Growth and Dry Matter Production of Sugar Cane in Warm Temperate Zone of Japan

4. Effect of air temperature on young plant growth and photosynthetic rate at the active-tillering stage and the late growth stage*

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Abstract Development of shoot and root under different air temperature conditions was examined to enhance the young plant growth in sugar cane. The number of set roots was not influenced by different air temperature in the range of 15°C to 30°C. The relationships between the development of shoot roots, and tillers and the increase of leaf number on the main stem depended on the air temperature conditions. Plant length was longer at higher air temperatures in the range of 15°C to 30°C. Therefore, it was considered that vigorous young plants with a higher growth activity and larger number of tillers could be obtained by using the setts from the middle or higher nodes and by maintaining the air temperature at 20°C or higher in sugar cane. Furthermore, the effect of the air temperature on the photosynthetic rate per leaf area was studied at the active-tillering stage and the late growth stage in sugar cane plants treated with different quantities of water. Optimum air temperature required for the increase of the photosynthetic rate per leaf area decreased from the active-tillering stage to the late growth stage along with the seasonal changes in air temperature in sugar cane plants growing in the temperate zone of Japan. Moreover, water requirement to maintain a higher photosynthetic rate per leaf area decreased with the progression of the growth stages as well as with the seasonal changes in air temperature during the growth of sugar cane in that zone.

Key words Air temperature, Photosynthetic rate, Seasonal change, Sugar cane, Water requirement, Young plant

Introduction
Sugar cane is characterized by a high dry matter yield with a high dry matter digestibility. Generally, the dry matter yield of newly planted crops is lower than that of ratoon crops in sugar cane. In the previous study, the slow growth observed for one month after planting in all the varieties used may be ascribed to the specific characteristics of sugar cane which requires a long period of

Received March 4, 1994

* This work was presented at the 58th (October, 1985) and 60th (October, 1986) Meeting of Tropical Agriculture Research Association of Japan
time for starting active growth in new plantings. Accordingly, the low dry matter yield of the newly planted crops compared with the ratoon crops is mainly attributed to the slow growth at the early growth stage in sugar cane. The duration of sugar cane growth which ranges from 6 to 7 months in the warm temperate zone of Japan, is the major limiting factor for sugar cane production in that zone. Consequently, since it is very important for sugar cane production to secure active growth at the early growth stage, cultivation of newly planted crops in the warm temperate zone of Japan is recommended. Takamura and Watabe reported that a higher crop growth rate of sugar cane could be obtained in the middle of August by the planting of germinated setts in a protected nursery. Therefore, it is suggested that newly planted crops could produce the same dry matter yield as that of ratoon crops by promoting the young plant growth.

On the other hand, leaf digestible dry matter (DMD) ranged from 45% to 54% and stem DMD from 72% to 78% in sugar cane. The development of stem accounts for most of the dry matter yield for forage production, because stem DMD is usually higher by 25% than leaf DMD. It has been shown that seasonal changes in the air temperature, rainfall and solar radiation influence the growth of sugar cane. According to Ono, seasonal changes in the elongation of internodes on the main stem were more pronounced than those observed in older sugar cane plants. Besides, many studies have shown that the elongation of the sugar cane stem is affected by the air temperature and soil moisture content. Moreover, Murayama et al. reported that the crop growth rate increased through the increase of the net assimilation rate brought about by irrigation in sugar cane. In the previous study, we observed that the leaf area ratio of sugar cane was lower than that of other C₄ crop species, and that the relative growth rate of sugar cane was maintained through the high net assimilation rate compared with other plants. Therefore, it is suggested that the analysis of the seasonal changes of the photosynthetic rate in the temperate zone of Japan is important to enhance the utilization of dry matter production of sugar cane within the short growth period in such a zone.

In this study, we examined the development of shoot and root under different air temperature conditions to enhance the young plant growth in newly planted sugar cane. Furthermore, the effect of the air temperature on the photosynthetic rate was studied at the active-tillering stage and the late growth stage in sugar cane plants treated with different quantities of water.

Materials and Methods

1. Expt. 1

The sugar cane varieties Ni1 and NiN2, in which the stems were harvested on 7 December 1984 in the experimental field of Okayama University were used for this experiment. Prior to examining the effect of the air temperature on the young plant growth, a germination test was conducted to compare the germination vigor of lateral buds taken from different nodes i.e., the lower nodes (1st node to 7th node), the middle nodes (8th node to 14th node), and the upper nodes (above 15th node). They were used as setts with one lateral bud each. On 21 April 1985, 20 setts from each nodal position were planted in plastic vats (56 × 33 × 16 cm depth), which were filled with sandy soil as nursery beds, under 30°C air temperature and natural sunlight conditions in the phytotron of Okayama University. The changes in the germination percentage of lateral buds taken from different nodes were monitored for 15 days after planting. The number of scale leaves in the lateral bud from different nodes was measured by using a microscope in Ni1.

