Lengthening versus Shortening Dark Periods and Blossoming in Sugar Cane as Affected by Temperature* 1, 2

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Abstract. Sugar cane, an intermediate day plant, clearly received a stronger stimulus to flower during lengthening nights than during shortening nights. Flowering was vigorous under warm, lengthening nights (21°) but less so under cool, lengthening nights (16-17°). Warm or cool shortening nights either failed to induce flowering altogether or reduced it substantially. Under the warmer nights the inductive dark period was 10 hours 57 minutes to 11 hours 26 minutes whether the nights were lengthening or shortening. Under cooler conditions, it was longer by from 20 minutes to nearly 2 hours.

With reference to their photoperiod requirements, sugar canes (Saccharum spp. L.) have been classified variously as intermediate (2, 3, 13, 15), short (17, 18), long-short (16), and stenophotoperiodic (12). Unlike short day or long day plants which have critical periods below which or above which they will blossom (10), sugar cane has an extremely narrow range of inductive night lengths and blossoms neither below nor above this range (2, 4). Ready blossoming occurs in a fixed dark period of 11 hours 30 minutes whether the plants go into treatment from continuous light, 22 hour days, 13 hour days, or from 8 hour days. The narrowness of range is demonstrated by the Hawaiian clone, H37-1933, which blossomed readily under controlled conditions with nights of 11 hours 32 minutes, feebly at 11 hours 58 minutes, and not at all at 10 hours 58 minutes or below, or 12 hours 26 minutes or above (2, 4).

Under natural conditions of lengthening nyctiperiods, low temperatures especially minimum temperatures, prevented blossoming (2). Yet when the plants were subjected to temperatures as low as 13 to 16° with a fixed night length, they blossomed but after a very long exposure. Below 12°, they failed to blossom regardless of the length of exposure to proper dark periods (2).

Other requirements for inducing cane plants to blossom are a relatively low nitrogen level, very low soil moisture stress, exposure to bright sunlight during the day, and a proper size, usually showing at least 2 to 3 well developed internodes (2, 4).

Vijayasaradhy et al. (17, 18), working at latitude 11° N, classed sugar cane as a short day plant on the basis of its flowering upon exposure to the natural sunset and with the natural dark period extended by 4 extra hours of darkness during and past the natural dawn. Current efforts in Honolulu at latitude 21° N to cause blossoming with 4 extra hours of darkness failed completely for even the readiest tasselers but these plants were put into darkness in the early afternoon and were taken out in the early morning so as to eliminate the natural sunset but not the natural dawn. Coleman (6) cited unpublished work by Burr who failed to induce flowering in 7 reluctant clones of cane by exposing the plants to 30 minutes of infra red [SIC] prior to the dark and proceeded to expose canes to longer periods of infra red (1 hr 21 min-2 hr 30 min) prior to the dark period. These also failed to blossom. In fact, H37-1933 which blossomed for Burr failed to do so under the longer exposures used by Coleman. Downs, Borthwick, and Piringer (7) reported that blossoming occurred more readily under incandescent than under fluorescent supplemental light for plants where stem elongation is a part of the flowering process. Perhaps the apparent disparity of results reported by the several sugar cane investigators may be reconciled by a better understanding of the red and far red effects on cane.

Chilton et al. (1) and Paliatseas et al. (13) induced blossoming of canes in Louisiana by imitating the increasing night lengths observed in Hawaii from June 21 on. The results provided Chilton with an explanation (personal communication) of blossoming north of the equator in September to November whereas south of the equator even with similar temperatures in between, blossoming does not occur then but largely in the March to May period. Later, however, Paliatseas (14) reported that using photoperiods of the increasing, decreas-
ing, or constant sorts made little difference in artificial induction.

It is the purpose of this paper to present data on the effects of lengthening versus shortening nights applied in Hawaii during the periods from June 21 to December 21 and from December 21 to June 21, maintaining the night temperatures in the darkrooms equal to those out-of-doors for the natural winter-spring and summer-autumn periods.

Procedure

Three clones of sugar cane were used: Co 312 and NCN 310, 2 commercial clones produced at Coimbatore, India, the latter selected in Natal, South Africa, and H37-1933 produced in Hawaii. Co 312 is a very heavy tasselier under Hawaiian conditions. NCN 310 is less easily forced into blossom but still is a heavy tasselier. H37-1933 is only a moderately heavy tasselier—in certain areas it blossoms profusely, in others not at all. In general, profuse tasseling in sugar cane fields is very undesirable and hence, clonal selections are based somewhat on this character, thus accounting for differences in the blossoming profusion of commercial canes.

