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EFFECT OF NO-TILL PRECISE SEEDING ON WHEAT (*TRITICUM AESTIVUM L.*) POPULATION QUALITY AT THE EMERGENCE STAGE

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ABSTRACT

Sowing techniques and planting density directly affect the shape and microenvironment of the canopy and, therefore, the final yield. A field experiment was carried out during two consecutive years, 2017 and 2018, at Nanjing Agricultural University, Jiangsu Experimental Farm. The objective of the study was to compare the effect of the drill seeding and punch seeding of wheat at the emergence stage. The experiment comprised of three (1.5, 3.0 and 4.5 cm distances between seed) treatments arranged in randomized complete block design with three replications in a plot size of 4.0 by 5.0 m. During the two seasons of the experiment, a general tendency was observed for the two modes of sowing; the reduction of the growth parameters (the dry weight of the roots, the aerial biomass, and the number of roots) seedlings as the planting density increased. However, several parameters showed significant statistical variations, such as the emergence rate by age ratio of the seedlings, the dry weight of the biomass, the leaf area, the dry weight of the roots, the root volume, the length, the root depth, and root/soil ratio. The results showed that competition between plants began to appear at the stage of sowing, and the higher the planting density, the more the growth of the wheat population of individuals is hampered. Beyond the results, we have demonstrated the interest of characterizing the phenotypes of wheat through multiple criteria, also considering the whole plant at the emergence stage.

Keywords: Seeding, Single grain, Wheat seedling, Emergence stage, No-till.

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INTRODUCTION

Wheat (*Triticum aestivum L.*) is a staple food for most populations internationally (Mohammadi *et al*., 2012). Additionally, wheat provides about 40% and 20% of the global food demand and food calories, respectively (Abbas and Niaz, 2019). However, global wheat consumption has increased from 733.3 million metric tons in the 2018/2019 marketing year to 751.5 million metric tons in 2019/2020 (Statista, 2020). The increase in demand is attributed to the rapidly growing world population, which has mandated an increase in production (Tchalla *et al*., 2020). Therefore, the world's food production must double by 2050 to feed the projected global population (Ray *et al*., 2013). To ascertain food security, the scientific community in recent years has conducted extensive research on most crops in general and wheat in particular, aiming at improved productivity.

Farmers have adopted different wheat planting techniques over the years, i.e., conventional drilling, zero tillage drilling, precision drilling, and broadcasting in winter wheat (Carver, 2005). However, there was no consistent relationship between planting techniques and subsequent yield performance (Abbas *et al*., 2009). From an agronomic perspective, a critical factor reflected in high wheat production is the robust understanding of early crop establishment factors (Soomro *et al*., 2009), including planting techniques, soil characteristics, seed viability, and plant machinery availability (Sulieman, 2010). Over the last 20 years, much emphasis has been placed on the precise seeding of wheat, and researchers have established that the yield of precise sowing techniques can be 7.5% to 22.3% higher than that of traditional sowing techniques (Haibo *et al*., 2015). However, because of the particular characteristics of wheat grain geometry, the mechanization of wheat precision seeding techniques was still in the research stage (Haibo *et al*., 2015). At this stage of research on the mechanization of wheat precise seeding, it is essential to have a database on the quality of the seedlings at each stage of growth to optimize the final quality of the cultivated population.

Plant survival and growth are closely linked to good seed germination, making the germination stage a critical step (Lortie *et al*., 2005; Turkington *et al*., 2005; Tielbörger and Prasse, 2009; Orrock and Christopher, 2010). Classically, the germination of seeds is done in response to signals such as the germinative power of the seed itself, its quality, the availability of water, nutrients, the amount of light (Baskin and Baskin, 1998) as well as the composition of the neighborhood of the seeds (Dyer *et al*., 2000; Tielbörger and Prasse, 2009; Houseman and Mahoney, 2015). Germination also depends on the sowing rate, which depends on the producer, the planting time, and the condition of the seedbed (Hemmat and Taki, 2001). Some studies have shown that the germination rate of seeds decreases with density (Houseman and Mahoney, 2015). The interactions of interspecific and intraspecific seeds (interspecific interactions are those which take place between the wheat seeds itself for the search for nutrients, while intraspecific interactions are those which occur between wheat seeds and other weed seeds present in the seedbed) may explain this density-dependent negative emergence. This suggests that the seeds can "feel" each other and affect germination. Greenhouse and lab studies by Houseman and Mahoney (2015) have proven this communication between seeds. However, these investigations are partial since, in the field conditions, these interactions between seeds can be due to chemical interactions or other ecological factors and dependent on the sowing method or the edaphic conditions mentioned previously.

Over the past few years, the agricultural robot has become an essential ally in agricultural machinery engineering research and development (Emmi *et al*., 2014). Recently, a kinematic model was built for a four-wheel-drive precision wheat sowing robot. The experiments were undertaken with this machine to provide a benchmark for the design of other precision wheat sowing robots. It is, therefore, vital to have a database as useful as it is to optimize these future sowing machines. The essential measures to consider are improving the sowing technique and the planting density to maximize sowing technology. However, under the conditions of direct seeding of single grain in the field conditions, no research work explains the seedling emergence stage. Therefore, we hypothesized that different direct seeding techniques and the planting density could affect the emergence stage of wheat. Hence, a two-year field study was designed to assess the effects of two direct seeding techniques and three planting densities at the emergence stage of wheat. The main objective of this study was to evaluate the impact of no-till precise seeding on wheat population quality at the emergence stage. The specific objectives were (1) to compare the effect of no-till drill seeding and punch seeding on the emergence rate of the seedlings, (2) and further analyze the emergence rate by age ratio and the aboveground and below-ground biomass under different treatment.

MATERIALS AND METHODS

Crop Husbandry and Experimental design: This study was conducted in Nanjing Agricultural University, Jiangsu Experimental Farm, Babaiqiao, Luhe, Jiangsu, China. The site was located at 31° 98'N, 118° 59'E, in a subtropical monsoon climate, with an annual rainfall of approximately 1000 mm and an average temperature of 15.8°C (Zhang *et al*., 2015). Rice-wheat rotation is a long-established agricultural system in this region. It was characterized by paddy season between June till late November. One month before rice harvest, the field was drained to allow the soil to dry out for mechanical harvesting, after which the subsequent crop season, i.e., wheat or canola, is ensued (Flinn and Khokhar, 1989). Soil organic matter, total nitrogen, available nitrogen, available phosphate and available Potassium were estimated at 8.24 gkg^{-1}, 0.97 gkg^{-1}, 12 $mgkg^{-1}$, 12.67 $mgkg^{-1}$ and 11.05 $mgkg^{-1}$, respectively. The pH, bulk density, and soil moisture content were established to be 7.6, 1.26 $g.cm^{-3}$, and 29.3%, respectively, according to the study by Lu (2000).