After the germination test, young plants of Ni1 from the middle node setts were maintained at four levels of air temperature (15, 20, 25 and 30°C) in the phytotron on and after 6 May 1985 for 40 days. Plant length, leaf number on the main stem, number of shoot roots and tillers were determined for 20 plants every 10 days during the treatment. The number of set roots (number of roots developed from the root band of setts) was counted at the end of the treatment. Nitrogen, phosphate and potassium were applied at the rate of 3.0g each per vat before planting. Watering was applied two times per day to
maintain the soil moisture content at 20% (dry weight basis). The soil moisture content was estimated from the values of electric resistance in soil that were measured through plaster blocks installed at a depth of 8cm in soil.

2. Expt. 2

Young plants (3.5 leaf age) of the sugar cane varieties Ni1 and NiN2, grown at 30°C in the phytotron with natural sunlight were transplanted at the rate of one plant per 1/5000a Wagner pot filled with sandy loam on 18 May 1985. They were cultivated in the green house of Okayama University until 20 July. Nitrogen, phosphate and potassium were applied at the rate of 3.2 g each per pot as basal dressing. All the pots were transferred to the Arid Land Research Center, Tottori University, for further experiments on 21 July.

Photosynthetic rate was measured for Ni1 at three levels of air temperature (25, 30 and 35°C) in the air conditioned apparatus “Aridtron” by using an Infrared Gas Analyzer on 23 to 25 July at the active-tillering stage. Aridtron was controlled at 50% relative humidity and 30klx light intensity at the top of the pot. Plant materials were watered starting from the day before the determination of the photosynthetic rate as follows: 500g pot⁻¹ d⁻¹ as water-saturated plot (equivalent of the field capacity), 350g pot⁻¹ d⁻¹ as control plot, and 200g pot⁻¹ d⁻¹ as water-saving plot. Leaf area per plant was measured after the determination of the photosynthetic rate. Six plants per each watered plot were used for the measurements.

The plants of the variety NiN2 were transplanted at the rate of one plant per 1/2000a Wagner pot that was filled with sandy loam on 26 July. All the three major elements were applied at the rate of 2.5g each per pot. Photosynthetic rate at the late growth stage was measured for NiN2 at different air temperatures (18, 20, 23, 25, 28 and 33°C) in the Aridtron controlled at 50% or 70% relative humidity and 30klx light intensity at the top of the pot on 6 to 9 November. Plant materials were watered starting from the day before the measurement as follows: 1000g pot⁻¹ d⁻¹ as water-saturated plot, 600g pot⁻¹ d⁻¹ as control plot, and 200g pot⁻¹ d⁻¹ as water-saving plot. After the determination of the photosynthetic rate, leaf area per plant was measured. Four plants per each watered plot were used for the determination of the photosynthetic rate.

Results and Discussion

1. Effect of air temperature on the young plant growth

The changes in the germination percentage of the lateral buds from different nodes in Ni1 and NiN2 are shown in Fig. 1. Germination percentage increased markedly in the lateral buds of the higher and middle node setts in both Ni1 and NiN2. Germination rate was around 80% in the lateral bud of the higher node setts and more than 80% in that of the middle node setts after the 15th day. Higher germination vigor was observed in the lateral buds of the setts from the higher and middle nodes. These results largely agreed with the findings of Clements2), Teruya and Hayashi25). Since the growing point of the lateral bud was covered with a few scale leaves, the number of scale leaves was counted in the lateral buds of the setts from the lower and middle nodes by microscopic observation. Lateral bud of the lower node setts had 11 scale leaves, namely 2 more scale leaves than that of the middle node setts. A larger number of scale leaves was observed in the lateral bud of the lower node setts in the current experiment, and this tendency was

![Fig. 1 Changes in germination percentage of lateral bud in setts from different nodes. Open circles indicate Ni1, closed circles indicate NiN2. ---, higher node setts; ----, middle node setts; ----, lower node setts.](image-url)
also reported by Teruya and Hayashi25). Although Ni1 used in the current experiment had 2 or 3 more scale leaves than that grown in Okinawa25), the germination rate was closely associated with the number of scale leaves in the lateral bud. On the basis of these results, the setts from the middle nodes were used in the following experiment.

