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Formula for Determining Number of Basic Seedlings at Scattered-Planting with Seedling Dry-Raised on Plastic Trays in Double-Season Rice

PAN Xiao-hua, CHEN Xiao-rong, YANG Fu-sun*
([1]*Key Laboratory of Crop Physio-ecology, Genetic and Breeding, Jiangxi Province*; *College of Agronomy, Jiangxi Agricultural University, Nanchang 330045, China*; * *Present Address*: *College of Agriculture, South China University of Tropical Agriculture, Danzhou 571737, China*)

Abstract: The tiller emergence in seedling nursery beds and field, and panicle formation in the field were investigated under scattered-planting with seedling dry-raised on plastic trays in double-season rice. A significant difference was noted in the non-synchronously-emerged tillers (the tillers that formed from latent buds and did not emerge following the normal tillering law on seedling nursery beds and recovered to grow after scattered-planting or transplanting) as well as the percentage of the available synchronously-emerged tillers between seedlings raised on plastic trays under dry-land conditions (DPT) and seedlings raised on nursery beds under wetland conditions (WB). The seedlings under DPT had some non-synchronously-emerged tillers, but those under WB had not. Therefore, the traditional formula for determining the number of rice seedlings was improved, and the formula for determining the number of basic seedlings under scattered planting with DPT in double-season rice was introduced. For early rice, it was $X=Y/\{(1+t_1r_1)[1+(N-n-SN)Rr_2]+(SN-3-t_1)R_2r_5\}$, and for late rice, it was $X=Y/\{(1+t_1r_1)[1+(N-n-SN)Rr_2]+(N-n-SN-3)Rr_2R_1r_3+(SN-3-t_1)R_2r_5\}$. Where, X represents reasonable number of basic seedlings per unit area at scattered-planting; Y, number of fitting panicles per unit area; t_1, total number of tillers per plant; r_1, percentage of the total available tillers; N, total number of leaves of the main culm; n, total number of elongated internodes in the main culm; SN, seedling leaf ages at scattered-planting; R, percentage of the primary tillers emerged in available node-position; r_2, percentage of the available primary tillers; R_1, percentage of the secondary tillers in the field (except the secondary tillers of the seedlings); r_3, percentage of the available secondary tillers; R_2, percentage of the asynchronously-emerged tillers after scattered-planting; r_5, percentage of the available non-synchronously-emerged tillers after scattered-planting.

Key words: double-season rice; seedling dry-raised on plastic trays; seedling scattered-planting; basic population; formula

Effects of the population structure on the development and growth of rice were achieved via influence of the growth and development of individual rice. The dynamics of tillers, leaves, and dry matter accumulation per plant resulted in different yield formation, which was directly connected with the basic rice population [1-2]. The number of basic seedlings was a key factor in rice production, which was disadvantageous to higher yield either too big or too small [3-6]. In order to establish the reasonable basic seedling population, Ling et al [3] developed a formula of basic seedlings based on the leaf-age-model, and indicated that the individuals could be vigorous only when the population was appropriate. Thereby, such kind of planting method was named small population and vigorous individuals [7-8].

The alteration of the seedling-nursing and transplanting methods in scatted-planting with seedlings raised on plastic trays under dry-land conditions (DPTS) had evidently affected the population development of rice in the field compared with the traditional transplanting method with seedling raised in nursery beds under wet-land conditions (WBT). Therefore, the decision of reasonable basic seedling population under DPTS should be somewhat different from traditional method. Ling et al [7] pointed out that the number of basic seedlings under DPTS should be increased by 20-30 percent than that under WBT. However, according to Dai et al [9] the number of basic seedlings for the high yield under DPTS was the same as that under WBT. Other researchers concluded that 4 [10], 3 [11], or 2 [12] plants per hill were optimum for the better population structure under WBT in different experiments, respectively. In above observation, the number of basic seedlings was not based on

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Corresponding author: PAN Xiao-hua (xhuapan@163.com)

specialized research on the law of tiller emergence and panicle development for the DPTS. In this article, we discussed the law of the tiller growth under DPTS by comparing the emergence and survival of the tillers in seedling nursery bed and field and panicle development in the field under DPTS and WBT, and a formula for determining number of basic seedlings for DPTS in double-season rice was established based on the formula by Ling et al [3]. The aim of this research was to provide a foundation for constructing the reasonable plant population in scattered-planting rice.

