Korean J. Crop Sci. 50(5): 301~308(2005)

Relationship between Planting Material Conditions and Major Agronomic Characters in Cassava

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ABSTRACT : This study was carried out to investigate the effect of stem-cutting (SC) length and portion on the major agronomic characters related with dry matter production and accumulation, and to examine their relationships in cassava. When cassava was planted with longer SCs or with older portion SCs, major canopy or source characters like leaf number and leaf area index developed excessively, while tuber yields could be reduced due to the decrease of root/shoot ratio, relative growth rate, root dry weight, and harvest index, particularly in the bitter varieties (high cyanide-level varieties). It was considered that the sweet varieties (low cyanide-level varieties) be early-bulked with higher tuber yield when they are planted with the 25-30 cm long SCs or with the SCs from young type to semi-mature portions of mother stems, while the bitter varieties with the 15-20 cm long SCs or with the SCs from semi-mature to hardwood portions of mother stems, respectively. However, a significant interaction between length and portion of SC was not observed in all agronomic characters.

***Keywords*:** Cassava, stem-cutting, source and sink characters, correlation, relationship

Screening early-bulking or early-maturing varieties with short growing period and higher tuber yield has been a major issue for a long time in cassava (O'Hair, 1990; Dimyati & Manwan, 1992; Ekanayake *et al.*, 1997a), and it has been known that these favorable agronomic characters may be determined by the quality and/or condition of planting materials (Lozano *et al.*, 1977; Otoo, 1996; Bradbury & Warren, 1988). Botanically, cassava (*Manihot esculenta* Crantz) is a perennial woody shrub that is best propagated vegetatively using stem-cuttings (SCs) or stakes because its tuberous roots are physiologically inactive and have no any viability for germination (Bradbury & Warren, 1988; Ekanayake *et al.*, 1997b; Leihner, 2002).

On the contrary, propagation by a seed is common under natural conditions and in breeding programs (Duke, 1983; Ekanayake *et al.*, 1998; Alves, 2002). Because availability of planting materials with good quality and condition is a prerequisite for successful production of cassava, a series of experimental trials have been conducted in many cassava-producing countries (Lozano *et al.*, 1977; Otoo, 1996; Ekanayake *et al.*, 1997a, 1997b, 1998; Leihner, 2002) including Indonesia (Dimyati & Manwan, 1992; Wargiono *et al.*, 1992, 1995).

In general, size or length of SCs, which determines number of nodes, and age of SCs are the major factors affecting cassava canopy development (Lozano *et al.*, 1977; Otoo, 1996; Ekanayake *et al.*, 1997a; Howeler, 2001), while storage roots formation or root bulking also depends on planting material (Lozano *et al.*, 1977; Duke, 1983; Ekanayake *et al.*, 1997a). Even though it has been known that matured hardwood SCs with 15 - 30 cm long are the best planting materials in cassava (Lozano *et al.*, 1977; Ekanayake *et al.*, 1998; Leihner, 2002), the responses of major agronomic characters, which are highly related with dry matter (DM) production and accumulation, to SC condition may be highly diverse (Grace, 1977; Otoo, 1996; Ekanayake *et al.*, 1997a), and growing and bulking period of cassava roots could be reduced by various SC treatments (Grace, 1977; Duke, 1983; Ekanayake *et al.*, 1997a).

As a result, it is of utmost importance that the optimum condition of SCs should be determined to obtain uniformity and germination vigor in their establishment as well as higher tuber yields in cassava. Also, it is necessary to investigate varietal responses of major agronomic characters to diverse SC conditions in order to screen early-bulking characteristics with higher tuber yield.

This study was carried out to investigate the effect of SC length and portion on major agronomic characters, and to determine their relationships in cassava.

MATERIALS AND METHODS

General methods

Two experiments were carried out for this study with different plant materials: Adira1 (*a low cyanide-level* or *sweet variety*, clone no. BIC30) and Adira4 (*a high cyanide-level*

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<Received June 6, 2005>

or *bitter variety*, BIC136) were tested in the first experiment, while Gading (*a low cyanide-level* or *sweet variety*, BIC10) and SPP (*a high cyanide-level* or *bitter variety*, BIC03) were used in the second experiment.

