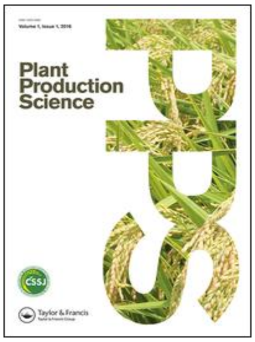


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# Year-Round Cultivation of Sweet Sorghum [*Sorghum bicolor* (L.) Moench] through a Combination of Seed and Ratoon Cropping in Indonesian Savanna

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**Abstract** : We studied the year-round cultivation of sweet sorghum, which is a raw material for the fermentation of monosodium glutamate, in East Java, Indonesia. In this savanna area, each year comprises 2 seasons-dry (April-September) and rainy (October-March). Seed crops were sown almost every month for 1 yr, and each seed cropping was followed by a ratoon cropping after the seed crop harvest. The stem-related traits of plants from different sowing or ratooning dates were studied at around 17 weeks after sowing or ratooning. For both plants derived from seed and ratoon, better crop establishment was observed when cultivation was commenced during the rainy season than during the dry season. Although sowing was undertaken each week in August and September during the most severe dry period, germination rate was very low (or zero) and even the germinated plants died within a short time. In contrast, ratoon cropping was started and plants were grown until harvest. In East Java, it is considered possible to produce sweet sorghum throughout the year, mainly by sowing, but also partially by ratooning during the most severe drought period of the dry season.

**Key words** : Dry season, Indonesia, Monosodium glutamate, Rainy season, Ratoon, Savanna, Sweet sorghum, Year-round cultivation.

East Java, the center of sugarcane production in Indonesia, is also the center of monosodium glutamate (MSG) production, which is currently derived mainly from cane molasses. Recently, in order to satisfy the food demands of its growing population, the cultivation of rice on the irrigable fields of Java Island has been promoted over the cultivation of sugarcane. Consequently, it has become difficult for MSG companies to secure their raw materials from East Java.

Sweet sorghum [*Sorghum bicolor* (L.) Moench] accumulates high quantities of sugar in its stem and has strong drought tolerance. It is a promising crop as a raw material for the fermentation industry because it can grow in the non-irrigable fields of savanna areas where sugarcane is difficult to grow. Sweet sorghum also is more tolerant to drought than maize. This plant can thus, to a certain extent, resolve the problem of raw material for the MSG industry, and could contribute significantly to East Javan agriculture if it were possible to cultivate it throughout the year in non-irrigable fields (Tsuchihashi and Goto, 2004; 2005).

Sweet sorghum, owing to its high adaptability to the environment, early maturity, and high biomass productivity, has been studied as a raw material for fermentation in the USA (Jackson et al., 1980), Japan (Hoshikawa et al., 1988; Inoue et al., 1988), and other countries. However, the large-scale commercial cultivation of sweet sorghum as a raw material for fermentation has not been realized economically. In Indonesia, grain sorghum is cultivated for feed. The traditional method for the cultivation of grain sorghum is optimized for seed production-sowing squarely 4 to 5 seeds at each point (60 cm×60 cm) without thinning. Fertilization is also optimized for feed production. This method, however, is not suitable for the cultivation of sweet sorghum from the viewpoint of stem enlargement and elongation (Tsuchihashi and Goto, 2002). In Indonesia, sweet sorghum was first introduced in the 1980s and was evaluated by the Indonesian Sugar Research Institute for sugar production (Sumantri and Purnomo, 1997); however, few studies have investigated its cultivation methods. In 1992, Ajinomoto started studying cultivation techniques in Indonesia (Sumantri and Purnomo, 1997), and from 1994 we started conducting the present series of studies (Tsuchihashi and Goto, 2004, 2005).

According to the climate classification of Köppen, East Java in Indonesia has a tropical savanna climate

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**Abbreviations:** DAR, days after ratooning; DAS, days after sowing; MSG, monosodium glutamate.

(Aw) with dry and rainy seasons (Miyake, 1983). Although almost all fields are used for cultivating crops (mainly paddy) during the rainy season, a large part of the non-irrigated fields is non-productive, except for a few portions on which corn is cultivated during the dry season. Considering the operational efficiency of an MSG factory, it would be desirable to supply raw material throughout the year. Previously, we conducted field experiments in the savanna area of Indonesia and confirmed that sweet sorghum was cultivatable during the rainy (Tsuchihashi and Goto, 2004) as well as the dry season, although the yield during the latter period was lower (Tsuchihashi and Goto, 2005). Moreover, we examined the elongated internodes comprising the stem and reported shorter and lighter stems with two fewer elongated internodes.