MATERIALS AND METHODS

The experiment was conducted in the agronomy station of College of Agronomy, Jiangxi Agricultural University from 2000 to 2001.

The soil for early rice contained 36.7 g/kg organic carbon, 1.736 g/kg total nitrogen, 40.24 mg/kg alkali-hydrolyzable nitrogen, 29.73 mg/kg available phosphorus, and 25.7 mg/kg available potassium. The soil for late rice contained 34.5 g/kg organic carbon, 37.4 mg/kg alkali-hydrolyzable nitrogen, 30.5 mg/kg available phosphorus, 26.0 mg/kg available potassium.

The varieties of early rice were two-line hybrid rice Anliangyou 25, Xiangliangyou 25, 1290S/F674 and conventional rice 9206. Those of late rice were three-line hybrid hybrid Guofeng 2, Xieyou 2347 and conventional rice Yuexiangzhan, Ganwanxian 30.

Seedlings were raised in two different ways, i.e. on plastic trays under dry-land conditions (DPT) and on nursery beds under wet-land conditions (WB). Urea was applied at the rate of 12 g /m^2, KCl at 20 g/m^2, and fused calcium-magnesium phosphate at 37.5 g/m^2 into seedling beds. The early rice was sown on 25th March, and scatteredly-planted (or transplanted) on 28th April. The seedling for transplanting (or scattered-planting) in early rice was at 33-day age. The late rice was sown on 15th June and scattered-planted (or transplanted) on 17th July, while the seedlings for transplanting (or scattered-planting) was at 32-day age. At 1.5-leaf stage, 0.25 mg/g paclobutrazol was sprayed for both seedling-raised ways. Furthermore, foliar fertilizer (0.1% urea solution) was sprayed on the seedlings under the DPT at 2.5-leaf stage and 10 days before scattered-planting, respectively. The seedlings were scattered-planted or transplanted in pots with diameter of 25 cm, four pots for each variety, with four 4 hills each pot and one seedling each hill. At the same time, 20 seedlings for each treatment (about 3×10^5 hills/ha) were scattered-planted (or transplanted) in the field.

The emergence of new tiller was inspected every 3 d, and marked by a label after scattered-planting or transplanting. In the label, the date of the emergence, node position in the main culm and death of the new tillers were recorded. The available panicle rate was calculated according to the number of the panicles forming from the tillers.

RESULTS

Effects of different planting methods on the tiller occurrence and percentage of available panicles after scattered-planting (or transplanting)

Effects of different planting methods on the occurrence of non-synchronously-emerged tillers

We used the term of non-synchronously-emerged tillers in this paper to define the tillers that formed from latent buds and didn't follow the normal tillering law (the *n*th leaf on the main culm and the first leaf of the tiller that emerges from the axil of the (*n*-3)th leaf grow synchronously) on seedling nursery beds and recovered to grow after scattered-planting or

Table 1. Effects of different seedling raising and planting ways on the occurrence of non-synchronously-emerged tillers.