Each experiment was carried out in the different experimental fields of Bogor Education Center, Education Office of Bogor district: the first experiment was conducted in the Karadenan field (141-163 m above sea level), Bogor, West Java, Indonesia, from May 2001 to January 2002, while the second experiment in the Nanggewer field (140 - 158 m above sea level), Bogor, West Java, Indonesia, from January to September 2004. The soil pH of the Karadenan field ranged between 4.89 and 6.21, while that of the Nanggewer field between 4.40 and 4.68. The dry season was recorded from May to August in 2001, while from June to September in 2004 (Committee of Meteorology and Geophysics, 2001, 2004).

Split-split plot designs with 3 replications were used in each experimental plot of size of 33.0 m^2 with a planting density of 40 plants per plot: the factorial components of each experiment were varieties (Adira1 & Adira4 or Gading & SPP) X SC length (10, 25, 40 cm) X SC portion (young tip (type), semi-mature, hardwood) = 18, and these components were apportioned to main plot, split plot, and split-split plot, respectively. In all experiments, the young tip (type), semi-mature, and hardwood portions were regarded as lower 20 - 60 cm, 60 - 100 cm, and more than 100 cm from the apex of more than 10 month-old plant stems after discarding the first 20 cm, and the 10, 25, and 40 cm long SCs were taken from the each portion.

After all experiments were finished, data of each experiment were combined together into *sweet varieties* or *bitter varieties* to take the mean values for further analyses and to minimize the deviations in parameters derived from year, climate, location, soil condition or variety. In the sweet varieties, the number of nodes SC^{-1} was 6.4 - 7.9 in 10-cm SCs, 15.8 - 25.2 in 25-cm SCs, and 22.4 - 24.8 in 40-cm SCs or 18.6 in young tip SCs, 15.7 in semi-mature SCs, and 16.4 in hardwood SCs, on average. Similarly, that of the bitter varieties was 6.6 - 8.0 in 10-cm SCs, 18.0 - 23.3 in 25-cm SCs, and 23.9 - 26.7 in 40-cm SCs or 19.3 in young tip SCs, 16.2 in semi-mature SCs, and 18.2 in hardwood SCs, respectively.

Cultivation was carried out by using the standard cultural practices (MOA, 2000) and other methods recommended (Tuherkih *et al*., 1990; Zuraida, 1993; Ekanayake *et al.*, 1997a; George *et al*., 2001): twice plowing and ridging with a height of 15 - 20 cm before planting; no basal fertilization and twice top dressing based on the criterion of N (urea) 200 kg, P (TSP) 150 kg, and K (KCl) 150 kg ha^{-1}; the first top dressing was applied with the ratio of N (1/3) + P (all) + K (1/2) at one week after planting, while the second one with the ratio of N (2/3) + P (0) + K (1/2) at 2 months after planting (MAP); all SCs prepared were planted vertically by hand in 4 rows $plot^{-1}$ with a planting space of 100 cm × 60 cm and a depth of 5 - 10 cm below the soil surface; weeding was conducted until 6 MAP.

Major agronomic characters

Leaf number, stem length (cm), leaf dry weight (g), stem dry weight (g), shoot dry weight (g), tuber number, root (tuber) dry weight (g), and total dry weight (g) $plant^{-1}$ were measured with three plants in each treatment and replication every 2 months after planting (MAP). The leaf dry weight, stem dry weight, shoot dry weight, root (tuber) dry weight, and total dry weight were observed using the dry method (Hidayat, 1978; Bradbury & Warren, 1988) at Indonesian Center for Agricultural Biotechnology and Genetic Resources Research and Development.

Also, tuber yield-related major characters such as root/shoot (R/S) ratio (g g^{-1}), leaf area index (m^2 m^{-2}, LAI), leaf area duration (m^2 · day, LAD), relative growth rate (g g^{-1} day^{-1}, RGR), harvest index (HI), tuber growth rate (g m^{-2} day^{-1}, TGR), and partitioning coefficient (PC) were determined using the methods described by O'Hair (1995), Sung & Lee (1997), and Ekanayake *et al.* (1998).

Relationship analysis

The simple correlation (Mather, 1964) and multiple regression equation (Gomez & Gomez, 1976) were analyzed to investigate the relationships between major agronomic characters and SC treatments.