On the other hand, because precipitation tends to decrease gradually toward the end of the dry season, the growth of plants is considered to differ depending on the sowing date. Moreover, "ratoon", which is based on the regeneration stems of sugarcane after harvest (Miyazato, 1986), can also be applied to sweet sorghum. It is advantageous to employ ratoon to start cropping during the dry season due to the presence of pre-existing root systems. Thus, a cropping system that combines ratoon as well as seed crops can be employed to overcome severe water shortage during the dry season and to realize year-round cultivation in this savanna area. Furthermore, it is very important to compare the seed and ratoon croppings for the same growing period in order to gather basic knowledge about the combination of seed and ratoon croppings. This study was conducted on a non-irrigated field in the savanna area of East Java. Sowing was conducted during almost every month for approximately 1 yr (seed croppings), and regeneration stems were used after the seed crops were harvested (ratoon croppings). The purpose of this study was to investigate the year-round cultivation of sweet sorghum by comparing the traits of stems across different sowing and ratooning dates, and also across seed and ratoon croppings.

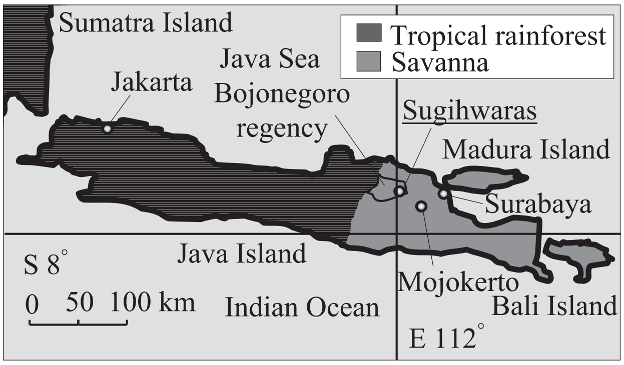


Fig. 1. Map of Java Island in Indonesia and Mojokerto city where two MSG factories of Ajinomoto are located, with climatic division of tropical rainforest and savanna.

## Materials and Methods

*Sorghum bicolor* cv. Wray (introduced from South Africa to the USA) (Salunkhe and Desai, 1988) was used for the field tests conducted in the Sugihwaras residency of the Bojonegoro Province (8°S, 112°E), East Java, Indonesia (Fig. 1). In our previous study, the Wray cultivar exhibited better growth and yield than cultivars Keller and Rio (Tsuchihashi and Goto, 2004). The soil type of the test field is Vertisols according to the USDA soil taxonomy (Miyake, 1983) and to the FAO classification (FAO and UNESCO, 1976). The meteorological data regarding daily precipitation and daily mean temperature (calculated as the average of maximum and minimum temperatures) were recorded

Table 1. Code and period of each cultivation of sweet sorghum conducted in 1996 and 1997.

| Code of cultivation | | Date ('yy/mm/dd) of | | |
|---|---|---|---|---|
| Seed croppings[1)] | Ratoon croppings[1)] | Sowing | Harvest-A[3)] | Harvest-B[4)] |
| S1 | R1 | '96/04/12 | '96/08/08 | '96/11/28 |
| S2 | R2 | '96/06/01 | '96/09/26 | '97/01/23 |
| S3 | R3 | '96/06/25 | '96/10/10 | '97/02/07 |
| S4 | R4 | '96/07/27 | '96/11/28 | '97/03/26 |
| –[2)] | – | – | – | – |
| S5 | R5 | '96/10/15 | '97/03/01 | '97/06/29 |
| S6 | R6 | '96/10/22 | '97/03/01 | '97/06/29 |
| S7 | R7 | '96/12/03 | '97/04/06 | '97/07/20 |
| S8 | R8 | '96/12/12 | '97/04/10 | '97/08/12 |
| S9 | R9 | '97/02/02 | '97/06/02 | '97/09/01 |

1) Seed croppings were started with sowing and ratoon croppings were started with the harvest of seed croppings.
2) In August and September in 1996, seed croppings could not be started because of severe dry condition.
3) Harvest-A means harvest of seed cropping and the start of ratoon cropping.
4) Harvest-B means harvest of ratoon cropping.

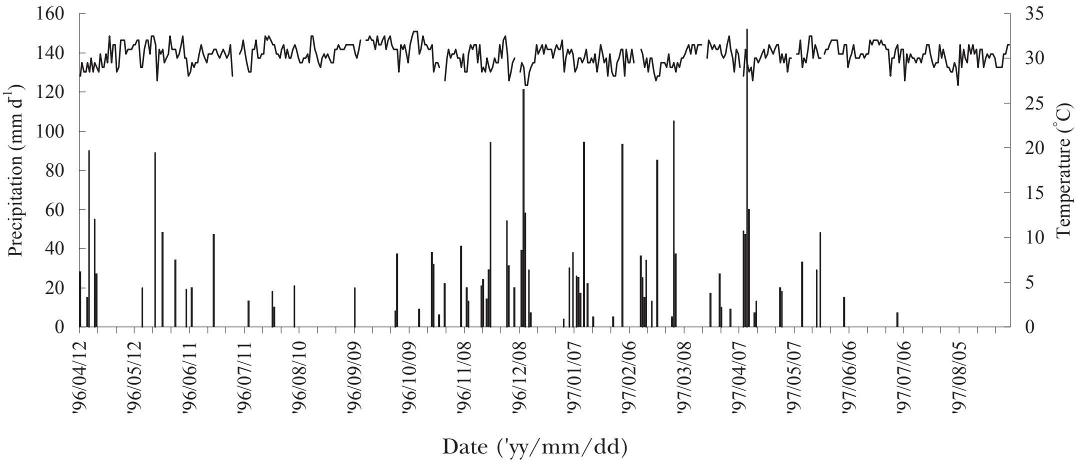


Fig. 2. Changes in daily precipitation and mean temperature during cropping periods at the test field in Indonesia.

at the test field for the series of cultivations that commenced on April 12, 1996.