Two years of field experiment was conducted during the 2017 and 2018 wheat season, in which wheat variety "Ningmai 13" was sowed in this study. Phosphate, urea and potassium chloride were applied on the soil surface at 120 $kghm^{-2}$,150 $kghm^{-2}$ and 135 $kg.hm^{-2}$, respectively (Zhang *et al*., 2015). The whole wheat season was rain-fed, and harvesting was performed manually and retrieved back to the laboratory. The daily average temperature and rainfall data during the period of the experiment in the region were acquired, as shown in Fig. 1.

In this study, direct seeding, a typical conservation agriculture system (Ozpinar and Ozpinar, 2015), was adopted and carried out in two different ways, i.e., drill seeding and punch seeding (Fig. 2 and 3) on no-till soil with an inter-row distance of about 20 cm, at three different seed distances between of 1. 5, 3 and 4.5 cm. The sowing dates were November 6, 2017, and November 8, 2018, respectively. The three densities and the two types of sowing subject to the treatment of this study were recorded as follows: T1.5, T3, and T4.5 for the drill seeding and C1.5, C3, and C4.5 for the punch seeding. All treatments were repeated three times and arranged a randomized complete block design with plots of 4 by 5 m.

Seeding and applied tools: Building optimal plant cover is essential for maximizing wheat yields. However, this requires a proper establishment of the seeds in the soil and control of the emergence stage. The traditional and even modern method of sowing which advocates the use of an approximate quantity to the number of seeds per square meter (200 to 250 seeds per m^2, 450 seeds per m^2) (McKenzie *et al*., 2007; Beres *et al*., 2011, 2016) does not allow the analysis of the interaction between the seeds since the distance between them is not uniform, which leads us to introduce this technique of sowing while respecting the spacing distance between the seeds which has not been introduced elsewhere until now.

In this study, the no-till drill seeding method was performed, which is executed by first artificially opening sowing ditches with a width of 5-6 cm and a depth of 3-5 cm along rows (Fig.2 a). Then the seeding itself, we used a metal plate with grid spacing designed in the laboratory with small holes of 5 mm and having a rubber pad underneath for filling and for keeping the seeds in place. After filling the small holes with seeds according to the desired spacing distance, the metal plate was turned by 180 degrees with both hands at a constant speed in the previously dug ditches as shown in Figs. (2 b, 2c), and once in the seedbed (Fig. 2d), the seeds are covered lightly with soil

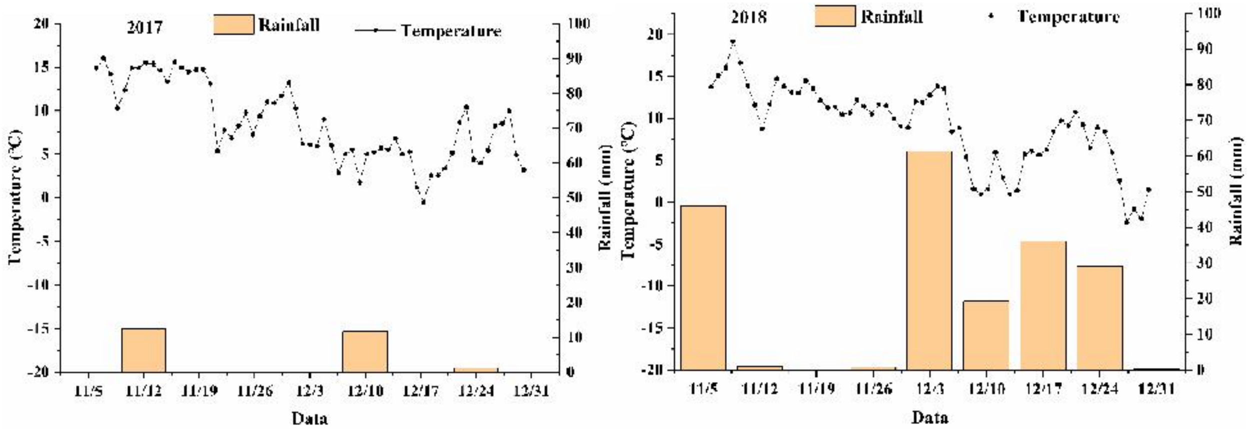


Fig. 1. Daily average temperature and rainfall of every year in the experimental field on Nov. & Dec.

Small in size, light, and easy to use, the precise seeding machined provides a basis for researching precision punching experiences (Fig.3). It consists of three parts: a seed filling device, a seed cleaning device, and a seed pressing device. The filling device is there to put the seeds in the respective holes. While the cleaning device makes it possible to remove excess seeds to guarantee the standard "one hole, one seed." And finally, the pressing device pushes the seeds for their transfer to the ground. To differentiate the distance between the seeds, this study varied the plates by 1.5, 3 and 4.5 cm corresponding to the distance between the holes. The seed drill is also equipped with a motor and a crank that can proceed with seeding either automatically using a power source (a battery, for example) or manually by operating the crank. In our case, this study opted for the second case because of the different treatments to be performed.

Fig. 2. The method of no-tillage precision drill seeding: (a) Artificial opening of seed ditches, (b) Installation of the seedling metal plate in the ditch, (c) Turning of the metal seed plate in the ditch, (d) Seed deposit of seeds in the ditch

