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Studies on Effect of Planting Density on the Growth and Yield of Sweet Potato (*Ipomoea batatas* Lam.)

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Introduction

The production efficiency of a plant is determined by the genotype and the environment. Among the environmental factors, planting density, which affects growth rate, efficiency of solar energy utilization and conversion, seems to determine the total biomass accumulation. Planting densities may be selected to complement the environmental factors that will produce the greatest economic yield per hectare[15].

Minimal information is available on the effects of planting density on dry matter production of sweet potato. Planting density has a pronounced effect on the growth of the plants[3]. Increases in dry matter of the cultivars tested were linear with time of sampling, regardless of spacing, and the final amount of dry matter produced by the cultivars under two planting spacings differed[3]. In an earlier study, Austin et al.,[2] reported the observations on the relative growth of tops and storage roots of several commercial sweet potato cultivars over a period of 3 seasons. However, the study did not show how the dry matter produced by the effect of planting density was distributed to the various organs of the sweet potato plant during the development.

A series of experiments was undertaken to know how cultivars differing in their morphology exhibit similar patterns in response to planting density, giving special references to the aspects of dry matter production on the field. In the present paper we report here the results of a study on the dry weight distributions in top (leaves and stems), tuberous root and partitioning of the 2 sweet potato cultivars. We also report the results of yield (total yield and marketable yield) of the 2 sweet potato cultivars.

Materials and Methods

The experiment was conducted on the experimental field of the Faculty of Agriculture, Kagoshima University in 1998. Two sweet potatoes (*Ipomoea batatas* Lam.) cv. Shiroyutaka (the *branching type-shorter stems and more branching ability*) and cv. Norin No. 16 (the *elongating type-longer stems and less branching ability*) were used in this experiment. They were planted with a row width of 1.0 meter. The hill distance in rows was changed, depending on the planting densities; 35 cm in the high densities plot (2.85 hills per m^2) and 70 cm in the low densities plot (1.42 hills per m^2). The main plot for the density treatment consisted of 24 rows and 5 hills in a row, which was divided into sub-plots for the two cultivars. The cultivars were planted with one-stem-cutting per hill. Each cutting was approximately 15 gram in fresh weight, 25 cm in length having 7 stem nodes. The 3 stem nodes were planted in the soil. The field was ploughed, rotorvated and mulching by the polyethylene film was done before planting. The fertilizer rate used was 60 kg N, 60 kg P, 180 kg K, 800 kg Mg lime and 10,000 kg cow dung per hectare. When necessary, herbicides were sprayed and hand weeding was done to weed control. Pesticides also were sprayed three times to prevent the leaf damage from insects.

Sampling was done at 50, 100 and 150 days after planting (DAP). Twenty hills for each cultivar were harvested at each sampling time and were separated into leaves, petioles, stems and tubers. Although the stems and leaves of each hill were combined, in a complicated way, with those of neighboring hills, they were carefully separated and cut off at the ground surface. Dead leaves and stems were not collected. The measurements included length of main stem, number of branches, leaf area, and fresh and dry weights (DW) of each organ. Total tuber yield, marketable tuber yield (>50g) and fresh and dry weights were recorded. The leaf area was measured with an automatic leaf area meter. Dry weights of leaves and stems sampling were determined after oven drying executed for 48 hours at 80℃. However, dry weights of tubers were determined after the tubers were cleaned, weighed, sliced and ovens for 120 hours at 80℃.

Results

Morphological characteristics

Fig. 1A shows that the differences between the high and low densities in leaf area (LA) per plant for sweet potato of both cv. Shiroyutaka and cv. Norin No. 16 were clear. Increasing planting density reduced the LA per plant in both cultivars. LA per plant was larger under low density than under high density in both cultivars. Shiroyutaka showed a larger LA per plant than that cv. Norin No. 16 did under both densities. The differences between the high and low densities in LA per m^2 in cv. Shiroyutaka were evident (Fig. 1B). Shiroyutaka showed a larger LA per m^2 than that cv. Norin No. 16 did under both densities. LA per m^2 was higher under high density in both cultivars. LA per m^2 of cv. Shiroyutaka under high density increased progressively from the beginning to 100 DAP and slightly declined at 150 DAP. It was due to leaf size and leaf length of cv. Shiroyutaka characteristic to it. No differences in LA per m^2 between both densities were observed in cv. Norin No. 16. The number of branches per plant and per m^2 reached maximum in both cv. Shiroyutaka and cv. Norin No. 16 grown under the two planting densities at 100 DAP and slightly declined until 150 DAP (Fig. 2). Number of branches per plant was higher in both cultivars under low density. Sweet potato cv. Norin No. 16 maintained a higher number of branches per plant compared to that of cv. Shiroyutaka under low density. Increasing planting density reduced the number of branches per plant in both cultivars. This relationship indicates that branch formation in sweet potato plant is highly plastic, responding to space available during the growing season. The number of branches per m^2 was higher in cv. Norin No. 16 under low density, while cv. Shiroyutaka produced a higher number of branches per m^2 under high density.

