Effects of Row Width and Plant Spacing Within Row on Yield and its Components in Sweet Sorghum (Sorghum vulgare Pers)

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栽植密度 差異가 단수수 (Sorghum vulgare Pers)의 收量및 收量構成要素에 미치는 影響

農村振興廳 作物試驗場

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ABSTRACT

Experiments on sweet sorghum(sorgo)with different population per unit area were conducted from 1966 to 1968 for the first time in Korea.

By increasing plant population stalk weight, refinable sugar and seed weight per plot were increased, but stalk weight per plant, brix percentage, sugar content, stem diameter and 1,000 seed weight were decreased. Plant height, maturity and lodging were not affected by the treatments.

The result obtained has suggested that the effects of plant spacing within row on the characteristics of plant growth and on yields were greater than those of row width.

Negative correlations existed between sugar content and sugar yield, and seed weight per plant and seed yield. The optimal plant population in this study ranged from 16,700 to 22,200 plants per 10a, row width of 60cm and plant spacing in row of 15 to 20cm resulted in the highest sugar and seed.

INTRODUCTION

Sweet sorghum(Sorghum vulgare Pers) was introduced to Korea about 40 years ago. No trials were made on sweet sorghum as a sugar crop, until a sweet sorghum improvement program was begun in 1965.

Experiments on sugar beet were attempted from 1957, However, the beet sugar industry in Korea couldn't be developed because of geographical limitations and some social reasons. The national demand for sugar is totally depending on importation from other countries.

Sweet sorghum that is widely adaptable and which can be grown with other crops by inter-cropping suggests the possibility of meeting of part of the demmand for the domestic sugar industry by small scale refineries. To develop a sweet sorghum sugar industry the introduction of varieties, breeding of new varieties and trials concerned with seeding time, fertilizers, ecology, plant density and cultivation practices are needed.

Reasonable cultural practices are importance for high yields per unit area, although continued selection of better varieties is also important. Plant density can not be changed after planting, while other cultivation practices like fertilization can be controlled. As in other crops, optimal combination of plant population, row width and plant spacing should be investigated high yield and good quality.

Trials on plant density were attempted to solve above mentioned problems from1966 to 1968.

LITERATURE REVIEW

Very few experiments on row spacing and plant population of sweet sorghum have been conducted for the purpose of improving sirup, sugar and forage production[5,6,7,11,14].

Broadhead et al.[2] reported that wider spacing resulted in higher brix. Sucrose and purity were slightly higher but those had no statistical significance. But stalk and sirup yields decreased as spacing increased with the early-maturing sweet sorghum variety Rex. However, results with the full-season variety, Hodo, indicate that extraction and sirup per ton of stalk weight increased with a decrease in stand density. Brix, sucrose, purity, and sirup per acre were not affected by spacings. But he described that Tracy and Sart varieties had a small statistically significant influence on the brix, while yields declined when plants were spaced wider regardless of maturity.

Results of most investigation[1,3,8,9,11,13] of row spacing and plant population to be problem in grain sorghum have shown that under conditions of abundant moisture supply, highest yields were obtained from narrow row spacings (10 to 20 inch) whereas under limited moisture supply, wider row spacing (40 inch) was preferable.

Stickler and Laude[11] found that 78,000 plants per acre gave a higher yield than 52,000 plant per acre, and a greater and a significance of plant population x row spacing interaction occurred. Soil temperature, light intensity at the soil surface, and water loss from the soil surface decreased as row width (40-, 24- 20-, 16-, 10-inches) decreased. Porter et al.[9] reported that planting rates which gave average plant population of 61,000, 108,000 and 152,000 had little influence on grain yield of irrigation grain sorghum in Texas.

Karchi, Zvi and Rudich. Y[4] indicated that optimal population under dryland conditions ranged between 20,000 and 72,000 plants per acre and 1000 to 600 cm^2 per plant in 1 m rows.

Robinson et al. [10] described that a liner trend for incrased yield occurred as row narrowed from 40 to 10 inches. Two of the components of yield-panicles per acre and seeds per panicle tended to increase with the narrow row spacings, whereas the third component - seed weight - tended to decrease and yield of grain at 6 - and 12-inches row spacing did not differ, but panicles from 6-inch spacing were higher in moisture than those from 12-inch spacing.

Steikler and Wearden[12] stated that grain yield were remarkably constant across stand densities because of intercompensations among individual components of yield.