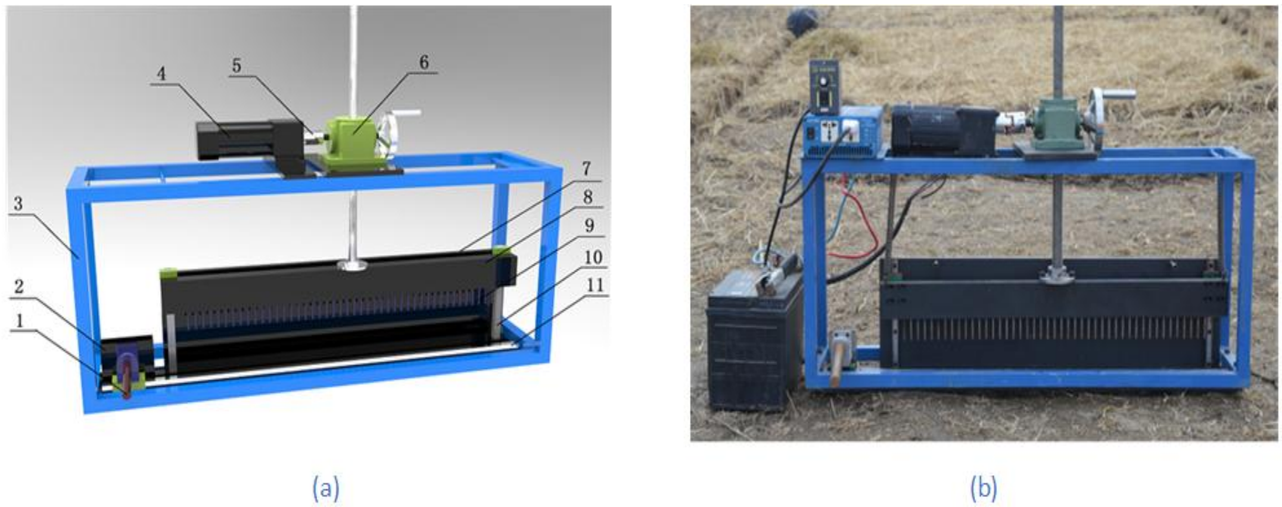


Fig. 3. (a) Pro/E model of precision punch seeder (electrically powered), (b) The in-situ state of precision punch seeder 1. Handle 2. Seedbox 3. Frame 4. Drive motor 5. Coupling 6. Lifting mechanism 7, grid plate 8. Pressure plate 9. Pressure lever 10. Vertical rail 11. Horizontal rail

Seedling emergence evaluation: Two types of evaluation of seed emergence in the field were calculated from the 9th day after planting: the seedling emergence rate (SER) and the seedling emergence rate by age ratio (SAR). This study considered five different age of emergence: one leaf, one leaf and one heart, two leaves, two leaves, and one heart and three leaves. At each level of emergence, the formula indicated by Coolbear *et al.* (1984) was used to calculate the emergence rate.

$$S = \frac{n}{N} * 100 \quad (1)$$

$$S = \frac{n_i}{N} * 100 \quad (2)$$

Where N stands for the number of seeds initially sown, n stands for the number of seedlings that emerged and n_i represents the number of seedlings that emerged at a certain age; i goes from 1 to 5 and represents age 1: one leaf, age 2: one leaf and one heart, age 3: two leaves, age 4: two leaves and one heart, age 5: three leaves.

Growth index evaluation of wheat seedlings: To explain the effect of the different treatments on the individual growth of the seedlings, a certain number of growth indices such as the weight of aerial biomass, that of the root system, the leaf area, the length of the roots, the weight ratio of above and below-ground biomass were measured. These parameters were obtained at several stages:

1. Field sampling. For non-destructive sampling, a rectangular tube (400 mm × 200 mm × 250 mm) and a hand hammer to plunge the sampling cylinder into the soil (fig 4(a)) was used on December 14, 2017, and December 17, 2018, for sampling the seedlings and the soil for additional laboratory analysis.
2. Once in the lab, a three-dimensional root configuration digitizer (Fig. 4 (b, c)) was used to obtain the coordinates of all the roots for a 3D representation using Pro-E software according to the protocol of Chen *et al.* (2014). Other parameters, such as:

- TRL (Total root length) : the sum of all root lengths in the root system of a single wheat plant,
- RN (Root number) : the number of spindle roots in the root system of a single wheat plant,
- RD (Root depth) : the distance between the root germination position and the maximum depth of rooting under the root system,
- REV (Root envelope volume) : refers to the total soil volume searched by the wheat root system and represents the ability of the root system to search the soil space

Finally, each seedling root system was separated from the aboveground part and dried at 105° C for 30 minutes and weighed to obtain the dry weight of the root system. Then comes the treatment of the aerial biomass. The leaves carefully placed on the white book sheet (Fig 4(d)) have been digitized using a Nikon D3200 digital camera (1920 by 1080 pixels) and analyzed using the image processing toolbox of MATLAB software to obtain the leaf area of each seedling. Furthermore, like the root system, the aboveground biomass (leaves and stems) were dried and weighed at the same temperature.

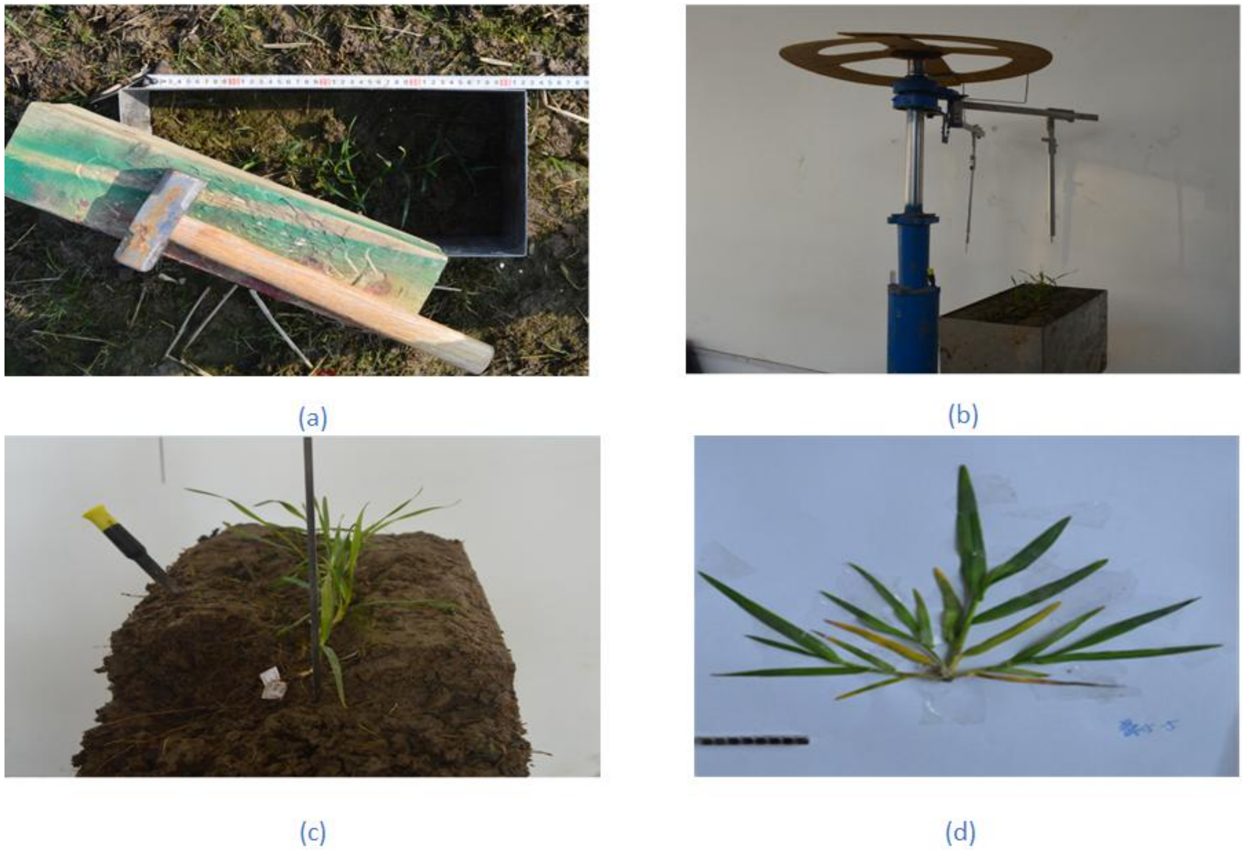


Fig. 2. (a) Hammer and soil sampling cylinder, (b) Three-dimensional root configuration digitizer (c) Exploration of the root system of seedlings, (d) Acquisition of the leaf area