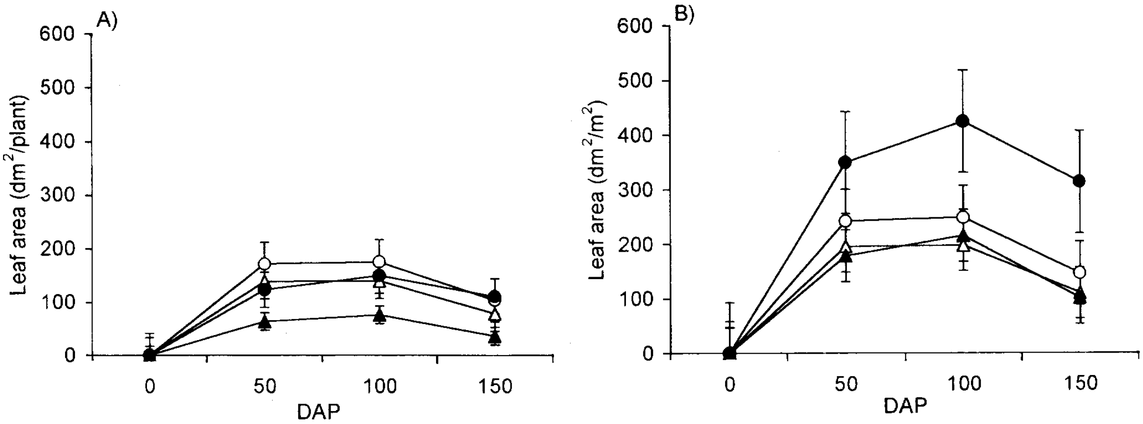

Fig. 1. Changes in leaf area (LA) per plant (A) and LA per m^2 (B) of two sweet potato cultivars and two planting densities during the growing season.
Symbol: ▲: 35 cm-Norin No. 16, ●: 35 cm-Shiroyutaka, △: 70 cm-Norin No. 16 and ○: 70 cm-Shiroyutaka.
Vertical bar indicates the value of LSD (0.05).

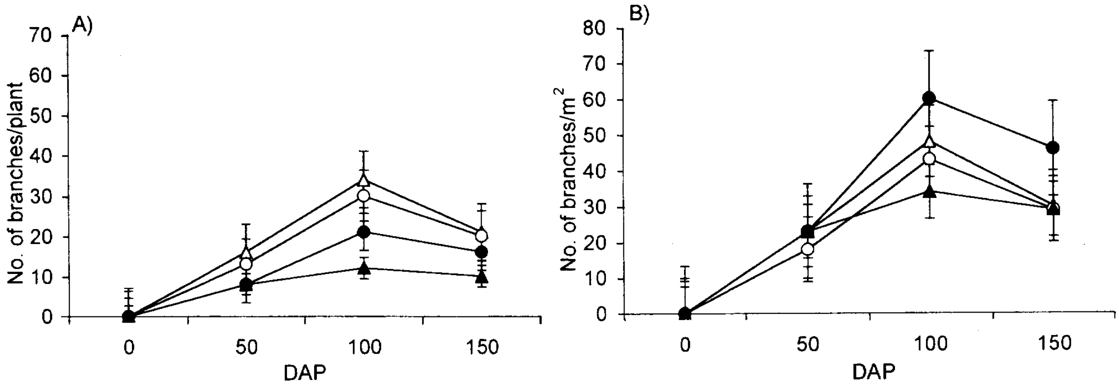

Fig. 2. Changes in number of branches per plant (A) and number of branches per m^2 (B) of two sweet potato cultivars and two planting densities during the growing season.
Note: Symbols are the same as those in Fig.1.
Vertical bar indicates the value of LSD (0.05).