MATERIALS AND METHODS

Experiments were carried out on clay loam soil of the Crops Experiment Station located at Suwon from 1966 to 1968.

The sweet sorghum variety, ''White collier (HC 6028 II-4)'', was planted in pockets on May 15. Five seeds were dropped together in a hill by hand. After emergence, the seedlings were thinned out to leave two plants per hill. And branches developed from the lower parts of main stem were removed.

The experiment was laid out in a split plot design with four replications. Each replication consisted of four main plots of row widths (40, 50, 60 and 70 cm) and four sub-plots of plant spacings within row (15, 20, 30 and 40 cm). And plot size was 3 to 3.5 x 6 meters. Fertilizers applied were compost of 800 kg per 10a and 8: 6: 8 kg per 10a of N, P_2O_5 and K_2O, respectively.

All counts and measurements were taken from 30 plants in the middle row of each plot to test the effects of the plant density and their correlations. The growth measurements were taken monthly and individually.

Brix was determined with a Hand Sugar Refractometer and readings obtained were adjusted at 20°C. Sugar analyses, such as sucsose content, sugar content, refinable sugar and purity were determined by the Smith's method with a polariscope.

RESULTS

Data for yields, yield components and plant population for each treatment are summarized.

As shown in Table 1, the growth and yield of sweet sorghum were greatly affected by the plant population per unit area varied with row width and plant spacing within row

Stem diameter brix percentage, sucrose content and 1,000 seed weight were decreased with increased plant populations per unit area.

On the contrary, stalk weight, refinable sugar and seed weight per 10a were increased with increasing plant density, while stalk weight, refinable sugar and seed weight per plant were decreased. There was no significant effect of plant population on plant height.

Table 1. Effects of row width and plant spacing within row on yields and yield components. (1966—1968)

Treatment: Row width	Treatment: plant spacing	plant population per 10a	plant height	Stem diameter	1,000 seed Wt.	1L seed Wt.	per plant: Stalk Wt.	per plant: Seed Wt.	per plant: Refinable sugar	Brix per cent	Sugar content	purity	Yields of 10a: Stalk Wt.	Yields of 10a: Seed Wt.	Yields of 10a: Refinable sugar
cm	cm		cm	mm	g	g	g	g	g		%	%	kg	kg	kg
40	15	33,300	250	15.2	11.37	638	105	2.44	9.60	17.69	14.61	86.35	3,511	81.4	320
	20	25,000	246	15.8	11.61	645	138	3.26	11.88	17.40	14.33	86.30	3,358	81.6	292
	30	16,700	255	16.2	11.93	661	184	3.63	16.26	17.62	14.54	86.93	3,066	60.5	271
	40	12,500	252	17.2	11.78	667	223	6.28	20.80	18.06	15.12	88.02	2,793	78.5	260
50	15	26,700	251	15.9	12.15	651	135	3.40	11.10	16.88	13.80	85.86	3,613	90.8	296
	20	20,000	247	16.3	11.40	647	163	4.24	14.30	17.68	14.65	86.94	3,313	84.8	294
	30	13,300	248	16.8	11.84	666	214	5.00	20.40	17.89	15.16	89.42	2,825	66.7	269
	40	10,000	249	17.5	12.15	617	253	7.24	23.50	17.90	14.99	88.61	2,527	72.4	235
60	15	22,200	253	16.2	11.17	671	159	4.87	14.58	1.55	14.61	87.46	3,623	108.2	328
	20	16,700	250	16.5	11.73	658	197	5.55	18.54	18.20	15.22	88.08	3,281	92.5	309
	30	11,100	246	17.3	12.25	632	230	6.62	21.06	17.83	14.87	87.91	2,558	73.5	234
	40	8,300	242	17.5	12.76	630	260	7.98	24.60	18.40	15.44	88.63	2,168	66.5	205
70	15	19,000	246	16.2	12.12	659	182	4.85	15.42	17.35	14.04	85.35	3,427	92.5	287
	20	14,300	248	16.8	11.85	661	209	5.38	18.97	17.83	14.69	86.50	3,020	76.8	274
	30	9,500	246	17.4	12.56	667	252	5.45	23.31	17.68	14.88	88.84	2,399	51.9	222
	40	7,100	247	18.6	12.41	664	311	6.49	28.70	18.02	14.99	88.07	2,218	46.2	205
Mean			249	16.7	11.94	652	201	5.17	18.31	17.75	14.75	87.46	2,981	76.6	269

Growth competition with different row width and plant spacing within row are given in Fig. 1-A and 1-B. The variation of plant height in each row width within the same plant spacing within row was greater than one of each plant spacing within row.

