USE OF GIBBERELLIC ACID TO INCREASE SUGARCANE YIELDS IN HAWAII

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ABSTRACT

A review of growth and yield responses of sugarcane to exogenously applied gibberellic acid (GA$_3$) is presented. Consistent increases over controls of fresh weight of stalk tissue of plants treated with GA$_3$ were obtained under the following conditions: (1) treating the best-responding varieties; (2) preferentially treating the higher elevation fields of lowland varieties; (3) timing the GA$_3$ applications to coincide with winter stunting; (4) allowing sufficient time before harvest for ripening of GA$_3$-produced growth, and (5) applying GA$_3$ serially in doses of 1.0 mg or less per stalk at 15-to-30 day intervals.

These conditions were met in field tests in Hawaii where significant gains were made in fresh weight per stalk without a reduction in cane quality. Weight gains were comparable to yield increases of 1.75 metric ton sugar per hectare. Thus, under carefully selected conditions, GA$_3$ appears to have good potential for use in Hawaii.

INTRODUCTION

Gibberellins were discovered in 1926 by the plant pathologist, Kurosawa, who was working on the bakanae disease of rice (Oryza sativa). Early symptoms of this disease include excessive stem elongation, increased lodging, and poor seed set; thus, the name bakanae or "foolish seedling" was coined for the disease. Kurosawa found that media in which the causative organism, Gibberella fujikuroi or Fusarium moniliforme, had grown would stimulate the growth of rice seedlings even though the seedlings were not infected (Kurosawa). In 1935, Yabuta obtained an active preparation from culture media and named it gibberellin after the fungus from which it was isolated.

Western scientists learned of the Japanese experiments in about 1950 and by 1955 had gibberellins available for experimental and commercial purposes. Within 5 years, many plant species and several physiological processes were found to be affected by gibberellins. The most obvious response to gibberellin applications was
the increase in stem length. Attempts to use gibberellic acid (GA₃) to increase sugarcane yields were first reported in 1956. Since then, a number of conflicting papers have appeared to report the effects of GA₃ on sugarcane and the potential of this hormone for increasing sugar yields. Our recent experiences seem to resolve some of the discrepancies of earlier reports and to indicate a positive potential for use of GA₃ on sugarcane in Hawaii.

In 1956, it was reported that a series of 4 applications of GA₃ caused a 50% increase in stalk fresh weight and a 300% increase in grams pol in young sugarcane stalks (Anon¹). The total amount of GA₃ used was 80 ug/stalk applied in the whorl of leaves surrounding the spindle leaf. This amount was found not to affect cane growth if the GA₃ was applied as a foliar spray rather than directly to the spindle (Anon²).

Field studies established to evaluate the effects of GA₃ on sugarcane yields and reported in 1958 and 1959 failed to show the expected yield increase (Coleman¹¹, Villareal and Santos²⁴). However, indications were given in one of these studies that sugarcane was most responsive to GA₃ when plants were grown under cool weather stress conditions (Coleman¹¹).

Subsequent studies reported in 1961 on individual stalk treatments again showed the potential for effective use of GA₃. The fresh weights and lengths of selected stalk segments were doubled and there was no effect on the pol: fiber ratio. These results were used to calculate a yield gain of 4.0 metric ton per pol hectare (Anon⁴)

To resolve some of the reasons for variable responses in sugarcane, Bull⁹ used growth chamber experiments to quantify the effects of temperature, variety, and plant age. The magnitude of the GA₃ responses was found to be a function of each variable. Greatest response was found with younger plants at lower temperatures.

Field trials in Australia with GA₃ confirmed many of the growth chamber results, established time-rate effects, and indicated a good potential for GA₃ to increase sugarcane yields. Significant gains (25% increases) in yields of sugar per hectare were obtained (Anon⁵). A major requirement for maximum response was an adequate time, usually a minimum of 3 months, between the last GA₃ application and harvest. The optimum amount of GA₃ was about 210 g per ha. Multiple applications were more effective than single applications. No significant differences were noted in cane yields when the time between applications was varied from 3 to 9 weeks.

In field trials in Hawaii²³, the high variance in mill harvest yields made it difficult to assess the effects of GA₃ treatment. Nevertheless, GA₃-treated plots showed gains in about two-thirds of the tests. The average gain per hectare was 11.2 metric tons cane and 0.9 ton pol.
Greenhouse experiments in Puerto Rico expanded information on the post-stimulatory slow growth phase that sugarcane exhibits following GA₃-promoted growth (Alexander, et al.², Mathur and Saxena¹⁴). This led to multiple applications of GA₃ in smaller doses as a method for avoiding the growth reduction (Alexander A.G.*, and Singh²⁰). Additional greenhouse experiments in the early 1970's included studies on possible enzymatic regulatory roles of GA₃ (Alexander⁶ and Gayler and Glaziou¹²) and the interaction of GA with mineral nutrition (Alexander⁵) and growth inhibitors or ripeners (Yates²⁶,²⁷).