In this area, the year can be divided into 2 seasons–the dry season (the relatively dry period from April to September) and the rainy season (the relatively humid period from October to March). Sowing was conducted during almost every month from April 1996 to February 1997. The seeds were sown at a row distance of 60 cm and at a plant distance of 10 cm with 3 seeds per sowing point. The plants were thinned out to stand alone at the third-leaf stage (16.7 plants $m^{-2}$). The field size of each crop was 500 $m^2$ (25 m × 20 m). In the months of August and September coinciding with a very severe drought, the seeds were sown every week. However, the germination rate was very low (or zero) and even the germinated plants died within a short time. After harvesting these plants from seed, ratoon was performed only once for each seed crop utilizing the regeneration stems. Each cropping was assigned a code–the seed crop sown on April 12 was designated S-1; the ratoon crop started on August 8, R-1, etc., (Table 1).

Fertilizer was applied 3 times; during sowing or ratooning, 14 d after sowing (DAS) or 14 d after ratooning (DAR), and 30 DAS or 30 DAR. The total amounts of added nutrients were N : 11.8 g $m^{-2}$; $P_2O_5$ : 9.2 g $m^{-2}$; and $K_2O$ : 12.3 g $m^{-2}$ for each sowing or ratooning. Pesticides and insecticides were also applied several times in order to control pests and diseases.

The plant height and total leaf number of 5 plants were measured every 2 wk until harvest. According to our previous study conducted in East Java, sweet sorghum was thought to be harvestable from 15 wk after sowing (105 DAS) (Tsuchihashi and Goto, 2004). In the present study, we harvested sweet sorghum plants derived from seed and ratoon at approximately 17 wk after sowing or ratooning at each harvestable stage (recorded in Table 1) depending on the climate and work schedule. The 5 plants mentioned above were collected from the field during harvest and divided into individual internodes. Internodes longer than 1 cm were treated as elongated internodes (Tsuchihashi and Goto, 2005). The length of each internode was measured. The number of non-elongated internodes was also calculated by subtracting the number of elongated internodes from the total leaf number. At the same time, 20 plants were collected from the field and after separating into each organ (i.e. ear (at neck node), leaf, leaf sheath, stem and root) their stem lengths and stem weights were measured.

## Results

### 1. Meteorological characteristics of the test field

Fig. 2 shows the changes in the daily precipitation and mean temperature at the test field. The mean temperature was approximately 30°C throughout the year and was not considered to be the main cause of the difference in growth during the different cultivation periods. The amount and frequency of the daily precipitation decreased gradually from April 12, 1996 (the date of the first sowing), and precipitation was recorded on only 1 d in August (August 7, 21 mm) and in September (September 9, 20 mm) in 1996. The rainy season began in October 1996 and continued until March 1997. The total precipitation during the rainy season was approximately 1,500 mm, which is the same as that in an average year. In the rainy season under study, there were 10 periods during which there was no rain for more than 6 d. On the other hand, the dry season in 1997 was severer than that in 1996, with only 1 d of rainfall each in June (June 3) and July (July 2), and no rain in August.

### 2. Plant height

Fig. 3 shows the changes in the heights of sweet sorghum plants. For seed crops, the S1 and S2 plants reached heights of 306 cm, whereas S3 and S4 plants attained heights of only 250 cm and 198 cm,

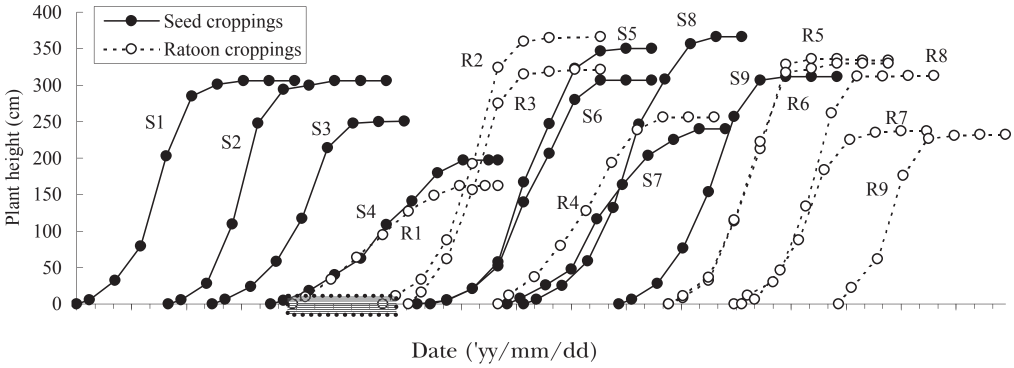


Fig. 3. Changes in plant height of sweet sorghum for each cultivation in Indonesia. Codes of cultivation (e.g. "S1", "R1") indicate seed and ratoon croppings shown in Table 1. In August and September '96, seed croppings could not be started because of severe dry condition (shown by hatching surrounded by dot-line).

