Effect of Stubble Shaving after High-Level Cutting on the Growth and Yield of Forage Sugarcane, KRFo93-1, under Multiple Ratooning Cultivation

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Abstract: In the production of sugarcane, stubble shaving that cuts the residual stubble of the previous crop is carried out to promote ratoon crop growth. On the other hand, in the production of feed crops, it is generally considered that high-level cutting increases the yield of the regrowth crop. In this study, the growth and yield of the forage sugarcane subjected to high-level cutting without stubble shaving (HC) were compared with those of the plants subjected to stubble shaving (Control) to clarify the necessity of stubble shaving in the cultivation of a forage sugarcane variety, KRFo93-1. The influence of high-level cutting on the growth and yield of ratoon crop was evaluated from the first ratoon crop (RC1) to sixth ratoon crop (RC6). Tiller number in the Control plot was not different from that in the HC plots in all ratoon crops from RC1 to RC6. Stem length was significantly larger in HC than in the Control plot at the initial stage of regrowth, and in RC1, RC3, RC5 and RC6 around the harvest time. Dry matter yield was significantly higher in HC than in the Control plot in RC1, RC3, RC5, RC6 and in the sum of the ratoon crops. Although no significant difference was observed in RC2 or RC4, the dry matter yield of HC exceeded that of Control plot. The increase in the dry matter yield of HC was due to an enhancement of stem growth, since the single stem dry weight were larger in HC than in Control plot. Thus, cultivation management without stubble shaving is recommended in KR Fo93-1.

Key words: Dry matter yield, Forage sugarcane, High-level cutting, Multiple ratooning cultivation, Stubble shaving.

It is important in food security to raise the food self-sufficiency ratio. Japan has a calorie-based food self-sufficiency rate of 39%, and a feed self-sufficiency rate of only 25% according to the statistical data of the Ministry of Agriculture, Forestry and Fisheries of Japan in 2010. The self-sufficiency rate of concentrated feed in Japan is as low as 10% and that of roughage has fallen from a previous high of 100% to a recent measurement of 78%. Therefore, improvement in the self-sufficiency rate is needed not only with respect to concentrated feed but also roughage.

Sugarcane (Saccharum spp. hybrid) is cultivated widely in the tropical and subtropical zones for use in sugar production (conventional sugarcane). The cane tops — the terminal young parts of shoots that are a by-product of conventional sugarcane production — are commonly used as roughage during winter on the Nansei Islands of Japan. In addition to the cane tops, entire shoots, including the stems, leaves and cane tops, are utilized as feed (Pate et al., 1984; Martin, 1997; Kawashima et al., 2002).

Interspecific hybrids with high biomass productivity and good ratooning ability can be obtained by crossing conventional sugarcane with wild sugarcane (S. spontaneum) (Roach, 1977; Jackson, 1994; Nagarajan et al., 2000). The first forage sugarcane variety in Japan, registered as KR Fo93-1, was bred through interspecific crossing (Sakaigaichi and Terajima, 2008). The forage sugarcane is harvested in a shorter cycle, i.e., in two harvests per year compared with one for conventional sugarcane, in order to prevent lodging and suit mechanical harvesting (Sakaigaichi et al., 2010). The dry matter yield of KRFo93-1 is more than twice that of Rhodes grass, which is a widely grown grass species on the Nansei Islands. In addition, the ability to perform multiple ratooning that contributes to less labor-intensive cultivation is much higher in KR Fo93-1
than conventional sugarcanes. Nutritive advantages have also been reported for KRFo93-1 such as low nitrate concentration (Ishikawa et al., 2009) and small fluctuation of nutritive value during growth (Suzuki et al., 2010). Thus forage sugarcane is expected to be a new useful forage crop to improve the feed self-sufficiency rate on the Nansei Islands.

In the cultivation of forage sugarcane, both corn harvesters and cane harvesters are used. The mechanical cutting height of forage sugarcane is set at about 15 cm above the ground as well as other feed crops because mixing of soil reduces silage quality. Therefore, this cutting height is remarkably different from that of conventional sugarcane, which is harvested at around ground level.

