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# THE EFFECT OF ULTRADIAN AND ORBITAL CYCLES ON PLANT GROWTH

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## ABSTRACT

All life on earth has developed under the 24 hr light dark cycle dictated by the earth's daily rotation. There is little information on the degree to which plant growth is obligated to this 24 hr cycle nor the effect of short cycle length on growth. In a series of experiments using sugar beets, we investigated the effects of varying cycles lengths on growth (0.37 hr to 48 hr). Each cycle was equally divided into a light and dark period so that each treatment regardless of cycle length received the same amount of light over the 17 weeks of the experiment. We used two growth parameters to evaluate the effects of cycle length, total fresh weight and sucrose content of the storage root. Both parameters showed very similar responses in that under long cycles (12 hr or greater) growth was "normal", whereas plants growing under shorter cycle periods were progressively inhibited. Minimum growth occurred at a cycle period of 0.75 hr. The yield at the 0.75 hr cycle, where was at a minimum, for total fresh weight was only 51 percent compared to the 24 hr cycle. The yield of sucrose was even more reduced at 41 percent of the 24 hr cycle.

## INTRODUCTION

In recent years , much effort has been put forth to learn how to grow plants in a controlled ecological life support system (CELSS) type environment (Wheeler and Tibbitts, 1984). These efforts are reflected in the Total a large number of NASA-sponsored workshops and symposia (Tibbitts and Alford, 1980; Moore et al.,1982; Fabricant, 1983) that have been and are planned to be held, and in the increasing number of papers published on this subject. Generally, the research has been directed toward the selection of candidate species, cultural methods and strategies to maximize food production in the minimum of time and space. Attention is now turning to concepts of how to maximize production per unit of energy used.Thus lighting becomes of concern due to its high energy demands. The energy requirement of light for photosynthesis can be managed through the manipulation of intensity, duration and integration time wise with other energy requiring functions.

The proposed space station in low earth orbit will be in sunlight for approximately one hour and darkness 30 min. of each orbit, i.e. and orbital photoperiod. Thus the available power from solar panels or direct sunlight will cycle on and off every 90 min. This means that any horticultural system growing plants on a 24 hr cycle will require engineering support. The question which arises from this is whether from a horticultural point of view there are significant benefits from growing on a 24 hr cycle or is it possible to achieve adequate plant production independent of cycle length. Because of the orbital photoperiod which the proposed space station will occupy it is desirable to known if sugar beet, a plant selected for CELSS (Tibbitts and Alford 1980) is affected by cycle length.

## METHODS AND MATERIALS

Ten seedballs of sugarbeet (Beta vulgaris L.), equally spaced, were placed in a circle 12 cm in diameter, and planted to a depth of 2.0 cm in No. 2 vermiculite contained in 20-liter pots lined with 1.5-ml polyethylene liners. The seedlings as they grew were gradually thinned to two plants per pot. The plants were watered daily with one-half strength Hoaglands nutrient solution (Hoagland and Arnon 1950) modified to include 0.5 mM NaCl (Ulrich et al. 1958). Plants from the time of planting to harvest were grown in controlled environment chambers (127 X 249 X 137 cm.). The temperature was a constant 20 degrees C and illumination was 650 uE/cm2/sec of photosynthetically active radiation supplied 80% by cool-white VHO fluorescent lamps and 20% by incandescent lamps.The relative humidity was not controlled but was approximately 70% ambient CO2 was used with about 20% make up air. A single growth chamber was used for each treatment. At the start of the experiment each chamber contained thirty-two 20-liter pots placed in a 4-row by 8-column pattern. Each harvest consisted of eight plants with two plants taken from each column. At the final harvest each chamber had a single row of eight pots along the center of the chamber. Plants were harvested at 5, 9, 13 and 17 weeks after planting. Fresh weights of tops and storage roots were taken on a pot basis and dried in a 70 degree oven for dry weights. Samples of pulp from the storage root were analyzed for sucrose.

RESULTS AND DISCUSSION

Figure 1 shows total yield fresh weight as a function of cycle length ( cycle length in this paper is expressed as the sum (hr) of a consecutive light and dark period).