Table 2. Periodical precipitation of each cultivation at the test field in Indonesia.

| Code[1)] of cultivation | | Starting date of cultivation ('yy/mm/dd) | Precipitation of each period[2)] (mm) | | | |
|---|---|---|---|---|---|---|
| | | | 0–35 DAS(DAR) | 36–80 DAS(DAR) | 81–105 DAS(DAR) | Total |
| Seed croppings | S1 | '96/04/12 | 235 | 257 | 31 | 523 |
| | S2 | '96/06/01 | 120 | 62 | 20 | 202 |
| | S3 | '96/06/25 | 41 | 41 | 45 | 127 |
| | S4 | '96/07/27 | 31 | 74 | 159 | 264 |
| | S5 | '96/10/15 | 353 | 500 | 262 | 1,115 |
| | S6 | '96/10/22 | 316 | 499 | 219 | 1,034 |
| | S7 | '96/12/03 | 346 | 495 | 147 | 988 |
| | S8 | '96/12/12 | 292 | 421 | 81 | 794 |
| | S9 | '97/02/02 | 453 | 391 | 71 | 915 |
| Ratoon croppings | R1 | '96/08/08 | 20 | 130 | 184 | 334 |
| | R2 | '96/09/26 | 152 | 615 | 123 | 890 |
| | R3 | '96/10/10 | 181 | 541 | 261 | 983 |
| | R4 | '96/11/28 | 363 | 465 | 245 | 1,073 |
| | R5 | '97/03/01 | 210 | 428 | 63 | 701 |
| | R6 | '97/03/01 | 210 | 428 | 63 | 701 |
| | R7 | '97/04/06 | 399 | 92 | 7 | 498 |
| | R8 | '97/04/10 | 350 | 92 | 7 | 449 |
| | R9 | '97/06/02 | 22 | 0 | 0 | 22 |

1) Code of cultivation indicates seed and ratoon croppings shown in Table 1.
2) Period is indicated by days after sowing/ratooning.

respectively. This decline in plant height corresponded with the decrease in precipitation during the cultivation period. The elongation rate of plants height also decreased from S2 to S3, and further to S4. Although sowing was performed each week during August and September in 1996, the germination rate was very low and even the germinated plants grew abnormally (died within a few days). S5 and S6 plants were germinated from seed sown in October and grew normally until harvest. After S7, seed was sown during the middle of the rainy season. The growing period of S5 to S9 coincided primarily with the rainy season; therefore, these plants grew well, attaining a height of more than 300 cm, with the exception of S7 plants.

For ratoon cropping, R1, which was started at almost the same time as S4, exhibited growth similar to that of S4 until 63 DAR (63 DAS). R2 was started during the very severe drought period, when seed cropping could not be performed, and reached a plant height of 366 cm. The plant heights of R3 and R4 were less

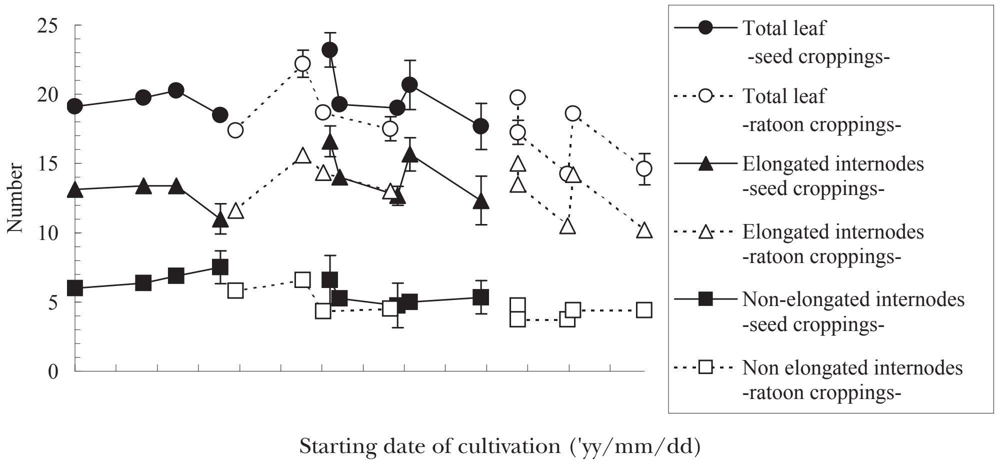


Fig. 4. Total leaf number, number of elongated internodes and non-elongated internodes of sweet sorghum in relation to start date for each cultivation in Indonesia. Vertical bars indicate the standard error (n=5).