The yield of the regrowth crop is increased by high-level cutting (Watanabe et al., 1969; Greub and Wedin, 1971; Tamura and Hoshino, 1971). Napier grass, which is a tall feed crop like sugarcane, also has been reported to exhibit increased growth of the ratoon crop in response to high-level cutting (Ito et al., 1991; Tudsri et al., 2002; Wijitphan et al., 2009). Thus high-level cutting is generally recommended in feed crops and the residual stubble is not removed. On the other hand, in the cultivation of conventional sugarcane, cutting the residual stubble of the previous crop at ground level or lower by stubble shaving is recommended as a post-harvest management technique in order to promote the growth of a ratoon crop (Yadav, 1992; Ahmed and Girdharan, 2000; Ramdoss et al., 2004; Singh and Singh, 2004; Singh et al., 2008).

To introduce laborsaving cultivation management, we examined whether the ratoon crop without stubble shaving has a yield as high as conventional management. However, fundamental information on this topic is still quite limited. In this study, the effect of high-level cutting on the growth and yield of KRFo93-1 under multiple ratooning cultivation was investigated. We also sought to clarify whether stubble shaving is necessary as post-harvest management for KRFo93-1.

Materials and Methods

1. Crop management

This study was conducted on a farmer’s field in Nishinoomote, Kagoshima prefecture, Japan (30º44’N, 131º04’E) from 2007 to 2011. The soil type in the field was Andosol. The forage sugarcane variety KRFo93-1 was used. Stem cuttings with one bud were planted on 16 April in 2007, where the planting density was 9.54 buds m$^{-2}$ (row space 110 cm, interhill space 9.5 cm). Chemical fertilizer was applied at the rate of 7.2 g N m$^{-2}$, 12.0 g P$_2$O$_5$ m$^{-2}$, and 6.0 g K$_2$O m$^{-2}$ per crop as basal dressing and at the rate of 9.0 g N m$^{-2}$ and 9.0 g K$_2$O m$^{-2}$ per crop as topdressing. The cultivation management conditions were almost the same as for conventional sugarcane, except that high earthing was not conducted. A harvest survey of plant crop was conducted on 4 October and the residual of crop were removed with a cane harvester at about 15 cm height above ground level, i.e., high-level cutting, on 10 October.

A control plot (Control) and high-level cutting plot (HC) were made in order to study the influence of high-level cutting on the growth of the ratoon crop (Fig. 1). The Control plot received the same post-harvest management as conventional sugarcane after harvested by high-level cutting. The ratoon crops of the Control plot underwent stubble shaving — i.e., cutting the residual stubble of the previous crop at ground level — upon the start of their regrowth. On the other hand, the ratoon crops in the HC plot were harvested by high-level cutting and not subjected to stubble shaving upon the initiation of regrowth.

This study was designed in a randomized block design with six replications. The area of each plot was 22.0 m$^2$ (four rows, 5.0 m long) and the plants in two central rows in each plot were investigated.
The ratooning cultivation was continued from the first ratoon crop (RC1) to the sixth ratoon crop (RC6) (Fig. 2). The harvest survey was conducted on 18 July 2008 in RC1, 14 May 2009 in RC2, 26 August in RC3, 17 May 2010 in RC4, 19 August at RC5 and 11 May 2011 in RC6. The residual of ratoon crops were harvested by the cane harvester on 23 July 2008 in RC1, 19 May 2009 in RC2, 27 August in RC3, 19 May 2010 in RC4, and 24 August 2010 in RC5. After that, stubble shaving of the Control plot was carried out immediately. As mentioned above, we harvested three times in two years in the first half period plant crop RC1 and RC2. In the second half period from RC3 to RC6, we harvested four times in two years, i.e., two harvests per year. The amount of chemical fertilizer applied to each ratoon crop was the same as that used for the plant crop.