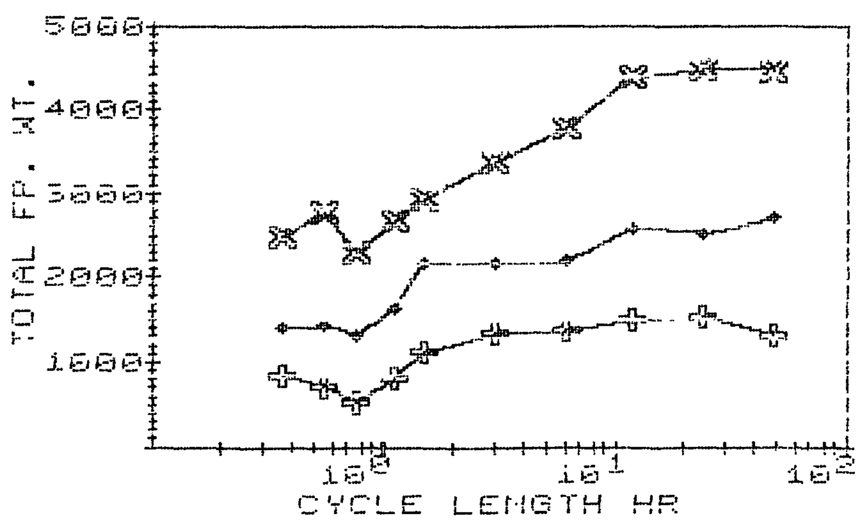


FIGURE 1 The total fresh weight per pot including the storage root (average of 8 pots/2 plants each in grams). (♣ = 9 weeks; + = 13 weeks; X = 17 weeks)

The three curves show the total fresh weight for harvests at 9, 13 and 17 weeks as a function of cycle time. The curve depicting the 9 week harvest for total fresh weight clearly shows that at a cycle time of 0.75 hr there occurs a minimum in yield. Yield increases at both longer and shorter cycles times. However the largest yields are always associated with the longer cycle times. The 17 week yield curve also shows a minimum at 0.75 hr cycle time. However in this curve the difference in yield between the longer and shorter cycle times is much more pronounced. This seems to indicate that as the plant ages, that the longer cycle times become more important in relation to yield. The importance of the yield minimum at 0.75 hr may only be in its relationship to the mechanism of action of this cycle phenomena. The response of the 13 week harvest as would be expected is somewhat intermediate between the other two harvests.

The curves in figure 1are a composite of two experiments run at different times in a single set of growth chambers one experiment covered cycle times from 0.37 to 1.5 hr and the other from 1.5 to 48 hr.. Although the environmental parameters and cultural practices were designed to be identical for both experiments. The experiment with the longer cycle treatments did show differences in yield in the overlapping treatment at 1.5 hr cycle time. This is most clearly shown in the 17 week harvest by an offset in the graph at the 1.5 hr cycle time where the two experiments have an overlapping treatment( figure 2).