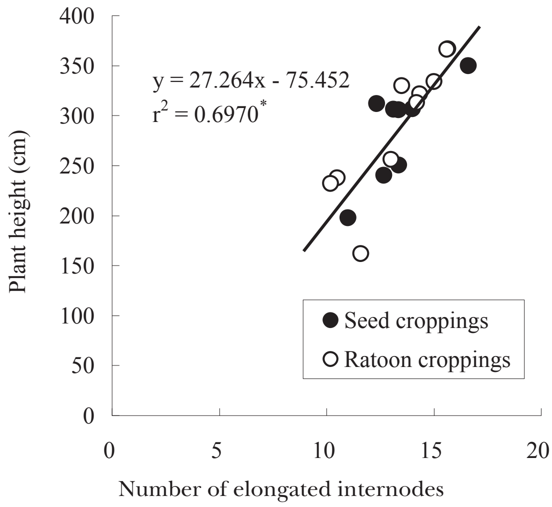


Fig. 5. Relation between number of elongated internodes and plant height of sweet sorghum during harvest in Indonesia.

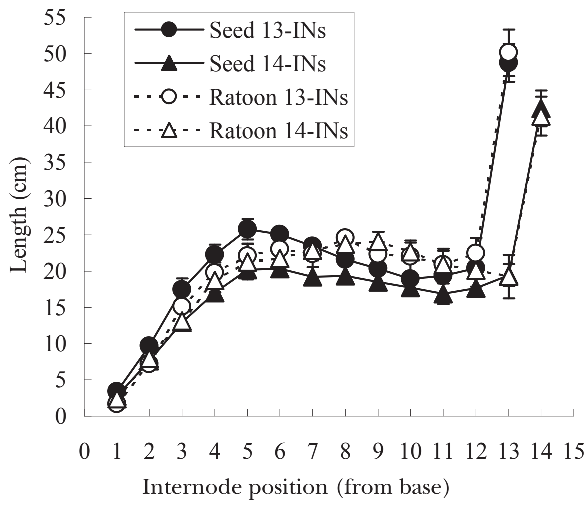


Fig. 6. Internode length of seed and ratoon croppings of sweet sorghum in Indonesia. The internodes position is from base (0) to top. Vertical bars indicate the standard error.

than that of R2. Although the plant heights of R5, R6, and R8 exceeded 300 cm, those of R7 and R9 failed to reach 250 cm. The plant heights tended to decrease as the ratooning date moved closer toward the severe dry season.

Table 2 shows the periodical precipitation during 0–35 DAS (DAR), 36–80 DAS (DAR), and 81–105 DAS (DAR). In this study, the precipitation during 0–35DAS (DAR) was less than 50 mm in S3, S4, R1, and R9. In S7, although 346 mm of rainfall was recorded during 0–35 DAS, only 4 mm of rainfall was recorded from 12 DAS to 31 DAS. In R9, only 22 mm of rainfall was recorded until 35 DAR, and then no rainfall was recorded until 105 DAR.

## 3. Internode characteristics

Fig. 4 shows the total leaf number, the number of elongated internodes, and the number of non-elongated internodes for each seed and ratoon cropping in relation to the start date. The total number of leaves for seed and ratoon plants was 17.7–23.2 and 14.6–22.2, respectively. The number of elongated internodes was 11.0–16.6 for seed plants and 10.2–15.6 for ratoon plants. The number of non-elongated internodes was 4.8–7.5 for seed plants and 3.8–6.6 for ratoon plants. Although the number of non-elongated internodes tended to be greater for seed plants than for ratoon plants, this value was relatively constant (at approximately 5) throughout the year.

Fig. 5 shows the relationship between the number of elongated internodes and plant height, which were significantly correlated.

In order to observe the differences in internode lengths between seed and ratoon plants, all plants with

13 (13-INs) and 14 (14-INs) elongated internodes were collected for all seed and all ratoon croppings, respectively. The average values of internode length and S.E. for each internode position are shown in Fig. 6. The neck nodes of the ears were longest for plants from both seed and ratoon reaching 50 cm for 13-INs and 40 cm for 14-INs. Although the longest internode (excluding the ear neck internode) in ratoon plants was located at a higher internode position from the base than in seed plants, overall, no large differences were observed between the 2 plant types.

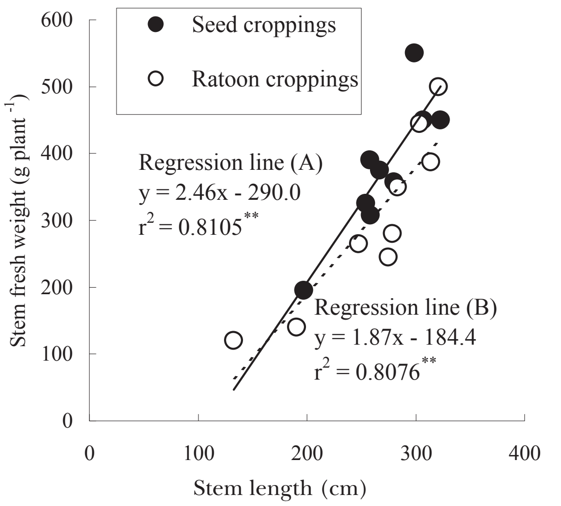


Fig. 7. Relation between stem length and stem fresh weight of sweet sorghum at harvest in Indonesia. Regression line (A) indicates correlation of seed croppings. Regression line (B) indicates correlation of ratoon croppings.