2. Measurements

The tiller number, stem number, stem length, stem diameter, juice brix of stem, dry matter ratio and single stem dry weight were measured at the harvest. The tiller and stem number were investigated in the two central rows, which were 5.0 m long. The stem number was defined as the number of tillers minus “suckers”. Suckers indicated small tillers that formed in the late growth period. Ten stems with healthy and typical growth were sampled from the two central rows. Five of these stems were used to measure the stem length, stem diameter and juice brix of the stem. Stem length was defined as the length from the ground to the top lamina joint. Stem diameter was measured at the minor-axis portion of the node in the middle of the stem. After squeezing the stem in a mill, the juice brix of the stem was measured with a refractometer (ATAGO; RX500α). The other five stems were chopped into small pieces and dried at 80°C over 48 hr to determine the dry matter ratio and single stem dry weight. The dry matter yield was calculated as the product of the stem number and single stem dry weight. Dry matter increase ratio was also calculated by dividing dry matter yield by growth days.

The tiller number and stem length were investigated in all ratoon crops from RC1 to RC6 to study the effect of high-level cutting on the growth of the ratoon crop. The tiller number was counted along the 5.0 m length of both central rows. The same ten stems as used in harvest survey were selected as samples, and their stem lengths were measured non-destructively. In the HG plot, the tillers emerging from above-ground stubble nodes were also investigated. The stem elongation rate was calculated by dividing the stem length between adjoining measurements by growth days.

The monthly mean temperature and precipitation over the course of this study were measured with the meteorological equipment of the NARO/KARC Tanegashima experimental station located near the examination site. One-way analysis of variance (ANOVA) was conducted by using the statistical analysis package, SPSS ver.10.0.

Results

1. Climatic conditions

The monthly mean temperature and precipitation over the study period are shown in Fig. 2. The monthly mean temperature of winter, and the temperature over the growth period were low in RC6 (Fig. 2). The monthly mean temperature was lowest in January, i.e., 7.8°C, and was 12.0°C even in March. Frost damage was not observed.
because the location was in the thermal belt. There was slight growth regulation due to water shortage (by visual observation). Five typhoons passed in the course of this study, but the damage to leaves was slight and no breakage of stems was observed.

2. Growth and yield of the plant crop

The dry matter yields in the Control and HC plots were 3.26 kg m\(^{-2}\) and 3.14 kg m\(^{-2}\), respectively, in the plant crop that had not been treated with stubble shaving. There was no significant difference in dry matter yield between the Control and HC plant crops. There were also no significant differences in the shoot characteristics, such as the stem number, stem length, stem diameter and juice brix of the stem at harvest time (data not shown).

3. Change in the tiller number and stem length in succeeding ratoon crops

The change in the tiller number in RC1 to RC6 is shown in Fig. 3. In the HC plot, tillers emerged not only from below ground nodes but also above ground nodes that were residual stubble of the previous crop. These tillers emerging from above ground nodes are represented by the tillers in “HC (above ground)” in Fig. 3. In RC1 to RC6, the tiller number in HC (above ground) was much smaller than that emerged from below ground nodes and disappeared mostly as they grew (Fig. 3). This was because tillers in HC (above ground) were less vigorous and died due to shading by tillers emerging from the below ground nodes and nutrient deficiency derived from less aerial roots (by visual observation). Therefore, afterward in this study, tiller number in HC was indicated as the number of tillers emerged from below ground nodes and not included the tiller number emerged from above ground nodes.

Almost the same change in tiller number was observed in the Control and HC plots in RC1 to RC6 (Fig. 3). The tiller number was largest in the start of the ratoon crop and decreased gradually thereafter at RC3 and RC5, which grew only in summer. Although there were variations in the timing of the start of regrowth in the ratoon crops, one consistently observed fluctuation was that the tiller number increased in spring in RC1, RC2, RC4 and RC6.

