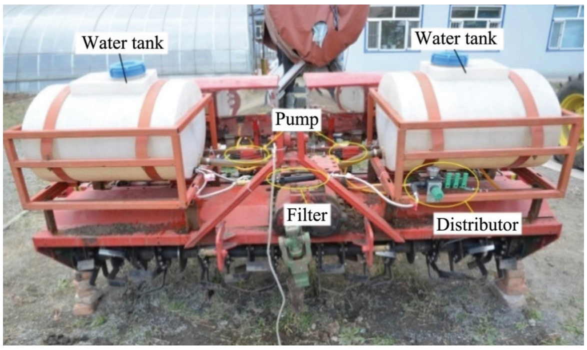
The purposes of this study were to determine the effects of a seed furrow liquid spraying device on the sowing quality and seedling growth, and to solve the problems of seeds bounce in the falling process and drought at the seedling stage in Northeast China.

2 Materials and methods

2.1 Design and working principle of the seed furrow liquid spraying device

The seed furrow liquid spraying device (Figure 1a) used to spray water into seed furrows consists of water tanks, a water tank frame, a filter, a distributor, circuit pumps, nozzles, switches, water pipes and water valves. To improve its water storage capacity and stability of the equipment, we equipped the device with two symmetrical tanks, which were connected by pipeline. Three pumps were fixed on the water tank frame and powered by tractor battery. The nozzles were mounted on the rear of the double-disc opener and the front of the seeder (Figure 1b), which guaranteed spraying liquid was finished before the seeds fell into the furrows. The double-disc opener had a diameter of 390 mm, a thickness of 4 mm, an angle of 14º between the rotary planes of the discs, and 90 mm height for the point of contact.

Working principle (Figure 2): Before the operation, the circuit switch needs to be opened and then the pumps start to run. The water in the tank is driven by the pumps and flows through the filter to the distributor, where the pressure gauge displays the real-time water pressure. The water pressure can be adjusted by turning the knob, depending on the actual operation situation. The water in the distributor flows into the three pumps, leaves the pump outlet and is finally sprayed into the seed furrows through the nozzles.



a. Distribution of each component

b. Configuration of nozzle and seeding part

Figure 1 Installation of the seed furrow liquid spraying device

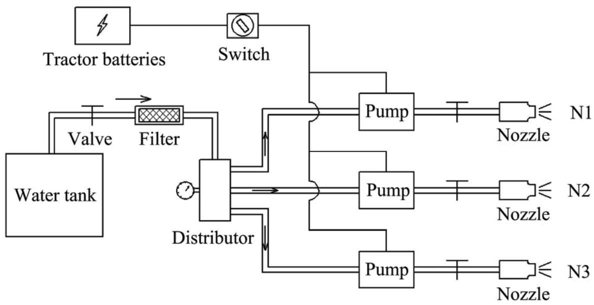


Figure 2 Working schematic of the seed furrow liquid spraying device

2.2 Study site

Experiments were conducted in the experimental field belonging to Jilin Academy of Agricultural Machinery (43.84°N; 125.33°E; elevation 228 m) in Changchun, China. The study site belongs to the continental monsoon climate of the North Temperate Zone and is located in the transition between semi-humid and semi-arid zones. Temperature increases and precipitation decreases from east to west. Average annual rainfall is 522-615 mm, and total sunshine time is 2500-2700 h. From June to August over the past 30 years, the average summer temperature is 15.2°C-23.1°C and the total precipitation varies in 300-350 mm, accounting for over 60% of annual rainfall. The soil type of the study site is the typical black clay in Northeast China. The average daily temperature was 19.8°C-22.1°C during the field experiments and almost no rain occurred before emergence.

2.3 Preparation before the experiments

The experiments were conducted on April 25-27, 2017. The experimental site was stubble land for maize planting and stubble cleaning was done in autumn, 2016. The soil physical properties were tested before experiments, including bulk density, cone index, moisture content and temperature.