Season	Variety or hybrid	PTO (%)		PDA (%)	
		DPT	WB	DPTS	WBT
Early rice	Angliangyou 25	50.0	0.0	66.7	0.0
	9206	41.7	0.0	40.0	0.0
	Xiangliangyou 25	58.3	0.0	42.9	0.0
	1290S/F674	25.0	0.0	66.7	0.0
Late rice	Guofeng 2	43.5	25.0	66.8	46.7
	Xieyou 2347	76.4	12.7	84.5	26.3
	Yuexiangzhang	46.5	17.5	100.0	0.0
	Gangwanxian 30	34.0	0.0	47.8	0.0

PTO, Percentage of the non-synchronously-emerged tillers; PDA, Percentage of the non-synchronously-emerged tillers developed into the available panicles; DPT, Seedlings were raised on plastic trays under dry-land conditions; WB, Seedlings were raised on nursery beds under wet-land conditions; DPTS, Seedlings were raised on plastic trays under dry-land conditions and scatteredly planted; WBT, Seedlings were raised on nursery beds under wet-land conditions and transplanted.

transplanting. The data in Table 1 showed that the average occurrence percentage of the non-synchronously-emerged tillers under DPTS and the average percentage of the non-synchronously-emerged tillers developed into the available panicle under DPTS were 43.75% and 54.08%, respectively, among the four varieties or hybrids in early rice, while no non-synchronous-emerged tiller was found under WBT. The occurrence percentage of the non-synchronously-emerged tiller in hybrid rice Angliangyou 25 and Xiangliangyou 25 was apparently higher than that of conventional variety 9206. There was a difference in percentage of non-synchronously-emerged tillers between late rice and early rice under DPTS, but the unanimous trend was found that the occurrence percentage of non-synchronously-emerged tillers under DPTS was higher than that under WBT. Moreover, the occurrence percentage of non-synchronously-emerged tiller in hybrid rice was also higher than that in conventional variety under DPTS.

Effects of different planting methods on tiller growth on the seedling nursery beds and in fields

For early rice, Table 2 indicated that before scattered-planting (or transplanting), the number of tillers per plant under WBT was more than that under DPTS and the average of the total four varieties under WBT and DPTS were 0.90 and 0.19 respectively. There were hardly any tillers more than 2.5 leaves for DPTS, while the number of tillers with less than 2.5 leaves under DPTS was lower than that under WBT. The average percentages of tillers developed into panicle after scattered-planting (or transplanting) in the four varieties under DPTS and WBT were 85.0% and 52.1%, respectively. The percentages of tillers with less than 2.5 leaves developed into panicle under DPTS were much higher than those under WBT, with the average value of the four varieties being 83.67% and 33.25% under DPTS and WBT, respectively.

For late rice, the average percentages of tillers developed into panicle in the four varieties under DPTS and WBT were 77.68% and 40.83%, respectively. The former was much higher than the latter, while the percentages of the tillers with more than 2.5 leaves developed into panicle were both high. However, there was a significant difference in the percentage of the tillers with less than 2.5 leaves developed into panicle between treatments of DPTS

Table 2. Effects of different planting ways on the tillers in the seedling-beds and fields.

Season	Variety or hybrid	Seedling raising and transplanting methods	Tillers in seedling nursery beds						Tillers in available node-position in field	
			Number of tillers per plant		Number of panicles per plant		Percentage of the tillers developed into the available panicles (%)		Percentage of tiller occurrence (%)	Percentage of available tillers (%)
			>2.5-leaf	<2.5-leaf	>2.5-leaf	<2.5-leaf	>2.5-leaf	<2.5-leaf		
Early rice	Anliangyou 25	DPTS	0.00	0.23	–	0.18	–	78.2	88.0	72.4
		WBT	0.33	0.25	0.33	0.08	100.0	33.3	76.7	78.2
	Xiangliangyou 25	DPTS	0.00	0.25	–	0.21	–	84.5	93.0	71.0
		WBT	0.42	0.75	0.33	0.33	80.2	44.4	68.3	81.2
	9206	DPTS	0.00	0.00	–	–	–	–	90.0	78.3
		WBT	0.08	0.42	0.08	0.08	100.0	20.2	80.0	91.7
	1290S/F674	DPTS	0.10	0.28	0.10	0.25	100.0	89.4	85.0	74.0
		WBT	0.42	0.92	0.33	0.33	80.3	36.3	66.7	72.6
Late rice	Guofeng 2	DPTS	0.22	0.66	0.21	0.54	97.7	81.8	85.0	79.4
		WBT	0.62	1.25	0.50	0.25	80.0	20.0	78.1	84.0
	Xieyou 2347	DPTS	0.20	0.55	0.20	0.42	100.0	95.3	87.5	77.1
		WBT	0.75	1.12	0.62	0.25	83.3	22.2	75.0	83.3
	Yuexiangzhan	DPTS	0.00	0.38	–	0.25	–	66.7	92.5	78.4
		WBT	0.38	0.88	0.38	0.12	100.0	14.3	87.5	82.1
	Ganwanxian 30	DPTS	0.15	0.35	0.15	0.22	100.0	64.3	80.0	78.1
		WBT	0.50	0.88	0.38	0.12	75.0	14.3	75.0	75.0