RESULTS AND DISCUSSION

The R/S ratio is one of major agronomic characters showing higher direct effects on the accumulation of DM in cassava roots (tubers) (Park *et al*., 2005). Fig. 1 shows the effect of SC length and portion on the R/S ratio. In all varieties, the R/S ratio was different significantly among SC lengths and also among SC portions at 2 MAP, obtaining higher R/S ratio values in the 40 and/or 25 cm long SCs and in the hardwood and/or semi-mature SCs. After 2 MAP, however, the R/S ratio tended to be much higher in the shorter SCs or in the younger portion SCs during remaining growing period.

It has been known that 15 - 30 cm long cuttings with 5 - 7 nodes are good as a planting material; cuttings with 1 - 3 nodes do not sprout well due to small amounts of nutrients; long cuttings give higher yields than short cuttings because long cuttings produce more stems and leaves; and hard-

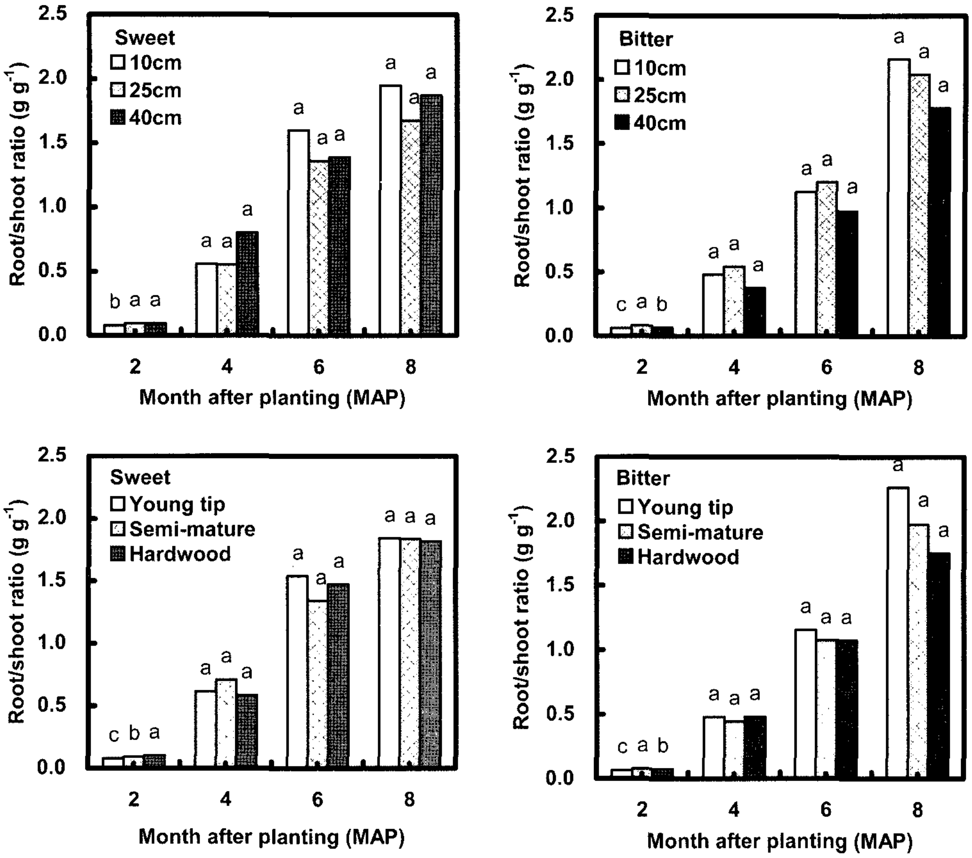

Fig. 1. Effect of SC length (upper) and portion (lower) on root/shoot ratio in cassava varieties. Bars having same letters within each MAP are not significantly different at 5% level of LSD.

wood cuttings give the highest establishment of canopy, while tip shoot cuttings the lowest (Grace, 1977; Otoo, 1996; Ekanayake *et al.*, 1997a). However, the results in this study (Fig. 1) indicated that even though the longer or older portion SCs accumulated more DM in both shoot and root part at the early developmental phase, these SCs favored the accumulation of more DM in shoot than in root after the phase in contrast to the shorter or younger portion SCs.

Generally, the distribution of produced DM to the economically useful plant parts is measured by harvest index (HI) and, in cassava, the HI represents the efficiency of storage roots production (Alves, 2002). In both SC length and SC portion treatments, the HI was significantly higher in the 40 and/or 25 cm long SCs or in the hardwood and semi-mature SCs at 2 MAP in all varieties (Fig. 2). After 2 MAP, nevertheless, there were no significant differences among these treatments, while the 10 cm long SCs or the young tip SCs seemed to give higher or similar HI values compared with other SCs in all varieties.

