

Effects of Planting Density and Planting Patterns of Young Seedlings Transplanting on the Growth and Yield of Rice Plants*

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Abstract : This study was carried out to examine the effects of planting density and planting patterns in reference to various characteristics at the panicle formation, heading and maturing stages in rice plants (*Oryza sativa* L., cv. Nipponbare).

In square planting plots, the plant length at the panicle formation stage was the tallest at a 49 hills/m² plot, at the heading and maturing stages it was taller in lower planting density plots. In row planting plots, the plant length decreased with increasing plant density. The number of culms of square planting plots was the largest at a 100 hills/m² plot at the panicle formation stage and at a 64 hills/m² plot at heading time. Those of row planting plots were the largest at the most dense plot (100 hills/m²). Top dry weights in square and row planting plots were maximized at plant densities of 64 and 100 hills/m² at panicle formation and heading stage, and 49 and 100 hills/m² at maturing stage. The highest panicle number was obtained at a 81 hills/m² plot of square planting and at a 100 hills/m² plot of row planting.

The percentage of ripened grains was the highest at a 25 hills/m² plot of square planting and at a 100 hills/m² plot of row planting. As a result, the highest yield was obtained at a 49 hills/m² plot of square planting, and at a 100 hills/m² plot of row planting. It is suggested that the best planting density to obtain the highest yield in paddy rice may also depend upon planting patterns.

Key words : Density effect, Grain yield, Planting density, Planting pattern, Rice plant (*Oryza sativa* L.).

稚苗植水稻の栽植様式と栽植密度が生育並びに収量に及ぼす影響：秋田謙司・田中尚道（神戸大学農学部・神戸大学大学院自然科学研究科）

要 旨： 稚苗植水稻個体群の密度効果を明らかにするために、栽植様式および栽植密度を変えて日本晴を標肥条件下で栽培し、幼穂形成期、出穂期並びに成熟期の諸形質に及ぼす影響について検討した。

栽植密度は正方形植が 9～100 株/m² 区、並木植が 10～100 株/m² の範囲であった。草丈は幼穂形成期には正方形植では 49 株/m² 区で最も長く、これより疎植でも密植でも短かった。しかし、出穂期や成熟期は疎植区で長く密植区で短かった。一方、並木植ではいずれの生育段階においても疎植区で長く、密植区で短かった。単位面積当り茎数は、幼穂形成期には正方形植は 100 株/m² 区が最高で、出穂期には 64 株/m² 区が最高であった。これに対して並木植ではいずれの時期でも 100 株/m² が最高を示した。単位面積当り地上部全重は、正方形植では幼穂形成期並びに出穂期には 64 株/m² 区が最高で、成熟期には 49 株/m² 区が最高であり、これより疎植でも密植でも減少した。並木植の全重は、いずれの時期にも密植区ほど大きかった。収量構成要素についてみると、穂数は正方形植では 64～81 株/m² 区、並木植では 100 株/m² 区が最高であった。1 穂粒数は、密植になるほど少なかった。登熟歩合は、正方形植では 64 株/m² 区、並木植では 70 株/m² 区が最高でこれより疎植でも密植でも低下することが認められた。精粒千粒重と栽植密度との間に有意な相関関係が認められなかった。

その結果、面積当りの精粒重は正方形植では 25 株/m² 区、並木植では 70～100 株/m² 区が高い値を示し、最高収量を得る最適密度は栽植様式によって異なっており、新しい栽培技術の確立はつねに品種特性や環境条件を十分理解して行われるべきものと考えられた。

キーワード： 栽植密度、栽植様式、収量、水稻 (*Oryza sativa* L.)、密度効果。

Planting density is one of the fundamental themes to increase crop yield. In rice, it has been examined by many researchers using mature seedlings. We reported that mature

seedlings have had tillers from the nodes upper than the seventh node, and young seedlings tillers from those upper than the third node³⁾. For this reason, the density effect influencing the morphological characteristics in rice plants which raised from young or

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mature seedlings must differ from one another.