### 4. Stem fresh weight

Fig. 7 shows the relationship between the stem length and the stem fresh weight at harvest. For both seed and ratoon croppings, a significant correlation was observed between stem length and stem fresh weight. A comparison of the regression expression revealed that the ratoon croppings have a less steep slope than the seed croppings.

Fig. 8 shows the stem fresh weight at harvest of seed and ratoon croppings. The harvesting period is indicated by horizontal bars representing 10 d, from 5 d before to 5 d after harvest. In seed plants, the stem fresh weight was maximum in S8 (harvested in April), followed by S6 and S7. In ratoon plants, stem fresh weight was heaviest in R3 (harvested in February), followed by R2 (harvested in January). From R5 to R9, stem fresh weight tended to decrease as the harvesting date became later. Stem fresh weight was lightest in R1, and relatively low for R4 (harvested in March).

## Discussion

According to the previous research conducted in East Java, sweet sorghum grows better in the rainy season than in the dry season (Tsuchihashi and Goto, 2005). Furthermore, the present study demonstrated that plant height tended to be shorter toward the latter period of the dry season. The effect of periodical precipitation on plant height was observed. In S3, S4, R1, and R9, precipitation during 0–35 DAS (DAR) was below 50 mm and the plant heights were less than 300 cm. In S7, plant height was also less than 300 cm, and although the precipitation during 0–

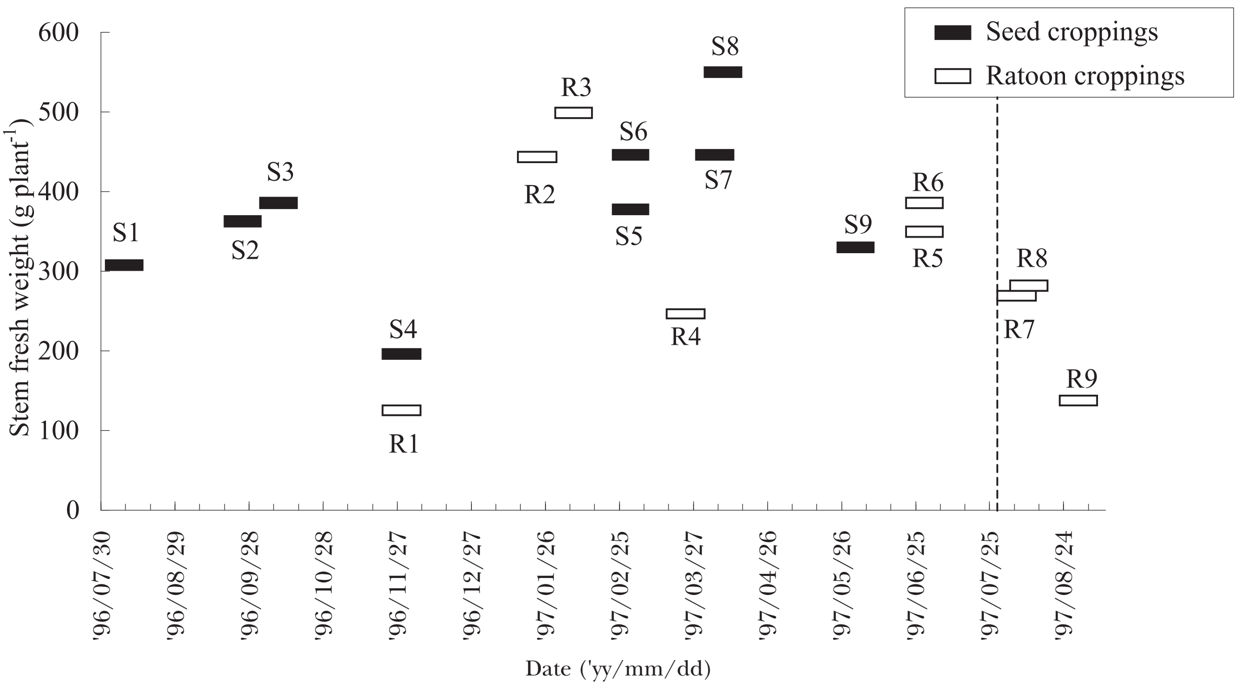


Fig. 8. Changes in stem fresh weight of sweet sorghum at harvest in Indonesia. Ten days of harvest comprise five days each before and after harvest.

35 DAS was 346 mm, that during 12–31 DAS was only 4 mm. Consequently, in the case where periodical precipitation during 0–35 DAS (DAR) is below 50 mm, or when no rain falls for more than 20 d, stem elongation is thought to be restricted.

