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Variability and correlation analysis between area of single seedling occupancy (ASSO) and rice individual characters under non-uniformity spatial distribution

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Abstract

In order to study the individual characters under non-uniformity spatial distribution, the variation characteristics of the area of single seedling occupancy (ASSO) were used as a control group to study morphological variability of rice. Different mathematical models were applied to combine the yield components of rice and some of its morphological index. Manfred Hühn's mathematical statistical model was used to analyze the possibility of increasing yield by non-regular spatial distribution. The plot models were constructed by inlaying individual unit area designed by computer simulation methods. A different ASSO was designed under non-regular horizontal distribution, Thiessen polygons were used to determine the ASSO. The result showed that, coefficients of variation of yield components were all less than those of ASSO, the effects of ASSO variability on effective panicles per plant and filled grain number of per panicle were the greatest; except flag leaf, the variation coefficient of most of the individual plant characters were greater than that of ASSO, and the variation coefficient of empty-shrivel grain number (0.3637) was the greatest. Most of individual plant characters suited the power function model, the setting percentage and filled grain number of per panicle kept steady after a quick increase as ASSO was increased, the spikelet number of per panicle peaked slowly and decreased slowly. The spikelet number of individual plants had linear relationships with individual bio-mass of single plant and dry matter of stem leaf in different degrees. The economic coefficient had linear relationships with setting percentage, had non-linear relationships with ASSO, yield of unit area, grain number of per panicle, filled grain number of per panicle, and average length of flag leaf. The effects of ASSO variability on 1000-grain weight and average length of flag leaf were small. It was possible to increase rice grain yield under non-regular spatial distribution which was proven by the mathematic statistical model with the condition of the ratio between the variation coefficient of ASSO and yield was greater than the correlation coefficient of the two (vA/vS> rSA).

Keywords: Area of Single seedling occupancy (ASSO); Non-uniformity Spatial Distribution; Rice (*Oryza sativa L.*); Variability; Yield.
Abbreviations: ASSO-area of single seedling occupancy; N-nitrogen; K-potassium; P-phosphorus; CV-coefficient of variation.

Introduction

Seedling transplantation is the main cultivation procedure for rice (*Oryza sativa*) production in many areas (Ren et al., 2011), which includes hand-transplanting, machine-transplanting, and broadcast-transplanting. The first experiment of broadcast-transplanting of rice seedlings was conducted in the 1950's, as reported by Peiris (1956) in Sri Lanka. Broadcast-transplanting of rice seedlings was successfully implemented in China in the 1980's (Zhang et al., 2008), and developed rapidly. The national agricultural promotion service center pointed out that broadcast-transplanting has been applied in more than 7 m ha. in the whole China since 2005, which is a quarter of the whole paddy planting area (Zhang et al., 2008). Due to the randomness of broadcasting in broadcast-transplanting, broadcast-transplanting has showed that, vertically, its insertion of tiller node into the soil was shallow and various in depth; horizontally, it leads to non-regular plant-spacing which means irregular distribution (Dai et al., 2000; Zhang et al., 2008). Some studies on oilseed rape found that the yield of oilseed rape rises with increasing uniformity of the spatial distribution of the individual plants across an area (Mülle and Heege, 1981). The previous research revealed that horizontal distribution under certain extent of non-regularity could increase the number of effective panicles, ameliorate population translucency, improve number of spikelets per panicle and number of filled grains per panicle; but over-irregular distribution was harmful to the growth of rice population (Chen et al., 2007; Yao et al., 2009). Moreover, Hühn (1999a, 1999b, 2000) proposed and examined a stochastic approach, which allows modeling and estimation of the effects of non-regular spatial patterns of the distribution of individual plants on yield. The individual area taken by per plant was estimated by using the area of Thiessen polygons that are defined as the smallest polygons that can be obtained by erecting perpendicular bisectors to the horizontal lines joining the center of a plant to the centers of its neighboring competitors (Hühn, 2003). They all used direct-sowing oilseed rape as test material, and as for the quantitative analysis of the relationship between ASSO and the characteristics of rice plant, the condition of the increasing yield under irregular distributed rice seedling is still unclear. The objectives of this experiment were to study the individual features of rice which were planted under non-regular distribution, and provide reference for optimizing the disorder of the plane structure. Computer simulation was used to design seedlings distribution with different separation distances (non-regular) based on the method of Hühn (2003). The rice seedlings were transplanted under fixed-point in the field according to the aforesaid model of non-regular distribution designed by the computer, and the characteristics of individual seedlings which took different areas were determined in this experiment.