Kira et al.¹¹⁾ studied theoretically the effects of planting density and proposed “the law of constant final yield”, which has greatly influenced various branches of crop science.

In rice, the law was supported by Kanda and Kakizaki¹⁰⁾ in dry weight experimental results and by Yamada et al.¹⁵⁾ in ear weight. In contrast, Hoshino et al.⁸⁾ found that the grain yield in Hokkaido (northern Japan) increased with increasing planting density, although Takeda's findings questioned this and opened the way for further investigations.

As Murayama¹³⁾ indicated, this discrepancy might be due to the different local practices of rice culture. Ishizuka and Tanaka⁹⁾ assested that the differences of rice culture between northern and southern Japan are mainly due to varietal characteristics and adaptability to local conditions. Thus, planting density has been discussed with local conditions, varietal characteristics, and cultivation techniques.

So far, most of density effect study was conducted in square planting conditions using mature seedlings as large as 6-leaf stage. However, as present transplanting in most parts of Japan carried out by rice transplanter¹⁻³⁾ with young seedlings and row planting, the planting patterns must also be taken into consideration to discuss a density effect.

The objective of this study as to investigate the effect of the planting density and the planting patterns on the morphological characteristics at panicle formation, heading and maturing stages and on the yield and yield components.

Materials and Methods

Experiments were carried out at the Experimental Farm, Faculty of Agriculture, Kobe University in 1985.

Young seedlings of rice cv. ‘Nipponbare’, were transplanted to the paddy field at leaf age 3.2. Each hill consisted of one seedling.

The experimental plots were designed to have eight square planting plots (9, 16, 25, 36, 49, 64, 81 and 100 hills/m²) and seven row planting plots (10, 15, 20, 30, 50, 70 and 100 hills/m²). These plots were located in the

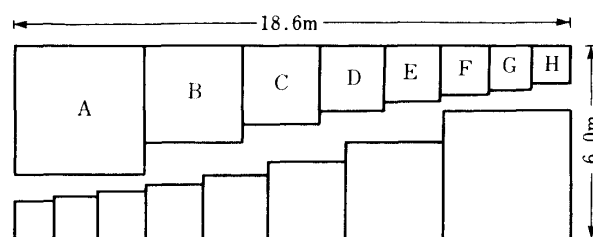


Fig. 1. Experimental design of square planting plot.

Planting density,

A : 4×4.3 m (9 hills/m²), B : 3×3.25 m (16 hills/m²), C : 2.4×2.6 m (25 hills/m²), D : 2×2.17 m (36 hills/m²), E : 1.71×1.86 m (49 hills/m²), F : 1.5×1.63 m (64 hills/m²), G : 1.33×1.44 m (81 hills/m²), H : 1.2×1.3 m (100 hills/m²).

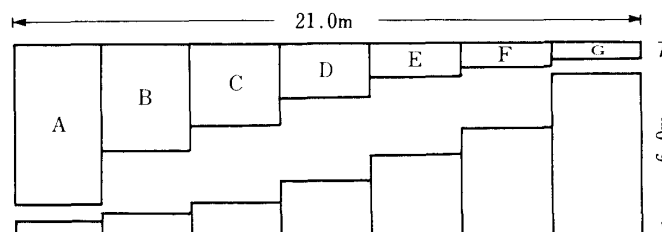


Fig. 2. Experimental design of row planting plot.

Planting density,

A : 3×5 m (10 hills/m²), B : 3×3.3 m (15 hills/m²), C : 3×2.51 m (20 hills/m²), D : 3×1.67 m (30 hills/m²), E : 3×1.01 m (50 hills/m²), F : 3×0.72 m (70 hills/m²), G : 3×0.50 m (100 hills/m²).

center of a 50 a (100 \times 50 m) field, with 2 replications as shown in Figs 1. and 2.

