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Influence of planting density on within-plot variation for the number of pods in soybean cultivars

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Abstract

The objectives of this research were to evaluate the influence of planting density on the non-heritable within-plot variation for the number of pods in soybean cultivars. Six cultivars were grown under three levels of planting density. The within-plot variation, assemblage of intraplant and interplant variations, was partitioned into following four variations ; the difference in the number of pods between main stems and branches ($\sigma_{m\cdot b}$), the variation between hills (σ_{hill}), the variation between plants within hills (σ_{ind}) and the residual variation (σ_{rem}). All of the four within-plot variations varied with cultivars and planting densities. In the high density, the difference between cultivars increased in $\sigma_{m\cdot b}$ but decreased in σ_{ind} and σ_{rem}. Cultivar × planting density interactions were evident in $\sigma_{m\cdot b}$ and σ_{rem}, indicating genetical control of plant response patterns to planting density was related to the phenotypic plasticity for pod setting in branches. There was no apparent association between seed yield per unit area and any of within-plot variations. $\sigma_{m\cdot b}$ was independent of the other three within-plot variations.

Key words ; Soybean, planting density, yield component, branch, phenotypic plasticity

Introduction

Soybean [*Glycine max* (L.) Merr.] plants produce a multitude of shoot apices and growth centers which may contribute to the total morphology[9]. The contributions made by the growth centers vary with genetic (cultivar) and environmental factors. Although soybean flowers are self-pollinated thus a plant population of a given cultivar may be genetically alike, it is generally recognized that the growth of individual plants under field conditions is lacking in uniformity. Such an intra-genotypic variability can not be ignored in practical management because of the feasibility of mechanical harvesting and the evaluation of seed quality in the market. Furthermore, it has been pointed out that the variability in morphology is directly related to the seed yield potential of the plants since

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all axillary meristems may develop as either branches with leaf and floral primordia or simply as floral primordia[1, 3].

It has been demonstrated that the relative contribution of pod setting in branches to seed yield changes with planting density[4, 5, 6, 8].Even though there is much information available on the effect of planting density on soybean seed yield, very little is known about the extents of intraplant and interplant variations and influence of planting density upon them.

A better knowledge of the influence of planting density on the response patterns of individual plants is needed for determining factors affecting within-plot variation which refers in this paper to assemblage of intraplant and interplant variations observed in the plot. The present study is an attempt to understand plant response patterns in different cultivars, by partitioning the variation for the number of pods within the plot into the variation between plant organs and the variation among plants.

Materials and Methods

The field experiment was conducted in 1984 at the reserch field of Obihiro University of Agriculture and Veterinary Medicine, on stratic fluffy brown andosols. Six cultivars recommended in Hokkaido, Chusei-hikarikuro, Kitamishiro, Kitamusume, Himeyutaka, Suzuhime and Toyosuzu were used. They were grown under three levels of planting density, 10. 1 plants m^{-2} (low), 15. 2 plants m^{-2} (medium) and 30. 3 plants m^{-2} (high). The experimental plots were randomized in a complete block spilit plot design with six replicates, arranging planting densities as main-plots and cultivars as sub-plots. Four seeds per hill were planted on May 25 and thinned to two plants per hill after emergence. The other crop managements were practiced as usual.

At the mature stage, eight hills of 16 plants were harvested from each plot. The number of pod sets on main stem and that on branches were counted separately in a plant basis. Seed yield and 100 seed weight were measured in a plot basis.

Seed yield per unit area can be divided into five components ; the number of hills per unit area, the number of plants per hill, the number of pods per plant, the number of seeds per pod and the weight of one seed. The number of pods measured in the plot, P_{ijk}, may be considered to consist of following four effects.

$$P_{ijk} = \mu + \alpha_i + \beta_j + \gamma_{jk} + \delta_{ijk}.$$

where μ is the grand mean, α_i is the main stem-branch effect or the overall difference in the number of pods between main stems and branches, β_j and γ_{jk} are the effects of the j-th hill and the k-th plant in the j-th hill, respectively. δ_{ijk} is the remaining effect including interactions. The sum of square of P_{ijk} may be partitioned into four parts corresponding to the effects in the avove formula,

$$SSp_{ijk} = SS_{m\text{-}b} + SS_{hill} + SS_{ind} + SS_{rem}.$$

From those five sum of squares, variables estimating the extent of within-plot variation for the number of pods in each cultivar can be obtained as follows.

$$\sigma_{total} = \sqrt{SSp_{ijk}/(2mn-1)},\quad \sigma_{m-b} = \sqrt{SS_{m-b}},$$
$$\sigma_{hill} = \sqrt{SS_{hill}/(m-1)},\quad \sigma_{ind} = \sqrt{SS_{ind}/m(n-1)},$$
$$\sigma_{rem} = \sqrt{SS_{rem}/(mn-1)}$$

where m and n are the number of hills and that of plants per hill within a plot.

