that is the possibility of fertilizing plants by increasing the carbon dioxide content of the air; fertilization in, perhaps, a different form from that we are used to. Dr. Harry Kohl of the Department of Landscape Horticulture, University of California at Davis. Harry:

CARBON DIOXIDE FERTILIZATION

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The idea of carbon dioxide fertilization is not a new one. In 1913 the first attempt at commercial application was reported from Europe and for some 20 years thereafter a fairly large amount of work was reported in this field. However, the practice was not adopted most probably because of the presence of injurious contaminants in the carbon dioxide used although lack of good control was also a problem and the limitations on its use were not understood.

In the mid 1950's the practice was revived largely because of the findings of Goldsberry at Colorado State University with carnations and has remained as a controversial, ill-understood practice since that time. A summary of a carbon dioxide survey made by Kennard Nelson in 1964 indicated that 1,478,600 sq. ft. under glass, almost all of which was in the northern tier of states, was receiving some added carbon dioxide. In the same summary a brief report of research work on flower crops by workers at six universities indicated mixed results. About half the findings showed significant gains (10% to 100%) from carbon dioxide fertilization. The other half showed essentially no gain. Only one reported a lower production by carbon dioxide fertilized plants.

Such varied results — even on the same crop — would seem to indicate that we should be thoroughly familiar with what carbon dioxide can and cannot do if a wise decision on if, as, when and how to use it is to be made. Presenting this necessary background is the reason for this paper.

Growth Efficiency

For most ornamental and vegetable crops the production is, grossly, the fresh weight of the crop produced. The amount of fresh weight produced per unit area per unit time is a measurement of the efficiency of production. But for each unit of fresh weight produced there is a minimum dry weight if the crop is of acceptable quality. In a sense then the good grower can be defined as one who can cause the plant to produce the maximum amount of fresh weight of acceptable quality from a given amount of dry weight. Temperature, water relations, mineral nutrition and photoperiod play primary roles here, not carbon dioxide, and hence if production is being restricted by inefficient use of dry weight it is unlikely that carbon dioxide fertilization will very effectively remedy the situation.

Dry Weight Production

Supposing that the dry weight available is being used as efficiently as possible the next concern is providing more dry weight (photosynthates) per unit area to be used in the production of the crop. Carbon dioxide can certainly play a direct role here, but before considering it let's look at some other possibilities. The first I would like to consider is conservation of photosynthates for the purpose of growing the crop, which means having as low an overhead in terms of stems, roots and non-functional leaves as possible. Since this is not of major concern in this paper we will not go into the details of this further but immediately suggest another possibility which is to increase the amount of light either by increasing the intensity during the light period or extending the light period. However, if light intensity is already high this can only be done effectively by increasing the duration of light. The addition of light should result in higher dry weight yield per unit area per unit time, provided said increase does not result in injury such as wilting due to increased water stress. The reason for the effectiveness of added light is, of course, to be found in its role in photosynthesis:

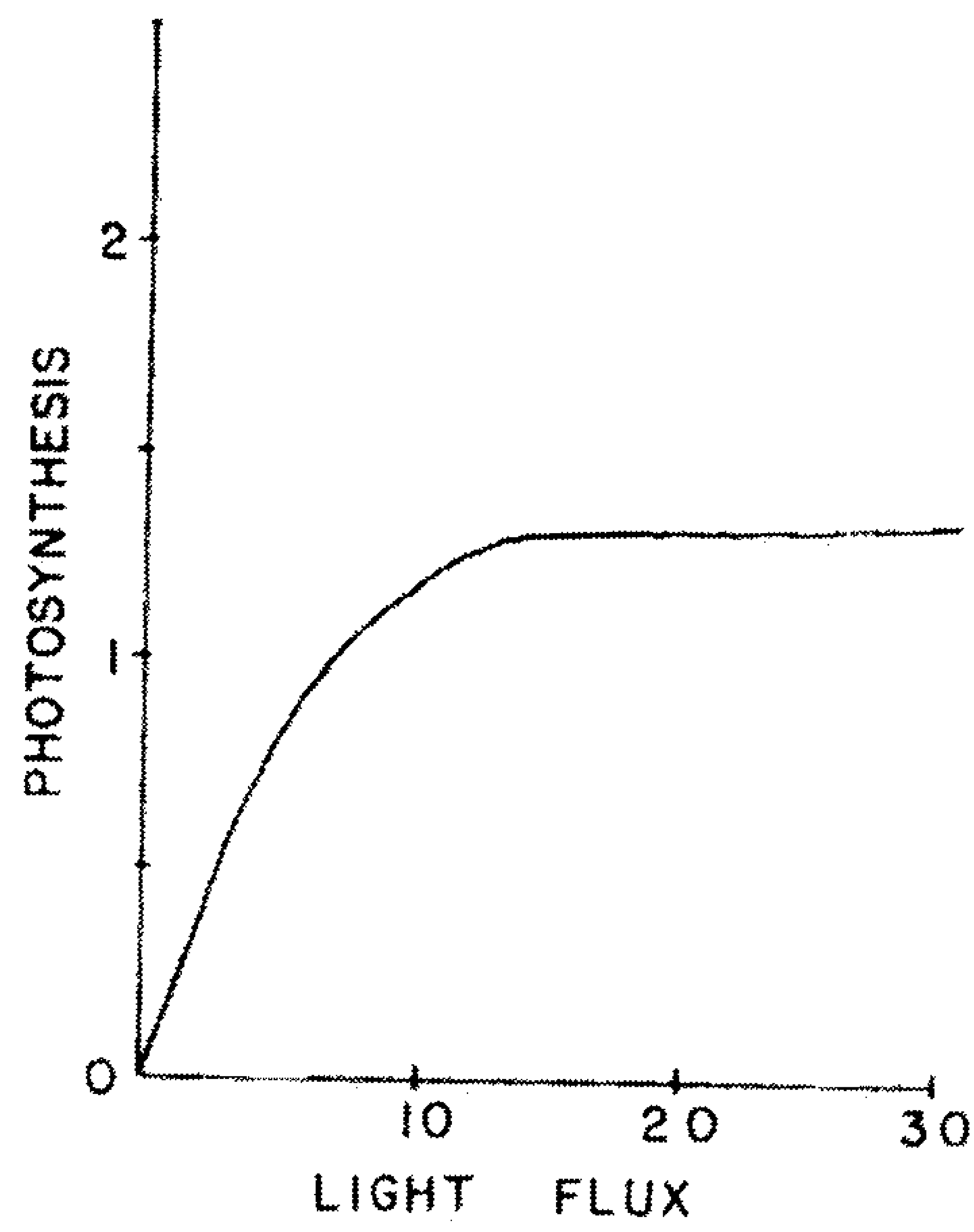

Fig 1 Photosynthesis (mm³ CO_2 cm^{-2} h^{-1} 10^{-2}) of single leaf of sugar beet as a function of light flux (erg sec^{-1} cm^{-2} 10^{-4}) Adapted from Gaastra

$$CO_2 + H_2O + light \rightarrow [CH_2O] + O_2$$

Again light is not our primary concern and so we will not attempt a complete discussion although we should not leave the topic without noting that addition of a quantity of light to a crop receiving a relatively small amount of light will result in a much larger absolute gain than if the same quantity of light is added to a crop growing under high light conditions as can be deduced from experimental data generalized in Figure 1.

Now let us examine photosynthesis as a function of carbon dioxide concentration. Gaastra has published data on photosynthesis of leaves of several species which in general show the following:

1. At very low light intensities (circa 300 f. c.) CO_2 concentrations greater than normal ambient, i.e. 300 ppm, did not result in higher photosynthetic rates.
2. At higher light intensities there was a distinct increase in the rate of photosynthesis at increased carbon dioxide levels. The average maximum increase was to 200% of the photosynthesis at ambient CO_2 levels. Saturation occurred at about 1000 ppm CO_2 although the gain at concentrations over 750 ppm was slight. (Fig. 2).
3. At higher temperatures (circa 85° F.) the gain in photosynthetic rate was greater than at lower ones (circa 70° F.) when CO_2 was increased to the same level. (Fig. 3).