Top and tuberous root DW

Total DW per plant and per m^2 of the two sweet potato cultivars plant grown under two planting densities showed a similar trend from the early stage to the final harvest (Fig. 3). Total DW per plant was higher under low density than that under high density in both cultivars. Shiroyutaka showed a higher total DW per plant than that in Norin No.1 under both densities. Total DW per m^2 was higher in cv. Shiroyutaka than that in cv. Norin No. 16 under both densities. It was higher under high density compared to that under low density. The pattern of the top-DW of the two cultivars sampled on different days after planting (DAP) for two planting densities is shown in Fig. 4. Top-DW per plant for both cultivars was higher under low density. Sweet potato cv. Shiroyutaka produced higher top-DW per plant than that cv. Norin No. 16 did under both densities. The differences in top-DW per m^2 between both the densities were observed in cv. Shiroyutaka. High density produced higher top-DW per m^2 in cv. Shiroyutaka. Shiroyutaka also produced higher top-DW per m^2 than that cv. Norin No. 16 did under both densities. A similar trend in tuberous roots-DW per plant and per m^2 was observed for both cultivars grown under two planting densities (Fig. 5). Tuberous roots-DW per plant and per m² increased progressively from 50 DAP and continuously to the final harvest. Sweet potato cv. Shiroyutaka produced higher tuberous roots-DW per plant than that cv. Norin No. 16 did under both densities. Low density showed the higher tuberous roots-DW per plant in both cultivars. Tuberous roots-DW per plant also higher under low density than that under high density in both cultivars. Sweet potato cv. Shiroyutaka produced higher tuberous roots-DW per m² under high density, while cv. Norin No. 16 produced higher tuberous roots-DW per m² under low density. Tuberous roots-DW per m² were higher in cv. Shiroyutaka than that cv. Norin No. 16 under both densities. The present results showed that top-DW per plant and per m² of the two sweet potatoes cultivars grown under both densities decreased, starting from 100 DAP to 150 DAP. On the other hand, the fact that both cultivars grown under both densities continuously increased the tuberous roots-DW per plant and per m², could be observed during the period from 100 DAP to 150 DAP. This was due to the fact that hot day and cool night temperatures, which prevailed during autumn, caused leaves to fall and the activity of stems had already been lost at later growth stages. We considered that the starch contents of stems were restricted in their translocation to tuberous root under ground.

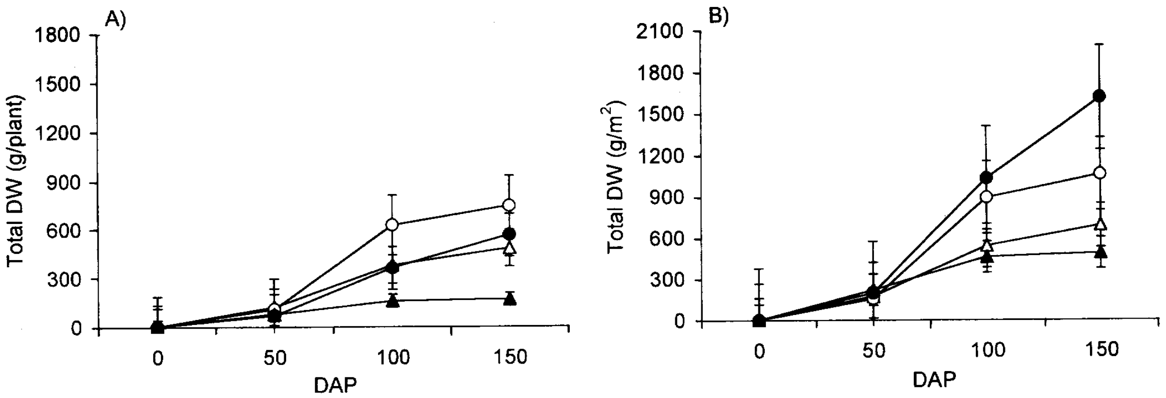

Fig. 3. Changes in total DW per plant (A) and total DW per m² (B) of two sweet potato cultivars and two planting densities during the growing season.
Note: Symbols are the same as those in Fig. 1.
Vertical bar indicates the value of LSD (0.05).