Statistical Analysis: All the data collected were analyzed to determine the statistical significance differences and interactions between the sowing techniques, the seed distances and the emergence stage parameters (germination rate and the other seedling growth parameters). The collected data was established to be normally distributed. Therefore no data transformation was performed in this study. One-way analysis of variance (ANOVA) was performed to determine if there were a significant difference between the treatments (sowing distances) and the emergence rate for each sowing technique. Also, two-way ANOVA was performed to analyze the effect of the sowing techniques on the emergence stage with reference to the treatment (Okinda *et al*., 2020). All statistical analyzes were performed using IBM Statistical Package for Social Scientists (SPSS 19.0), and the graphs preparation were completed using Excel 2010 software.

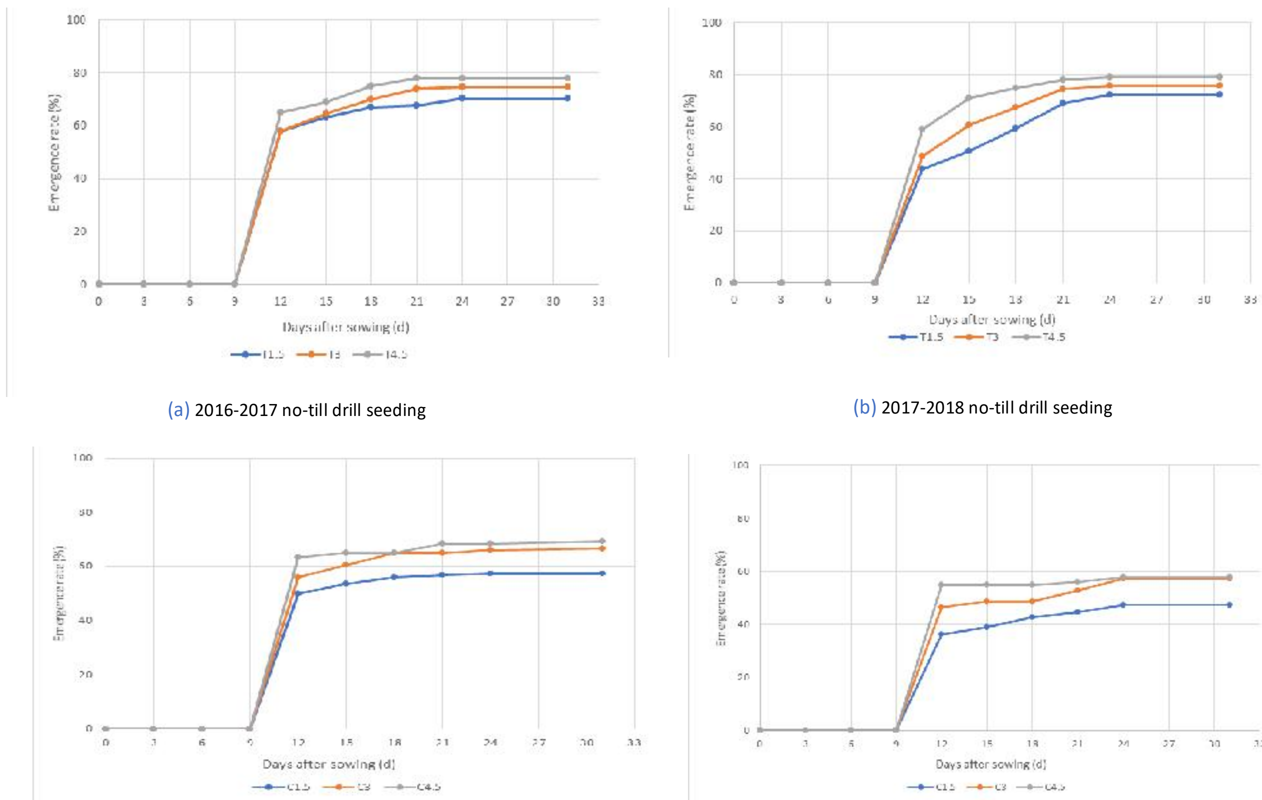
RESULTS

Evaluation of seedling emergence time and rate: Fig. 5 shows the dynamics of the emergence of seedlings under the different sowing modes during the 2016/2017 and 2017/2018 seasons. The emergence time follows a classic S function, as shown in Fig. 5. Increasing the distance between seeds during sowing reduces the density of plants and increases the emergence time (Fig.6). The emergence rate for the spacing of 4.5 cm between the seeds was high under the no-till drill seeding compared to the no-till punch seeding method. The seeds started growing on the 9th day (Fig.7). On the 12th day, the highest germination rate of all the treatments was recorded.

During the 2016/2017 season, the seedlings under T1.5 and T3 took an average of 11.6 days to reach 50% emergence and an average of 11.3 days for T4.5. The seeds in this last case took around 21 days after sowing to achieve complete development. For the 2017/2018 season, the same trend was recorded under the same treatments with a slightly higher emergence time under the T1.5 and T3, 14.7 days and 24 days to reach total emergence.

The emergence time for the two seasons was relatively high for the seedlings under C1.5 and C3 (12, 11.7 and 12, 12.6days) and C4.5 (11.4 and 11.6). However, the time taken to reach full emergence varied between 24 and 31 days. Note that in Fig. 6, BED is days from planting time to the beginning of emergence; 50%ED: Days from planting time to 50% of emergence; EED: Days from planting time to ending of emergence.

Although the emergence rate is an important indicator reflecting the growth of crops at the emergence stage, it can only reflect the macroscopic emergence of the crop group. It cannot reflect the information on the individual growth stage within the crop emergence group.



(a) 2016-2017 no-till drill seeding

(b) 2017-2018 no-till drill seeding

(c)2016-2017 no-till punching seeding

(d) 2017-2018 no-till punching seeding

Fig. 3. Emergence dynamics of winter wheat under different seeding technology

The statistical results of the seedling emergence rate and seedling age ratio of wheat under no-till drill seeding are listed in Table 1 and Table 2. It can be seen that as the planting density increases, the emergence rate trend in 2016-2017 decreases, but the difference in emergence rate has not reached a significant level. However, the dynamics of the seedling emergence can indicate that the seedlings of different treatments of wheat are showing all one (1) leaf 12 days after sowing. Fifteen (15) days after sowing, one leaf and one heart seedlings appeared under T3 and T4.5, accounting for 17.34% and 27%, respectively. With the increase in the distance between seeds, the planting density decreases.