Results

Analysis on the main characters of rice and its variability under non-regular horizontal distribution

Variations of yield and its components

The average area of sampling point (ASSO) was 541.01cm^2, the largest area was 816.70 cm^2, which is 3.03 times as the smallest, the variation range and coefficient of variation were 202.5% and 32.93% respectively (Table1). The number of effective panicles was the most variable among different individual plants. The variation range and coefficient of variation were 250% and 29.37%. The number of spikelets and filled grains of per panicle had great variability too, and the latter had greater variability than that of the number of spikelets, its variation range and coefficient of variation were 71.0% and 3.62% higher than that of spikelets. Seed setting rate and 1000-grain weight had small variability, and the variation range and coefficient of variation of 1000-grain weight were 11.3% and 3.62%. Because rice has an automatically coordinated ability, the coefficient of variations of yield character index was generally less than that of ASSO. But the number of effective panicles per plant and filled grains per ear had 47.5% and 31.1% higher variation range than that of ASSO, which showed that the number of effective panicles and filled grains of per ear were easily affected by non-regular distribution. The rice plant could have a secondary adjustment by changing filled grains of per ear when the plant has too much space occupation difference and overladen density difference which also showed that there is certain load bearing of the number of filled grains of per ear in a certain area, even if increase spikelets by other measurement, the plant would adjust the relationship with the environment by reducing seed setting rate. Compared with the control group, yield components index were all higher than that of the control group, except setting percentage, and the mean value of yield were 11.87% higher than that of control group (CK).

Main character traits and its variability of single plant

All the main characters had great variability except the average length of sword leaf. The variation range was higher than that of ASSO. The coefficients of variability were almost all higher than that of ASSO also, except for the whole plant dry matter, and stem leaf dry weight (Table 2). The variation range of filled grains reached to 736.9% which was 3.64 times as that of ASSO, the ear weight, grain weight. Total grains were also 3.26, 3.43 and 2.72 times as that of ASSO, respectively; empty and abortive grains, whole plant weight and stem leaf weight had smaller variation range compared with other characters, but still 2.34 times, 2.31 times and 1.87 times as that of ASSO. Except the length of sword, the coefficient of variability of all the other characters were all in the range of 32%-36.5%, the coefficient of variability of the number of empty and abortive grains reached 35.370%. The variation range and coefficient of variability of single flag leaf length was the smallest, which was 18.8% and 21.9% of ASSO respectively. The growth of single plant is not only affected by the area it occupies, but also affected by its own quality (the competitiveness and utilize on resource). The difference of the ability of taking advantage of resource was obviously under high density and low density. We found that characters of a single plant which under high density (ASSO 270-452cm^2) and low density (ASSO 634-817cm^2) had higher coefficient of variability than that of middle density (ASSO 452-634 cm^2) in this experiment. High quality seedlings could utilize more resources while the weak seedlings utilized less resources which led to the increase of difference of every plant when planted in high density condition; the seedlings with higher qualities could take good advantage of the resources, and compensate the surplus space by tillering and some other ways in low density condition, while the low quality seedlings could not take good advantage of the resources, so that biomass and yield of unit area were reduced, which led to big differences between single plants. So cultivating strong seedlings has significant sense in compensating the effects of non-regular distribution on yield when it is applied in broadcasting etc.