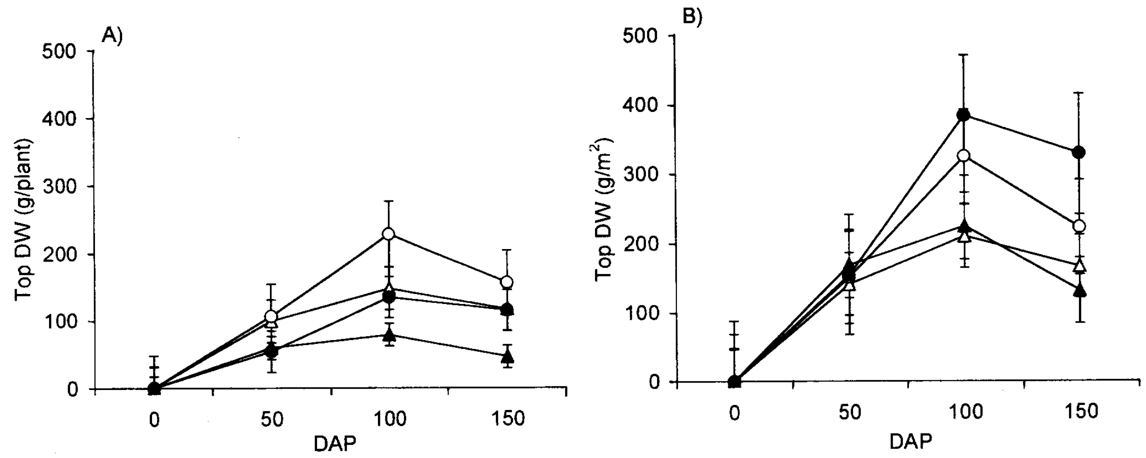

Fig. 4. Changes in top-DW per plant (A) and top-DW per m² (B) of two sweet potato cultivars and two planting densities during the growing season.
Note: Symbols are the same as those in Fig.1.
Vertical bar indicates the value of LSD (0.05).

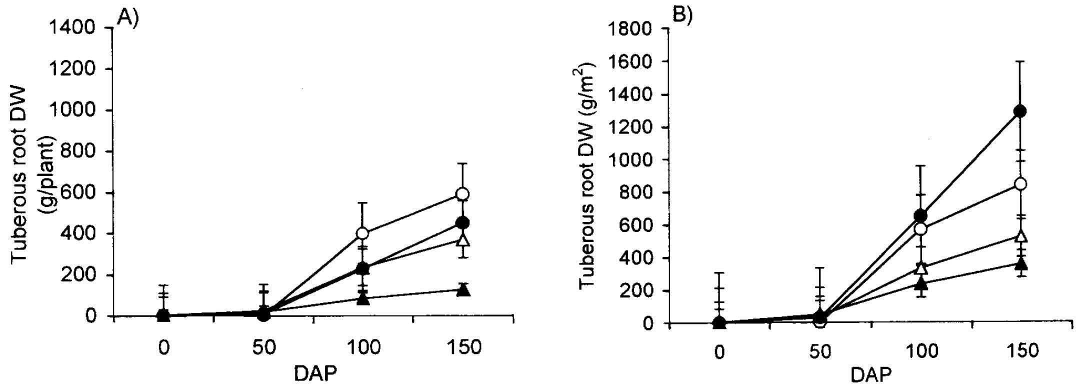

Fig. 5. Changes in tuberous roots-DW per plant (A) and tuberous roots-DW per m^2 (B) of two sweet potato cultivars and two planting densities during the growing season.
Note: Symbols are the same as those in Fig. 1.
Vertical bar indicates the value of LSD (0.05).

Dry matter partitioning

The partitioned percentage to various parts of the two sweet potato cultivars is shown in Fig. 6. At 50 DAP, partitioning to the leaves was higher in both cultivars under both densities and decreased until 100 DAP but then it was stabilized until the end of the season. High density showed higher results in partitioning ratio to the leaves than that low density did. Partitioning ratio to the stems for both cultivars under both densities increased from 50 DAP to 100 DAP and tended to be stabilized until 150 DAP. Partitioning ratio to the stems was higher under low density than that under high density. No difference was observed in partitioning ratio to the leaves and the stems between both cultivars.