As a result, even though the shorter or younger portion SCs gave the lowest HI at the early developmental phase, these SCs were capable of distributing DM to the storage roots as much as the longer or older portion SCs during the storage roots bulking phase. These results also showed that even though the longer or older portion SCs could produce more DM with higher rates at the early developmental phase, these SCs simultaneously accumulated larger quantities of DM in shoot at the storage roots bulking phase, particularly in the longer SCs of the sweet varieties or in the older portion SCs of the bitter varieties. In addition, there was a significant interaction of variety × SC length on the HI at 4 MAP (Fig. 2).

The results (Fig. 2) disagreed with the observations reported by Ekanayake *et al.* (1997a) describing that older cuttings from more mature parts of the stem give better yield but agreed with the report by Otoo (1996) obtaining that hardwood cuttings give the highest establishment of canopy. Wargiono *et al.* (1992) also found a similar result with this study that short stakes of 2 - 3 nodes gave similar fresh root yields compared with long stakes (10 - 12 nodes). Moreover, Dahniya & Kallon (1984) suggested that direct field planting under the wet and tropical condition could multiply the hardwood stakes of 4.3 - 16.1 cm long.

As a whole, the correlation coefficients of the stem length, stem dry weight, shoot dry weight, LAI, LAD, and

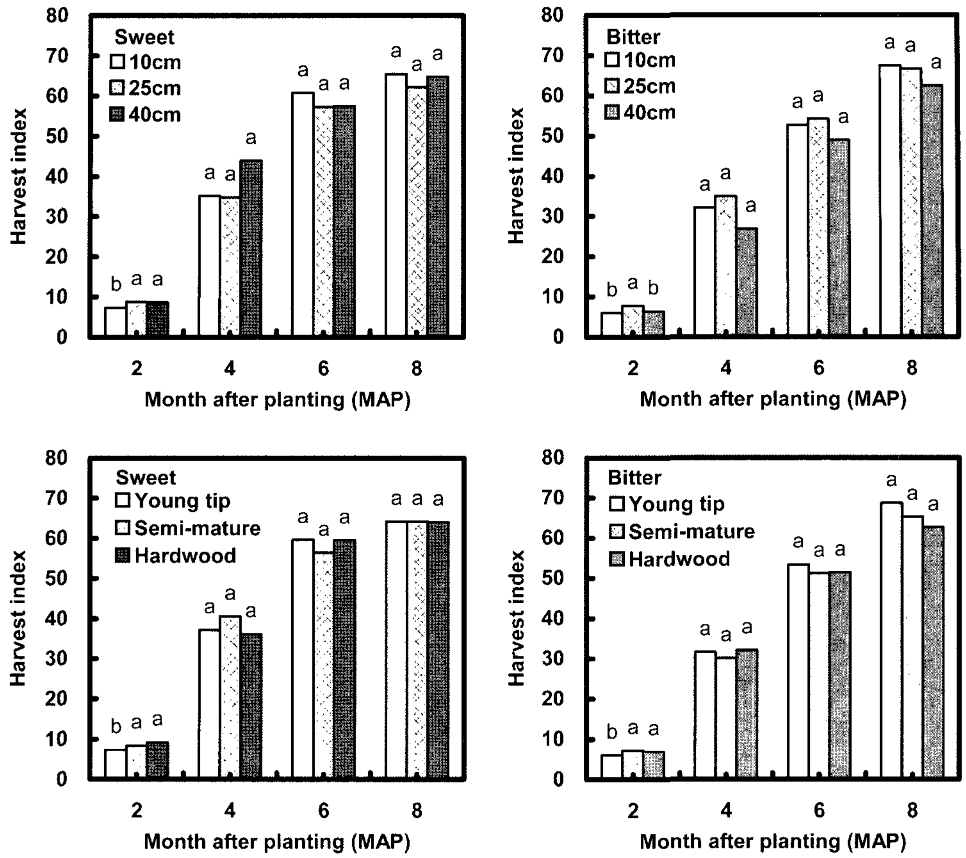

Fig. 2. Effect of SC length (upper) and portion (lower) on harvest index in cassava varieties. Bars having same letters within each MAP are not significantly different at 5% level of LSD.

total dry weight with the SC length were significantly positive, while those of the R/S ratio, HI, TGR, and PC were negative (Table 1). In the sweet varieties, the leaf dry weight, LAI, LAD, and total dry weight showed significant and positive correlations, while the R/S ratio and PC were negatively correlated with the SC length. Similarly, even if the leaf number of the bitter varieties showed a significant and positive correlation with the SC length, the tuber number, root (tuber) dry weight, total dry weight, R/S ratio, HI, TGR, and PC were correlated with the SC length negatively. Therefore, these results showed that when cassava is planted with longer SCs, canopy- or source-related major agronomic characters are more stimulated at the expense of the development of sink-related characters (Marschner, 1995).