By 1975, the 20th year after the original work on the effect of GA₃ on sugarcane, several generalizations could be made:

1. The greatest increases of growth in response to GA₃ occur when sugarcane is growing under stress of cool weather or drought.
2. Although all sugarcane varieties respond to GA₃, considerable differences exist among varieties in the magnitude of response to a given amount.
3. The amount of GA₃ in a single application, required to produce maximum weight is a function of variety, environment and efficiency of application. Nevertheless, the maximum GA₃ per hectare should not exceed 210 g.
4. Maximum effectiveness of a given amount of GA₃ is obtained with multiple applications of a traditional amount.
5. The amount of fresh weight gain due to GA₃ is highly variable because it is a function of the plant interaction with the environment. However, the gain is generally around 11 metric tons per hectare and can be increased by optimizing the conditions listed above.

ADAPTATION TO HAWAIIAN CONDITIONS.

It is now necessary to expand the above summary of results with GA₃ on sugarcane to the particular cropping system practiced in Hawaii. As noted, the maximum effect of GA₃ on sugarcane was seen when the cane was stunted or dwarfed by growing it under cool, growth-limiting conditions (Bull⁹, Coleman¹⁷ and Mongelard and Mimura¹⁵). Data presented in Fig. 1 show that stalk fresh weight, stalk length, and sugar content per stalk were greatly increased by GA₃ at lower temperatures but not at higher temperatures. GA₃ had almost no effect on these parameters when plants were grown at temperatures of 23°C or higher.

The annual mean temperature distribution and the volume growth rate of sugarcane in Hawaii show essentially coincident curves (Fig. 2). Growth rates are relatively high in the summer months when the mean temperature is about
Percent increase in:

(1) Stalk (2) Sugar (3) Fresh Length Content Weight
(cm/stalk) (g/stalk) (g)

--- 2,000 200

Stalk length

Fresh weight

Sugar content (per stalk)

fig. 1: Effect of weekly doses of 0.02 mg/stalk of gibberellic acid on 3-month-old plants of sugarcane (W. Pindar) growing at various temperatures. Data expressed as a percent of the values of the controls not treated with GA3. (Data from Bull, 1964.)

26°C and they are relatively low during the winter months when the mean temperature is just over 20°C (Stender27). While summer growth cannot be greatly increased by GA3, because of the gibberellin x temperature interaction, that of winter can be significantly increased with GA3.

The sugarcane crop in Hawaii is generally grown for 24 months. Thus, regardless of planting or ratooning dates, winter occurs during developmental stages of maximum growth potential (Fig.3) (Shaw and space Swezey18). The potential yield loss to slow growth during winter seasons can be extrapolated from a generalized growth curve obtained by averaging the growth curves of crops planted throughout the year (Fig. 4). If growth rates were not reduced by winter season, yields of the Hawaiian sugarcane corp would be expected to be increased by about 14% for each winter of the crop cycle (Moore18).
GA$_3$ has potential for reducing the winter loss, but the potential is limited in part by characteristics of sugarcane response to GA$_3$. It has been reported that GA$_3$ stimulates about 1 month of stalk growth and causes lowering of cane quality for about 3 months (Villarea and Santac). It has also been demonstrated that for maximum results, a minimum of 3 months is required between the last GA$_3$ application and harvest Anon. Additional time may be required if, as in Hawaii, chemical ripeners crop is scheduled for harvest early in the milling (Fig. 5). In addition, the inhibitory effect on tillering and the phytotoxic effects of high amounts of GA$_3$ on young sugarcane plants, (Moore and Singh) should preclude the use of this compound during the first winter of later-started crops. Thus, optimum use of GA$_3$ would be obtained by selectively treating crops in one winter or both, depending on the stage of development of the crop during the cool months.