and WBT. The average percentage of the four varieties under DPTS and WBT were 77.0% and 17.7%, respectively.

The tiller occurrence and panicle development in field had significant effects on panicle formation of rice population. The emergence of leaf under DPTS was slower than that under WBT as seedlings under DPTS had been affected by light drought during seedling period. Before transplanting to the field, the number of leaves under DPTS was 0.2-0.5 less than that under WBT, but the seedlings under WBT needed several days to revive after transplanting, being almost the same as the time for developing one node in the main culm. Therefore, the number of nodes for available tiller emergence under DPTS was one more than that under WBT after transplanting. The results showed that the percentage of tiller emergence at the 4th-7th nodes in the four varieties under DPTS was 86.25%, while the 5th-7th nodes were the available tiller nodes in the field for the WBT, and the average the percentage of tiller emergence for the three nodes was 78.90%. The law of the tiller emergence was nearly the same for both early rice and late rice. Moreover, there was no much difference in the two planting methods on percentage of tillers that occurred on the available nodes in the field and finally developed into panicle under the DPTS and WBT, being 78.15% and 81.10%, respectively.

Effects of different planting methods on the dynamics of tiller emergence after transplanting or scattered-planting

It was found that there was an obvious stagnant duration (3-6 d) for the emergence of tillers for WBT after transplanting, namely reviving period, but such stagnant duration was not noted for DPTS after scattered-planting. Though the number of basic seedlings under DPTS was lower than that under WBT at transplanting, but the former could overtake or even exceed the latter by 9-12 d and 12-15 d after scattering in early rice and late rice, respectively, indicating an evident advantage under DPTS.

Effects of different planting methods on tillering duration

The values in Table 3 showed that under the same sowing and transplanting or scattered-planting time, new tillers under DPTS were found 3-4 days earlier than those under WBT after transplanting or scattered-planting in the field, either in early rice or late rice, which was due to the longer duration for reviving under the WBT. The difference in the critical time for available tiller emergence between the two planting methods was not significant. The critical time for available tiller emergence under DPTS was postponed for about 3 d compared with WBT, while tillering peak deferred for 3-4 days, and the available tillering duration in the field (from initial tillering to critical time for available tiller emergence) prolonged for 4-6 days.

Deduction of the formula for determining number of basic seedlings under DPTS and its diversification of the parameters in double-season rice

Deduction of the formula for determining number of basic seedlings

Based on the law of the tiller growth under DPTS, the formula for number of basic seedlings could be deduced as follows.

Reasonable number of basic seedlings (X) should be the number of the fitting panicles per unit area (Y) divided by number of available panicles per plant (ES) with the universal formula in theory, being $X=Y/ES$. Under certain planting conditions, Y of a rice variety

Table 3. Effects of different planting methods on the tiller-occurring period.