The major agronomic characters, moreover, such as the leaf number, stem length, leaf dry weight, stem dry weight, shoot dry weight, LAI, and LAD of total varieties showed highly positive correlation coefficients with the SC portion, while the tuber number, root (tuber) dry weight, R/S ratio, HI, TGR, and PC showed lower positive or higher negative correlations (Table 1). The LAI and LAD of the sweet varieties also showed significant and positive correlations with the SC portion but the correlations of the root (tuber) dry weight, R/S ratio, TGR, and PC with the SC portion were lower positive or higher negative.

Similarly, although the leaf number, stem length, leaf dry weight, stem dry weight, shoot dry weight, LAI, and LAD of the bitter varieties showed higher positive correlations with the SC portion, the correlations of the R/S ratio, HI, TGR, and PC with the SC portion were lower positive or higher negative with the SC portion (Table 1). Therefore, these results also indicated that canopy- or source-related agronomic characters are stimulated at the expense of the development of sink-related characters when cassava is planted with older portion SCs.

The relationships between leaf number and SC length, and SC portion are shown in Fig. 3. In all varieties, the leaf number increased in proportion to the SC length or SC portion and showed the highest values in the 40 cm long SCs or in the hardwood portion SCs. In particular, the bitter varieties showed an almost linear relationship between the leaf number and the SC length compared with the sweet varieties.

In like manner with the leaf number, the LAI of the sweet varieties showed almost linear relationships with the SC length and also with the SC portion. However, in the bitter varieties, the relationship between the LAI and the SC

Table 1. Simple correlation between major agronomic characters and SC treatments during growing period in cassava†.

Characters	Varieties	Treatments		Characters	Varieties	Treatments	
		SC length	SC portion			SC length	SC portion
LN	Total[1)]	0.989	0.925	TDW	Total	0.998*	0.906
	Sweet[2)]	0.953	0.915		Sweet	0.999*	0.407
	Bitter[3)]	0.997*	0.939		Bitter	-0.999*	0.968
SL	Total	1.000**	0.846	R/S ratio	Total	-0.976	-0.970
	Sweet	0.966	0.344		Sweet	-0.044	-0.873
	Bitter	0.980	0.962		Bitter	-0.838	-0.981
LDW	Total	0.990	0.995	LAI	Total	0.999*	0.986
	Sweet	1.000**	0.818		Sweet	0.997*	0.999*
	Bitter	0.576	0.969		Bitter	0.056	0.950
SDW	Total	0.999*	0.978	LAD	Total	0.999*	0.993
	Sweet	0.954	0.460		Sweet	1.000**	0.999*
	Bitter	0.938	0.982		Bitter	0.692	0.940
SHDW	Total	1.000**	0.982	HI	Total	-0.880	-0.958
	Sweet	0.980	0.557		Sweet	0.515	0.502
	Bitter	0.906	0.979		Bitter	-0.691	-0.914
TN	Total	0.861	0.806	TGR	Total	-0.945	0.262
	Sweet	0.910	0.810		Sweet	0.992	0.033
	Bitter	-0.947	0.800		Bitter	-0.976	0.502
RDW	Total	0.938	0.675	PC	Total	-0.905	-0.922
	Sweet	0.962	0.297		Sweet	-0.771	-0.855
	Bitter	-0.968	0.925		Bitter	-0.851	-0.928

†LN: leaf number, SL: stem length, LDW: leaf dry weight, SDW: stem dry weight, SHDW: shoot dry weight, TN: tuber number, RDW: root (tuber) dry weight, TDW: total dry weight, R/S ratio: root/ shoot ratio, LAI: leaf area index, LAD: leaf area duration, HI: harvest index, TGR: tuber growth rate, PC: partitioning coefficient.
[1)]Examined with the mean values of four test varieties.
[2)]Examined with the mean values of Adira1 (planted in 2001) and Gading (planted in 2004).
[3)]Examined with the mean values of Adira4 (planted in 2001) and SPP (planted in 2004).
*Significant at P=0.05 (t-test), **Significant at P=0.01 (t-test).