Chemical fertilizers, N, P₂O₅ and K₂O were applied at a rate of 6.0 g per m² each as basal dressing, and 3.5 g as topdressing, at the stage of tillering and heading.

Plant length, the number of culms and top dry weight were measured for 10 plants in each plot at the panicle formation, heading and maturing stages.

Yield components and grain yields were measured at the maturing stage. Grains sunken into salt water with 1.10 in specific gravity were regarded ripened ones.

Results and Discussion

In this study, in square planting plots at panicle formation stage, the maximum plant

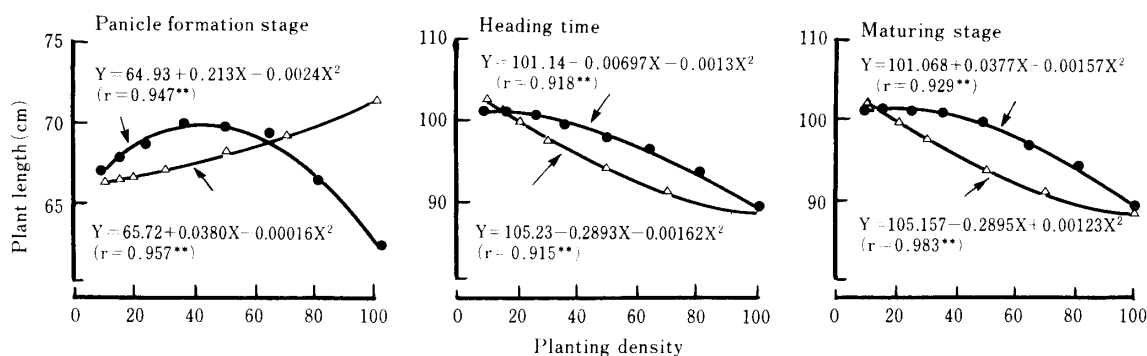


Fig. 3. Effects of planting density and planting patterns on the plant length at panicle formation stage, heading time and maturing stage.

● : square planting, △ : row planting.

Panicle formation stage

● $Y = 64.93 + 0.213X - 0.0024X^2$ ($r = 0.947^{**}$), △ $Y = 65.72 + 0.0380X - 0.00016X^2$ ($r = 0.957^{**}$)

Heading time

● $Y = 101.14 - 0.00697X - 0.0013X^2$ ($r = 0.918^{**}$), △ $Y = 105.23 - 0.2893X + 0.00162X^2$ ($r = 0.915^{**}$)

Maturing stage

● $Y = 101.068 + 0.0377X - 0.00157X^2$ ($r = 0.929^{**}$), △ $Y = 105.157 - 0.2895X + 0.00123X^2$ ($r = 0.983^{**}$)

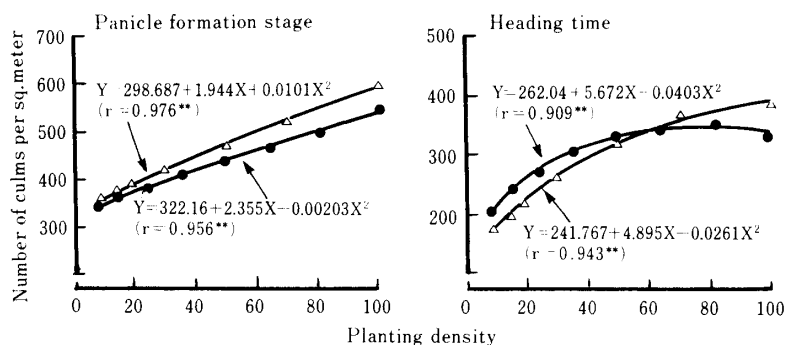


Fig. 4. Effects of planting density and planting patterns on the number of culms per m^2 at panicle formation stage and heading time.