However, variation of stem diameter, brix percentage, sucrose content, stalk weight and refinable sugar in each plant spacing within the same row width was greater than those in row width within the same plant spacing.

Especially, as shown in Fig. 1-A the greatest variation of stalk weight among intrarow plant spacings, 2802±677, in 60*cm* row within the same row width was biger than the greatest one among row width, 2452±327 in 40*cm* plant spacing within the same plant spacing.

In stem diameter, the greatest variation(17.4±1.2) among intrarow plant spacing in 70*cm* row within row width was greater than the greatest one (17.9±0.7)among row width in 40*cm* intrarow plant spacing within the same plant spacing.

And in Fig. 1-B, the variation of refinable sugar, 233±28, in 40*cm* intrarow plant spacing is greatest among intrarow plant spacing, but the variation within the same row width, 266±62 in 60*cm* row was greater than the former.

Results mentioned above clearly indicate that the greater environmental variation affecting the yield and growth was obtained by intrarow plant spacing than by row width.

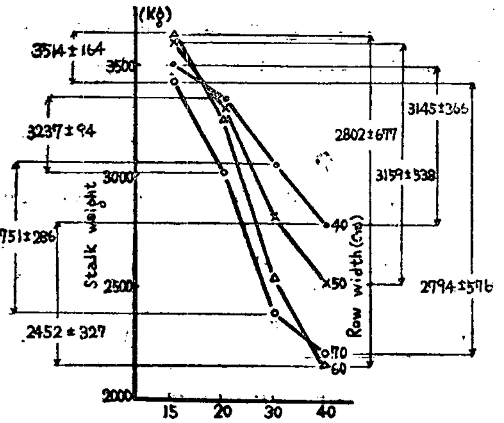

Fig. 1-A

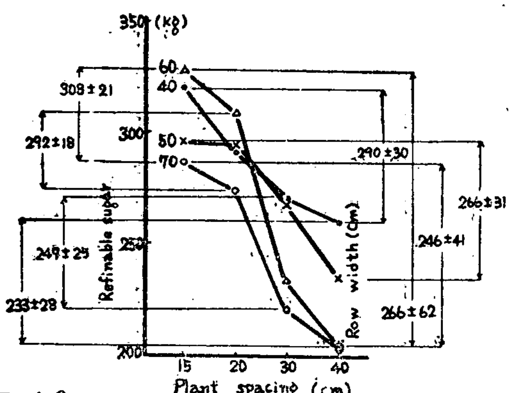

Fig. 1-B

Fig. 1 Variation of stalk weight (Fig. 1-A) and refinable sugar (Fig. 1-B) between row width and plant spacing within row. (1966-1968)

Results of ANOVA for stalk weights suggest that this experiment has been carried out under the relatively uniform soil fertility because of non-significant difference among replications over the experimental period from 1966 to 1968.

However, there were highly significant difference (1% level) in 1966 and 1967, and 5% of significant difference in 1968 between row widths.

Plant spacing within row was highly significant (1% level) in all of 3 years; and interaction of row width X plant spacing within row was significant at the level 5% only in 1967.

Highly significant difference of refinable sugar among row width was obtained only in 1966. Among plant spacings, however, a highly significant difference was recognized in all of 3 years. And row width x plant spacing interaction was only significant at the level of 5% in 1967.

The analysis of variance for these synthetic data of the 3 year period results indicate that there was no significant difference among replications. But there were significant differences among years, row widths, plant spacing within row, year x plant spacings with in row interactions (1 %level), and among year x row width interactions (5%level).

In other words, these results suggest that sweet sorghum growing is greatly dependent on the weather conditions and the effect of intrarow spacing on yield is greater than that of row width.