The stem length was significantly larger in the HC than that emerged from below ground nodes and disappeared mostly as they grew (Fig. 3). This was because tillers in HC (above ground) were less vigorous and died due to shading by tillers emerging from the below ground nodes and nutrient deficiency derived from less aerial roots (by visual observation). Therefore, afterward in this study, tiller number in HC was indicated as the number of tillers emerged from below ground nodes and not included the tiller number emerged from above ground nodes.

Fig. 3. Effect of stubble shaving after high-level cutting on the tiller number.

Control: High-level cutting with stubble shaving, HC: High-level cutting without stubble shaving.

RC1 to RC6 mean first to sixth ratoon crops.

*, † and n.s. indicate the significant difference at 5%, 10% of probability and not significant, respectively.

Seasons are defined as follows, spring; March to May, summer; June to August, autumn; September to November, winter; December to February.

Tiller number in “HC” does not include the number of tillers emerging from the above ground nodes “HC(above ground)”. 
Fig. 4. Effect of stubble shaving after high-level cutting on the stem length.
Control: High-level cutting with stubble shaving, HC: High-level cutting without stubble shaving.
RC1 to RC6 mean first to sixth ratoon crops.
**, *, † and n.s. indicate the significant difference at 1%, 5%, 10% of probability and not significant, respectively.
Seasons are defined as follows, spring; March to May, summer; June to August, autumn; September to November, winter; December to February.

Fig. 5. The stem elongation rate in the Control and HC plots.
Control: High-level cutting with stubble shaving, HC: High-level cutting without stubble shaving.
RC1 to RC6 mean first to sixth ratoon crops.
**, *, † and n.s. indicate the significant difference at 1%, 5% of probability and not significant, respectively.
Seasons are defined as follows, spring; March to May, summer; June to August, autumn; September to November, winter; December to February.
but the stem length of HC exceeded that in the Control. The stem elongation rate was higher in RC3 and RC5, whose growing periods were only in summer (Fig. 5). Average stem elongation rate in RC3 and RC5 was 2.27 and 1.97 cm day\(^{-1}\) in HC, respectively. In RC1 and RC2, the stem elongation rate was also large in high temperature seasons such as summer. On the other hand, the stem elongation was small during low temperature seasons such as winter (Fig. 5). Therefore, the stem elongation rate throughout the whole growth period was low in RC1, RC2, RC4 and RC6. Average stem elongation rate in RC1, RC2, RC4 and RC6 was 0.68, 0.62, 0.49 and 0.43 cm day\(^{-1}\) in HC, respectively.

The period taken for canopy development was shorter in the HC than the Control plot because of the vigorous early growth in HC (Fig. 6).

### 4. Growth and yield of ratoon crops

The shoot characteristics and dry matter yield at the harvest time in RC1 to RC6 are shown in Table 1. There were no differences in tiller number, stem number and sucker number between the Control and HC plot in RC1 to RC6 (Table 1). The stem length, stem diameter and single stem dry weight were larger in the HC plot than in the Control plot, and significant differences in these parameters were observed in RC1, RC3, RC5 and RC6. In RC1 to RC4, the difference in the juice brix of the stem between the Control and HC plot was small, but in RC5 and RC6, it was significantly larger in the HC plot. The dry matter yield was higher in the HC plot than in the Control plot as well as single stem dry weight, and a significant difference in dry matter yield was observed in RC1, RC3, RC5, RC6 and sum of ratoon crops. Although the difference was not significant, the dry matter yield was also higher in RC2 and RC4 than in the Control.

The sum of dry matter yield in the plant crop and RC1 to RC6 for four years was 16.9 kg m\(^{-2}\) in the Control and was 18.9 kg m\(^{-2}\) in the HC plot (calculated from dry matter yield in plant crop described in Results and that in ratoon crops in Table 1). Calculated annual dry matter yield in the Control plot was 4.24 kg m\(^{-2}\) yr\(^{-1}\) and that in the HC plot was 4.71 kg m\(^{-2}\) yr\(^{-1}\). As shown above, both plots showed high dry matter productivity under multiple ratooning cultivation and the HC plot performed 11% higher yield