In this study, σ_{total} is defined as a variable to measure the total variation for the number of pods within a plot. σ_{m-b} measures the overall difference in the number of pods between the main stems and branches. σ_{hill} and σ_{ind} measure the variation among hills and the variation among plants within hills, respectively. σ_{rem} is defined as the residual variation.

For assumptions of analysis of variance[10], tests were carried out and all of the five variables were transformed into square root prior to the statistical analysis.

Results

Table 1 and Table 2 show that averaged across cultivars, σ_{total} was mostly constant over the different levels of planting density. Similarly the differences in σ_{hill} between planting densities were small and not significant. At the high density of 30.3 plants m^{-2}, σ_{m-b} increased by more than 30% but σ_{ind} and σ_{rem} were minimized. As the increase in planting density, seed yield per unit area increased and the number of seed per plant decreased. 100 seed weight was not affected by planting density.

The difference between cultivars was found significant in all of the variables representing the within-plot variation for the number of pods and three yield component characters. To compare the degree of genetic variation under each level of planting density, heritability values were estimated and presented in Table 3. The genetic variation for σ_{total} decreased with increase in planting density. The differences between cultivars in σ_{hill} and σ_{ind} became less marked and non significant at the high density. In contrast the difference between cultivars in σ_{m-b} was maximized at the same density (h^2 = 79.24%).

Table 1. Average values of the variables, across cultivars, representing the within-plot variation for the number of pods and component characters of soybean yield under three levels of planting density

	σ_{total}	σ_{m-b}	σ_{hill}	σ_{ind}	σ_{rem}	Yield/ area -gm^{-2}-	No.of seeds/ plant	100 seed weight -g-
Low[1)]	3.046	3.871	3.208	3.010	2.819	284	101.8	29.4
Medium	2.944	3.804	3.191	2.855	2.522	295	70.4	29.3
High	3.020	5.070	2.954	2.399	2.270	370	44.3	29.7

Note) σ_{total} is the total variation for the number of pods in the within-plot. σ_{m-b} is the overall difference in the number of pods between main stems and branches. σ_{hill} and σ_{ind} are the variation between hills and between plants within hills, respectively. σ_{rem} is the residual variation for the number of pods.

1) Planting density ; Low : 5.05 hills (10.1 plants)/㎡, Medium : 7.6 hills (15.2 plants)/㎡, High : 15.15 hills (30.3 plants)/㎡.

Table 2. Analysis of variance for the variables representing the within-plot variation for the number of pods and seed yield.

Items	d. f.	Mean squares σ_{total}	σ_{m-b}	σ_{hill}	σ_{ind}	σ_{rem}
Blocks	5	31.45*	245.9	142.5*	94.2**	10.4
Densities, D.	2	22.44	1827.2**	71.8	357.5**	279.9**
Errors (a)	10	8.40	132.1	28.3	14.0	8.5
Cultivars, C.	5	210.30**	2092.2**	312.0**	203.7**	259.0**
C × D	10	14.02	343.2**	30.7	27.9	19.7*
Errors (b)	75	7.96	84.9	37.1	22.2	8.6

Table 2. Continued

Items	d. f.	Yield/area[1)]	Mean sqaures No. of seeds/plant	100 seed weight
Blocks	5	0.1887	0.173	1.17
Densities, D.	2	7.2820**	96.223**	3.12
Errors (a)	10	0.5526	0.590	0.32
Cultivars, C.	5	3.0106**	20.989**	1222.27**
C × D	10	0.5720	0.902**	2.04
Errors (b)	75	0.3544	0.334	1.02

Note) Each variable refers to footnote in Table 1 .
1) Transformed into logarithm.
*, ** ; Significant at the 5% and 1% levels, respectively.

Table 3. Heritability values of the variables representing the within-plot variation for the number of pods and those of component characters of soybean yield under three levels of planting density

	σ_{total}	σ_{m-b}	σ_{hill}	σ_{ind}	σ_{rem}	Yield/ area	No. of seeds/ plant	100 seed weight
Low[1)]	56.15%	51.59	36.54	37.17	70.12	49.04	96.84	94.41
Medium	42.05	52.71	33.20	31.93	60.45	45.20	92.05	99.14
High	33.49	79.24	14.53	18.44	44.56	29.96	81.18	98.38

Note) Each variable refers to footnote in Table 1.
1) The same as in Table 1.