Accordingly, the proportion of one-leaf seedlings gradually reduced, and the proportion of one-leaf and one-heart seedlings gradually increased. The difference in seedling emergence rate between T1.5 and T4.5 reached a significant level. At 18 days after seeding, two-leaved seedlings appeared in the three density treatments, and as the planting density increased, the proportion of two-leaved seedlings showed a decreasing trend. T1.5 has the largest proportion of one-leaf seedlings compared with the other two treatments. Twenty-one (21) days after sowing, two-leaves and one-heart seedlings appeared in T3 and T4.5, accounting for 2% of the total, while two- leaves and one-heart seedlings did not appear in T1.5. Two-leaves and one-heart seedlings began to appear in T1.5 from 21 to 24 days after seeding. From 24 to 31 days after sowing, three-leaved seedlings started to appear in each treatment. The proportion of three-leaves seedlings decreased gradually with increasing planting density 31 days after seeding. The difference between the proportion of three-leaves seedlings under T1.5 and the other two treatments reached a significant level, and the difference between T3 and T4.5 was not significant. The difference in seedling age in 2017-2018 also reaches a significant level in terms of the proportion of seedling age at different post-sowing stages. Twenty-one days after sowing, the proportion of seedling age of one-leaf, two-leaves, and two-leaves and one heart seedlings in T1.5 reached the most significant level compared with the other two treatments. However, the total emergence rate was different from that of T4.5. A similar situation has occurred during the period of the remaining periods.

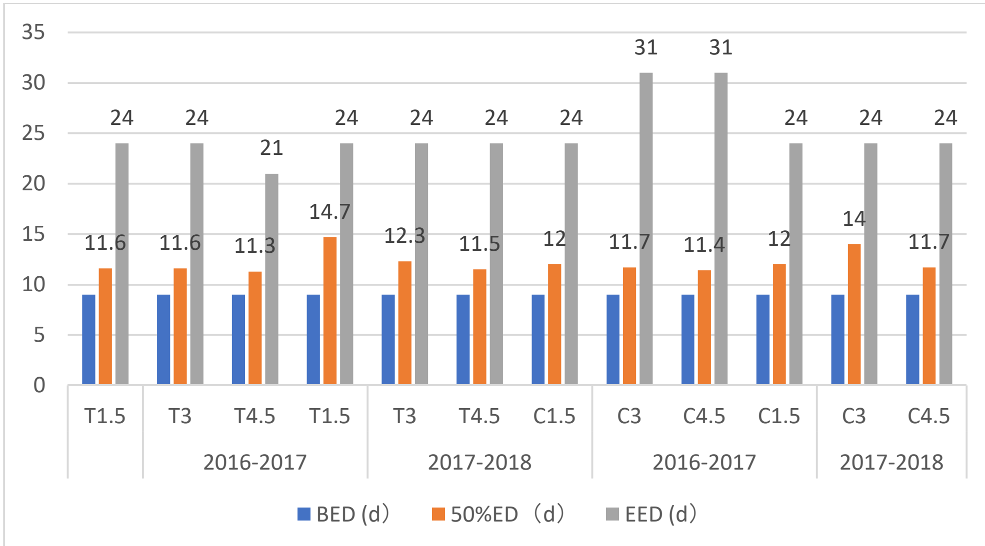
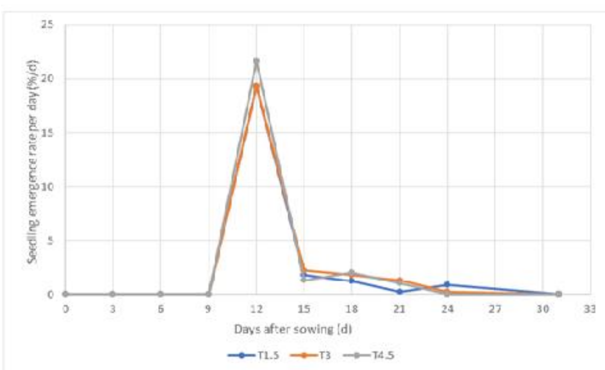
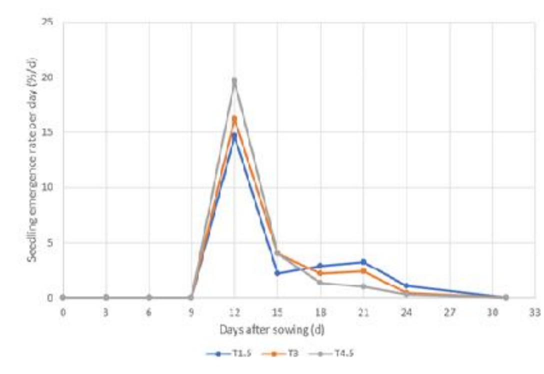


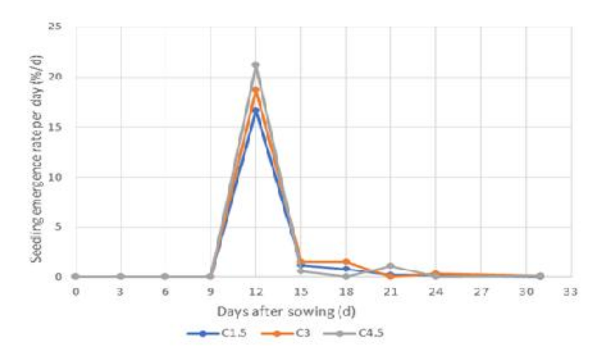
Fig. 4. Effects of seeding technology on emergence time of winter wheat



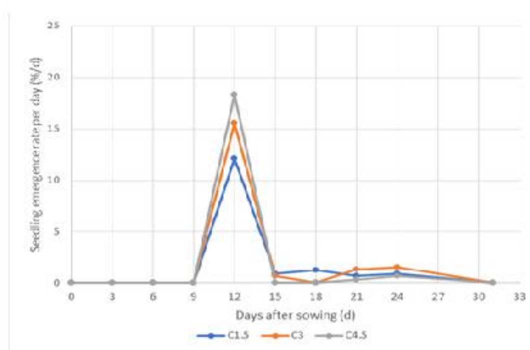
(a) 2016-2017 no-till drill seeding



(b) 2017-2018 no till drill seeding



(c)2016-2017 no-till punching seeding



(d) 2017-2018 no-till punching seeding

Fig. 5. Effect of seeding technology on seedling emergence rate per day of winter wheat

Table 1. Effect of planting density in seedling emergence rate and seedling age ratio of winter wheat in no-tillage drill seeding (2016-2017).