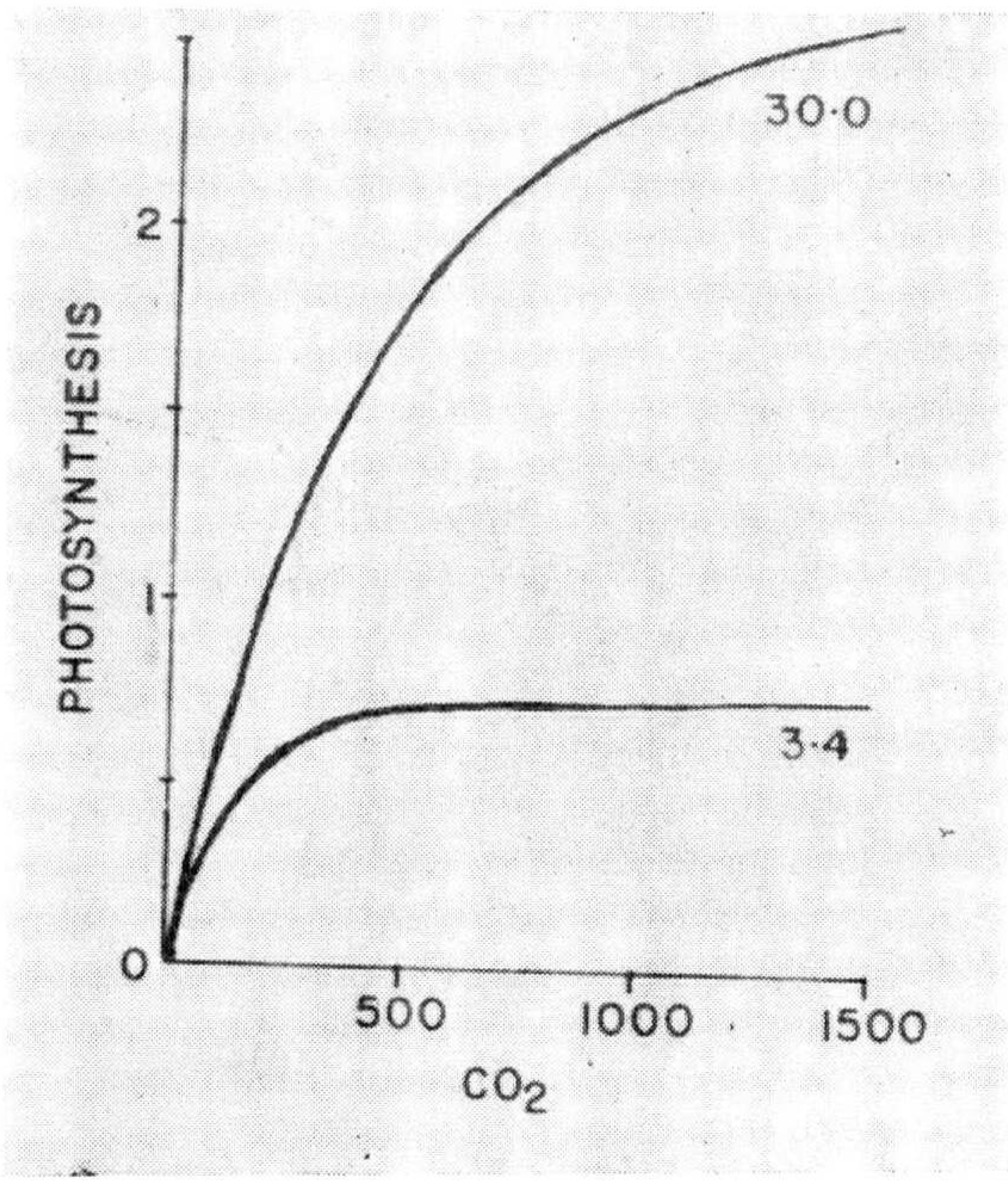

Fig. 2. Photosynthesis ($mm.^3$ CO_2 cm^{-2} h^{-1} 10^{-2}) of single leaf of sugar beet as a function of carbon dioxide concentration in ppm at high and low light intensity. Adapted from Gaastra.