Season	Seedling-raised way	Transplanting (day/month)	Initial tillering (day/month)	Critical time for available tiller emergence (day/month)	Tillering peak (day /month)	Duration of available tiller emergence in the field (d)
Early rice	DPTS	28/04	01/05	23/05	26/05	23
	WBT	28/04	04/05	20/05	23/05	17
Late rice	DPTS	17/07	20/07	16/08	20/08	26
	WBT	17/07	23/07	13/08	16/08	20

was relatively stable, while *ES* was diverse. *ES* was determined by the number of node-positions of available tillers. Ling et al [3] pointed out that critical leaf-age for available tiller emergence was *N-n* leaf-age, and node-positions for available tiller emergence possibly produced by the main culm under WBT equaled to *N–n–SN*–1. According to this study, node-positions for available tiller emergence under DPTS equaled to *N–n–SN* since there was no reviving duration under DPTS after scattered-planting. Where, *N* means the total number of leaves on the main culm, *n* was the total number of elongated nodes in the main culm and *SN* was leaf age of seedling at scattered-planting.

As the tillers taken by seedlings under DPTS were slightly damaged during scattered-planting, the percentage of the tillers developed into the available panicles (r_1) was high, and the number of available panicles developed from the tillers taken by seedlings (number of tillers per plant, t_1) equaled to $t_1 r_1$.

According to the order of emergence, the tillers were divided into primary, secondary, and high-position tillers. High-position tillers could be ignored as they usually would not be able to develop into panicles. It has been proved previously that not all the tillers on the available node-positions could occur, and not all occurred tillers could develop into panicles. Accordingly, in this experiment the percentage of the primary tillers in available node-position developed into the available panicles (*R*) and percentage of the primary tillers developed to the available panicles (r_2), percentage of the secondary tillers（except those of the secondary tillers of the seedlings）(R_1) and percentage of the secondary tillers developed into the available panicles (r_3) were investigated. The tillers occurred in compliance with the law of synchronous growth of leaf and tiller after scattered-planting to the field could be deduced the number of secondary tillers on leaf-position under DPTS at critical leaf-age for available tiller equaled to *N–n–SN*–3.

Therefore, the number of panicles per plant developed from the tillers in accordance with the leaf and tiller synchronous growth law (*T*) equaled to $(1+t_1r_1)[1+(N–n–SN)Rr_2]+(N–n–SN–3)Rr_2R_1r_3$.

The occurrence percentage of the non-synchronously-emerged tillers and percentage of the non-synchronously-emerged tillers developed into the available panicles after scattered-planting were R_2 and r_5 respectively, so number of panicles per plant (*NT*) developed from the non-synchronously-emerged tillers equaled to $(SN–3–t_1) R_2r_5$.

Therefore, the number of panicles per plant (*ES*) under DPTS after scattered-planting in the field equaled to *T*+*NT*, namely

$$ES=(1+t_1r_1)[1+(N–n–SN)Rr_2]+(N–n–SN–3)Rr_2R_1r_3 +(SN–3–t_1)R_2r_5$$

To sum up, the reasonable number of basic seedlings (*X*) for DPTS was

$$X=Y/\{(1+t_1r_1)[1+(N–n–SN)Rr_2]+(N–n–SN–3)Rr_2R_1r_3 + (SN–3–t_1) R_2r_5\}.$$

This experiment showed that the secondary tillers produced from the tillers that occurred after scattered-planting (except the secondary tillers produced from the tillers taken by seedling) could not develop into panicles within the critical leaf-age for available tiller in early rice under DPTS and could be overlooked. Nevertheless, R_1 equaled to 0.60-0.65，r_3 to 0.2-0.7 in late rice and could not be overlooked as the values were big. Therefore, the formula for suitable number of basic seedlings (*X*) under DPTS could be simplified as follows:

For early rice, $X=Y/\{(1+t_1r_1)[1+(N–n–SN)Rr_2]+ (SN– 3–t_1) R_2r_5\}$;

For late rice, $X=Y/\{(1+t_1r_1)[1+(N–n–SN)Rr_2] + (N–n –SN–3) Rr_2R_1r_3+ (SN–3–t_1) R_2r_5\}$.

Diversification of the parameters

From the results of our experiment, the parameters in formula for number of the basic seedlings could be summarized in Table 4. Under present research conditions, the most fitting number of basic seedlings under DPTS was about 9.9×10^5/ha for hybrid and about 1.32×10^6/ha for conventional rice in early season, and about 5.1×10^5/ha for hybrid and 6.6×10^5/ha for conventional rice in late season.