Single bud stem cuttings were planted 3 to a 12 inch pot in a very fertile garden soil and heavily fertilized with a complete fertilizer. When the plants showed 2 to 3 well developed internodes (3 and one-half to 4 and one-half months old) they were ready for treatment. Although heavy fertilization was practiced during the developmental stage, once treatment began no more fertilizer was applied unless the plants became so deficient in nitrogen that there was danger of the meristem dying.

Three runs, each made up of 3 series, are being reported upon: the first, a cool cycle, started December 21, 1965, and continued until June 21, 1966. The second, a warm cycle, started on June 21, 1966, and continued until December 21, 1966, and the final run, again a cool cycle, began December 21, 1966, and continued until June 21, 1967. In each run, the 3 clones were exposed to 3 dark period conditions: Series I, 12 pots of each clone were left out-of-doors under natural day and night conditions. Thus, in the spring cycle, the nights were shortening and, in the fall, lengthening. Series II, 12 pots of each clone were put onto carts for wheeling in and out of the lengthening night conditions. In this series, the plants were put into total darkness from the normal day at exactly 4:00 PM each day. Electrical controls turned on 8 "Daylight" 8 foot fluorescent lights at the appropriate time. Light intensities at plant levels ranged from 730 to 3200 lux. Temperatures in the darkrooms each night were maintained the same as the minimum temperature the previous night outside. At 8:00 AM the plants were wheeled outside into the very strong sunlight, which often during the day exceeded 13,000 milliphots. At the start of Series II the night length was 10 hours 40 minutes which is the normal night length from twilight to twilight in Hawaii on June 21 to 22 (9). The value assigned to the twilight times will be described later. The nights were lengthened exactly as occurs naturally, beginning at the start with 10 hours 40 minutes and ending 6 months later with 13 hours 04 minutes. At first the nights were lengthened only by a few seconds, and then the increments increased gradually up to 70 seconds each night followed then by the reverse shortening of the incremental increases.

For Series III, 12 pots of each clone were put onto carts and were wheeled into total darkness at exactly 4:00 PM daily and treated as in Series II except that the night lengths started with 13 hours 04 minutes and were shortened to 10 hours 40 minutes over the period of 6 months. During the 8:00 AM to 4:00 PM period all 3 series were in full sunlight.

Once treatments began all pots were kept drenched with water. Sugar cane is very sensitive to drought and will not blossom if under stress; in fact, the imposition of a mild drought is 1 means used to prevent flowering in commercial fields (2).

In order to determine the length of the effective dark period it is necessary to determine rather precisely the time when the meristem ceases producing leaves and starts producing the inflorescence. Two procedures are available. One is to have a large number of stalks and each day section 1 or more of them and observe the stage of development. The other is based on leaf counts of each stalk (4, 5) which enables the investigator at blossoming time to determine the date when the meristem changed to a flowering tip. Inside the spindle leaf just emerging, there are 8 leaves ranging in size from 1 almost fully grown and ready to emerge down to the newest leaf just forming at the stem tip. As 1 leaf emerges at the spindle, another one 8 leaves younger is just being formed.

When the plants are put into treatment a tag is placed under a particular leaf and counts are made weekly from this leaf up to and including the newest emerged leaf. These counts continue until the last leaf before the inflorescence, the flag, emerges followed by the inflorescence itself. By knowing the number of the flag as related to the originally tagged base, it is simple to determine the week within which the meristem stopped producing new leaves merely by subtracting 8 from the number of the flag leaf and tracing back to its appearance. Since the tip undoubtedly continues to be vegetative until enough of the stimulus to flower has accumulated, 10 days prior to the estimated date are arbitrarily included in estimating the inductive night lengths.
Results
and Discussion

The minimum temperatures experienced in the 3 cycles are shown in figure 1. For the warmer summer-autumn cycle, the minima for the first 4 months, June to October, remained near 21°. It is during this period that induction occurred even though exertion of the inflorescence may not occur until late October or November. In the winter-spring cycles, the minima during the inductive period were in the 16 to 18° range.

The results of the 3 complete runs are presented in table I. Under the warm, lengthening nights, blossoming in Series II was complete for all 3 clones. The inductive night periods ranged from 10 hours 57 minutes to 11 hours 26 minutes. By contrast, under the cool, lengthening nights, some blossoming occurred in all clones, but it was less complete and was characterized by the appearance of many abortive inflorescences indicative of a weakened response (8). The effective night length was the same for the profuse clone as before but from 20 to 50 minutes longer for the other 2.