Correlation between the various plant populations and yields or yield components for the 3-year period

Table 2. Correlation coefficients between the various plant populations and yield components. (1966-1968)

Yield components	Plant populations			
	1966	1967	1968	Mean
Plant height	0.2338	0.2231	0.3897	0.3593
Stem diameter	−0.8448**	−0.8705**	−0.7634**	−0.9323**
Brix	−0.6054*	−0.5103*	−0.1920	−0.6458**
Sucrose content	−0.5346*	−0.4324	−0.4768	−0.6471**
Sugar content	−0.5315*	−0.4759	−0.4776	−0.6707**
Purity	−0.5303*	−0.3496	−0.6072*	−0.7161**
1,000 seed Wt.	−0.6798**	−0.4329	−0.2757	−0.6879**
Stalk Wt/plant	−0.6547**	−0.9128**	−0.9531**	−0.9629**
Stalk Wt/plot	0.9761**	0.8379**	0.6019*	0.8931**
Refinable sugar/plant	−0.9515**	−0.9019**	−0.9399**	−0.9594**
Refinable sugar/plot	0.9735**	0.7927**	0.1093	0.8560**
Seed Wt/plant	−0.3518	−0.8585**	−0.8502**	−0.8799**
Seed Wt/plot	0.5173	0.5502*	0.2031	0.6352**

* Significant at 5 percent **Significant 1 percent

are summarized in Table 2. Stem diameter (r=−0.9223**), brix(r=−0.6458**), sucrose content(r=−0.6471**), sugar content(r=−0.6707**), purity (r=−0.7161**), 1,000 seed weight(r=−0.6879**), stalk weight/plant (r=−0.9629**), refinable sugar (r=−0.9594**) and seed weight/plant (r=−0.8799**) were inversely proportional to the plant population levels, respectively. Therefore, the characteristics affecting sugar quality were negatively correlated, directly and indirectly, with plant populations. In other words, factors decreased with increasing plant population.

On the other hand, stalk weight per plot, refinable sugar per plot and seed weight per plot were positively correlated(r=0.8391**, 0.8569** and 0.6352**) with plant population levels, indicating that these 3 factors were increased with increasing plant population. But plant height was not affected by the number of plant population.

The values of characters affecting on quality and yield per plant were decreased with increasing population, while yield per plot were increased with increasing plant population.

Correlation values of interactions between yield components are shown in Table 3.

Plant height : plant height was not correlated with each characteristics except purity.

Stem diameter : Stem diameter was positively correlated with brix (r=0.5982*), sucrose content (r=0.6026*), sugar content (r=0.6210**)and purity (r=0.6744**), but was negatively correlated with stalk weight (r=−0.8934**), refinable sugar (r=−0.8819**) and plant population(r=−0.9323**).

Brix:Brix was positively correlated with sucrose content, sugar content and purity at 1% level, but negatively correlated with stalk weight, refinable sugar and plant population, and it was highly depending on plant population.

Sucrose content : Sucrose content showed positive correlation with sugar content (r=0.9991**) and purity (r=0.6671**). But it was negatively correlated with stalk weight (r=−0.6955**), refinable sugar (r=−0.5001*) and plant population (r=−0.6471**).

Sugar content : Like sucrose content, sugar content was positively correlated with purity(r=0.4987*), while it was negatively correlated with stalk weight (r=−0.7811**), refinable sugar (r=−0.5134*) and plant population (r=−0.6707**).

Purity: Purity was negatively correlated with stalk weight (r=−0.5503*), refinable sugar(r=−0.5683*) and plant population (r=−0.7161**).

Stalk weight: Stalk weight was positively correlated with refinable sugar (r=0.9667**) and plant population (r=0.8931**).

Refinable sugar also was positively correlated with plant population (r=0.8569**).

Data in Table 3 indicate that brix, sucrose content, sugar content, purity and stem diameter which can increase sugar yields and its quality, were increased with decreasing stalk weight, refinable sugar plant population.

Table 3. Correlation values between yield and its components of sweet sorghum "white collier" (1966-1968

	Stem diameter	Brix	Sucrose content	Sugar content	Purity	Stalk weight	Refinable sugar	Plant population
Plant height	−0.3704	−0.2820	−0.2437	−0.2520	−0.5648*	0.4912	0.5316*	0.3593
Stem diameter		0.5982*	0.6026*	0.6210**	−0.6744**	−0.9034**	−0.8819**	−0.9323**
Brix			0.9606**	0.9606**	0.7049**	−0.4046	−0.4900	−0.6458**
Sucrose content				0.9991**	0.6671**	−0.6955**	−0.5001*	−0.6471**
Sugar content					0.4987*	−0.7811**	−0.5134*	−0.6707**
Purity						−0.5503*	−0.5783*	−0.7161**
Stalk weight							0.9667**	0.8931**
Refinable sugar								0.8569**

*Significant at 5 percent **Significant at 1 percent

Correlation between seed yield components, yields per unit area and per plant were in Fig.2-B.