The changes in plant length and leaf number of the main stem monitored for 40 days during the air temperature treatment are shown in Fig. 2. Plant length increased markedly in the higher air temperature plot. Then, in the 30°C plot followed by the 25°C, 20°C and 15°C plots the plant length was longer at the end of the treatment. There were fewer leaves on the main stem in the 15°C plot than in the other plots, and the difference was not significant during the treatment in the three plots except for the 15°C plot.

On the other hand, since the number of set roots observed at the end of the treatment ranged from 31 to 35, the difference was not significant among all the plots (Table 1). The number of set roots is limited by the number of root primordias in the root band of setts, and only some of the primordias develop17). According to Miyazato12), some of the root primordias remain dormant under normal conditions, and rooting from dormant primordias occurs when the environmental conditions change rapidly. In the current experiment, the number of set roots was similar at the four levels of air temperature. The development of set roots was definitely affected by the air temperature under stable conditions.

Figure 3 shows the changes in the number of shoot roots and tillers during the treatment. The first shoot root was observed after the 10th day when the plant was at the 3rd leaf stage in the 25°C plot, and was not observed in other plots. The number of shoot roots was apparently smaller in the 15°C plot than in the other plots, while the differences between 30°C and 20°C, and 20°C and 25°C were not significant at the end of the treatment. Generally, set roots display a lower environmental resistance ability, and sugar cane is very susceptible to various environmental changes for a certain period of time until shoot root emerges after planting22). According to Lin and Hoshikawa11), the first shoot root emerges at the 13th leaf (8 scale leaves and 5 complete leaves) emergence stage, and this time relationship does not change with the soil moisture content, soil fertility, planting season and age of setts. According to Miyazato12), the effect of the air temperature on root growth is poorly documented. Generally, the minimum temperature for root growth ranges between 10°C and 12°C, and the optimum temperature ranges between 32°C and 35°C in sugar cane.

### Table 1
Set root number at the end of the air temperature treatment in Ni1

<table>
<thead>
<tr>
<th>Air temperature</th>
<th>Set root number</th>
</tr>
</thead>
<tbody>
<tr>
<td>15°C</td>
<td>34.1±2.9</td>
</tr>
<tr>
<td>20°C</td>
<td>31.3±3.9</td>
</tr>
<tr>
<td>25°C</td>
<td>35.5±3.9</td>
</tr>
<tr>
<td>30°C</td>
<td>34.6±2.0</td>
</tr>
<tr>
<td>LSD (P = 0.05)</td>
<td>9.8</td>
</tr>
</tbody>
</table>

Values represent mean±standard error.
It was interesting to note that the first shoot root was observed at the 3rd complete leaf stage in the 25°C plot in the current experiment, and that shoot root development varied with the air temperature conditions.

Increase of the tiller number during the treatment was different in the four plots (Fig. 3). The first tiller was observed after the 10th or 20th day when the plants were at the 3rd leaf stage in the 30°C, 25°C and 20°C plot. However, no significant differences in the tiller number were observed at the end of the treatment in three plots except for the 15°C plot. Although, the primary tiller bud appears on the 6th to 9th node, tiller from the 6th node can not grow sufficiently and that from the 7th node appears at the soil surface when the plant is at the 5th leaf extraction stage in conventional cultivation of sugar cane12). Since, the first tiller was observed at the 3rd leaf stage (the 4th leaf extraction stage) in the current experiment, it was considered that the development of the tiller from the lower node was affected by the changes in the air temperature.

Sugar cane varieties which developed many stems at a late stage could not grow well within a limited period of time for sugar cane production in the warm temperate zone of Japan4). Therefore it is important to secure a larger number of tillers at the early growth stage to obtain a higher dry matter yield in that zone. Although the plant length was longer at higher air temperatures, no distinct differences in the number of leaves on the main stem, shoot roots and tillers were observed for air temperatures in the range of 20°C to 30°C. Consequently, it may be possible to obtain vigorous young plants of sugar cane by maintaining the air temperature at 20°C and higher.

2. Effect of air temperature on the photosynthetic rate in plants treated with different quantities of water

The changes in the photosynthetic rate per leaf area with air temperature at the active-tillering stage in the N11 plants treated with different quantities of water are depicted in Fig. 4. Photosynthetic rate was maximum at 30°C and decreased at 35°C in the water-saturated plot. The lower the air tempera-
ture in the range between 25°C and 35°C, the larger the photosynthetic rate per leaf area in the control plot and water-saving plot. The photosynthetic rate of the plants in the water-saturated plot was almost the same as that of the plants in the control plot at 25°C and 35°C, and larger than that of the plants in the control plot and water-saving plot at 30°C. Photosynthetic rate of the plants in the water-saving plot was lower than that of the plants in other plots at air temperatures ranging from 25°C to 35°C.