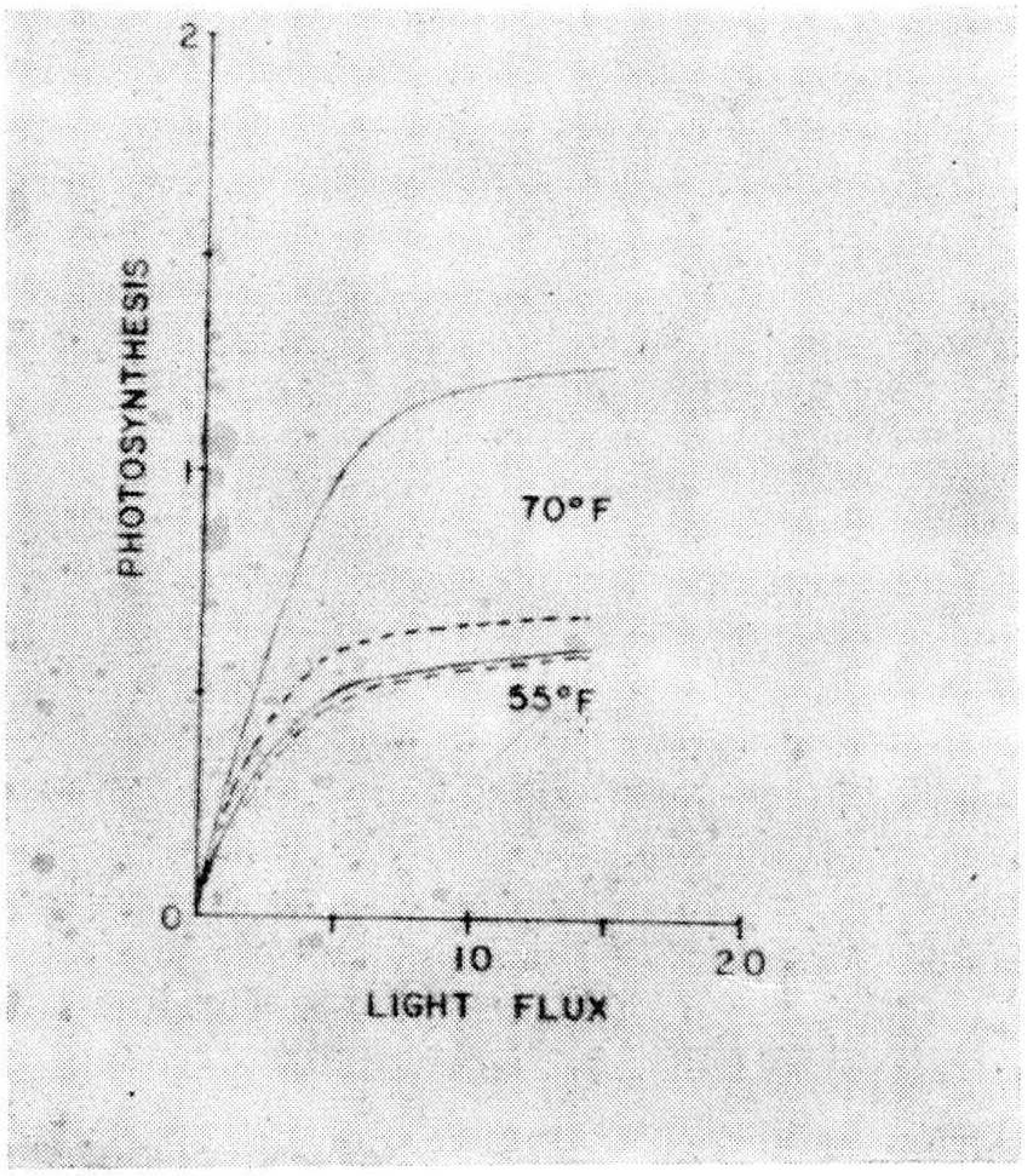

Fig. 3. Photosynthesis (mm.[3] CO_2 cm^{-2} h^{-1} 10^{-2}) of tomato leaf as a function of light flux (erg sec^{-1} cm^{-2} 10^{-4}). The dashed lines are for a carbon dioxide concentration of 300 ppm while the full-drawn lines are for a higher concentration. The two lower curves are for 55° F. (approx.) and the two upper curves are for 70° F. (approx.). Adapted from Gaastra.