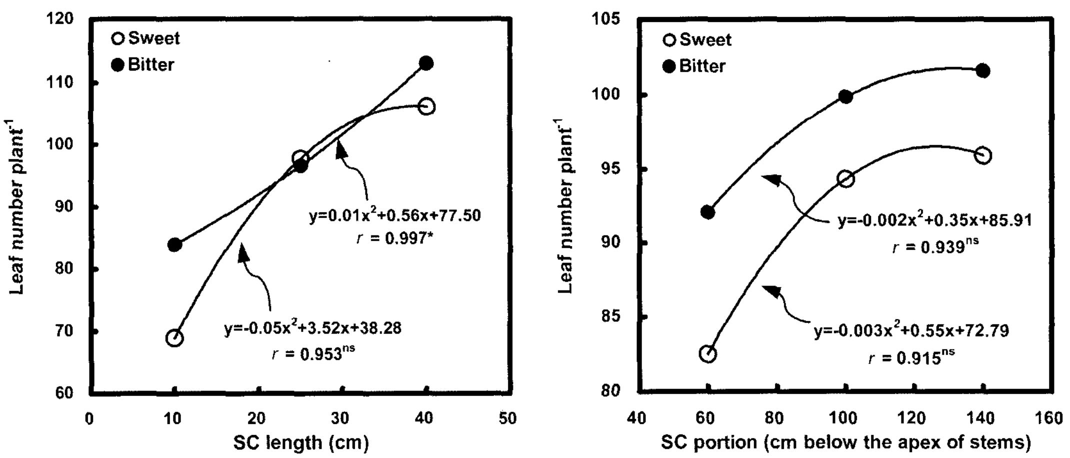

Fig. 3. Relationship between leaf number and SC length (left), and SC portion (right) during growing period in cassava varieties.

length was relatively lower compared with that of the sweet varieties. Therefore, it seemed that the SC length less affect the LAI of the bitter varieties. Nevertheless, the LAI increased in proportion to the SC portion and obtained the highest values with the hardwood portion in the bitter varieties (Fig. 4).

The root (tuber) dry weight of the sweet varieties increased in proportion to the length or portion of SCs. The sweet varieties, nevertheless, obtained the lowest root (tuber) dry weight values in the 10 cm long SC or in the semi-mature SC (Fig. 5). On the contrary, the root (tuber) dry weight of the bitter varieties decreased in proportion to the SC length with a higher

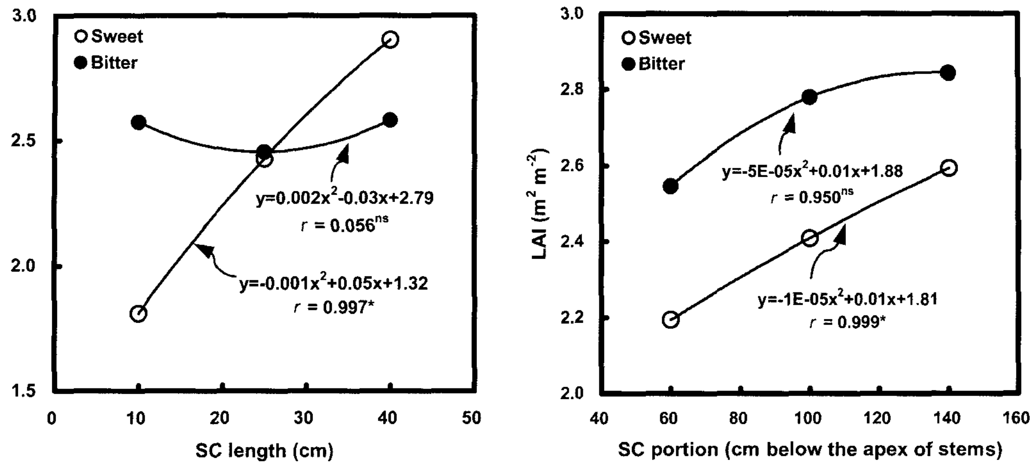

Fig. 4. Relationship between leaf area index (LAI) and SC length (left), and SC portion (right) during growing period in cassava varieties.