Maximum value of the photosynthetic rate per leaf area in the water-saturated plot was the same as that in some sugar cane varieties under 30klx reported by NAKAMA et al. However, the maximum photosynthetic rate per leaf area was recorded at a leaf temperature of about 35°C in three types of sugar cane plants classified by SHIMABUKU and KUDO as tropical type, subtropical type and temperate type. In the current experiment, a larger photosynthetic rate per leaf area was found at an air temperature of 30°C and a lower one in all the watered plots. According to INOUE, the canopy temperature of the corn community varied in the same way as that of the ambient air temperature and was lower by 2 to 5°C under constant conditions for the other factors. Then, since the canopy temperature was relatively lower than the mean temperature of the upper layer of the crop community, the leaf temperature could be estimated by the canopy temperature using the following equation in corn: leaf temperature = -0.86 + 1.08 x canopy temperature. In the current experiment, six plants per each watered plot were set up in the Aridtron for the determination of the photosynthetic rate at the active-tillering stage. By applying the findings of INOUE to the current experimental conditions for the determination of the photosynthetic rate, the leaf temperature of the sugar cane plant was estimated to be higher by 0.6°C to 3.6°C than the ambient air temperature. Therefore, it was considered that the optimum temperature for the increase of the photosynthetic rate per leaf area of sugar cane grown in the temperate zone of Japan was not appreciably lower than that of the plants grown in Okinawa under adequate watering conditions.

Figure 5 shows the changes in the photosynthetic rate per leaf area with the air temperature in the range from 18°C to 33°C at two levels of atmospheric humidity at the late growth stage in NiN2 plants treated with different quantities of water. The lower the air temperature (18°C to 33°C), the larger the photosynthetic rate per leaf area at both 70% and 50% relative humidity in all the watered plots. The water-saving plot showed the most conspicuous changes in the photosynthetic rate with the air temperature at two levels of atmospheric humidity followed by the water-saving plot and the control plot. However, the photosynthetic rate of the water-saving plot was larger than that of the water-saturated plot and control plot at temperatures ranging from 18°C to 25°C at 70% relative humidity. Water-saving plot showed a larger photosynthetic rate per leaf area than the control plot and water-saturated plot at air temperatures ranging from 18°C to 23°C at 50% and 70% relative humidities.

The air temperature associated with the higher photosynthetic rate was found to be lower during the winter season than during the summer season in evergreen broad leaf trees distributed in the temperate zone. Optimum air temperature for the increase of the photosynthetic rate changed with the planting seasons in young wheat seedlings.
In the current experiment, the highest value of photosynthetic rate per leaf area of sugar cane was recorded at 30°C in the water-saturated plot at the active-tillering stage and at 18°C in the water-saving plot at the late growth stage. The air temperatures in the Aridtron associated with the highest values of photosynthetic rate per leaf area at the active-tillering stage or the late growth stage were almost equal to the maximum daily air temperatures in the growing season of the plant materials used in the current experiment\(^1\). Consequently, optimum air temperature for the increase of the photosynthetic rate is likely to vary with the seasonal changes of the air temperature during the growth period of sugar cane in the temperate zone of Japan. Moreover, the highest value of photosynthetic rate per leaf area was observed in the water-saturated plot at the active-tillering stage and in the water-saving plot at the late growth stage, respectively. Abundant sunshine and dry conditions are important for the ripening of sugar cane for sugar production\(^1\). According to Murayama et al.\(^1\), the crop growth rate increased through the increase of the net assimilation rate from July to August and did not change during other periods by irrigation in sugar cane. It is likely that the amount of water required for sugar cane growth changes with the progression of the growth stages and also with seasonal changes of the air temperature.

As described above, it is considered that the relationships between crown root development, tiller development and the increase of the leaf number on the main stem vary with the changes in the air temperature. Then, vigorous young plants with higher growth activity and larger number of tillers may be obtained by using the setts from the middle or the higher nodes and by maintaining the air temperature at 20°C or higher in sugar cane. Moreover, the optimum air temperature for the increase of the photosynthetic rate decrease from the active-tillering stage to the late growth stage along with the seasonal changes in the air temperature during the growing season of sugar cane in the temperate zone of Japan. Water requirement to maintain a higher photosynthetic rate decreases with the progression of the growth stages and with the seasonal changes in the air temperature during the growing season of sugar cane in that zone.

**Acknowledgments**

The authors are indebted to Mr. Masakatsu Yamane, Associate Professor, Arid Land Research Center, and Dr. Masao Toyama, Associate Professor, Arid Land Research Center, Tottori University, for the determination of the photosynthetic rate.

**References**