In our previous study of sweet sorghum conducted in East Java for seed crop during the rainy season, we reported the importance of field condition until approximately 35 DAS to engender thicker stems because the stem diameter is determined by that time (Tsuchihashi and Goto, 2004). This timing corresponds to the beginning of floral initiation (House, 1985). As compared to the seed crop during rainy season, heading tends to be earlier in the dry season, and earlier for ratoon plants. Consequently, we assume that total leaf number and the number of internodes had already been decided depending on the field condition until 35 DAS (DAR). In R4, although the precipitation was 1,073 mm during growth, 363 mm during 0–35 DAR, and the periods of no rain were few, the plant height was 240 cm. Since the seed crop (S4) corresponding to R4 was the smallest among all seed crops, the stem elongation of ratoon plants may be suppressed, even under conditions of sufficient rainfall, if the corresponding seed plants exhibit poor growth. In R9, on the other hand, though the precipitation was only 22 mm during 0–35 DAR and no precipitation was recorded after that, the plants reached a height of 231 cm and could be harvested. Ratoon plants appeared to have better tolerance to drought conditions and have the advantage when started growth during the latter period of the dry season (August and September).

The number of elongated internodes exhibited a significant correlation with plant height, and was considered to be an indicator of plant height (Fig. 5). In our previous study, the stem lengths of the same number of internodes (14 internodes) was 60 cm shorter in the dry season than in the rainy season. In the dry season, the stem length with average number of internodes (12 internodes) was ca. 20 cm shorter than that with 14 internodes. These revealed that the difference in stem length is attributable to the differences in the number of internodes (25%) (Tsuchihashi and Goto, 2005). The present study confirmed this tendency. The total number of internodes is same as that of leaf. Thus, the number of elongated internodes is obtained by subtracting the number of non-elongated internodes from the total leaf number. The number of non-elongated internodes tended to be constant. As mentioned above, water stress during 0–35 DAS (DAR) is thought to cause a reduction in total leaf number; this in turn leads to a reduction in plant height via a decrease in the number of elongated internodes.

A comparison of the internode lengths at each position in seed and ratoon plants bearing the same number of elongated internodes revealed no large differences between the 2 plant types, although the shapes of their growth curves did differ slightly (Fig. 6). Previously, the internode length at each position was reported to exhibit a similar pattern for seed plants from dry and for those from rainy season (Tsuchihashi and Goto, 2005). It is estimated that the internode length at each position exhibits a similar pattern regardless of the season (dry or rainy), or whether plants are derived from seed or ratoon.

Stem length significantly correlated with stem fresh weight, and was considered to be an indicator of stem fresh weight (Fig. 7). The regression expression of ratoon plants exhibited a less steep slope than that of seed plants, suggesting that the stems of ratoon plants tend to be lighter than those of seed plants when they grow to heights greater than 300 cm.

Since sweet sorghum is a raw material for the fermentation industry, its year-round cultivation is desirable. The results of this study, which involved sowing sweet sorghum in almost every month, indicated that there were 4 periods during which no harvests could be obtained from sowing–the gaps between (1) S1 and S2, (2) S3 and S4, (3) S4 and S5, and (4) S8 and S9. During these gaps, the possibility of starting seed cropping are considered: (1) S1 and S2 exhibited good growth, and it is thought to be possible to harvest at any time between S1 and S2 by adjusting the sowing date. (2) It is highly possible to perform sowing depending on rainfall. (3) During the period between S4 and S5, since the germination rate was very low and even the germinated plants grew abnormally (died within a few days), no harvestable material were obtainable from seed plants. (4) Sowing is also possible between S8 and S9. These results suggest that it would not be possible to produce sweet sorghum throughout the year relying only on the plants derived from seed. Meanwhile, in the gap between S4 and S5, harvest was possible from R1, R2, and R3. Harvest is thought to be possible by starting ratoon from seed cropping between S1 and S2. Consequently, this study demonstrated that it is possible to produce crops of sweet sorghum in the savanna area of East Java throughout the year mainly from seed plants but also partially from ratoon plants during the most severe drought period of the dry season.

Ratoon cropping does not involve sowing because it utilizes regeneration stems, and it is a useful means of starting cultivation under drought conditions. However, the stems of ratoon plants tended to be lighter than those of seed plants when the plants grew taller (Fig. 7). This is partly because field management, i.e., the usage of fertilizers, has not yet been optimized for ratooning. In addition, the growth of plants from ratoon tended to be poor as can be seen from the correlation between S4 and R4, even when precipitation during the cropping period is sufficient.

Generally, it is suggested that ratoon cropping using current cultivation methods is less effective compared to seed cropping. In order to enhance the value of ratoon croppings, it is considered important to develop a management technique for better growth.