Soil bulk density at the depths of 0-100 mm and 100-200 mm was measured using a 50 mm height stainless steel cylinder with a volume of 100 cm^3. At least five soil samples were collected randomly. Each sample was dried at 105°C in an oven (SKG-01) for 12 h to constant weight. Soil bulk density (ρ, g/cm^3) was calculated as follows[31]:

$$\rho = \frac{M}{V} \tag{1}$$

where, M is dry mass of the soil sample, g; V is volume of the stainless steel cylinder, cm^3.

Soil cone index at the depths of 0-100 and 100-200 mm was measured using an SC900 Soil Compaction Meter (Spectrum Technologies Inc.) with 1/2" diameter cone tip. Soil moisture content was measured using a time domain reflectometry TDR (Spectrum Equipment, TDR300 Soil Moisture Meter, USA). The study site was measured five times randomly using a 12 cm probe. Soil temperature was measured 5 times randomly by a digital soil thermometer.

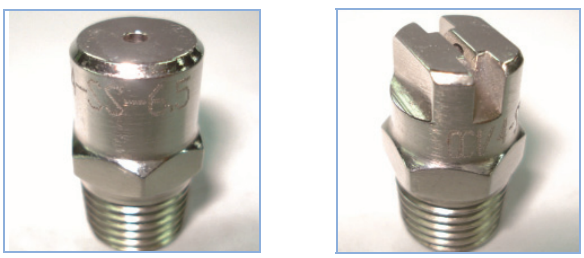
Some soil physical properties from the study site measured before experiments are shown in Table 1. The study site almost suffered no rain before the seed emergence.

Table 1 Some soil physical properties from the study site measured before experiments

Soil property	Depth/mm	1	2	3	4	5	Mean
Bulk density /g·cm^{-3}	0-100	1.215	1.281	1.019	1.143	1.245	1.181
	100-200	1.302	1.389	1.108	1.221	1.321	1.268
Cone index /MPa	0-100	0.691	0.621	0.794	0.817	0.69	0.723
	100-200	1.127	0.982	1.345	1.863	1.73	1.409
Moisture content/%		12.0	11.7	11.9	13.7	13.1	12.5
Temperature/°C		10.2	9.1	9.2	9.7	8.9	9.4

2.4 Experimental design and treatment methods

The operating distance of the device was 60 m in each experiment, including the 10 m adjustment areas at two ends and the 40 m data acquisition area in the middle. Four levels of water volume were set, including 0 L/m (V0, control group), 0.6 L/m (V1), 1.2 L/m (V2) and 1.8 L/m (V3). Before the operation, the water volume of each nozzle was calibrated by adjusting the water valve. Two types of nozzles (Figure 3) were designed: conical nozzle (N1) and sectorial nozzle (N2).



a. Conical nozzle (N1) b. Sectorial nozzle (N2)

Figure 3 Two types of nozzles selected in the experiments

A 2BYMQF-4 maize seeder was used here (Figure 4) and the performance indexes were shown in the Table 2. The 2BYMQF-4 maize seeder was powered by a 66.2 kW John Deere 904 tractor and adopted the spoon type seed metering device in the study. The working speed of the seeder was 7.3 km/h, the seeding depth was 3-5 cm, the row spacing was 50-60 cm, the theoretical seed spacing was 26 cm, the planting density was 50-70 thousand plants/hm^2, and the variety of maize seeds was Hongxin 808.

Figure 4 2BYMQF-4 maize seeder with the seed furrow liquid spraying device. Four levels of water volume and two types of nozzle were set in the experiments

Table 2 Performance indexes of the 2BYMQF-4 maize seeder

Performance indexes	Values
Overall dimensions (L×W×H)/cm	232×340×127
Line number	4
Row spacing/cm	40-70
Seed spacing/cm	12-40
Fertilizer adjustment range/kg·hm^{-2}	190-1280
Seeding depth/cm	3-8
Fertilizing depth/cm	3-8 (under the seed)
Working speed/km·h^{-1}	9.2-0.88
Production efficiency/hm^2·h^{-1}	0.65-0.98
Matched power/kW	55.2-77.2