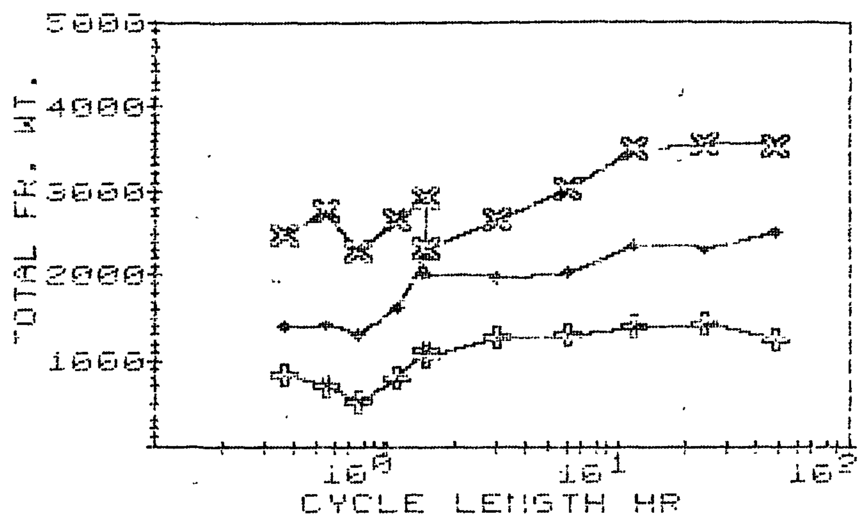


FIGURE 2 Total fresh weight without normalization of the data from the experiments with the longer cycle lengths, 1.5 to 48 hr.
(✚ = 9 weeks; + = 13 weeks; X = 17 weeks)

This difference between experiments, run at different times but in the same set of growth chambers, in the nonnormalized curves does provide additional evidence that common cultural practices, although they do affect yield, do not seem to affect the observed responses related to cycle time.

The yield differences shown in figure 1 are not small in that even a conservative estimate indicates a yield of 50 to 30 percent for weeks 9 and 17. Thus if the growth differences are calculated for the 9 week harvests for the longer cycles (12 to 48 hr) and compared with the 0.75 hr cycle plants (45 min) there is a difference of 66 percent. When calculated for the 17 week harvest the yield difference is decreased but is still 50 percent. Similar cycle treatments to buckwheat and cosmos by Garner and Allard (1931) showed an even greater yield difference, in some cases as much as 88 fold difference. The yield curves for the three different harvest dates all show the same general shape curve in that there is a minimum at the 0.75 hr cycle time with higher yields at both shorter an longer cycle times. However the size of the minimum at 0.75 hr is less at the later harvests. The high degree of parallelism between the curves for these three harvests is strong evidence that this phenomena is related to the variable of this experiment, cycle time rather than some specific aspect of a certain phase of growth and development. These sugar beets at the time of the 17 week harvest were large plants, thus these plants have passed through all the growth stages up to flowering.

Sugar beets are rather unique in that, in addition to total biomass being a good index of yield, the percent sucrose in the storage root is an excellent index of the amount of photosynthate available to the plant in excess of its needs for immediate growth. Thus if the concentration of sucrose is graphed as a function of cycle time it should provide a independent evaluation of the effects of cycle time on photosynthesis versus other aspects of plant growth and development. Figure 3 shows this graph where there is also a minimum in sucrose concentration at the 0.75 hr cycle time which continues up to the 13 week harvest.

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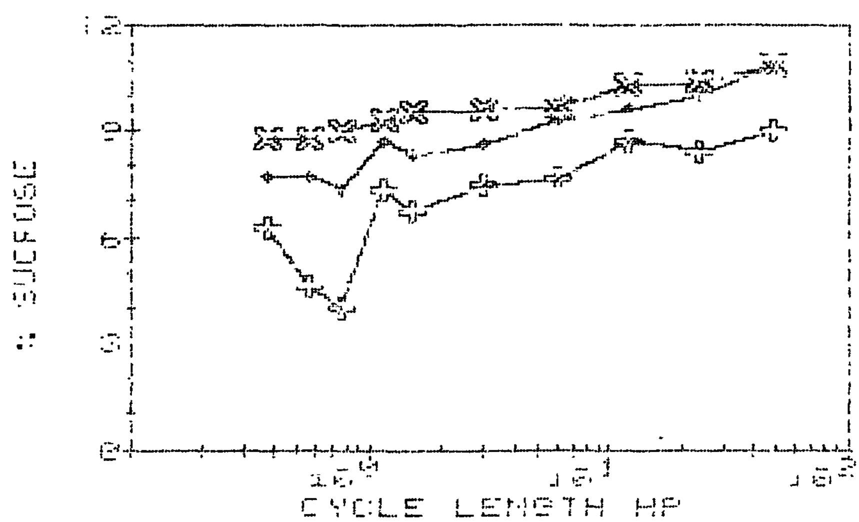


FIGURE 3 Sucrose percentage in the storage root. Each harvest curve is the average of 8 pots/ 2 plants each. (♦ = 9 weeks; + = 13 weeks; X = 17 weeks)

This minimum in sucrose concentration occurs in conjunction with a minimum in biomass. If the photosynthetic capacity of the plant had remained the same, then in the presence of reduced growth as occurred under the 0.75 hr cycle it would be expected that the sucrose concentration would have risen. However as seen in figure 3 there is also a minimum in sucrose concentration. This reduction in sucrose concentration has to be related to a greater effect of the cycle treatment on the photosynthetic mechanism than the rest of the plants growth and development.