Related model between ASSO and single plant morphology and ear characters

Fit the model of ASSO and some single plant morphological character

Theoretically, when single seedling takes more area, the space it occupies is larger, it could grow more vigorously, and plant biomass is higher. But the single plant could not grow infinitely, when the area it takes reaches to some certain extent, the speed of plant biomass increases could not be higher. Therefore the change of single plant character with ASSO generally fits the power function. But at the initial change, there are three possibilities for the growth of single plant with the change of ASSO: I Linear change, the biomass increases the same proportion as area increases; II Power function change, biomass increases more slowly than its ASSO does; III Exponential function change, biomass increases more quickly than its ASSO does. Those three models were used respectively to fit with each index of single rice plants, the fitted equations were showed in Table 4. It showed that, except for the average length of sword leaf, all the index of the three functions reached significant levels, and the coefficient of variability all obeyed the following: power function>linear function>exponential function, which meant the changing rate of each index is lower than that of ASSO when the area is in the range of the designed area in this experiment. But if the forepart of the whole range of ASSO(ASSO270-634cm^2), we found that though the power function still had the biggest coefficient of variability, the linear function and exponential function were already close to the power function. The difference of average correlation coefficient between linear function and exponential function and power function were reduced to 0.0062 and 0.00897 from 0.0067 and 0.02456. It showed that in a certain range of the initial increase of ASSO, the change rate of single plant character index might keep the same speed as the change rate of area or even larger, which has significant sense in improving population quality and yield under non-regular distribution condition. The b in the power function meant the change rate of the index when ASSO increased, when b was greater, the change rate is higher, it could be affected by ASSO more easily. From all the indexes, the b of filled grains of per plant, grain yield of per plant, and ear weight of per plant were all greater (more than 0.69) and approximate to each other, which showed that ASSO had greater effects on it. The increase of ASSO would lead to a quick reduction of those indexes which is harmful to the adjustment of non-regular distributed population yield; the b of average

Table 1. Variability character and quantity of rice main yield characters under non-regular level spatial distribution.

	Max value	Min value	Mean value	Standard deviations	Variation range (%)	Coefficient of variation (%)	CK
ASSO (cm^2)	816.70	269.98	541.01±25.71	178.14	202.5	32.93	529.00
Effective panicles per plant	21.0	6.0	13.2±0.52	3.60	250.0	29.37	12.7
Spike lets per ear	204.8	78.0	147.3±3.69	25.54	162.6	17.34	130.4
Filled grain per ear	134.0	40.2	96.7±2.93	20.28	233.6	20.96	92.0
Seed-setting rate (%)	72.7	49.1	65.4±0.83	5.80	48.2	8.81	70.6
1000-gain weight (g)	31.92	28.68	29.87±0.15	1.02	11.3	3.62	28.83
Yield($kg.m^{-2}$)	1.211	0.260	0.707±0.28	0.194	365.1	30.43	0.632

Table 2. Quantity and its variability trait of main character of single plant under non-regular spatial distribution.

	Max value	Min value	Mean value	Standard deviations	Variation range (%)	Coefficient of variation (%)	CK
ASSO (cm^2)	816.70	269.98	541.01±25.71	178.14	202.5	32.93	529.00
Spikelets per plant	3046.0	468.0	1814.1±87.28	604.71	550.9	33.34	1658.0
Filled grains per plant	2017.0	241.0	1192.0±59.58	412.81	736.9	34.63	1170.0
Empty and abortive grains per plant	1301.0	227.0	622.1±32.66	226.25	473.1	36.37	448.0
Dry weight per plant (g)	121.55	21.41	73.63±3.48	24.13	467.7	32.77	67.74
Ear and grain weight (g)	66.83	8.80	41.67±1.96	13.60	659.4	34.29	39.46
Grains weight(g)	55.83	7.03	35.61±1.68	11.65	694.2	34.68	33.73
Stem and leave weight (g)	55.13	11.50	33.96±1.59	10.99	379.4	32.37	30.93
Average flag length (cm)	40.33	29.20	35.37±0.37	2.56	38.1	7.22	37.14

sword length approach to 0, so the sword leaf was affected little by ASSO; the b of effective panicle, stem and leaf weight, plant biomass, spikelets of per plant was increased successively. The effects of ASSO were getting strong, which showed that rice plants could adjust number of effective panicles and increment of unit area by tillering.

Analysis of statistic model of the effects of non-regular horizontal distribution on rice yield

Some values according to equation(3), (4) and (5) were obtained under the condition of this experiment: S=33.585, standard deviation=11.64854, coefficient of variation 34.68%, A=541.0058, standard deviation=178.1365, coefficient of variation 32.93%, r_{SA} 69.067%. Entering the data into equation (4), we got the yield changing percentage. This was caused by non-regular horizontal distribution (4.6%), which proved that the yield could be increased under some certain extent of non-regular distribution.