2.5 Seedling status

In this study, the sowing quality was reflected by qualified rate of seed spacing (QR), variability coefficient of seed spacing (CV), lateral deviation of seed position (LD). After sowing, the position data of all the seeds in each treatment were counted three times at 10-m-long rows randomly. The qualified rate of seed spacing (QR), variability coefficient of seed spacing (CV) and lateral deviation of seed position (LD) were calculated as follows:

$$QR = \frac{m_1}{m-1} \times 100\% \tag{2}$$

$$CV = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \mu)^2}}{x_t} \tag{3}$$

$$LD = \frac{s_1 + s_2 + \cdots + s_n}{100} \times 100\% \tag{4}$$

where, m_1 is the number of seed spacing which is in the range of [$0.5x_t$, $1.5x_t$]; m is the number of seeds sown per 10 m theoretically; n is the number of seeds sown per 10 m actually; x_t is the theoretical seed spacing; u is the average of all the seed spacing measured; s_1, …, n are the lateral deviation of seed position.

From the beginning to the end of seedling emergence, the emerging seedlings after each treatment were counted three times every two days at 5 m long rows. The mean emergence time (MET) and percentage of emergence (PE) were calculated as follows[32]:

$$MET = \frac{N_1T_1 + N_2T_2 + \cdots + N_nT_n}{N_1 + N_2 + \cdots + N_n} \tag{5}$$

$$PE = \frac{S_{te}}{m} \times 100\% \tag{6}$$

where, N_1, …, n are the number of emerging seedlings since the time of previous count; T_1, …, n are the number of days after sowing; S_{te} is the total number of emerging seedlings per 5 m; and m is the number of seeds sown per 5 m.

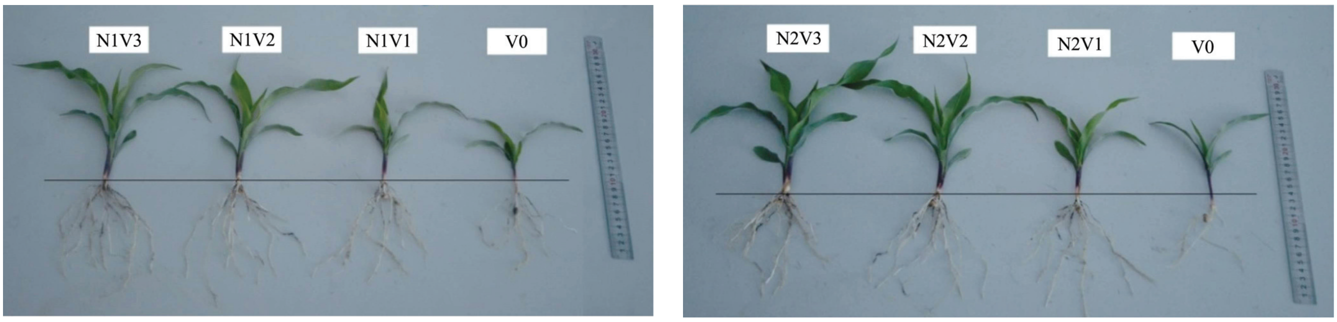
Maize plants from different treatments were collected on the 30th day after sowing (trefoil-shooting stage). Aboveground biomass (AB) was measured five times randomly after every treatment, and was determined by oven-drying the aboveground samples containing leaves and stems at 75°C for 48 h[33].

Root samples were collected from every treatment. After removal of the aboveground parts, each pot was saturated with water and the root system was removed from the soil and washed using a low-pressure water jet[34]. The washed roots were then oven-dried at 65°C for 48 h. Root shoot ratio (RSR) is the ratio of root biomass (RB) to aboveground biomass (AB).

On the 30th day after sowing, the maize emergence after each treatment is shown in Figure 5, and the maize plant biomass after each treatment is shown in Figure 6.

N1V3 N1V2 N1V1 V0 N2V3 N2V2 N2V1 V0

Figure 5 Maize emergence in different treatments



a. Treatments with conical nozzle (N1) b. Treatments with sectorial nozzle (N2)

Figure 6 Maize plant biomass in different treatments

2.6 Statistical analyses

Analysis of variance (ANOVA), appropriate for randomized complete block design, was used to analyze the variances of the obtained data.