DISCUSSION

The traditional method for transplanting rice seedlings is mainly by manual, with the seedlings raised on nursery beds under wet-land conditions. In order to determine the number of basic seedlings at

Table 4. Diversification of the parameters in the formula.

Parameter	Hybrid rice		Conventional rice	
	Early rice	Late rice	Early rice	Late rice
N	12	15	12	15
n	4	5	4	5
SN	4.8–5.1	5.7–5.9	4.7–4.9	5.8–6.1
t_1	0.2–0.3	0.6–0.8	0.0	0.4–0.5
R	0.85–0.93	0.85–0.88	0.9	0.80–0.93
R_1	0.34–0.53	0.60–0.65	0.46	0.6
R_2	0.25–0.58	0.44–0.76	0.42	0.34–0.47
r_1	0.75–1.00	0.83–0.86	-	0.67–0.75
r_2	0.71–0.74	0.77–0.79	0.78	0.78
r_3	0.50–0.60	0.40–0.60	0.40	0.20–0.70
r_5	0.43–0.67	0.67–0.85	0.40	0.48–1.00
Y ($\times 10^4$/ha)	360–390	360–390	450–480	420–450

Fitting panicles per unit area (Y) was based on *Mode Map of High Yield and Simplified Planting Technology for the High Quality Rice* established by Jiangxi Agricultural University et al [13].

transplanting, much research had been done on different regions, soils, varieties, fertilizer-application and seasons [14-15], and the reasonable values for the number of basic seedlings [16], plant density [17], row spacing [18] and number of seedlings per hill [19] at transplanting in various regions were provided, but the application is limited. Ling et al [3] formulated an equation for determining the number of basic seedlings under the traditional transplanting method, which was fitted to different seedlings, leaf age and varieties when transplanting based on the leaf-age-model, namely $X=Y/\{(1+t_1)[1+(N\text{-}n\text{-}SN\text{-}1\text{-}\alpha)\ r_1]+t_2r_2\}$. Jiang et al [20] had analyzed the percentage of the tillers on seedling developed into the available panicles [3] according to the law of growth and development of early rice and late rice, and advanced a formula for determining number of basic seedlings in early rice and late rice. The formula was added by surviving percentage of 3-leaf tillers taken by seedlings on seedling nursery beds based on the formula for number of basic seedlings by Ling et al [3] and tiller-occurring percentage according to the synchronous growth law of leaf and tiller within critical leaf-age for available tiller in the field. They further suggested that these tillers could develop into panicles. However, in our investigation, it was discovered that all the 3-leaf tillers taken by seedlings could not developed into panicles, so the percentage of those tillers developed into available panicle was not considered in our formula, which was one of the differences between our formula and another formulas.

The emergence of tillers might not follow the synchronous growth law of leaf and tiller, namely non-synchronously-emerged tillers due to the alteration in seedling-raised and transplanting methods for DPTS relative to WBT. Our formula was based on the percentage of the non-synchronously-emerged tillers as well as the percentage of synchronously-emerged tillers developed into available panicle and those two indexes were included, which was another difference between other formulas and ours.

The formula for the number of basic seedlings under DPTS in double-season rice obtained in this study was validated by a plot experiment in 2002 [21]. Taking the values calculated from the formula for number of basic seedlings under DPTS in double-season rice as the middle population treatment, another two values, i.e. higher and lower than the above value as higher and lower population treatments were used in the experiment. The results showed that the middle population treatment displayed the highest grain yield among the three treatments with good yield components as a whole. Moreover, the tillering dynamic and percentage of tillers developed into panicles, root-bleeding intensity per spikelet, leaf area index and structure, dry matter accumulation and transportation in rice plant in the middle population treatment were the most reasonable as well in the three treatments. This indicated that the formula is useful in rice production under scattered-planting with dry-raised seedling on plastic trays.

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