Discussion

The mathematical model was built to research the effects of density on crop yield and ear number from population aspect since the early 1980s(Mo et al., 1980). This experiment accomplished some analysis on some morphogical and economic characters from the aspect of the single plant, and found that coefficients of variation of yield components were all less than that of ASSO. It showed that the rice plant had high self-adjusting abilities, which is the premise for increasing yield in throw-transplanting. The coefficient of variation of most of the single plant character indexes was greater than that of ASSO, which is the theory basis for throw-transplanting. In a broad range of ASSO, most of single rice plant characters obeyed the power function, whose increasing speed was smaller than that of ASSO. Grain number of per single plant had linear relationships in different extents with single plants' biomass and stem leaf dry weight; economic coefficient had different linear and nonlinear relationship with ASSO, yield of unit area, grain number of per panicle, filled grain number of per panicle, and

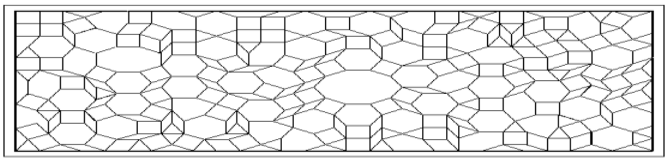

Fig 1. The plot inlayed with elementary areas(the equilateral polygons with 23cm side length were conducted by computer methods to get the points where seedlings were planted in Fig2).

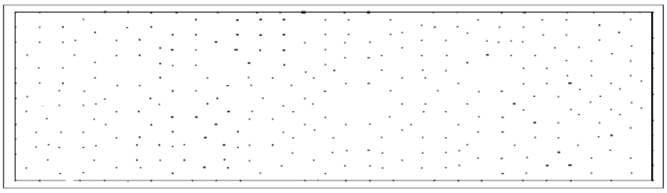

Fig 2. Each point in model(the points were obtained from the vertexes of polygons according to Fig 1, the points are set as the place where the seedlings would be planted)

average length of flag leaf, but 1000-grain weight and average length of flag leaf were affected little by ASSO. Those characteristics of the single plant have differences from population models, but they have their own characteristics which could be utilized to control the uniformity of seedling distribution in a certain range to obtain the best character indexes and highest yield. The effects of ASSO on some rice yield characters were studied by thinning out some seedlings after uniform planting, and it was proposed that the yield would not be affected when the gap area is less than 1000^{cm} (Dai et al., 2001). Some similar research done by oversea indicated the non-regular distribution was caused by sowed-machine on oilseed rape, the result showed that yield would be reduced positively under non-regular spatial distribution, and the effects of non-regular spatial distribution by mathematic model was determined. Rice has stronger self-adjusting ability than

Table 3. Coefficient of variability for each character under different ASSO range.

ASSO(cm^{2})		Spike lets	Filled grain	Empty and abortive grain	Dry weight of per plant (g)	Dry of weight Ear and grain (g)	Grain weight (g)	Dry of weight Stem and leave (g)	Average length of flag leaf (cm)
270-453 cm^2	Mean value	1292.35±127.8	838.12±90.1	454.24±45.8	52.03±5.1	27.71±2.9	23.55±2.6	24.32±2.3	35.11±0.7
	CV(%)	40.77	44.31	41.60	40.64	42.99	45.00	38.84	8.59
453-626 cm^2	Mean value	1979.93±84.6	1317.43±58.3	662.50±32.8	81.85±3.4	43.82±1.9	37.20±1.7	38.02±1.7	35.10±0.6
	CV(%)	15.99	16.56	18.52	15.57	16.57	16.75	16.61	6.12
626-817 cm^2	Mean value	2226.13±119.9	1456.00±80.6	770.13±55.2	89.72±4.5	48.76±2.2	41.08±2.2	40.97±2.1	35.98±0.6
	CV(%)	22.20	22.83	29.57	20.64	21.92	22.21	21.55	6.78

CV: Coefficient of variation.

Table 4. Related models between ASSO and main charaters of single rice (n=48) a, b are constant value.