3 Results and discussion

3.1 Sowing quality

Table 3 showed the effects of water volume and nozzle type on the sowing quality of maize. The water volume and nozzle type both had significant effects on qualified rate of seed spacing (QR), variability coefficient of seed spacing (CV), lateral deviation of seed position (LD) (p<0.05). In all the treatments, the sowing quality after the N1 and V0 treatments were poor, while that were opposite in the N2 and V3 treatments. There are two reasons for the difference in seed sowing quality. One is that the seed will produce a certain speed when reaching the seed furrow. Under the speed, the seed will bounce and the bounce direction is random. The other is that different sizes of clods in the seed furrow will make the seed rolling and the rolling direction is also random.

Table 3 Effects of water volume and nozzle type on the sowing quality of maize

Treatments	Qualified rate of seed spacing (*QR*) /%	Variability coefficient of seed spacing (*CV*) /%	Lateral deviation of seed position (*LD*) /mm
Nozzle type			
N1	87.7±1.1 b	14.5±3.5 a	6.3±1.1 a
N2	88.4±1.7 a	13.4±2.7 b	5.3±1.0 b
Water volume			
V0	85.2±0.7 c	20.8±0.9 a	10.3±0.5 a
V1	87.1±0.3 b	17.3±1.7 b	7.0±0.6 b
V2	87.5±0.2 b	13.3±0.1 c	5.5±0.9 c
V3	89.6±1.0 a	11.3±0.8 d	5.0±0.5 c

Note: * Means within the same column followed by the same letter are not significantly different (p<0.05).

In the treatments of different nozzle types, the sowing quality in the N2 treatment was significantly better than that in the N1 treatment: QR (N2>N1), VC (N2<N1) and LD (N2<N1). The reason is that unlike the conical nozzle (N1), the water curtain from

the sectorial nozzle (N2) is perpendicular to the ground, so its impact on the ground is greater than the N1, resulting in the smaller mean weight diameter of the surface soil, reducing the big void of the seed furrow, effectively suppressing the bounce and rolling of seed in the seed furrow.

In the treatments of different water volumes, the QRs in the experimental groups were significantly higher than those in the control group, and the QR was increased with the increase of the water volume (V3 > V2 > V1 > V0). The VCs and LDs in the experimental groups were significantly lower than those in the control group, and the VCs and LDs were reduced with the increase of the water volume (V3 < V2 < V1 < V0). The reason is that the water was sprayed onto the soil surface of seed furrow, improving the soil moisture content, reducing the coefficient of restitution. When the seed fallen into the seed furrow, it would be adhered to the surface soil without bouncing and rolling.

3.2 Mean emergence time (MET)

Figure 7 shows the effects of water volume and nozzle type on the MET of maize. Clearly, MET was affected significantly by the water volume (p<0.05), but not significantly by the nozzle type.

MET was significantly shortened after V1, V2 or V3 treatment compared with the control (V0). MET maximized after the V0 treatment and minimized after the V2 or V3 treatment. The average METs after the V1, V2 and V3 treatments (10.84 d, 10.18 d and 9.96 d) were 1.47 d, 2.13 d and 2.35 d shorter compared with the V0 treatment (12.31 d). The reason may be that the soils around the maize seeds at the seedling stage enjoyed more moisture in the V1, V2 and V3 treatments compared with the control (V0). Sufficient moisture is beneficial to seed germination and ensures an earlier emergence. Our findings are consistent with Voorhees et al.[18] and Gemtos et al.[19].

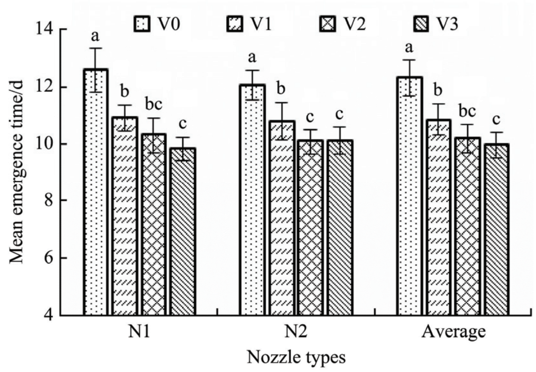


Figure 7 Effects of water volume and nozzle type on the mean emergence time (MET) of maize

3.3 Percentage of emergence (PE)

PE was affected significantly by the water volume (p<0.05), but rarely by the nozzle type (Figure 8). In all treatments, the PE always maximized after the V3 treatment and minimized after the V0 treatment.