1,000 seed weight(r=−0.6879**), stalk weight per plant(r=−0.9629**) and seed weight per plant (r=−0.8799**) were decreased with increasing plant population per unit area except seed weight (r=0.6352**).

On the other hand, individual stalk weight (r=0.7238**) and seed weight per plant (r=0.6163**) except seed weight per plant(r=−0.6589**) increased 1,000 seed weight.

Accordingly, individual seed weight (r=0.8664**) was also increased, but seed weight per plot (r=−0.6956**) was decreased with increasing stalk weight per plant.

Most of them were highly correlated with each other.

DISCUSSION

Effects of plant density on sweet sorghum yield and its characteristics were investigated and compared with results of other workers.

Yield per plant: With increasing plant population, per plant stalk weight, refinable sugar, stem diameter and seed weight were tended to decrease. Plant density, however, had no effect on plant height.

Yield per plot: Stalk weight, refinable sugar and seed weight per plot were increased with increasing plant population. Data on the similar experiment was also reported by Robinson et al.[10].

They described that two components of yield, panicles per area and seed per panicles-increased with narrow spacings whereas the third components, seed weight-decreased.

Sugar content and quality: Effects of plant density on sugar content and quality were unexpectedly remarkable. As plant population increased, brix, sucrose content, sugar content and purity decreased, and negatively correlated with plant population (1% level). Broadhead et al.[2] also obtained the same results that "wider spacing resulted in higher brix, sucrose and purity were slightly higher. But stalk and sirup yields decreased as spacing increased''.

Interrelationship among yield components: Correlations among characteristics related with sugar yield were presented in Fig.2-A.

As plant height increased, purity decreased and refinable sugar showed slight increase. Among other 6 characteristics, however, no difference was found.

As in the works of Lyons[6,7] and Broadhead et al.[2], stem diameter had significantly positive correlation with brix, sucrose content, sugar content and purity, having negative correlation stalk weight per plot, refinable sugar yield and plant population.

Plant population showed highly significant positive correlations with stalk weight per plot, and refinable sugar yield per plot. However, a highly negative correlation was found with stem diameter and sugar content.

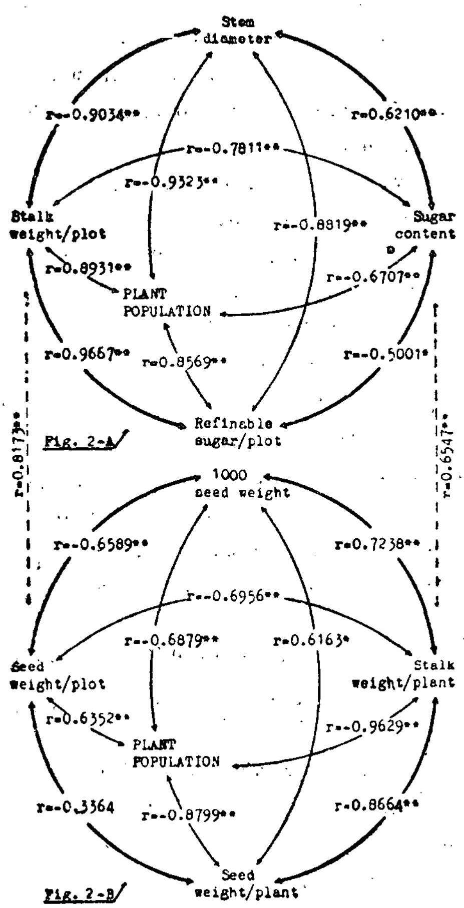

Fig.2-A: Interrelationship among components of stem diameter, stalk weight, sugar content and refinable sugar, Fig.2−B :1,000 seed weight, seed weight per plant, seed weight per plot and stalk weight per plant of sweet sorghum.

Stalk weight per plot x stem diameter and sugar content were in negative correlation and the same tendencies were obtained among sugar yield, stem diameter and sugar content. Correlations between stalk weight per plot x sugar yield and stem diameter x sugar content were positive.