Panicle formation stage

● $Y = 322.16 + 2.355X - 0.00203X^2$ ($r = 0.956^{**}$)

△ $Y = 298.687 + 1.944X + 0.0101X^2$ ($r = 0.976^{**}$)

Heading time

● $Y = 262.04 + 5.672X - 0.0403X^2$ ($r = 0.909^{**}$)

△ $Y = 241.767 + 4.895X - 0.0261X^2$ ($r = 0.943^{**}$)

length was obtained at planting density of 36 and 49 plants/ m^2 , while in row planting plots, it was constantly longer in higher density plots (Fig. 3). Thus, the effect of planting density apparently differed between both planting patterns. At both heading and maturing stages, plant length was greatest in lower density plots than in higher density plots of both planting patterns.

Therefore, it is likely that the differences of plant length at different planting density

resulted from different elongation rates, which was highly associated with the increase of the number of culms in a given area and growth rates during the reproductive phase. Since young seedlings, transplanted to the paddy field at earlier time, resulted in more tillering from the basal node, their subsequent growth was obviously different from that of mature seedlings.

Among morphological characteristics in the rice population, that most affected characteris-

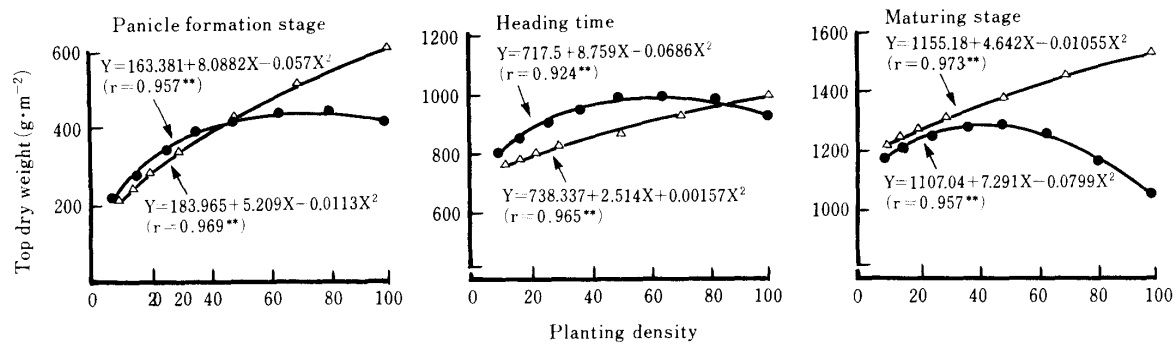


Fig. 5. Effects of planting density and planting patterns on the top dry weight per m² at panicle formation stage, heading time and maturing stage.

Panicle formation stage

● $Y = 163.381 + 8.0882X - 0.057X^2$ ($r = 0.957^{**}$), △ $Y = 183.965 + 5.209X - 0.0113X^2$ ($r = 0.969^{**}$)

Heading time

● $Y = 717.5 + 8.759X - 0.0686X^2$ ($r = 0.924^{**}$), △ $Y = 738.337 + 2.514X + 0.00157X^2$ ($r = 0.965^{**}$)

Maturing stage

● $Y = 1107.04 + 7.291X - 0.0799X^2$ ($r = 0.957^{**}$), △ $Y = 1155.18 + 4.642X - 0.01055X^2$ ($r = 0.973^{**}$)

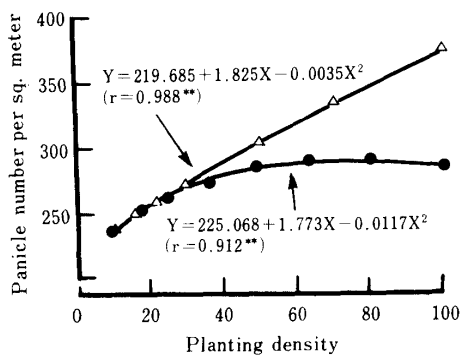


Fig. 6. Effects of planting density and planting patterns on the panicle number at maturing stage.