The above information would appear offhand to make a decision in favor of CO_2 fertilization inevitable if the cost of the gas and its distribution and control is at all reasonable. In fact it would appear inconceivable that all experimental work with CO_2 fertilization did not result in increased yield and yet this has not always been the case. Why?

It is my considered opinion that the answer lies in one of two places. Either cultural practices are not adjusted to take advantage of increased dry weight production or the carbon dioxide fertilized plant is made more susceptible to dark weather. Allow me to give examples. First, regarding the adjustment of cultural practices, let us consider the production of some crop such as standard chrysanthemums upon which CO_2 fertilization is superimposed. The spacing, fertilization program, temperature, number of flowers per square foot, the vegetative period, and the response group (flower development time) are all fixed knowingly or unknowingly, to the light intensities and carbon dioxide content normally available so that under those conditions a crop of good quality can be produced. Within such a restrictive framework any potential increase in dry weight production due to carbon dioxide fertilization can express itself only in a most limited form. Perhaps during the vegetative period a few more leaves can be formed and individual leaves can be larger.

But the spacing is too close for these leaves to be of more use to the plant than the fewer, smaller leaves which the non-fertilized plant grew in the same length of time. The extra leaf surface actually becomes a parasitic burden with time since it cannot receive enough light to be useful. Again, during early growth the fertilized plants might produce somewhat thicker stems and a larger root system. Normally this would be an asset as a foundation for a superior plant but for the plant restricted to growth in a limited area such a root system is a luxury, so to speak; it costs more dry weight to maintain and isn't needed except to help supply the excess, parasitic leaf surface. With the above in mind it is a moot question whether the crop which is harvested from the fertilized plants will be worth more than that from the unfertilized plants. If the amount of eventually parasitic tissue is large and light is unusually low during the late stages of production the CO_2 fertilized crop could well be worth less. It may have a higher dry weight overall but not in the flower and useful stem harvested. On the other hand with some changes in growing practices a considerable positive gain might have been realized from carbon dioxide fertilization. For the problem of producing these standard mums I would suggest that the vegetative period might be reduced so that the leaf surface per unit area is essentially normal. The flowering period might be reduced as well by using a variety having a shorter response time. The net result could well be the production of equal worth in an overall shorter time.

Unfortunately, the above explanation is rather long and tedious and, even so, not complete. Even more serious is that the reasoning has not been tested by appropriate experiments. It can, however, be tested by experiments and enlarged upon in the process.

An example of the second way in which I feel negative results might be recorded following carbon dioxide fertilization is by an increased susceptibility of the plants to a low light period. As an example of what I mean here let us assume that we are giving supplementary carbon dioxide to a winter rose crop during relatively bright weather and further let us suppose that the crop is responding beautifully with half again the normal number of breaks about two weeks away from full bloom. At this point let us assume that the weather becomes overcast and remains so for two weeks. What result can we expect? Near disaster, I expect, for we have built up a very large overhead in the form of dry weight needed to support the large canopy and at the crucial moment the productive ability of the leaves has been reduced not only proportionately to the reduction for the unfertilized plants but, as Fig. 3 indicates to essentially the *same* low rate as that of the unfertilized plants. Proportionately the photosynthetic potential is reduced much more for the fertilized plants. Immediate cessation of growth, excessive leaf drop, small — perhaps unsalable — flowers, and an injured plant which will take a long time to recover productiveness would be expected. The unfertilized plants will, of course, also be reduced in productiveness during this period but their lesser crop should at least be salable and the plants should recover more quickly. With this situation as with the chrysanthemums a change in cultural practices may have allowed us to take advantage of carbon dioxide fertilization without such serious risk. In this case I would suggest that rather than build up the excess number of shoots per unit area that the grower slightly increase his growing temperature in the fertilized houses during the bright period not forgetting to reduce them immediately with the onset of overcast weather. In this way production can at least be increased during the bright weather. It is my understanding that tests on roses using higher temperatures along with carbon dioxide fertilization are in progress at Pennsylvania State University.