		Equation	a		b		r	
			270-817cm^2	270-634cm^2	270-817cm^2	270-634cm^2	270-817cm^2	270-634cm^2
Biomass per plant	(1)	y=a+bx	23.2427	7.6240	0.0931	0.1327	0.6876^{**}	0.7162^{**}
	(2)	$y=ax^b$	1.2372	0.3279	0.6515	0.8724	0.6973^{**}	0.7170^{**}
	(3)	$y=ae^{bx}$	37.8848	27.0681	0.0012	0.0020	0.6645^{**}	0.7073^{**}
Effective panicles	(1)	y=a+bx	5.1807	3.9684	0.0130	0.0160	0.6460^{**}	0.6333^{**}
	(2)	$y=ax^b$	0.3893	0.2459	0.5501	0.6265	0.6530^{**}	0.6264^{**}
	(3)	$y=ae^{bx}$	6.8914	5.7920	0.0010	0.0014	0.6332^{**}	0.6278^{**}
Spike lets per plant	(1)	y=a+bx	567.1228	272.8581	2.3049	3.0496	0.6790^{**}	0.6819^{**}
	(2)	$y=ax^b$	29.6987	11.5828	0.6556	0.8123	0.6873^{**}	0.6842^{**}
	(3)	$y=ae^{bx}$	924.4582	707.7724	0.0012	0.0018	0.6590^{**}	0.6692^{**}
Filled grain per plant	(1)	y=a+bx	327.0924	93.8125	1.5987	2.2029	0.6899^{**}	0.7040^{**}
	(2)	$y=ax^b$	15.5385	4.7737	0.6918	0.8890	0.6976^{**}	0.7056^{**}
	(3)	$y=ae^{bx}$	584.4136	408.0772	0.0013	0.0021	0.6693^{**}	0.6894^{**}
Grain yield per plant	(1)	y=a+bx	9.1512	2.3088	0.0452	0.0628	0.6907^{**}	0.7042^{**}
	(2)	$y=ax^b$	0.4325	0.1230	0.6937	0.9036	0.6983^{**}	0.7053^{**}
	(3)	$y=ae^{bx}$	16.4535	11.9545	0.0013	0.0020	0.6696^{**}	0.6907^{**}
Average length of sword leaf	(1)	y=a+bx	34.9493	35.7982	7.80 E-05	-0.0016	0.0544^{ns}	0.0755^{ns}
	(2)	$y=ax^b$	33.3263	39.3374	0.0096	-0.0188	0.0479^{ns}	0.0752^{ns}
	(3)	$y=ae^{bx}$	34.9509	35.8053	2.21 E-05	0.0000	0.0544^{ns}	0.0755^{ns}
Dry weight of Panicle per plant	(1)	y=a+bx	10.7838	3.2792	0.0534	0.0727	0.6993^{**}	0.7076^{**}
	(2)	$y=ax^b$	0.5055	0.1576	0.6953	0.8897	0.7065^{**}	0.7087^{**}
	(3)	$y=ae^{bx}$	19.3857	14.2599	0.0013	0.0020	0.6787^{**}	0.6953^{**}
Dry weight of Stem and leaf per plant	(1)	y=a+bx	12.4590	4.3448	0.0398	0.0600	0.6441^{**}	0.7056^{**}
	(2)	$y=ax^b$	0.7820	0.1730	0.6016	0.8519	0.6568^{**}	0.7056^{**}
	(3)	$y=ae^{bx}$	18.5246	12.8156	0.0011	0.0019	0.6195^{**}	0.7010^{**}

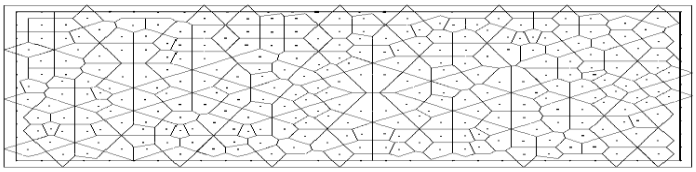

Fig 3. Divide the area taken by each point which means ASSO (the polygons at the edge were not drawn to make the figure aesthetic. ASSO was calculated by erecting perpendicular bisectors from the line of one point to its neighbors.)