Sugarcane varietal differences in response to GA$_3$ are well documented (Bull and Moore). We tested the growth responses of 10 Hawaiian commercial varieties to 1.4 or 4.2 mg GA$_3$ per stalk given in a single application to the upper leaf whorl. All varieties grew in response to both treatments and there were no statistically significant differences among them to either dose. However, there were significant differences among varieties in how they responded to the increase from 1.4 to 4.2 mg GA$_3$. For example, some varieties such as H50-7209, H58-4392 and H60-5657, grew significantly more in response to the 4.2 mg treatment than to the 1.4 mg

**FIGURE 2.** Relationship — between mean monthly temperature and the growth in volume of sugarcane. (Growth data from Stender, 1964.)
FIGURE 3. Effect of season on growth of sugarcane in Hawaii. The four curves represent crops planted four different times. (Modified from Shaw and Swezey, 1937).

treatment. Other varieties, however, e.g. H54-775, H56-278 and H56-4848, gave either a very small increase or actually grew less in response to the greater than to the lesser amount of GA$_3$ (Fig. 6). The former are varieties selected and cultured in lowland conditions under solar radiations and temperatures higher than those existing in the highland environment. The latter varieties are recognized as highland types. Thus, the responses of the varieties could be correlated with the environmental distribution of each.

By describing the environment in terms of the mean daily solar radiation, a correlation coefficient of 0.723 was found between the environmental zone of the variety and its mean weight increasing amounts of GA$_3$. It appears that the high-elevation varieties have a relatively low requirement for applied GA$_3$, while the low elevation varieties can utilize relatively higher amounts of GA$_3$. Consequently, in Hawaii we have placed emphasis on treating lowland varieties which are growing at their highest elevation range.

The amount of applied GA$_3$ required to produce maximum gains in sugarcane fresh weight and sucrose per stalk is a function of cultivar, environment, and physiological condition of the crop. Applications of GA$_3$ in excess of the amount which produces maximum increases in stalk fresh weight result in no additional growth increases and may at times result in adverse plant reactions such as loss...
Figure 4. The effect of season and gibberellic acid treatment on theoretical yield of sugarcane. (A) Generalized crop growth curve and yield without GA$_3$. (B) Yield potential in response to GA$_3$ treatment one winter season: (B-1) GA$_3$ applied 1st winter; (B-2) GA$_3$ applied 2nd winter season. (C) Yield potential with GA$_3$ treatments both winter seasons. Note that GA$_3$ can be expected to elicit more growth in the 1st winter than the 2nd winter because by the 2nd winter the crop has nitrogen deficit.

of chlorophyll, reduced leaf area, stalk splitting and breaking, and less stalk fresh weight gain than by untreated stalks (Moore and Burem). To overcome this problem, we used serial applications of fractional amounts of GA$_3$ to increase growth gains due to GA$_3$ while simultaneously reducing plant damage caused by the same amount of GA$_3$ given as a single application (Burem and Moore).

GA$_3$ treatment variables tested on a per stalk basis included:

1. Number of GA$_3$ applications
2. Amount of GA$_3$ applications
FIGURE 5. Time of crop starting and harvesting on a 24-month cycle and identification of which winter each crop has potential for treatment with GA₃.

3. Number of days between successive applications
4. Total amount of GA₃ applied.

A shorthand method will be used subsequently to designate each treatment, including information on each variable. For example, 3 x 0.5 @ 15 means that 3 applications of 0.5 mg GA₃ per stalk were made at 15-day intervals for a total of 1.5 mg GA₃ per stalk.

The results of an experiment designed to determine the optimum time interval between successive 1.0 mg GA₃ per stalk applications are presented in Table 1. The 1.0 mg GA₃ applications at 15 and 30 days showed significantly greater growth increases than a single 1.0 mg or a single 2.0 mg application and were greater than applications at 45-day intervals. Although the 15-day and 30-day interval treatments produced similar growth gains, the 15-day treatment resulted in considerably more dead and broken stalks, 18% vs. 2.8%. Most broken stalks apparently have grown rapidly following GA₃ application and produced internodes longer than the sheath normally enclosing them. Consequently, they were easily broken by the weight of the leaf canopy and wind.

Three or four applications of 0.5 mg GA₃ per stalk per application were tested at 15 and 30-day intervals to determine whether doses smaller than 1.0
FIGURE 6. Dose response curves to increasing amounts of GA$_3$ of sugarcane varieties selected for culture in different environmental zones. Data represent the mean stalk fresh weight increase over untreated controls of 30 stalks of each of the three varieties of each type. Lowland varieties were H50-7209, J58-4392, and H60-5657, Highland varieties were H54-775, H56-278, and H56-4848.

mg per stalk might make more effective use of GA$_3$ (Table 2). The treatment schedule of 2 x 1.0 @ 30, determined to have produced the best sugarcane growth response in the previous experiment, was included in this test as a reference. The 15-day interval treatments produced more growth than the untreated controls but less than any of the 30-day interval treatments. The 3 x 0.5 @30 treatment, while not significantly different from the 2 x 1.0 @ 30 reference treatment, gave a greater weight gain and fewer dead stalks. Four applications of 0.5 mg at 30-day intervals produced significantly higher stalk fresh weights and lengths and fewer dead stalks than all other treatments.
TABLE 1. Mean difference (treatment minus check) in stalk fresh weight, stalk length, and percent dead stalks of seven commercial cultivars of sugarcane treated with one or two applications of gibberellic acid (GA\(_3\)).