DAP(d)	Treatment	SER (%)	SAR$_1$ (%)	SAR$_2$ (%)	SAR$_3$ (%)	SAR$_4$ (%)	SAR$_5$ (%)
	T1.5	58.00^{a}	58.00^{a}	0	0	0	0
12	T3	58.00^{a}	58.00^{a}	0	0	0	0
	T4.5	65.00^{a}	65.00^{a}	0	0	0	0
	T1.5	63.33^{a}	63.33^{a}	0.00^{b}	0	0	0
15	T3	64.67^{a}	47.33^{ab}	17.34^{ab}	0	0	0
	T4.5	69.00^{a}	42.00^{b}	27.00^{a}	0	0	0
	T1.5	67.00^{a}	30.00^{a}	23.00^{a}	14.00^{b}	0	0
18	T3	70.00^{a}	14.00^{b}	16.67^{a}	39.33^{a}	0	0
	T4.5	75.00^{a}	11.00^{b}	20.00^{a}	44.00^{a}	0	0
	T1.5	67.67^{a}	8.333^{a}	22.34^{a}	37.00^{b}	0.00^{a}	0
21	T3	74.00^{a}	6.67^{a}	12.67^{b}	52.67^{ab}	2.00^{a}	0
	T4.5	78.00^{a}	4.00^{a}	8.00^{b}	64.00^{a}	2.00^{a}	0
	T1.5	70.33^{a}	3.00^{a}	12.00^{a}	50.00^{a}	5.33^{a}	0
24	T3	74.67^{a}	1.33a^{b}	6.00^{b}	43.33^{a}	24.00^{a}	0
	T4.5	78.00^{a}	0.00^{b}	3.00^{b}	52.00^{a}	23.00^{a}	0
	T1.5	70.33^{a}	1.33^{a}	7.33^{a}	17.33^{a}	40.67^{a}	3.67^{b}
31	T3	74.67^{a}	1.00^{a}	3.67^{a}	11.33^{a}	26.67^{b}	32.00^{a}
	T4.5	78.00^{a}	0.00^{a}	2.00^{a}	14.00^{a}	26.00^{b}	36.00^{a}

DAP: Days After Planting; SAR: Seedling Age Ratio. Different letters in the same column meant a significant difference among different planting densities of the same statistical period at 0.05 level ($p < 0.05$), the same below.

Table 2. Effect of planting density in seedling emergence rate and seedling age ratio of post-paddy wheat in no-tillage drill seeding（2017-2018）

DAP(d)	Treatment	SER (%)	SAR$_1$(%)	SAR$_2$ (%)	SAR$_3$ (%)	SAR$_4$ (%)	SAR$_5$ (%)
	T1.5	44.00^{b}	44.00^{b}	0	0	0	0
12	T3	48.67^{b}	48.67^{b}	0	0	0	0
	T4.5	59.00^{a}	59.00^{a}	0	0	0	0
	T1.5	50.67^{c}	47.67^{a}	3.00^{c}	0	0	0
15	T3	60.67^{b}	37.33^{b}	23.33^{b}	0	0	0
	T4.5	71.00^{a}	34.00^{b}	37.00^{a}	0	0	0
	T1.5	59.33^{c}	20.00^{a}	25.66^{a}	13.67^{c}	0	0
18	T3	67.33^{b}	12.00^{b}	20.66^{a}	34.67^{b}	0	0
	T4.5	75.00^{a}	9.00^{b}	12.00^{b}	54.00^{a}	0	0
	T1.5	69.00^{b}	19.33^{a}	8.00^{a}	41.67^{b}	0.00^{b}	0
21	T3	74.67^{ab}	1.33^{b}	8.67^{a}	56.00^{a}	8.67^{a}	0
	T4.5	78.00^{a}	2.00^{b}	9.00^{a}	56.00^{a}	15.80^{a}	0
	T1.5	72.33^{b}	7.00^{a}	15.67^{a}	43.67^{b}	6.00^{c}	0
24	T3	76.00^{ab}	1.33^{b}	6.67^{b}	55.33^{a}	12.67^{b}	0
	T4.5	79.00^{a}	0.00^{b}	4.00^{b}	33.00^{c}	42.00^{a}	0
	T1.5	72.33^{b}	1.67^{a}	7.67^{a}	15.67^{a}	41.33^{a}	6.00^{b}
31	T3	76.00^{ab}	0.67^{a}	3.33^{b}	11.33^{b}	18.67^{b}	42.00^{a}
	T4.5	79.00^{a}	0.00^{a}	0.00^{c}	11.00^{b}	23.00^{b}	45.00^{a}

DAP: Days After Planting; SAR: Seedling Age Ratio. Different letters in the same column meant a significant difference among different planting densities of the same statistical period at 0.05 level ($p < 0.05$), the same below.

Under the no-tillage punch seeding condition, the emergence dynamics and seedling age ratio dynamics of winter wheat plants in 2016-2017 and 2017-2018 were shown in tables 3 and 4. It can be seen that the emergence rate of wheat seedling did not reach a significant level 18 days after sowing and 24 days after sowing, and there was a significant difference between different emergence rates in other periods. The seedling emergence rate at different ages of different treatments reached a significant level at 18 days after sowing and 24 days after sowing in

2016-2017. Moreover, the emergence rate and seedling age ratio of wheat seedling in different treatments did not reach a significant level in 2017-2018, except for 31 days after sowing; similar situations occurred in other periods.

For both seasons and under different seeding methods, the difference between the two index systems showed that the conventional seedling emergence rate statistical method might not accurately characterize the differences between treatments. In contrast, the dynamic index of seedling age ratio can define the significant differences between treatments, indicating that the seedling age ratio can more accurately characterize the effect of planting density on the growth of winter wheat seedlings.

Table 3. Effect of planting density in seedling emergence rate and seedling age ratio of post-paddy wheat in no-tillage punch seeding (2016-2017).