For the ratoon shoots of sugarcane, lodging, caused by lighter stems or by raising the stem base from the ground, is often a problem. Moreover, ratoon shoots in sugarcane emerging from deeper layers exhibit better stem characteristics (length, diameter, and dry matter production of stems) than those emerging from shallow layers (Miyahira and Kamiya, 1984). The importance of securing stems from deeper layers in sugarcane has also been reported by Satou and Yoshida (2001). In the case of sweet sorghum, although the ratoon stems generated from greater depths resulted in taller plants and heavier dry matter production (Goto et al., 1988), the positions of the tiller buds from which the ratoon stems are obtained are different from those of sugarcane. The harvested stems of plant canes (first cropping of sugarcane) elongate from the tiller buds of the seed canes, which are planted in the ground. Therefore, the base of the harvested stems and their tiller buds for the next cropping (ratoon) also exist below ground level. For sweet sorghum cropping, on the other hand, because it employs seeds for the first cropping, the mesocotyl emerging from the seed elongates and forms a stem near the ground surface regardless of the sowing depth. Therefore, the tiller buds for the ratoon stems are present near the ground surface or higher. Consequently, the lower position of sweet sorghum at harvest is not at ground level but 5 to 10 cm above it. Moreover, it has yet to be confirmed whether the relationship between the harvesting height and ratoon growth and the yield in Indonesia is same as that in Japan. In the case of rice, fertilizer application before harvesting is known to improve the regeneration buds (Tadokoro et al., 1999).

This year-round cultivation study of sweet sorghum revealed that it can mature throughout the year. In the future, cultivation techniques specific for each cropping season should be developed. Since the lesser seed crop may suppress the growth of ratoon crop (as in the case of S4 and R4), even under conditions with sufficient rainfall, it is suggested that good growth of seed crops is important for improvements in ratoon growth. The development of these cultivation techniques is a topic for future researchers aiming to enhance the value of sweet sorghum as raw material for the fermentation industry.

## References


FAO and UNESCO. 1976. FAO soil map of the world. Vol IX. Southeast Asia.

Goto, Y., Sakai, K., Hoshikawa, K. and Otomo, K. 1988. The productivity in the regrowth tiller of sweet sorghum, relating with its nodal position. Rep. Tohoku Br. Crop Sci. Soc. Jpn. 31 : 75-76**.

Hoshikawa, K., Takahashi, K. and Goto, Y. 1988. Characteristics of sweet sorghum with special reference to the cultivation in converted field from paddy. Res. Rep. Biomass Convers. Prog. 10 : 28-50*.

House, L. R. 1985. The sorghum plant : Growth stages and morphology. In House, L. R. A Guide to Sorghum Breeding. Second edition. ICRISAT, Andhra Pradesh. 11-25.

Inoue, Y., Koinuma, K., Mochizuki, N. and Tarumoto, I. 1988. Selection of superior varieties in sweet sorghum (*Sorghum bicolor*). Res. Rep. Biomass Convers. Prog. 10 : 1-13*.

Jackson, D.R., Arthur, M.F., Davis, M., Kresovich, S., Lawhon, W.T., Lipinsky, E.S., Price, M. and Rudolph, A. 1980. Development of sweet sorghum as an energy crop. Volume 1. Agricultural task. Work Performed Under Contract No. W-7405-ENG-92. U.S. Department of Energy. 1-169.

Miyahira, E. and Kamiya, J. 1984. Study on system of ratoon shoots in sugarcane. Bull. Okinawa Agric. Exp. Sta. 9 : 59-66*.

Miyake, M. 1983. Soil in Indonesia. JIRCAS report No. 46 : 17-24**.

Miyazato, K. 1986. Ratoon cultivation. In Sugarcane and its Cultivation. Japan Centrifugal Sugar Industry Association, Naha. 229-236**.

Salunkhe, D.K. and Desai, B.B. 1988. Postharvest biotechnology of sugar crops. Chapter 4 : Sweet Sorghum. CRC Press, Florida, U.S.A. 75-98.

Satou, M. and Yoshida, N. 2001. Characteristics of sugarcane variety 'NiF8' on stalk emergence or growth, and effect of dense planting, fertilizer application and early ridging to stalk emergence or growth. Bull. Kagoshima Agric. Exp. Sta. No.29 : 9-22**.

Sumantri, A. and Purnomo, E. 1997. Sweet sorghum research and development in Indonesia. Proceedings of First International Sweet Sorghum Conference. Institute of Botany, Chinese Academy of Sciences, China. 49-57.

Tadokoro, M., Kameshima, M., Yamamoto, Y. and Nakamura, H. 1999. Double cropping of paddy using ratoon, case study in Nangoku city, Kochi prefecture. Jpn. J. Crop Sci. 68 : 580-583**.

Tsuchihashi, N. and Goto, Y. 2002. Development of sweet sorghum as the raw material for fermentation in Indonesia. Research for current cultivation condition of grain sorghum and the introduction of sweet sorghum in Solo river area. Jpn. J. Trop. Agric. 46 (Extra issue 2) : 55-56.

Tsuchihashi, N. and Goto, Y. 2004. Cultivation of sweet sorghum (*Sorghum bicolor* (L.) Moench) and determination of its harvest time to make use as the raw material for fermentation, practiced during rainy season in dry land of Indonesia. Plant Prod. Sci. 7 : 442-448.

Tsuchihashi, N. and Goto, Y. 2005. Internode characteristics of sweet sorghum (*Sorghum bicolor* (L.) Moench) during dry and rainy season in Indonesia. Plant Prod. Sci. 8 : 601-607.


* In Japanese with English abstract.
** In Japanese.