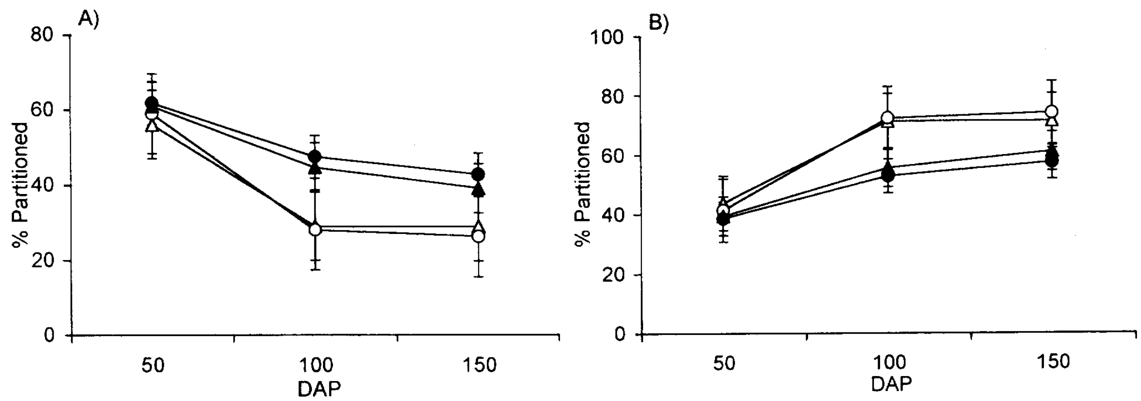

Fig. 6. Changes in partitioned to leaves (A) and stems (B) of two sweet potato cultivars and two planting densities during the growing season.
Note: Symbols are the same as those in Fig.1.
Vertical bar indicates the value of LSD (0.05).

Yield and yield components

Comparison of initial total yield and marketable yield of the two cultivars grown under the two planting densities during growing season is represented in Table 1. Total and marketable yields per area and per plant of cv. Norin No. 16 were higher under low density than those under high density. Meanwhile, total and marketable yields per ha of cv. Shiroyutaka were higher under high density. No differences in total and marketable yields per plant were observed in cv. Shiroyutaka. Sweet potatoes cv. Shiroyutaka produced a higher'yield than cv. Norin No. 16 did.

Table 2 shows the yield components of the two sweet potato cultivars grown under two planting densities during sampling time. Total and marketable tuber numbers per plant of both cultivars were higher under low density, while there were no differences in total and marketable tuber numbers per m^2 in both cultivars. The present results showed the fact that there was no difference in total and marketable tuber numbers per plant and per m^2 between both densities in both cultivars.

High planting density increased the average tuber weight (g per tuber) of total and marketable tubers in cv. Shiroyutaka (Table 2). At 100 DAP there was no difference in average tuber weight of total and marketable yields in both cultivars and both densities. At the end of growing season (150 DAP) cv. Norin No.16 produced a higher average tuber weight of total and marketable yields under low density, while cv. Shiroyutaka produced higher average of total and marketable yields under high density. The average tuber weight of total and marketable yields was higher in cv. Shiroyutaka than that in Norin No. 16.

Table 1. Total yield, marketable yields per area and per plant of two sweet potatoes cultivars grown under two planting densities.

Cultivar	*DAP	Total yield (ton/ha)		Marketable yield (ton/ha)	
		Low	High	Low	High
Norin No. 16	50	1.04 (0.07)	1.79 (0.06)	0.0 (0.00)	1.50 (0.05)
	100	11.12 (0.77)	7.76 (0.26)	10.10 (0.71)	7.10 (0.24)
	150	15.60 (1.09)	12.54 (0.43)	15.00 (1.05)	12.12 (0.42)
Shiroyutaka	50	0.13 (0.00)	1.11 (0.03)	0.00 (0.00)	0.17 (0.00)
	100	17.2 (1.20)	22.50 (0.82)	16.92 (1.18)	23.20 (0.81)
	150	28.07 (1.96)	42.00 (1.47)	28.07 (1.96)	42.07 (4.47)

*: Days after planting.
( ): Figures in the parenthesis show per plant values (kg fresh weight per plant).
Low: Low planting density, High: High planting density.