DAP(d)	Treatment	SER (%)	SAR_1(%)	SAR_2 (%)	SAR_3 (%)	SAR_4 (%)	SAR_5 (%)
	C1.5	50.00^{b}	50.00^{b}	0	0	0	0
12	C3	56.11^{ab}	56.11^{ab}	0	0	0	0
	C4.5	63.33^{a}	63.33^{a}	0	0	0	0
	C1.5	53.61^{b}	50.28^{a}	3.33^{b}	0	0	0
15	C3	60.56^{ab}	50.56^{a}	10.00^{b}	0	0	0
	C4.5	65.00^{a}	42.50^{a}	22.50^{a}	0	0	0
	C1.5	56.11^{a}	20.28^{a}	27.78^{a}	8.06^{c}	0	0
18	C3	65.00^{a}	15.56^{ab}	26.67^{a}	22.78^{b}	0	0
	C4.5	65.00^{a}	10.84^{b}	18.33^{a}	35.83^{a}	0	0
	C1.5	56.67^{b}	10.28^{a}	20.83^{a}	25.56^{c}	0	0
21	C3	65.00^{ab}	7.22^{a}	13.33^{ab}	44.44^{b}	0	0
	C4.5	68.33^{a}	9.17^{a}	8.33^{b}	50.83^{ab}	0	0
	C1.5	57.22^{a}	6.11^{a}	1.39^{a}	45.00^{a}	4.72^{c}	0
24	C3	66.11^{a}	3.33^{a}	2.78^{a}	38.89^{a}	21.11^{b}	0
	C4.5	68.33^{a}	9.17^{a}	2.50^{a}	21.67^{b}	35.00^{a}	0
	C1.5	57.22^{b}	4.44^{a}	1.11^{a}	15.83^{a}	15.00^{b}	20.83^{b}
31	C3	66.67^{ab}	0.00^{a}	1.11^{a}	9.44^{a}	26.11^{a}	30.00^{ab}
	C4.5	69.17^{a}	2.50^{a}	0.00^{a}	13.33^{a}	16.67^{b}	36.67^{a}

DAP: Days After Planting; SAR: Seedling Age Ratio. Different letters in the same column meant a significant difference among different planting densities of the same statistical period at 0.05 level ($p < 0.05$), the same below.

Table 4. Effect of planting density in seedling emergence rate and seedling age ratio of post-paddy wheat in no-tillage punch seeding (2017-2018).

DAP(d)	Treatment	SER (%)	SAR_1(%)	SAR_2 (%)	SAR_3 (%)	SAR_4 (%)	SAR_5 (%)
	C1.5	36.33^{b}	36.33^{b}	0	0	0	0
12	C3	46.67^{a}	46.67^{a}	0	0	0	0
	C4.5	55.00^{a}	55.00^{a}	0	0	0	0
	C1.5	39.00^{b}	34.33^{a}	4.67^{b}	0	0	0
15	C3	48.67^{ab}	30.67^{a}	18.00^{a}	0	0	0
	C4.5	55.00^{a}	29.00^{a}	26.00^{a}	0	0	0
	C1.5	42.67^{b}	18.00^{a}	18.00^{ab}	6.67^{b}	0	0
18	C3	48.67^{ab}	15.33^{a}	14.67^{b}	18.67^{a}	0	0
	C4.5	55.00^{a}	19.00^{a}	24.00^{a}	12.00^{ab}	0	0
	C1.5	44.67^{b}	8.00^{a}	16.67^{b}	20.00^{a}	0	0
21	C3	52.67^{ab}	6.00^{a}	23.33^{b}	23.33^{a}	0	0
	C4.5	56.00^{a}	1.00^{b}	40.00^{a}	15.00^{a}	0	0
	C1.5	47.33^{a}	4.33^{a}	5.67^{b}	30.00^{a}	7.33^{b}	0
24	C3	57.33^{a}	2.67^{a}	14.67^{a}	29.33^{a}	10.67^{ab}	0
	C4.5	58.00^{a}	2.00^{a}	17.00^{a}	25.00^{a}	14.00^{a}	0
	C1.5	47.33^{a}	0.67^{a}	4.67^{a}	16.33^{a}	19.67^{a}	6.00^{a}
31	C3	57.33^{a}	2.00^{a}	6.67^{a}	18.67^{a}	21.33^{a}	8.67^{a}
	C4.5	58.00^{a}	1.00^{a}	8.00^{a}	20.00^{a}	22.00^{a}	7.00^{a}

DAP: Days After Planting; SAR: Seedling Age Ratio. Different letters in the same column meant a significant difference among different planting densities of the same statistical period at 0.05 level ($p < 0.05$), the same below.

Seedling biomass and root system indexes evaluation: The aboveground biomass and the root system could express the population effect of crops. Table 5 shows that under no-tillage and drilling, with the increase of planting density of wheat in 2016-2017, the dry weight of the aboveground part of wheat seedlings decreased gradually. T1.5 was statistically different compare to the two treatments, but the difference between T3 and T4.5 was not significant.

For the leaf area data of wheat seedling, there was a significant difference between T1.5 and the other treatments (T3 and T4.5). However, there was no significant difference between T3 and T4.5. The difference in root index was not significant among different treatments. The correlation index of shoot and root of wheat seedlings with varying treatments in 2017-2018 showed a decreasing trend with the increase of planting density, except the root-shoot ratio of T1.5, which was not significantly different compare to the two others treatments.

Table 5. Effects of seeding technology on aboveground and root of post-paddy wheat seedlings.

Year	Treatment	Dry weight above ground (mg)	Leaf area (mm^2)	Root dry weight (mg)	Root envelope volume (mm^2)	Total root length (mm)	Root depth (mm)	Root-to-aboveground ratio
2016-2017	T1.5	31.000^{b}	355.978^{b}	12.000^{a}	4.86^{a}	492.264^{a}	129.957^{a}	0.403^{a}
	T3	44.570^{a}	651.903^{a}	14.860^{a}	5.29^{a}	453.888^{a}	105.597^{a}	0.338^{a}
	T4.5	45.140^{a}	587.313^{a}	17.290^{a}	5.71^{a}	619.605^{a}	122.890^{a}	0.395^{a}
2017-2018	T1.5	26.333^{b}	420.526^{b}	16.500^{b}	4.83^{b}	359.524^{b}	79.788^{b}	0.647^{a}
	T3	47.833^{a}	1019.989^{a}	33.000^{a}	6.00^{b}	752.375^{a}	119.500^{a}	0.712^{a}
	T4.5	49.167^{a}	1087.173^{a}	37.667^{a}	7.50^{a}	781.831^{a}	119.500^{a}	0.781^{a}
2016-2017	C1.5	23.833^{b}	276.605b	10.667^{a}	4.33^{a}	330.487^{b}	101.583^{a}	0.478^{a}
	C3	25.667^{b}	373.946ab	13.833^{a}	5.00^{a}	398.841^{ab}	101.417^{a}	0.614^{a}
	C4.5	37.167^{a}	466.817^{a}	14.500^{a}	5.67^{a}	484.989^{a}	105.600^{a}	0.390^{a}
2017-2018	C1.5	20.833^{b}	373.052^{b}	17.000^{b}	4.67^{a}	333.303^{b}	92.833^{b}	0.860^{a}
	C3	30.333^{b}	526.460^{b}	23.170^{ab}	4.50^{a}	301.541^{b}	83.078^{b}	0.764^{ab}
	C4.5	51.500^{a}	1360.094^{a}	33.170^{a}	5.33^{a}	489.756^{a}	134.750^{a}	0.650^{b}

Different letters in the same column meant a significant difference among different planting densities at 0.05 level ($p < 0.05$)

Under no-tillage punch seeding, the aboveground dry weight, leaf area, and root dry weight of wheat seedlings after two seasons decreased with the increase of planting density. The difference between the aboveground dry weight of the first treatments (C1.5 and C3) and the aboveground dry weight of the C4.5 treatment reached a significant level.