With the use of nozzle N1, the PE was highest (85.91%) after the V3 treatment, but lowest (79.89%) after the V0 treatment. With the use of nozzle N2, similar conclusions were obtained. The average PEs after the V1, V2 and V3 treatments (84.35%, 84.66% and 85.84%) increased by 3.58, 3.89 and 5.07 percentage points respectively compared with the control (V0) (80.77%). This is because the mean weight diameter of soil furrows was reduced and the soil moisture content of the seedbed was improved under the impact of water, the maize seeds contacted well with the soils. The sufficient contact between seed and soil and the high soil moisture content can increase the percentage of emergence[35].

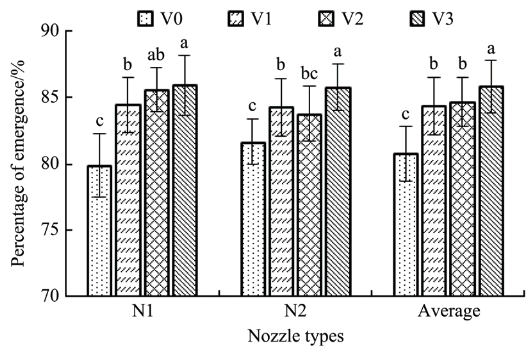


Figure 8 Effects of water volume and nozzle type on the percentage of emergence (PE) of maize

3.4 Root biomass (RB) and aboveground biomass (AB)

RB and AB of maize were affected both significantly by the water volume (p<0.05), but not significantly by the nozzle type (Figures 9 and 10). The root growth and aboveground part growth were significantly different after the V1, V2 or V3 treatment compared with the control (V0).

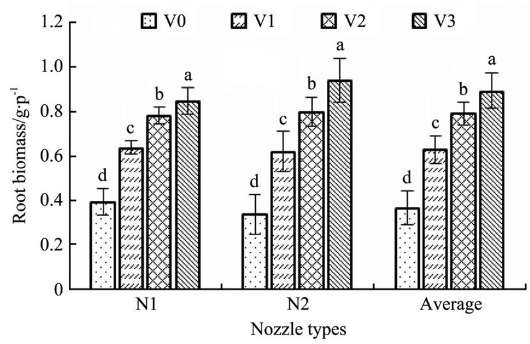


Figure 9 Effects of water volume and nozzle type on the root biomass (RB) of maize

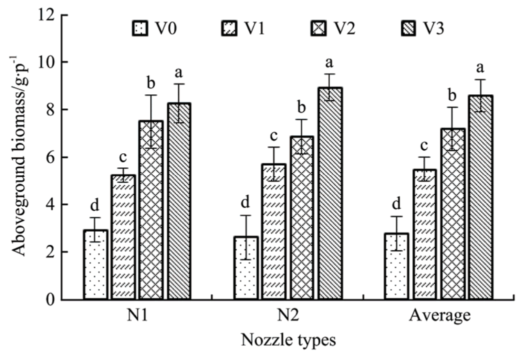


Figure 10 Effects of water volume and nozzle type on the aboveground biomass (AB) of maize

In all treatments, the V0 treatment resulted in the minimum RB (0.34-0.39 g/plant) and minimum AB (2.61-2.92 g/plant) (Figures 9 and 10). The V3 treatment resulted in the maximum RB (0.85-0.94 g/plant) and maximum AB (8.28-8.93 g/plant). The RB and AB increased significantly with the elevation of water volume. This is because the device significantly can humidify the soils around the seeds and then effectively promotes the germination of seeds. The growth of the root system was accelerated with the increase of soil moisture content and could promote the absorption of water, fertilizer, amino acids and other substances, providing conditions for the growth of the aboveground parts. The photosynthetic products from the aboveground parts were transported to the roots and promoted the root growth. Appropriate soil moisture content enhanced the interaction between root systems and aboveground parts. Our results are consistent to the findings by Kang et al.[36] and Magaia et al.[37].