● $Y = 225.068 + 1.773X - 0.0117X^2$ ($r = 0.912^{**}$)

△ $Y = 219.685 + 1.825X - 0.0035X^2$ ($r = 0.988^{**}$)

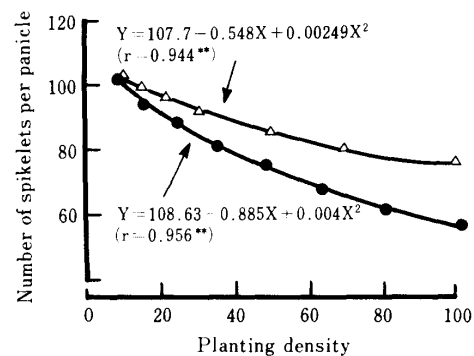


Fig. 7. Effects of planting density and planting patterns on the number of spikelets per panicle at maturing stage.

● $Y = 108.63 - 0.885X + 0.004X^2$ ($r = 0.956^{**}$)

△ $Y = 107.7 - 0.548X + 0.00249X^2$ ($r = 0.944^{**}$)

tic by planting density was the number of culms. The maximum number of culms in square planting plots was observed at planting density of 100 plants/m² at panicle formation stage, and at plant density of 64 plants/m² at heading time (Fig. 4). The maximum number of culms in row planting plot was observed at planting density of 100 plants/m² at any sampling time. However, it decreased at planting density over 100 plants/m² according to other results (unpublished), suggesting that it was also maximized at 100 plants/m².

From the view point of matter production,

growth rate of top dry weight generally shows a monomodal or bimodal curve in which the peak appeared at 10 to 12 weeks after transplanting (around heading time). In this experiment (Fig. 5), top dry weight increased with increasing planting density to the density of 64 plants/m² at panicle formation stage and heading time, and to the density of 49 plants/m² at maturing stage. In row planting plots, it was maximized at 100 plants/m² plot at each sampling time, suggesting that density effects differ between both planting patterns.

Yield components consisted of the number

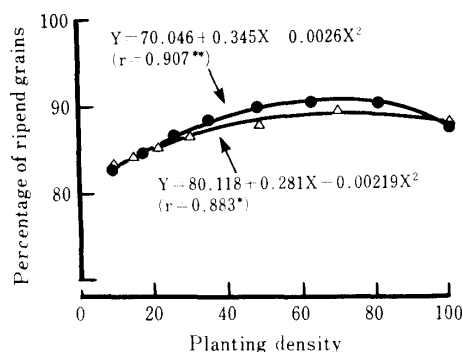


Fig. 8. Effects of planting density and planting patterns on the percentage of ripened grains at maturing stage.

● $Y = 70.046 + 0.345X - 0.0026X^2$
 ($r = 0.907^{**}$)
 △ $Y = 80.118 + 0.281X - 0.00219X^2$
 ($r = 0.883^{**}$)

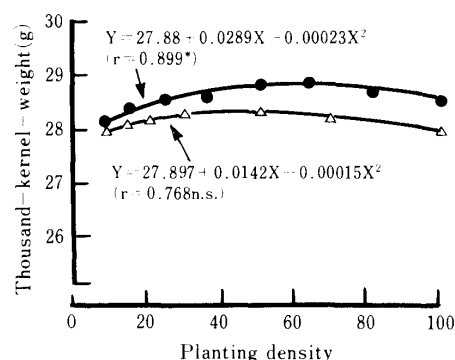


Fig. 9. Effects of planting density and planting patterns on the thousand-kernel-weight at maturing stage.

● $Y = 27.88 + 0.0289X - 0.00023X^2$
 ($r = 0.899^{*}$)
 △ $Y = 27.897 + 0.0142X - 0.00015X^2$
 ($r = 0.768 \text{ n.s.}$)

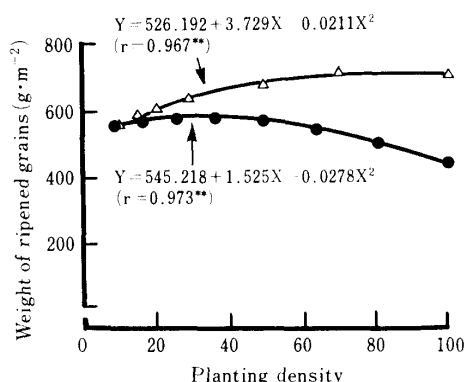


Fig. 10. Effects of planting density and planting patterns on the weight of ripened grains at maturing stage.