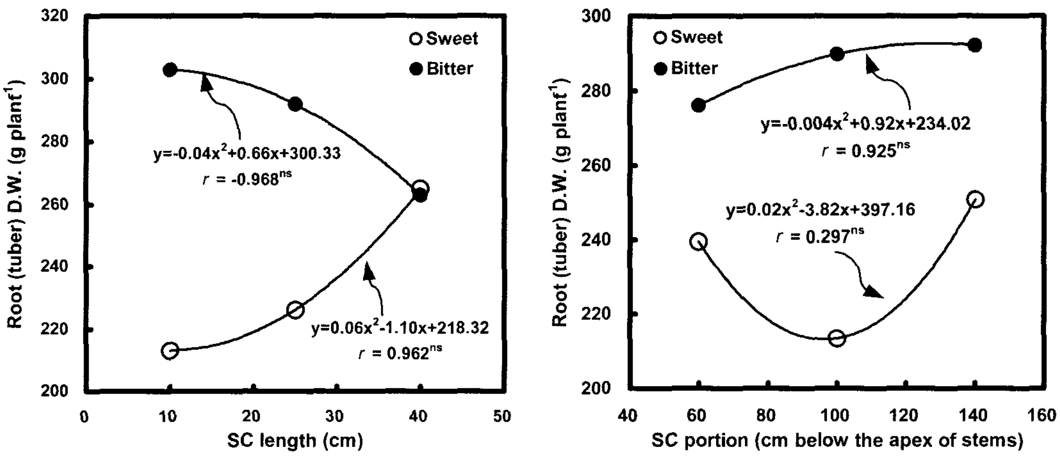

Fig. 5. Relationship between root (tuber) dry weight and SC length (left), and SC portion (right) during growing period in cassava varieties.

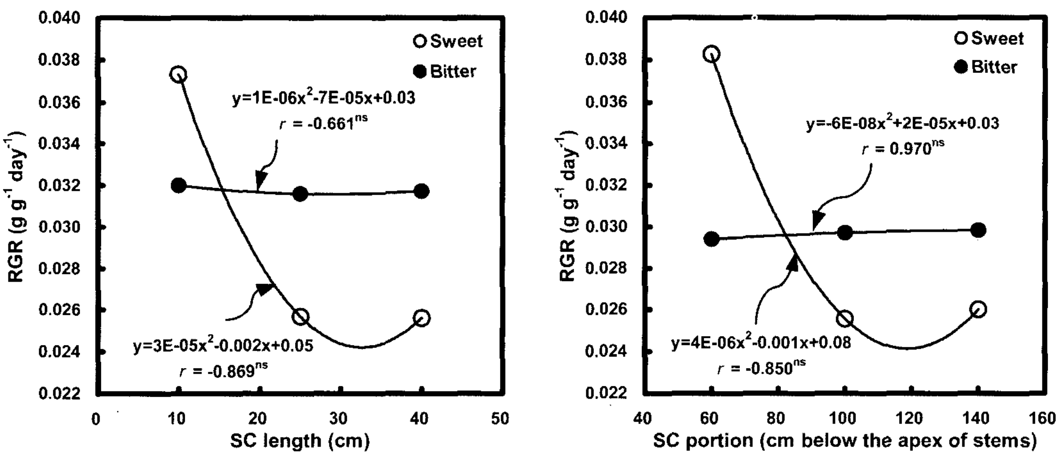

Fig. 6. Relationship between relative growth rate (RGR) and SC length (left), and SC portion (right) during growing period in cassava varieties.

negative correlation coefficient and, as a result, the 10 cm long SC gave the highest root (tuber) dry weight values. However, these bitter varieties increased the root (tuber) dry weight in proportion to the SC portion and the young tip SC gave the lowest root (tuber) dry weight values (Fig. 5).

Both the sweet varieties and the bitter varieties obtained higher RGR values when they were planted with the shorter SCs. The RGR of the sweet varieties, in particular, decreased steeply in proportion to the SC length or SC portion with higher negative correlation coefficients (Fig. 6). As a result, the shorter or younger portion SCs gave the highest RGR values in the sweet varieties. On the contrary, the SC portion less affected the RGR of the bitter varieties during the growing period.

In fact, the HI is an important trait which can be used at all stages of selection as an indirect selection for root yield because not only this value is highly correlated with root yield (r=0.763) but also it has a high heritability (Marschner, 1995; Jennings & Iglesias, 2002; Park *et al.*, 2005). The bitter varieties showed the reduction of HI in proportion to the SC length or SC portion, obtaining the highest HI values in the 15 - 25 cm long SC or in the younger portion SCs (Fig. 7).