| Ratoon number | Treatment | Tiller number | Stem number | Sucker number | Stem length | Stem diameter | Juice brix | Dry matter ratio | Single stem dry weight | Dry matter yield | Dry matter increase ratio |
|---------------|-----------|---------------|-------------|---------------|-------------|---------------|-----------|------------------|------------------------|----------------|----------------------------|
|               | Control   | 22.1          | 20.5        | 1.6           | 178         | 18.9          | 4.9       | 15.9             | 112                    | 2.31           | 8.2                        |
|               | HC        | 21.9          | 20.7        | 1.2           | 192         | 19.7          | 4.5       | 16.2             | 130                    | 2.68           | 9.5                        |
| RC1           | n.s.      | n.s.          | n.s.        | **            | n.s.        | n.s.          | n.s.      | n.s.             | †                      | n.s.           | †                          |
| RC2           | Control   | 54.5          | 20.3        | 34.2          | 178         | 13.5          | 12.9      | 28.1             | 139                    | 2.83           | 9.6                        |
|               | HC        | 50.9          | 20.1        | 30.8          | 184         | 14.2          | 12.8      | 27.8             | 148                    | 2.98           | 10.1                       |
| RC3           | n.s.      | n.s.          | n.s.        | **            | n.s.        | n.s.          | n.s.      | n.s.             | n.s.                   | n.s.           | n.s.                       |
| RC4           | Control   | 19.5          | 18.5        | 1.0           | 216         | 17.8          | 6.0       | 19.3             | 135                    | 2.49           | 25.1                       |
|               | HC        | 18.3          | 17.6        | 0.7           | 225         | 19.7          | 6.2       | 19.6             | 167                    | 2.91           | 29.4                       |
| RC5           | Control   | 39.4          | 26.6        | 12.8          | 128         | 18.0          | 8.4       | 22.2             | 99                     | 2.63           | 10.0                       |
|               | HC        | 38.9          | 27.1        | 11.9          | 130         | 18.9          | 8.4       | 21.9             | 108                    | 2.91           | 11.1                       |
| RC6           | Control   | 49.8          | 17.8        | 32.0          | 97          | 15.2          | 8.2       | 20.5             | 69                     | 1.24           | 4.8                        |
|               | HC        | 47.3          | 18.3        | 29.0          | 113         | 17.5          | 9.0       | 21.5             | 93                     | 1.69           | 6.5                        |
| SUM           | Control   | –             | –           | –             | –           | –             | –         | –                | –                      | –              | –                          |
|               | HC        | –             | –           | –             | –           | –             | –         | –                | 13.7                   | –              | –                          |

Control: High-level cutting with stubble shaving, HC: High-level cutting without stubble shaving.

**,** *, † and n.s. indicate the significant difference at 1%, 5%, 10% of probability and not significant, respectively.

compared with the Control plot.

Discussion

There was no difference in the tiller and stem number, between the Control and HC plots (Fig. 3, Table 1). On the other hand, stem length was significantly larger in the HC than in the Control at the initial stage of regrowth in every ratoon crop, and there was a significant difference between the HC and Control plots in single stem dry weight at harvest time each in RC1, RC3, RC5 and RC6 (Fig. 4, Table 1). The dry matter yield in the HC plot was higher than that in the Control, and significant differences were observed between the two plots in each in RC1, RC3, RC5 and RC6 (Table 1). Thus, the trends in single stem weight and dry matter yield were similar in the ratoon crops. Therefore, the increase in dry matter yield in HC is thought to be derived from enhancement of the stem growth.

The increased stem length in the HC plot shown in Fig. 4 could be due to the absence of sucker damage caused by stubble shaving. Suckers formed in the late growth period in the Control plot were cut with a stubble shaver when the stubble of the previous crop was removed. On the other hand, suckers in the HC plot were not cut with a stubble shaver and grew as tillers in the next ratoon crop. This difference at the initiation of the ratoon crop could have been responsible for the better growth in the HC plots. The sucker number in the preceding crops (RC2 and RC4) was larger in RC5 and RC6 (Table 1), resulting in the higher growth and yield of HC (Figs. 4, 6, Table 1). A similar result was reported for Napier grass — i.e., regrowth enhancement was observed when a large number of shoot apexes survived below the cutting height (Ito et al., 1992).