Under warm, shortening nights, blossoming failed completely in 2 of the 3 clones. In the third, the most profuse tassel, the number blossoming was substantially reduced and there were many abortive blossoms. The night length was about the same as was noted for the lengthening nights. It is not unlikely that had the temperatures been higher, blossoming during shortening nights would have been completely prevented. Under cool conditions, shortening nights prevented blossoming in both cycles for H37-1933, in 1 cycle for NCo 310, and reduced it by half in the other. For the very profuse Co 312, blossoming was complete in 1 cool, shortening night series, and mixed in the second. In this, a few stalks blossomed early in the cool cycle and many blossomed late in the cycle when temperatures were rising. Under the cool, shortening nights blossoming occurred in night periods longer by about an hour. The late tassels performed in a night length similar to that for warm, lengthening nights.

Under natural out-of-door conditions, blossoming occurred only under the warm, lengthening nights and not at all under the cool, shortening nights of spring. Of interest is the fact that in the number III Series, in which shortening nights were given, blossoming was stronger under the cold conditions than under warm conditions.

In all cases, blossoming in Series II occurred some 10 to 14 days earlier than out-of-doors. Much of this discrepancy can be explained away by the influence of the natural twilights to which

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Table I. Summary of Experimental Results, Blossoming Percentages and Effective Night Periods

<table>
<thead>
<tr>
<th>Cycle and series</th>
<th>H37-1933</th>
<th>NCo 310</th>
<th>Co 312</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blossoming</td>
<td>Night length</td>
<td>Blossoming</td>
<td>Night length</td>
</tr>
<tr>
<td>First cycle: Dec 65-June 66 (16-17°)</td>
<td>% hrs:min</td>
<td>% hrs:min</td>
<td>% hrs:min</td>
</tr>
<tr>
<td>I Natural night</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>II Lengthening night</td>
<td>12 11:33-11:45</td>
<td>100 11:36-12:15</td>
<td>100 11:02-11:12</td>
</tr>
<tr>
<td>III Shortening night</td>
<td>0</td>
<td>48 12:05-11:56</td>
<td>100 12:50-12:29</td>
</tr>
<tr>
<td>Second cycle: June 66-Dec 66 (ca 21°)</td>
<td>% hrs:min</td>
<td>% hrs:min</td>
<td>% hrs:min</td>
</tr>
<tr>
<td>I Natural night¹</td>
<td>14(23)¹ 11:09-11:32</td>
<td>71 10:50-11:15</td>
<td>100 10:51-11:22</td>
</tr>
<tr>
<td>II Lengthening night</td>
<td>100 11:08-11:26</td>
<td>100 10:57-11:16</td>
<td>100 10:57-11:04</td>
</tr>
<tr>
<td>III Shortening night</td>
<td>0</td>
<td>32(18)¹ 11:36-10:53</td>
<td></td>
</tr>
<tr>
<td>Third cycle: Dec 66-June 67 (16-18°)</td>
<td>% hrs:min</td>
<td>% hrs:min</td>
<td>% hrs:min</td>
</tr>
<tr>
<td>I Natural night</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>III Shortening night</td>
<td>0</td>
<td>0</td>
<td>(a) 8 12:16-12:07</td>
</tr>
</tbody>
</table>

¹ Percentages in ( ) indicate stalks in which the blossoms were formed but which aborted.
² The natural night is the time between sunset and sunrise less the 26 minutes of twilight.

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Series I was exposed. Although the tropical twilights are relatively short, the increase in light intensity from 10 lux on to full sunlight is very rapid, requiring on the actual site some 18 minutes of time. With a similar period in the evening there is a total of easily perceptible light of some 36 minutes. The discrepancy between blossoming in Series II in the darkrooms where there was no twilight indicated a night some 26 minutes shorter than when blossoming occurred out-of-doors. When applied to the twilight, 26 minutes represented the twilight time in which light intensity exceeded 40 lux.

Additional reasons (11) for discrepancies between the darkroom night and the natural night may involve the lack of the evening twilight which is high in red and far-red energy and the prolonged exposure to fluorescent light which is essentially without far-red energy instead of the natural morning twilight. Additional reasons may include the opportunity for high CO₂ concentrations in the enclosures in contrast to the free circulation and drainage of air outside. Finally, the darkness in the enclosure is complete in contrast to the dim light outside (street and building lights at a distance as well as lunar light).

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Literature Cited