However at the 17 week harvest there does not appear to be a minimum but rather a constant decline in sucrose concentration with decreasing cycle time. This seems to imply that at the 0.75 hr cycle time there is a minimum in the amount of photosynthate available for growth. All plants in these experiments received the same amount of total light the only difference being cycle length. Thus the observed difference can not be related to differences in the amount of light received but only to differences in the plants ability to utilize this light. The work of Bonde (1955) showed a minimum in chlorophyll content in the leaves of cocklebur under cycle times less than an hour. He also indicated that the chlorophyll decrease was equally noticeable at three light intensities 500, 1000, and 1500 FC. However he reached the conclusion that yield reduction was not due to effects on the photosynthetic mechanism because sucrose sprays had no offsetting effects on yield reduction (Bonde 1956). Unfortunately he did not determine if in fact the sucrose was absorbed by the plant. The change in the characteristics of the curve at the 17 week harvest in (figure 3) to just a yield decrease at shorter cycles times rather than the clear display of a minimum at 0.75 hr seems to suggest that there is a degree of adaptation with age to at least one aspect of the reduction in photosynthate. The consistent decrease of sucrose percentage with decreasing cycle length compared with the break in slope (at the 12 hr cycle length of the total fresh weight in the 17 week harvest (figure 1) would suggest that with increasing age longer cycle lengths may be more favorable.

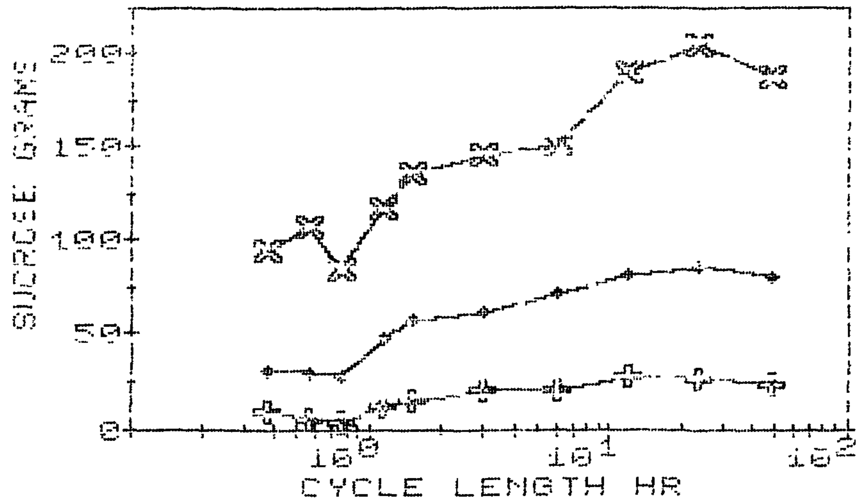


FIGURE 4 Total sucrose per pot. Each harvest curve is the average of 8 pots/ 2 plants each. (✚ = 9 weeks; + = 13 weeks; X = 17 weeks)

The amount of sucrose accumulated in the root as a function of cycle length and harvest date is shown in figure 4. This aspect of yield also shows the same general trend in that increased yield is definitely associated with longer cycle lengths, 12 hr or longer. The higher yield at the shorter cycles compared to the 0.75 hr cycle could be a very important factor in determining the mechanism of action but there is still a 30 percent decrease in comparison to the longer cycles. This seems to indicate that the longer cycle times will be necessary for the higher growth rates. These observed responses to cycle length is not predictable from standard text book plant physiological principles.The experiments reported here show that the plants response to differences in the light dark cycle length even though the total light recieved during the duration of the experiment was identical.

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