Table 2. Some yield components of two sweet potato cultivars grown under two planting densities.

Cultivar	DAP*	No. of tuber/m^2				Average tuber weight (g/tuber)			
		Total yield		Marketable yield		Total yield		Marketable yield	
		Low	High	Low	High	Low	High	Low	High
Norin No. 16	50	2.54 (1.78)	3.60 (1.29)	0.0 (0.00)	2.0 (0.70)	41.24	48.70	0.00	75.67
	100	9.64 (6.75)	5.70 (2.00)	5.90 (4.15)	3.85 (1.35)	115.50	134.31	171.78	184.30
	150	8.57 (6.00)	8.57 (3.00)	7.14 (5.00)	6.54 (2.29)	182.09	146.40	210.44	185.30
Shiroyutaka	50	0.78 (0.55)	5.00 (1.75)	0.00 (0.00)	0.17 (0.06)	17.56	22.37	0.00	104.6
	100	5.78 (4.05)	7.90 (2.77)	5.07 (3.55)	6.65 (2.33)	298.38	296.62	334.83	348.5
	150	6.57 (4.60)	6.02 (2.11)	6.57 (4.60)	6.02 (2.11)	427.35	697.89	424.58	697.8

*: Days after planting.
( ): Figures in the parenthesis show per plant values.
Low: Low planting density, High: High planting density.

Discussion

In the above-described studies, it may seem that the effects of densities are to be compensated by changes in plant form. This may be due to the indeterminate growth habit and branching pattern in sweet potato. Plant density effects were significant for the number of branches formed and the timing of branch formation[12]. Main stem length and number of branches per plant were significantly affected by the competition for light among the plants growing under high density. Pattern of leaf growth also affected by the increasing density. Although high planting density reduced DW of top and tuberous roots per plant in cv. Norin No. 16, weight per unit area showed an increasing trend in cv. Shiroyutaka. This may be attributed to the light-interception differences, which occurred in plant canopies of both cultivars under different densities. In their study on this, Somoda and Kays[13] reported that the absence of differences in the leaf loss percent per plant, even though plant size varied greatly in sweet potato canopy morphology, leaf distribution, would suggest that losses were largely due to the inadequate light with canopy.

The total dry matter per area was affected by planting density. Total dry matter per area increased progressively and continued to increase up to the final harvest under high density only in cv. Shiroyutaka. In cv. Shiroyutaka, net assimilation production continued to increase up to the final harvest, despite the rapidly decreasing top-DW. These results were agreed with Lowe and Wilson[7] in the two sweet potato cultivars *A28/7* and *03/62*, the total dry weight continued to increase up to the final harvest. Such continued increasing in the total dry matter production may be interpreted as an indication of efficiency of the shoot system in assimilating manufacture throughout the growing season. Alternatively, continued increasing in tuber bulking to the end of the growing season in cv. Shiroyutaka may be indicative of the efficiency of tuber growth in providing a sink for assimilation. The plants with higher storage root sink potential show the higher dry matter production capacity in cv. Shiroyutaka. Hozyo et.al.,[5], Nakatani et. al.,[9,10] had reported that the plants with higher storage root sink potential show both higher distribution ratio of dry matter to the storage root, and higher dry matter production through higher photosynthetic activity[5,9,10] resulting in higher yield[4].

In our result with general description of top-DW and tuberous-DW, we observed that the top-DW per plant and per m^2 of both the cultivars grown under both densities decreased after 100 DAP until the end of the season. On the other hand, the tuberous roots-DW per plant and per m^2 continuously increased during the later part of the season. One possible explanation is that hot day and cool night temperatures, which prevailed during autumn, caused leaves to fall and the activity of stems had already been lost at later growth stages. We considered that starch contents of stems were restricted in their translocation to tuber under ground. Our results are similar to the work by Tsuno and Fujise[14], who reported that the growth of tubers or the largest acceptor (sink) was inhibited by being exposed to sunlight. The treated plant was depressed in the photosynthetic activity and increased in starch content of leaves due, presumably, to the fact that translocation of photosynthates from leaves was restricted.