3.5 Root shoot ratio (RSR)

RSR at the maize seedling stage was affected significantly by water volume (p<0.05), but not by the nozzle type (Figure 11). Under different water volumes, the RSRs were significantly different and decreased significantly by the increase of soil moisture content (Figure 11).

In all treatments, the RSR maximized in the V0 treatment and minimized in the V3 treatment. The average RSRs after the V1, V2 and V3 treatments were 12.45%, 15.89% and 21.08% lower than that after the V0 treatment, respectively. Obviously, the experimental groups had the lower RSRs compared to the control group. This finding was consistent with Bonifas et al. (2005)[38]. The reason is that the drought stress (control group) inhibited the growth of both roots and aboveground parts, but aboveground parts were affected more, which ensured the balance between the water absorption of the root system and the water consumption of aboveground parts, so the RSR of the control group (V0) was larger. Similarly, water spraying (experimental group) promoted root growth, but the aboveground parts also grew rapidly and faster, so the RSRs of the experimental groups (V1, V2 and V3) were smaller. These findings are consistent with Passioura (1983)[30].

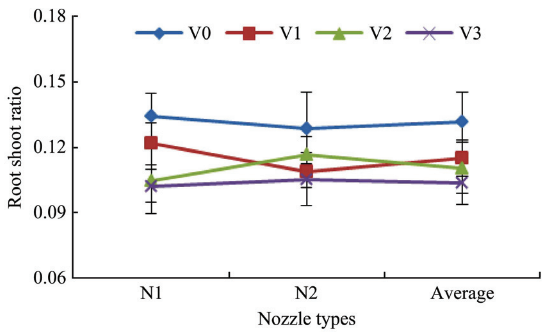


Figure 11 Effects of water volume and nozzle type on the root shoot ratio (RSR) of maize

4 Conclusions

To solve the problems of seeds bounce in the falling process and drought at the seedling stage, we designed a seed furrow liquid spraying device, which can adjust the spraying water volume according to the demand of land. Spraying water into seed furrow further humidified the soils around the seeds, effectively suppressing the bounce and rolling of seed in the seed furrow and significantly promoting the growth and development of seeds, which were manifested as poor sowing quality, low mean emergence time, high percentage of emergence, high root biomass and aboveground biomass, and low root shoot ratio. The sowing quality in the N2 treatment was significantly better than that in the N1 treatment. The qualified rate of seed spacing was increased with the increase of the water volume (V3 > V2 > V1 > V0). However, the variability coefficient of seed spacing and lateral deviation of seed position were the opposite. Under the same experimental conditions, the mean emergence time after the V1, V2 and V3 treatments decreased by 1.47 d, 2.13 d and 2.35 d respectively, and the percentage of emergence increased by 3.58, 3.89 and 5.07 percentage points respectively compared with the V0 treatment. The root biomass and aboveground biomass both minimized after the V0 treatment, and increased significantly with the elevation of spraying water volume. The root shoot ratios differed significantly under different water conditions. The root shoot ratios after the V1, V2 and V3 treatments decreased by 12.45%, 15.89% and 21.08% respectively compared with the V0 treatment. The best performance in sowing quality and seedling growth were found in the N2V3 treatment.

Acknowledgements

We acknowledge that this work was financially supported by the 13th Five Year National Key R & D Plan Project (Grant No.: 2017YFD0700701), the Development Programme of Science and Technology of Jilin Province of China (Grant No. 20170312005ZX, 20160441004SC). We also highly appreciate Huili Liu from Jilin University for structure design and selection, and Zhaochen Liu and Xuhui Fan from Jilin Academy of Agricultural Machinery for equipment modification and field work. Finally, we are very grateful to Shanghua Wu for providing the experimental site.

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