Though the sucker number in the preceding crop (RC5) was small in RC6 as well as in RC2 and RC4, the stem length and dry matter yield of RC6 in the HC plot also exceeded those in the Control plot (Fig. 4, Table 1). The reserve carbohydrate content of stubble in the preceding crop could have contributed to the better growth in the HC plot. It is known generally that reserve carbohydrate of residual stubble after harvest is important for the regrowth in feed crops (Kumai and Sanada, 1973; White, 1973; Ichii and Sumi, 1983). As shown in Table 1, the juice brix of the stem was significantly higher in the HC plot than in the Control plot in RC5. Therefore, the content of reserve carbohydrate in the stubble of the RC6 crop at the start of regrowth should be higher in the HC crop than in the Control crop. It seems likely that the larger amount of stubble reserve carbohydrate promoted the ratoon crop growth in the HC plots in RC6. Although there was no difference in the juice brix of the stem between the Control and HC plots in RC2 to RC4, the content of reserve carbohydrate should be high in the HC plot because the residual stubble was removed in the Control plot. Therefore, it is probable that the growth and dry matter yield in the HC plots in RC1 to RC5 could be enhanced by the same effect as in RC6.

The growth period of RC6 was almost the same as that of RC4, but the growth duration of RC6 had a markedly low temperature (Fig. 2). The yield of RC6 relative to that of RC4 was 47% in the Control and 58% in the HC plot (Table 1), and HC showed a smaller decrease. Under severe environmental conditions such as low temperature, the HC plot could achieve a more stable yield than the Control plot due to enhancement of stem growth for similar reasons, such as the usage of sucker and reserve carbohydrate.

HC — i.e., the cultivation management without stubble shaving, has some advantages other than high yield. First, this post-harvest management technique is less labor intensive compared with conventional plant management, since the additional work of stubble shaving is not needed. Secondly, faster early growth in HC is thought to reduce labor for weed control. Slow early growth has been pointed out as a problem in sugarcane cultivation (Allison et al., 2007). In the present study also, the early growth was greater in the HC than in the Control plot, and the period taken for canopy development was shorter in HC than in the Control (Figs. 5, 6). Therefore, it is expected that the improvement of early growth in HC contributes to weed control by shading with the shoots of forage sugarcane, and leads stable growth of the ratoon crop.

Stubble shaving as a part of post-harvest management is recommended in conventional sugarcane (Yadav, 1992; Ahmed and Giridharan, 2000; Ramdoss et al., 2004), and stubble shaving is effective even in multiple ratooning cultivation (Singh and Singh, 2004; Singh et al., 2008). Roots have the function of absorbing water and nutrients. The root mass of a stem generated at shallow soil depth is smaller than that generated at deep soil depth because of the limited rooting zone (Miyahira and Kamiya, 1984). Thus stubble shaving is considered to be important to prevent concentrating the rooting zone at the soil surface (Yadav, 1992).

The dry matter yield in the HC plot exceeded that in the Control plot in this study, and this result did not correspond with the general knowledge of conventional sugarcane cultivation. Wild sugarcane is known as a breeding material that can be used to improve ratooning ability (Roach, 1977; Jackson, 1994). KRFo93-1 was bred by using wild sugarcane. It has been reported that an interspecific hybrid of sugarcane had a larger root mass and distribution (Sakaigaichi et al., 2007) and a higher physiological activity (Terajima et al., 2005) compared with conventional sugarcane. Although we cannot discuss this topic because we did not obtain sufficient data on the roots, the reason for the adaptability to high-level cutting observed here could be that KRFo93-1 has excellent below-
ground characteristics, such as rooting zone and root function. In the future, it will be necessary to examine the varietal difference of adaptability to high-level cutting.

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