Interrelationships (Fig. 2-B) among seed weight per plot and 1,000 seed weight, seed weight per plot, and stalk weight per plot were negative. Seed weight per plant, stalk weight per plant and 1,000 seed weight decreased with increasing plant population, on the other hand, seed weight per plot was increased by increasing plant population. These results were in partial coincidence with those of Karchi et al. and Stickler et al.

Competition between row width and plant spacing: High plant population (wide spacing) produced high yield. More effect on yield was obtained by plant spacing than row width.

Plant spacing of 15cm generally resulted in high stalk yield regardless of row width. And the highest stalk yield of 3,678kg/10a was produced by row swidth of 50cm and plant spacing of 15cm. Refinable sugar yield per 10a, however, was highest in row width of 60cm and plant spacing 15cm.

Row width of 60cm and plant spacing 15–20cm, therefore, seems to be the most effective. Then the optimal population will range from 16,700 to 22,200 plants per 10a.

The same tendencies wer observed in works of Stickler et al.[11,12], Porter et al.[9] and Broadhead et al.[2].

Simple factors such as year, row width and plant spacing within row gave great effects on refinable sugar yield per 10a. For high yield reasonable combination of above mentioned factors is required. Of all factors plant spacing is suggested to be the most decision factor.

SUMMARY

This experiment was laid out in a split plot design with fourreplications. Each replication consisted of four main plots of row widths (40, 50, 60 and 70cm) on four sub-plots of plant spacing within row (15, 20, 30 and 40cm) on sweet sorghum (sorgo). And it was carried out from 1966 to 1968 to investigate the effects of plant density on yield, sugar accumulation and yield components. Results are summsrized as follows:

1. Fresh weight, stalk weight, head weight and stem diameter were decreased by increasing the plant population per area. But plant height, maturity and lodging were not significantly affected. Accordingly, growth and yield components were affected more greatly by plant spacing than by row width.

2. Sweet sorghum is relatively sensitive to plant density. Its correlations with year, row width and plant spacing were highly significant (1% level). And its interaction with other factors were also significant (1–5% level).

3. Stalk weight, refinable sugar and seed weight per 10a were increased by increasing plant population. But the inversion was recognized in yield per plant.

4. Brix, purity and sucrose content which control sugar content and quality were tended to decrease with increasing plant population.

5. Wide plant spacing and increasing stem diameter were decision factors which resulted in high brix, sucrose content, sugar content and purity. But the most reasonable combination of various factors having positive or negative correlation with yield is assumed to be row width of 60cm, plant spacing of 15–20cm and plant population of 16,700–22,200 plants per 10a.

摘 要

本試驗은 단수수(Sweet sorghum, Sorgo)에 對한 畦巾4水準 (40, 50, 60, 70cm)과 株間 4水準 (15, 20, 30, 40cm) 등을 相互 組合하여 栽植密度·差異가 收量, 糖分蓄積및 收量構成要素에 미치는 바를 알고저 1966年부터 1968年까지 3個年間 實施한 바

1, 單位面積當 栽植本數가 增加함에 따라 個體當 生體重, 稈重, 穗重및 稈直徑등이 적어지는 傾向으로서 負相關關係를 볼수 있으나 草長, 熟期, 倒伏등에는 別다른 差異를 認定할수 없었다. 따라서 栽植密度 差異가 生育및 收量構成要素에 미치는 影響은 畦巾보다도 株間이 더욱 支配的이였다.

2. 栽植密度에 比較的 銳敏한 作物로서 年次, 畦巾, 株間등 單要因은 各各 1%, 이들을 組合한 2,3要因의 相互作用에도 各各 5~1%의 높은 有意性이 있었다.

3. 稈重, 可製糖量, 種子重등의 10a當 收量은 栽植

本數가 增加함에 따라 같이 增加하나 이와는 反對로 이들의 個體當 收量은 減少하는 傾向이였다.

4. 糖分含量과 品質을 決定하는 Brix度, 糖度, 純糖率등은 栽植本數가 增加함에 따라 各各 낮아지는 傾向이다.

5. 糖分含量을 높게 栽培하려면 疎植하여 稈直徑을 굵게 하므로서 Brix 度, 糖度, 稈中糖分, 純糖率등이 各各 높아진다. 그러나單位面積當 糖收量을 最高로 높이는 데는 여러가지 正, 負相關關係에 있는 모든 形質을 合理的으로 組合하여 10a當 16,700～22,200本(畦巾 60cm×株間 15—20cm에 株當 2本)이 適當하리라 본다,

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