The proportion of dry matter partitioning in leaves was higher under high planting density, while the proportion of dry matter partitioning in stems was higher under low planting density. Sasaki[11] reported the same phenomenon. He explained that the proportion of dry matter accumulation in stems except leaves and tuberous roots was higher under low planting density. Small differences in dry matter accumulation during early stages revealed that the competition among plants under both densities was negligible. After the establishment of the sink demand, i.e., 50 DAP; the majority of dry weight was comprised of tuberous roots dry weight.

Results of the studies of yield per area and yield component revealed that the total yield and particularly the marketable yield of cv. Shiroyutaka were greater under high densities. This was associated with the longer bulking period observed in this cultivar. In the ordinary culture it has been well recognized that there is a large variance in the storage root sink potential (the potential for the storage roots becomes large) among the cultivars and breeding clones[6,9]. In this cultivar also it is possible to release the tuberous root sink from the competitive effects of the top sink leading to increasing the tuberous root growth. In cv. Shiroyutaka, presumably a higher capacity for tuberous root growth in the latter half of the season and / or higher assimilation production by the top system resulted in the higher yield of this cultivar. In contrast low total and marketable yields observed in cv. Norin No. 16 under high density may be associated with the lower crop growth rate (CGR) and tuber growth rate (TGR) and shorter bulking period observed in this cultivar. Higher TGR, compared to CGR under high density, indicates the translocation of assimilation from top to tuberous roots during the latter part of the season. This translocation may be enhanced more by the rapid decline of leaf area and interplant competition under high density rather than under low density.

Generally, as the in-row spacing increases (20 to 81 cm) the total yield decreases slightly, while the number of the oversized tuberous root increases[1]. The results of the present study showed those both total and marketable yields per area increased with increasing in the planting density in cv. Shiroyutaka. Total and marketable tuber yields decrease in weight with the increasing in planting density in cv. Norin No.16. In addition, decreasing in weight of both total and marketable yields may be due to the intense interplant competition that prevailed at high planting density treatment. Low and Wilson[8] found that the tuber numbers and the mean tuber weight (size) were the important components of sweet potato yield.

Based on these observations, we conclude that the responses, of total tuber yield and marketable tuber yield of the two sweet potato cultivars tested, to planting density do not follow the similar course. It is apparent that the population giving a higher yield of specific number of tuber does not give the maximum yield. The production of a higher yield of cultivar was tested by the average tuber weight under different planting densities. However, the production of each cultivar is genetically determined by cultivar characteristic.

Summary

Studies on the effect of planting densities of sweet potato on the above ground in term of dry matter production were executed. The two main crops of sweet potato cultivars Norin No.16 and Shiroyutaka and the two levels of planting density (35 and 70 cm X 100-cm spacing) were examined. The differences between the two densities in LA per m^2 were evident in cv. Shiroyutaka. The LA per m^2 of cv. Shiroyutaka under high planting density increased progressively from early to 100 DAP and slightly declined until 150 DAP. It was due to leaf size and leaf length characteristic to cv. Shiroyutaka. Increasing planting density reduced the number of branches per plant in both cultivars. This relationship indicates that branch formation in sweet potato plant is highly plastic, responding to the space which is available during the growing season. Top-DW per plant and per m^2 for both cultivars grown under both densities was decreased after 100 DAP until 150 DAP. On the other hand, tuberous root-DW per plant and per m^2 continuously increased during this period. It was due to the fact that hot day and cool night temperatures during autumn caused leaves to fall and the activity of stems had already been lost at the later growth stages. We considered that starch contents of stems restricted their translocation to tuberous root under ground. No difference was observed in partitioning ratio to the leaves and stems between both cultivars and densities. Sweet potato cv. Shiroyutaka produced higher yields than cv. Norin No.16. Sweet potato cv. Norin No. 16 shows the higher total and marketable yields per plant and per area under low planting density, while cv. Shiroyutaka shows the higher total and marketable yields per ha under high planting density. No differences were observed in total and marketable yields per plant between densities in cv. Shiroyutaka. There was no difference in total and marketable tuber numbers per plant and per m^2 between both densities and cultivars. High planting density increased the average tuber weight (g per tuber) of the total and marketable tubers in cv. Shiroyutaka.

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