oilseed rape, and it had been proven that a certain degree of non-regular distribution could increase yield in some experiments. Hühn et al.(2000) established the mathematic statistical model of the effects of non-regular distribution on crop yield, and applied it in machine-sowing in oilseed rape. The mathematic statistical model was used in this experiment, and showed that certain extent of non-regular distribution could increase yield. In practical production, horizontal distribution of seedlings could be classified into three classes: I distributed in uniformity as square; II distributed uniformity relatively, such as wide-narrow row, double triangle, optimized broadcasting etc.; III non-regular broadcasting. From the results of present researches, most of the results which got high yield tend to the second distribution method, and it is considered that this distribution method could adjust rice group growth and grain growth, which could always increase yield effectively. The advantage of the second method was also proven in this experiment, but because wide-narrow row and double triangle are troublesome, especially double triangle distribution. The methods must be demonstrated by professionals in villages which are not easily accepted by peasants. Optimized broadcasting is an optimized throw-transplanting method which was created by peasants to overcome over-irregular caused by throw-transplanting, the throwing point is controlled manually to get relatively uniformity and order (Yao et al., 2009). This experiment showed that, a certain width and length could be set in advance (by visual measurement) in the practice of fixed-throw, the seedlings could be thrown with a general regular (wide-narrow row or double triangle) instead of strictly uniformity, which could not only increase the efficiency of transplanting, but also control the horizontal distribution in a good range (Ren et al., 2008; Yao et al., 2009). From the individual level, different ASSO could lead to the differences of resources taken by single rice plant directly, which could cause the small environment around single seedling to be different, this is the theoretical base in different resource distributions among individuals. Compared with uniformity distribution, relative uniformity but unordered distribution increased effective panicles of per plant, spikelets and filled grains of per ear, but reduced setting percentage which is the same as the other paper (Chen et al, 2007). It showed that rice filled grain number could be only increased limitedly by non-regular horizontal distribution. Setting percentage would be reduced to adapt environment when the environment around rice exceed its loadbearing.

Material and methods

Plant materials and growing conditions

The experiment was conducted in a paddy at Gucheng town of Chengdu city, Sichuan province, China (lat. 30°93 N, long. 103°91 E) in 2005. Hybrid rice combinations Dyou 527 were used as test material. Brassica spp. intercropped with Brassica juncea var. multiceps Tsen et Lee. were planted as previous crop before this experiment was taken on the site. The experiment was taken on fluviatile loam sandy soil, and its chemical properties were as follows: organic matter content 31.11 g . kg^{-1}, available N 142 mg . kg^{-1}, available P 74 mg . kg^{-1}, available K 81 mg. kg^{-1}, total N 1.8 g . kg^{-1}, total P 0.274 g . kg^{-1}, total K 40.32 g . kg^{-1}. Fertilizer inputs as a basal dressing were at the following rates: Swine manure 22.5 t. ha^{-2}, urea 142.5 kg. ha^{-2}, monocalcium phosphate 375 $kg.ha^{-2}$, muriate of potash 187.5 kg. ha^{-2}. Basic fertilizer was applied before transplanting. The soil must be turned over to confirm the fertilizer was distributed uniformly. 150 kg. ha^{-2} urea were used at tillering stage and 150 kg. ha^{-2} muriate of potash were used at booting stage. The seeds were sown on 5th, April and the seedlings were transplanted on 27th, May. Each plot was 17.92 m^2 (6.4m × 2.8m), 336 hills were transplanted with single seedling per hill in every plot, the control group (CK) was transplanted using single seedling per hill as square at 23cm×23cm spacing. The land was leveled off two days before transplanting, and wheat-straws were used to fix the points in the field according to the elementary figure model. Irrigation water was kept at 1-3 cm depth for 1 week after transplanting to aid in seedling establishment. Pests were controlled according to the standard recommendation and other rice management was similar as that in the paddy field.

Design and calculation of plot model

Design plot model in order to simulate non-regular spatial distribution, elementary figures (including hexagon, tetragonum, triangle, rhombus with 30-degree acute angle and with 60-degree acute angle) with the same side length(23cm) with different areas were used to fill the plot(Fig 1). These elementary figures were mutually exclusive and collectively exhaustive of the total area of the plot. The vertexes of those polygons were set as the point where the rice plants were planted. Some certain points were removed according to requirements (Fig2). Some of the points were deleted to control the ASSO in the range of 270-860cm^2. Calculate the ASSO taken by each individual seedling was estimated by Thiessen polygons method: the smallest polygon that was obtained by erecting perpendicular bisectors from the line of one point to its neighbors. The area of this polygon is the space occupied by that seedling (Fig3). The areas were calculated and numbered by computer programs.