The cultivar × planting density interaction was evident in σ_{m-b} because Kitamishiro and Suzuhime showed a smaller number of pods on branches at the high density result in increased σ_{m-b}. The cultivar × planting density interaction observed in σ_{rem} was due to more decreased variability of Suzuhime at the high density. These interactions suggest that the genetical control of response to planting density can be related to the ability of pod setting on branches. It was also in the case of the number of seeds per plant.

The relationships among the variables and seed yield characters are shown in Table 4. The correlation coefficients were calculated over six cultivars and three levels of planting density since cultivar × planting density interactions in some variables were considered. No relationship of σ_{m-b} with the other three variables of within-plot variation was appeared. σ_{hill}, σ_{ind} and σ_{rem} had positive and significant correlations each other, and these three variables were also correlated with the number of seeds per plant. There was no apparent association between seed yield per unit area and the within-plot variation which was a subject of this research.

Table 4. Correlation matrix, over cultivars and planting densities, among the variables representing the within-plot variation for the number of pods and component characters of soybean yield.

		(2)	(3)	(4)	(5)	(6)	(7)
σ_{m-b}	(1)	−0.209	−0.289	−0.094	0.124	−0.057	−0.389
σ_{hill}	(2)		0.708**	0.805**	−0.233	0.504*	−0.372
σ_{ind}	(3)			0.782**	−0.204	0.648*	−0.228
σ_{rem}	(4)				−0.426	0.808**	−0.624**
Yield/ area	(5)					−0.479*	0.267
No. of seeds/ plant	(6)						−0.575*
100 seed weight	(7)						

Note) Each variable refers to footnote in Table 1.
*, ** ; Significant at the 5% and 1% levels, respectively.

Discussion

The experimental results indicated that the four variables representing the within-plot variation for the number of pods were affected by cultivar and planting density. At the high planting density, overall difference in the number of pods between main stems and branches (σ_{m-b}) increased. Seed yield of soybean under a higher planting density is contributed by the seed yield produced in main stems because of the reduction both in the number of branches and the number of pods per branch[4, 5, 6, 8]. The greater σ_{m-b}, therefore, at the high density would result from the larger reduction in the number of pods on branches. Genetic variation in σ_{m-b} also increased at the high density and cultivar × planting density interaction was exhibited. On the other hand, the effects of cultivar and planting density on σ_{hill} and σ_{ind} were additive. This suggests that σ_{m-b} is a more sensitive parameter of phenotypic plasticity[2] to various planting densities as compared with σ_{hill} and σ_{ind}. This variation can be expanded by including several factors, for example, variation for the number of pods in the i-th node of main stem, or that in the primary and the secondary branches.

Any variable of the within-plot variation was not correlated to seed yield per unit area. But some cultivars such as Chusei-hikarikuro and Suzuhime showed the relatively stable seed yield per unit area but fluctuated σ_{m-b} under three levels of planting density. As suggested in rice plant[7], this implies that stability of seed yield may be closely associated with a higher phenotypic plasticity of the component characters.

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ダイズ品種における着莢数のプロット内変異と栽植密度

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摘　　要

ダイズ６品種を３水準の栽植密度で栽培し，プロット内の個体間および個体内の着莢数の変異を，主茎対分枝（σ_{m-b}），株間（σ_{hill}），株内個体間（σ_{ind}）および残余の変異（σ_{rem}）に分割し，これらの品種間差異ならびに子実生産との相互関連を検討した。これら４つのプロット内変異は，その推定値として各試験区での着莢数の偏差平方和の分割をもとに，おのおの標準偏差の平方根変換値で評価した。

σ_{m-b}の品種間差異は密植区で増大したが，これは分枝着莢数の減少程度が品種間で大きく異なったことによる。σ_{hill}，σ_{ind}，σ_{rem}の遺伝的変異は，逆に密植区で最小となった。個体当たり子実数と100粒重は，どの栽植密度でも大きな遺伝的変異を示した。

４つのプロット内変異は，いずれも単位面積当たりの子実収量と独立であった。σ_{hill}，σ_{ind}およびσ_{rem}は互いに密接に関連し，いずれも個体当たり子実数と正の有意な相関関係があった。σ_{m-b}は他の３つのプロット内変異と独立であった。

以上から，栽植密度の変化に対しダイズ品種は，着莢数について固有のプロット内変異を発現するが，特に主茎と分枝の着莢数の差異（σ_{m-b}），およびそれらの株間と株内個体間の変異（σ_{rem}）が品種間で大きく異なることがわかった。また，着莢数のプロット内変異は，子実収量と直接的な関連をもたないが，競合のより激しい密植条件下で収量増のみられた品種は，分枝着莢数が減少するとともに株間あるいは株内個体間変異も減少していた。

キーワード：ダイズ，栽植密度，収量構成要素，分枝，表現型可変性

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