The effect of SC length on these bitter varieties disagreed with the report by George *et al.* (2001) observing that a significant reduction in root yield was noticed when stakes of 10 cm length were used. On the contrary, the sweet varieties showed positive relationships between the HI and the SC length, and the SC portion, obtaining the highest HI values in the 30 - 40 cm long SC or in the semi-mature to hardwood portion SCs (Fig. 7). Nonetheless, the effect of SC portion on the HI was relatively lower in the sweet varieties. These results supported the report by George *et al.* (2001) observing that a stake of 25 - 30 cm long was found to be ideal for obtaining high root yield.

Leihner (2002) described that a stake should be at least 20 cm long and have a minimum of 4 - 5 nodes with viable buds to ensure crop establishment, and stems should be sufficiently lignified to ensure that stakes do not dry out to fast after planting while over-lignified tissue should be avoided. However, as a consequence of the results in this study (Fig. 1 to 7 & Table 1), it was suggested that when cassava is planted with too longer SCs (30 - 40 cm) or with too matured portion SCs, major source-related characters such as the leaf number and LAI would grow excessively, causing mutual shading of the basal leaves, in the sweet and bitter varieties of cassava. On the contrary, using these SCs as planting materials may cause the reduction of tuber yield due to the decrease of other important source- or sink-related characters like the RGR, root (tuber) dry weight, and HI, especially in the bitter varieties. In general, cassava plant must have enough leaf area to produce carbohydrates but it should not produce so much leaf and stem that no carbohydrates remains available to fill the storage roots (Cock, 1985).

As a whole, research trials in India, Indonesia, Philippines, Malaysia, and Thailand indicated that higher tuber yields are obtained when stakes are cut from mid- and lower-part of stems from mother plants that are about 8 - 12 months old (Howeler, 2001). The most suitable length of SCs was found to be 15 - 20 cm in Thailand (Tongglum *et al.*, 1988), 20 - 23 cm in Malaysia (Tan, 2001), and 25 - 30 cm in India (George *et al.*, 2001). However, this study could ascertain that varietal responses to SC length and to SC portion are very different in cassava. As a result, it was supposed that the sweet varieties are suitable to be planted with the SCs of 25 - 30 cm long or with those from young to semi-mature portions of mother stems, while the bitter varieties with the SCs of 15 - 20 cm long or with those from semi-mature to mature portions of mother stems, respectively, to obtain higher DM and yield of tubers.

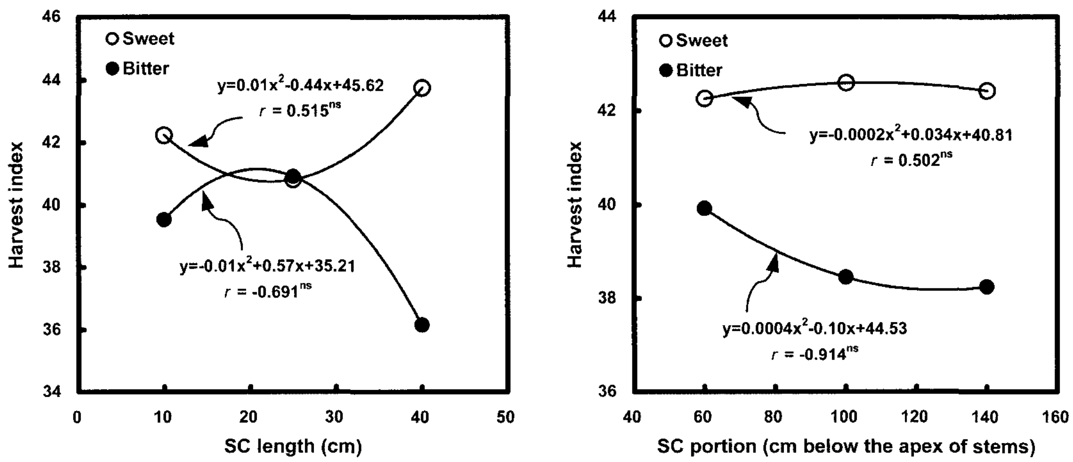

Fig. 7. Relationship between harvest index and SC length (left), and SC portion (right) during growing period in cassava varieties.

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