The results showed that the seedling growth status of the different seasons was different, which indicated that the seedling growth status of winter wheat was greatly affected by the season. In the same year, different sowing methods and planting densities have different effects on the growth of wheat seedlings, which indicates that the development of wheat seedlings was affected by both sowing methods and planting densities.

DISCUSSIONS

The final grain yield of cereals in general and that of wheat, in particular, is determined by the sowing method, planting density, biotitic and abiotic factors (Easson *et al.*, 1993; Lloveras *et al.*, 2004; Chen *et al.*, 2008). However, in research on single-grain sowing, it is urgent to know which sowing technique and at what dose should it be applied to obtain a better result. The emergence stage, which occurs immediately after sowing, is revealed as the critical period that controls the establishment of the final grain yield. Some research results show a decrease in the rate of emergence of seeds when the population density increases (Stratton, 1992; Miller *et al.*, 1994; Turkington *et al.*, 2005). These results confirm those of our study, which show during the two growing seasons a decrease in the germination rate going approximatively from 65% to 36.33% when the distance between seeds goes from 4.5cm to 1.5cm (Table 2 to 5). This rate also varies from one sowing method to another. The high emergence rate (65%) was recorded under the no-till drill seeding method during both growing seasons. This can be explained by the fact that the sowing machine which pushes the seeds into the ground would have slightly damaged the physics of the seed. Besides, the microenvironment of the seed in the soil is restricted, which does not promote rapid germination (Brunel, 2008). The seeds were sown by preparing the seedbed beforehand by digging a light pit (no-till drill seeding method) are found in conditions favoring the rapid germination of the seeds. The germination of seeds is done in response to signals such as the germinative power of the seed itself, its quality, the availability of water, nutrients (soil properties) , the amount of light (Baskin and Baskin, 1998)

The precise quantification of the effect of the dose and the sowing method on the emergence rate cannot be dissociated from the fine test methods and growth indices, such as the number of leaves appearing at the germination stage. Lati *et al.* (2012) pointed out the effect of population density on the emergence of crops and mentioned that early growth could be assessed based on the leaf number of the plants. It is in this perspective that we evaluated, in addition to the overall emergence rate of the seedlings, the emergence rate at different ages, which more precisely represents the number of leaves that appeared at a given time. Based on five ages selected, namely the appearance of a first heart, one heart and one leaf, two leaves, two leaves, and one heart and three leaves, we had evaluated the germination rate under different doses and sowing method during both growing seasons. This allowed us to record a significant statistical difference in the emergence rate between the different treatments, which was not the case when calculating the overall emergence rate. The same tendency was observed for the two sowing methods and during the two years. This shows the importance of considering the emergence at different age of growth of seedlings to better interpret the effect of the dose and the mode of sowing. Population density is a major factor that controls the intensity of competition between plants in the search for land resources and also that of spatial competition from the upper and underground parts of crops (Weiner *et al.,* 2001). Increasing the seed dose reduces the space between plants and, therefore, increases competition between plants and deteriorates individual plants' growth status (Page *et al.*, 2010). The dry weight of the seedlings is one of the important indexes for evaluating the growth and development of cereals plant, and it is also the basis for the formation of the final grain yield (Fageria, 2007).

The root system is also an essential organ for plants to absorb water and nutrition closely related to shoot formation. Proper root development promotes the growth of shoot (Bui *et al*., 2015). The initial stage of the intra-species competition was defined as the stage in which significant differences in biomass could be detected in different planting densities (Pagano and Maddonni, 2007). The results showed that the dry weight of shoot, dry weight of root, and root quantity of wheat per plant decreased gradually with the increase of planting density of no-tillage of wheat from 2016 to 2017. The difference of dry weight index between the T1.5 and the other two treatments reached a significant level, and the growth status of wheat seedlings in 2017-2018 was similar except for the root-shoot ratio. Under the mode of no-tillage and punching seeding, the dry weight of shoot, leaf area, and root dry weight of wheat seedlings decreased with planting density.

Moreover, there were significant differences in dry weight and leaf area between different treatments. The results showed that the competition between plants began to appear in the seedling stage of wheat. The higher the planting density, the more hindered the growth of the individual wheat population.

Moreover, the effects of different years on seedling emergence dynamics and seedling of wheat were different. This may be due to the difference in field average temperature and rainfall at the emergence stage of wheat during the two years (fig. 1). The results showed that the growth of wheat was greatly affected by the season, and the annual climate might be one of the important factors. The seedling stage is an important physiological period of crops, which indicates the stage from sowing to germinating and the emergence of seeds. Turkington *et al.* (2005) and Houseman and Mahoney (2015) found a mutual perception among plant seeds, which was related to seed secretions. The chemical signal mechanism between plants was affected by planting density and finally showed the emergence rate of crops. The effect of planting density on seedling emergence of winter wheat may also be related to the interaction between seeds, which has not been studied in this paper.

Conclusion: Wheat production must combine several agronomic practices and a level of technology to capture and maximize the use of resources for optimal plant growth. The single grain seeding technology combined with population density management offers a new opportunity to study the intraspecific interaction of wheat. The whole procedure of single seed management and monitoring allowed us to capture the procedural effects of wheat performance and segregate each ecology and physiology mechanism. The reduction in grain spacing from 4.5 to 1.5 cm in this study allowed us to observe a reduction in the germination rate from 65% to 36.33%. The method of sowing associating the preparation of a small ditch before the deposit of the seed was more efficient and that during two years of culture. Several factors indeed condition the final grain yield. However, the most important and the most crucial is the germination rate. Once this stage is understood and mastered, all other factors can in one way or another be managed to achieve better results.

Although these results were obtained throughout two growing seasons, we believe that all the parameters evaluated deserve to be studied on many wheat varieties to confirm the general observations made in this study. This study paved the way, showing the potential value of simultaneously measuring the aerial and underground biomass parameters to understand the factors that govern the development and growth process of a single wheat plant. It has revealed several potential factors which are responsible for intra-species competition and which require further examination.

Conflicts of Interest: The authors declare that there is no conflict of interest regarding the publication of this paper.

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