<table>
<thead>
<tr>
<th>Treatment schedule</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mg GA(_3) per appl.</td>
<td>Interval between appl.</td>
</tr>
<tr>
<td>1 x 1.0</td>
<td>0</td>
</tr>
<tr>
<td>1 x 2.0</td>
<td>0</td>
</tr>
<tr>
<td>2 x 1.0</td>
<td>15</td>
</tr>
<tr>
<td>2 x 1.0</td>
<td>30</td>
</tr>
<tr>
<td>2 x 1.0</td>
<td>45</td>
</tr>
</tbody>
</table>

* Means within a column with a different letter are significantly different \((P < 0.10)\) by Duncan’s Multiple Range Test.

TABLE 5. Mean difference (treatment minus check) in stalk fresh weight, stalk length, and percent dead stalks of seven commercial cultivars of sugarcane treated with 1.5 or 2.0 mg GA\(_3\) per stalk in 2 to 4 applications at 15 or 30 day intervals.

<table>
<thead>
<tr>
<th>Treatment schedule</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mg GA(_3) per appl.</td>
<td>Interval between appl.</td>
</tr>
<tr>
<td>3 x 0.5</td>
<td>15</td>
</tr>
<tr>
<td>4 x 0.5</td>
<td>15</td>
</tr>
<tr>
<td>2 x 1.0</td>
<td>30</td>
</tr>
<tr>
<td>3 x 0.5</td>
<td>30</td>
</tr>
<tr>
<td>4 x 0.5</td>
<td>30</td>
</tr>
</tbody>
</table>

* Means within a column with a different letter are significantly different \((P < 0.10)\) by Duncan’s Multiple Range Test.

These multiple-application experiments show that the greatest sugarcane growth responses are from properly timed, frequent, small doses of GA\(_3\) rather than from a single large dose. On the other hand, frequent windy and rainy winter days, the large area to be treated, and the cost of aircraft applications all favor few
### TABLE 3  Effect of aerially applied gibberellic acid on length and fresh weights of six Hawaiian commercial cultivars of sugarcane.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Cultivar</th>
<th>Number paired blocks</th>
<th>Stalk length (cm)</th>
<th>Stalk weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>( \bar{x}_T )</td>
<td>( \bar{x}_C )</td>
</tr>
<tr>
<td>Single application</td>
<td>H50-7209</td>
<td>8</td>
<td>233</td>
<td>207</td>
</tr>
<tr>
<td>140 g GA(_3) per hectare</td>
<td>H54-775</td>
<td>3</td>
<td>179</td>
<td>155</td>
</tr>
<tr>
<td></td>
<td>H56-4848</td>
<td>2</td>
<td>230</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>H57-5174</td>
<td>2</td>
<td>206</td>
<td>184</td>
</tr>
<tr>
<td></td>
<td>H59-3775</td>
<td>18</td>
<td>226</td>
<td>195</td>
</tr>
<tr>
<td></td>
<td>H60-8489</td>
<td>1</td>
<td>248</td>
<td>226</td>
</tr>
<tr>
<td><strong>Means of CVs for single app.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two applications</td>
<td>H50-7209</td>
<td>1</td>
<td>212</td>
<td>179</td>
</tr>
<tr>
<td>70 g + 70 g GA(_3) per hectare</td>
<td>H57-5174</td>
<td>4</td>
<td>205</td>
<td>173</td>
</tr>
<tr>
<td></td>
<td>H59-3775</td>
<td>7</td>
<td>281</td>
<td>239</td>
</tr>
<tr>
<td><strong>made at about 30 day intervals</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mean of CVs for two app</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Difference between GA\(_3\)-treated and non-treated stalks significant at 0.10 level of probability as determined by standard Student's t-test.