● $Y = 545.218 + 1.525X - 0.0278X^2$
 ($r = 0.973^{**}$)
 △ $Y = 526.192 + 3.729X - 0.0211X^2$
 ($r = 0.967^{**}$)

of panicles, the number of grains per panicle, the percentage of ripened grains and the kernel weight.

In the present experiment, the maximum number of panicles was obtained at planting density of 64 to 81 plants/m² in square planting plots, and at 100 plants/m² in row planting plots (Fig. 6). The larger number of culms was obtained in the case of young seedlings than for mature seedlings, and the plants grown from the young seedlings had a number of non-productive tillers. Moreover, productive tillers decreased with increasing planting

density, and the decrease ratio of productive tillers was larger in square planting plots than in row planting plots. Consequently, the number of panicles was less in square planting plots than in row planting plots.

The yield components has compensatory effects mutually. In general, however, the number of panicles and the number of grains per panicle are correlated inversely. The number of spikelets per panicle decreased with increasing planting density, with a higher decreasing rate in square planting plots (Fig. 7). Moreover, the number of spikelets per panicle and the percentage of ripened grains are also correlated inversely, the percentage of ripened grains showed a maximum at planting density of 64 plants/m² in square planting plots and 70 plants/m² in row planting plots (Fig. 8). Therefore, it is suggested that the process of translocation and accumulation of assimilated products at the ripening period differs with planting densities.

The weight of one thousand kernels of ripened grains was not correlated significantly with planting density, although it was heavier at high density square planting plots than at high density row planting plots (Fig. 9).

As a result, the maximum yield, or weight of ripened grains per m² in square planting plots was obtained from the plot of planting density of 25 plants/m², which might be an optimum plant density ($Y = 545.218 + 1.525X - 0.0278X^2$ $r = 0.973^{**}$). On the other hand, in row

planting plots, 70 to 100 plants/m² plots were the best ($Y = 526.192 + 3.729 X - 0.0211 X^2$, $r = 0.967^{**}$) (Fig. 10). The law of constant final yield could be applied in these plots. In other experiments (unpublished), the grain yield in row planting plots did not increase at higher densities, over 100 plants/m². Thus, it is likely that the maximum grain yield in the row planting plots could be obtained at a planting density of around 100 plants/m².

As planting density effects were controlled essentially by nutrient and light intensity conditions, the difference between square planting and row planting may also be caused by the mutual effects of nutrient and light conditions.

The present experiment was carried out under conditinal fertilizing conditions. According to our studies of the relationship between planting density and amount of fertilizer application, the maximum grain yield was obtained at planting density of 16 to 25 plants/m² in the plots lightly dressed by basal fertilizer, while in the plots heavily dressed by topdressing it was obtained at 25 plants/m² plot and was greater than the lightly dressed plots. Further, the decreased rate of grain yield at the plots of higher planting density compased to optimum planting density was larger in lightly dressed plots than in heavily dressed plots.

On the other hand, from these results, there seems to be a more inter-plant competition in square planting than in row planting i.e. light energy might be utilized more efficiently in row planting⁴⁾.

As pointed out by Downs and Hellmers⁵⁾, it is concluded that the optimum growth conditions may be affected by various factors. Donald⁵⁾ recognized that the grain yield decreased at higher planting density than optimum planting density. Although in this experiment plants at higher density were not damaged by external factors such as diseases and insects, in practice, those must be taken into account.

And also, local conditions and varietal characteristics must be taken into consideration in order to develop advanced cultivation techniques.

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* In Japanese with English summary.

** In Japanese, the title was tentatively translated by the present authors.