Theory

An equation(equation 1) was used by Hühn (1990) with a second-order equation to simulate yield of unit area under non-regular horizontal distribution(equation 1) to describe the effects of irregularity extent on yield by the second derivative. Manfred hühn deduced equation 2 by integrating predecessors' results.

$$Y \cong f(\overline{A}) + 1/2\sigma_A^2 f''(\overline{A}) \quad (1)$$

$$Y \cong \frac{\overline{S}}{\overline{A}} + \left(\frac{\sigma_A^2}{\overline{A}^2} + \frac{3\sigma_A^2}{\overline{A}^4}\right)\left(\frac{\overline{S}}{\overline{A}} - r_{SA}\frac{\sigma_S}{\sigma_A}\right) \quad (2)$$

$\overline{S}$ =average yield of single plant, $\overline{A}$ =average ASSO, σ_s=variance of single plant yield, σ_A=variance of ASSO, r_{SA}=coefficient of correlation between ASSO and yield of single plant. $\sigma_A/\bar{A}$, and $3\sigma_A/\bar{A}$ could be combined as coefficient of variation, and equation could be replaced by the follows (equation3).

$$Y \cong \frac{\overline{S}}{\overline{A}} + \left(\nu_A + 3\nu_A^3\right)\left(\nu_A - r_{SA}\nu_S\right)\frac{\overline{S}}{\overline{A}} \quad (3)$$

ν_A =coefficient of variation of ASSO, Vs=coefficient of variation of single plant yield, so changing percentage of yield which was caused by non-regular horizontal distribution could be expressed as follows (equation 4):

$$\frac{\left(\nu_A + 3\nu_A^3\right)\left(\nu_A - r_{SA}\nu_A\right)100}{1+\left(\nu_A + 3\nu_A^3\right)\left(\nu_A - r_{SA}\nu_A\right)} \quad (4)$$

Equation (4) should be greater than 0, if we want to increase yield by non-regular horizontal distribution, that is $v_A - r_{SA}v_S > 0$; due to $v_A>0$ and $v_S>0$;so, when $1>r_{SA}>0$, which could be simplified as :

$$v_A > r_{SA}v_S \text{ or } v_A/v_S > r_{SA} \quad (5)$$

When rSA<0, though the inequality is constant established, it is inconformity to the biology sense.

Therefore, yield increasing could be obtained under non-regular horizontal distribution when the ratio between coefficient of variation of ASSO and its yield is greater than their coefficient of correlation. $v_A/v_S > r_{SA}$ was established inevitably when $v_A>v_S$, which meant increasing yield is insure as long as coefficient of variation of single plant yield is less than that of its ASSO.

Test items and data processing

The experiment was performed according to non-uniformity without repetition, due to the huge workload. 59 representative points were selected from all the plants according to the calculated results of ASSO from Fig3. Labels with the aforesaid numbers were hung on the selected plants before the mature stage. Samples were taken at the mature stage, effective panicles, and the length of flag leaf per plant were investigated. The panicles and stem leaf of the samples were separated and oven-dried at 70 ºC to a constant weight after restraining enzyme activity for 30min by oven at 105 ºC respectively. Dry weights were taken using a digital electric balance (the accuracy was 0.0001) and means were calculated for each treatment. The panicles characters including the number of effective panicles, seed-setting percentage, grain number per panicle, filled grain number per panicle, 1000-grain weight, and yield components were then determined. Filled grains were separated by an air blower under the same working condition from the empty and abortive grains. Statistical analyses were made by Office Excel 2003 and the SAS-Stat package (SAS Institute Inc. 1996). The Curxpt32 was used to establish relationship models between area of single seedling occupancy and individual characters.

Conclusions

Optimized broadcast-transplanting was made out to lighten the burden of stooping in hand transplanting which could reduce the labor cost, and hopefully be accepted by peasants. A relative uniformity is required in optimized broadcast-transplanting, and means an appropriate degree of non-uniformity is allowed, when this non-uniformity does not affect the yield negatively, high yield might be obtained. The non-uniformity of seedlings caused by broadcast-transplanting is inevitable, while the uniformity is relative. There are many non-uniformities in broadcast-transplanting, not only in distribution of seedlings (horizontal), but also in morphological structure (stereoscopic). Both of them would have effects on yield and its components. The ear characters were poor in this experiment, the average of spikelets per ear was less than 100, and setting percentage was only 65.4%. Mainly because of low temperature, rainy and high humidity days were met during rice heading stage, sunlight was 45% less than in usual years, precipitation was increased by 25%, and environment loadbearing was limited, which affected setting percentage seriously. Only some important characters of rice which varied with ASSO under non-regular distribution in horizontal was discussed in this paper. The quantitate description of non-uniformity, irregularity, the repeatability under these problematic conditions and the stereoscopic change etc. need further research.

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