In Summary

There is considerable evidence that carbon dioxide fertilization can be worthwhile. However, it is neither foolproof nor a cure-all as some might suggest. In its use the grower should try to decrease growing time for a crop rather than increase the plant load per unit area. For most crops, especially young plants, an increase in growing temperature during bright weather — but not during dull weather — is an appropriate procedure.

Effective concentrations above 750 ppm are probably not worthwhile. Furthermore, during dull weather, concentrations of more than 300 ppm are not worthwhile. This last statement should not be interpreted to mean that there should be no carbon dioxide input during dull weather for, if there is no ventilation, greenhouse carbon dioxide concentrations may fall below 300 ppm which should result in a reduction in photosynthesis even at low light intensity.

The above points are of major importance but two other points are of interest as follows:

1. At the end of the night the carbon dioxide concentration in a closed greenhouse is higher than normal and for the first hour after sunrise the stomates are opening so that it would seem wasteful to add carbon dioxide during this period.

2. Unless there is a reasonable amount of air circulation in the greenhouse the carbon dioxide concentration near the leaf, i.e. the effective carbon dioxide concentration, may be considerably lower than the average concentration.

The economics of carbon dioxide fertilization are difficult to figure out because of many factors such as importance of quick turn-over for a holiday, percent of time the vents can be closed when the weather is fairly bright, the cost of the equipment, the cost of the gas, and, of course, the possible overall additional production. Each business situation is unique and it is beyond my competence to advise as to whether a particular enterprise should use carbon dioxide fertilization.

What I hope I have been able to do in this paper is to in-form you on the way to try carbon dioxide fertilization properly.

As a final encouraging statement for you as propagators, interested particularly in the growth of young plants, I would say that it is here where plants are relatively uncrowded and in an exponential phase of growth that I feel the largest gains from carbon dioxide fertilization are likely to be realized.

MODERATOR FURUTA: We have with us this morning Arthur Myhre from Western Washington Research and Extension Center, Puyallup, Washington. He will discuss with us at this time, "Chemical Pre-Emergence Weed Control". Arthur:

CHEMICAL PRE-EMERGENCE WEED CONTROL IN WESTERN WASHINGTON

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The need for weed control in ornamental nursery plantings is without doubt one of the major problems which confront nurserymen in western Washington. Our moderately cool summer temperatures and abundant moisture cause weeds such as pigweed, lambsquarter, chickweed, smartweed, groundsel annual blue grass, horsetail, quackgrass, etc. to grow and spread with much rapidity. These weeds are commonly found here and are widespread in their distribution.

Extensive weed control research investigations involving the testing of chemical herbicides on different kinds of species and varieties of ornamental shrubs have been underway for nine years at the Western Washington Research and Extension Center, Puyallup, Washington. Cooperating on this project is Dwight V. Peabody, Jr., Northwestern Washington Research and Extension Unit, Mount Vernon, Washington. Our weed control studies have been designed especially for nurserymen. The procedure for testing pre-emergence herbicides is as follows: Rooted shrub cuttings are taken directly from the propagation frames and are lined out in the spring in nursery row plots. Approximately one month later herbicides are applied by machine properly equipped to provide good agitation of spray materials, accurate calibration, and adequate and uniform coverage. Previous to spray application, soil is cultivated and crop plants hoed so that soil is weedfree (no existing weeds). Weed seeds common to this area are sown to insure adequate and uniform infestation throughout the plots. In order to activate the chemical and to bring about fast weed seed germination in the surface soil, irrigation follows spray application when rainfall does not appear imminent. Generally, the herbicides are sprayed directly upon the plant foliage and between the rows and the soil thereafter is left undisturbed. However, certain herbicides were incorporated into the soil directly after application and were found to be more effective when treated in this manner.