### TABLE 4. Effect of gibberellic acid on sugarcane quality as determined by pol-ratio analysis

<table>
<thead>
<tr>
<th>Treatment</th>
<th>No. tests</th>
<th>Pol</th>
<th>Purity</th>
<th>Pol% cane</th>
</tr>
</thead>
<tbody>
<tr>
<td>140 g/hectare</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Check</td>
<td>7</td>
<td>11.40</td>
<td>81.65</td>
<td>10.01</td>
</tr>
<tr>
<td>Treatment</td>
<td></td>
<td>12.28</td>
<td>89.20</td>
<td>10.79</td>
</tr>
<tr>
<td>( \Delta T-C )</td>
<td></td>
<td>0.88</td>
<td>7.55</td>
<td>0.78</td>
</tr>
<tr>
<td>70 g + 70 g/hectare</td>
<td></td>
<td>14.83</td>
<td>84.67</td>
<td>13.00</td>
</tr>
<tr>
<td>Check</td>
<td>2</td>
<td>14.87</td>
<td>85.38</td>
<td>12.97</td>
</tr>
<tr>
<td>Treatment</td>
<td></td>
<td>0.04</td>
<td>0.71</td>
<td>-0.03</td>
</tr>
<tr>
<td>( \Delta T-C )</td>
<td></td>
<td>0.04</td>
<td>0.71</td>
<td>-0.03</td>
</tr>
</tbody>
</table>
applications at high rates and at the longest possible interval. As a workable compromise, we settled on two applications spaced at 30-day intervals.

We established field tests to compare the effectiveness of a single application of 140 g per hectare with the effectiveness of two applications of 70 g GA$_3$ per hectare (Table 3). This test was conducted on more than 1600 hectares of cane growing on each of the sugar producing islands of Hawaii and covered the major commercial varieties in the various ecological zones. There was a significant gain in length and fresh weight with either method for application; however, the divided application resulted in 49% greater weight gain. The increase in weight for the single application was 187 g per stalk and that for the multiple application was 278 h per stalk. At 70,000 stalks per hectare, these weight gains per stalk are equivalent to 13.1 and 19.5 metric tons cane per hectare. The quality of cane treated with GA$_3$ is at least equal to and generally better than that of untreated cane, provided that sufficient time (minimum of 3 months) is allowed between treatment and harvest (Table 4). The above calculated increases due to GA$_3$ for cane tonnage at a quality level where 9 tons of cane produce 1 ton of sugar would result in a calculated yield increase of 1.46 to 2.17 metric tons sugar per hectare.

**OUTLOOK FOR GA$_3$ USE IN SUGARCANE**

In Hawaii, where sugarcane is grown through a cool winter season, GA$_3$ can overcome winter stunting of growth to increase cane and sucrose yields. The magnitude of yield increase is not constant for it is a function of variety, environment (location and climate), and amount and method of GA$_3$ application. Nevertheless, we repeatedly measured a gain of around 230 g per stalk when GA$_3$ is used at the rate of two 70 g per hectare applications. This gain per stalk is equivalent to 16 metric tons cane per hectare or 1.5 to 2.0 metric tons sugar per hectare. The GA$_3$ we use is Abbott’s “Pro-Gibb Plus” which currently costs about $80 per hectare plus application costs of around $15 per hectare. Thus, for an investment of $115 per hectare, we should receive an average of 1.75 metric tons sugar worth about $460.00. This makes the use of GA$_3$ highly attractive in Hawaii.

**REFERENCES**


USO DE ACIDO GIBBERILICO EN HAWAII PARA AUMENTAR RENDIMIENTOS DE CAÑA DE AZUCAR

Paul H. Moore

RESUMEN

Se presenta una reseña sobre el crecimiento y respuestas en rendi-
imiento de caña de azúcar tratadas con ácido giberílico (A₃G). Consistente se obtuvieron aumentos sobre el testigo en peso verde del tallo de plantas tratadas con A₃G bajo las siguientes condiciones: (1) tratando las variedades que mejor respondían; (2) tratando los campos más elevados; (3) aplicando el A₃G para coincidir con el invierno; (4) permitiendo suficiente tiempo antes de la cosecha para que madure el crecimiento producido por el A₃G y (5) aplicando el A₃G en dosis de 1.0 Mg o menos por tallo a intervalos de 15 a 30 días.

Estas condiciones se alcanzaron en ensayos de campo en Hawaii donde se obtuvieron aumentos significativos en peso verde por tallo sin reducción de calidad de la caña. Los aumentos en pesos eran comparables a aumento en rendimiento de 1.75 toneladas métricas de azúcar por hectárea. Por lo tanto, bajo condiciones cuidadosamente seleccionadas el A₃G aparentemente pudiera resultar factible en Hawaii.