AN EXPERIMENT IN GROWING SALAD VEGETABLES AT AN ANTARCTIC STATION

By JACK HILL

THIS paper is based on the brief preliminary account of experimental work carried out at Halley Bay (lat. 75°30′S., long. 26°42′W.) during 1962 (Hill, 1962) but more detailed analysis, additional information and further suggestions resulting from subsequent work and inquiry have been included.

The work was not part of an official scientific programme and it was primarily motivated by a personal interest in the possibility of growing a limited supply of fresh salad vegetables in the existing conditions at an Antarctic station. This paper is an account of this experiment, when tomatoes, lettuces, radishes, mustard and cress, and peas were successfully grown during the year spent at Halley Bay as radio operator.

The system of soilless culture, known as hydroponics, was used and the work was carried out in both artificial light and natural daylight. Some crops were grown to maturity in completely artificial conditions, i.e. inside the station hut using only artificial light and hydroponics, whilst others were part grown under these conditions and "finished off" in a specially constructed outside "greenhouse", again using hydroponics, but making use of the available natural light.

The methods used are described and the results obtained are given together with details of further work being carried out in this field at present. For this work "growing cabinets" are in use and details of these are given. It is hoped that others may find this paper useful for future work along these lines.

The requirements for plant growth are light, food material, moisture, warmth and air, each of which interacts with the others. Light is required for the complex process of photosynthesis, a reaction in which carbon dioxide from the air and water combine with the assistance of light energy to form plant foods consisting of starches and sugars. For satisfactory growth, the water absorbed by the plant must contain certain food materials (nitrogen, phosphorus, potassium, calcium and magnesium) in the form of mineral salts, together with varying but balanced amounts of very small quantities of several trace elements. Maintenance of an optimum temperature is necessary for growth; temperatures above or below the normal will result in the plant dying, whilst air is required for the processes of respiration, including photosynthesis.

When all these requirements are satisfied, plant growth under normal conditions presents few problems, but it will be appreciated that under Antarctic conditions these requirements are extremely difficult, if not impossible, to satisfy naturally. For the purpose of the work at Halley Bay it was therefore necessary to provide artificially an environment suitable for the growth of plants.

Some of the British Antarctic Survey stations in the Antarctic Peninsula have small conventional greenhouses, which may be considered as modifying the natural environment. From time to time, plants, bulbs, etc. have been grown in them but, to the best of my knowledge, always in soil "imported" from Port Stanley, Falkland Islands. One of the problems of using this soil is that it soon goes sour (partly because of its low pH) and it is quickly depleted of plant food. Whilst this latter problem can be largely corrected by the addition of artificial fertilizers, it still does not provide a satisfactory growing medium.

METHOD

Hydroponics

The first consideration at Halley Bay was the choice of an alternative to soil, hence the method known as "hydroponics" was used. Hydroponics, a Greek word literally meaning "working with water", is a system of growing plants with their roots suspended in water in which chemicals are dissolved. It is by no means a new method and it has been used by researchers into plant physiology for over a century, but it was not until 1929 that this technique was applied to the growth of commercial crops (Gericke, 1940).

The system adopted at Halley Bay was a modification of true hydroponics, known variously as "gravel culture", "vermicularponics", etc. and it is basically differentiated from true hydroponics by using a medium such as gravel, sand, vermiculite or any combination of these or any other suitable material, instead of water. The material chosen must satisfy certain requirements: that it retains moisture without waterlogging, is sufficiently "open" to allow good aeration of the root systems of plants, is not toxic to plant life and is completely inert. The function of this material is to provide an anchorage for the plant roots, and to encourage and facilitate the development of such root systems.

A mixture of gravel and vermiculite in the proportion of 60 per cent ¼ in. (6·5 mm.) gravel and 40 per cent vermiculite was used. This was mixed well and placed in containers with dimensions of approximately 18×12 in. (45×30 cm.) and 6 in. (15 cm.) deep. Four such "growing trays" were made up from wood and tinplate, and each tray was fitted with a drainage hole at one end by inserting a short length of copper tube through the bottom of the tray and soldering in place. Four coats of paint inside and out proved adequate as a sealer and preventative against corrosion. These trays were used continuously throughout the indoor experiment.

As the growing medium used in the trays is completely inert, it must be supplied with the elements essential for plant growth, and there are several ways of doing this. Perhaps the simplest way is to apply dry fertilizer to the surface of the growing medium and then water it in by spraying. Another method is to apply a nutrient solution, i.e. fertilizers dissolved in water, to the surface, allowing this to soak through to the plant roots. The first method is essentially a manual job and it is time consuming, but the second one lends itself to some automation. It was used initially but was soon discontinued in favour of the much better sub-irrigation method.

Methods of irrigation

Drip-feed (Fig. 1a). This method consists of providing a continuous drip-feed supply of nutrient solution (Appendix A) from an overhead tank or container through a rubber tube and regulated by blood-transfusion type clips. The rate of feed was adjusted so as to just keep the growing medium moist. Any excess was allowed to drain off into metal trays below.

Sub-irrigation. The growing trays were fitted along one end with 1 in. (2·5 cm.) pipes drilled with $\frac{1}{16}$ in. (1·6 mm.) holes at intervals of 1 in. (2·5 cm.). The nutrient solution was passed into these pipes by rubber tubes from an overhead tank and allowed to flood into the growing medium (Fig. 1b). The $\frac{1}{16}$ in. (1·6 mm.) holes ensured even distribution of the solution over the whole of the tray. A drain hole and tap was provided at the opposite end towards which the bottom of the tray had a slight fall to ensure good drainage. Once each day the trays were flooded to within 1 in. (2·5 cm.) of the top and allowed to stand for a period of up to 1 hr. before being drained (see Appendix A). Excess solution was then returned to the overhead tank. More solution was added to the tank as it became depleted due to being absorbed by the plants, and losses from evaporation. This method was later modified for use in the outside greenhouse (Fig. 1c). The modified system was much simpler and required considerably less pipe-work but it was a fully manual operation.

Both methods are satisfactory but sub-irrigation is the better one. The growing medium is extremely well aerated by this system, as practically all the air is expelled as the solution rises in the tray and a fresh supply is drawn in as it drains away. With the introduction of trip-switches and a small pump, this system could be made fully automatic.

Artificial light

The second main consideration was that of providing sufficient light. It is difficult to say exactly what the light requirements of plants are, since they vary considerably from one species to another, and experiments are still going on in this field. Antarctic lighting conditions may be briefly summarized as insufficient for two-thirds of the year and more than enough for the remaining one-third. This means that the actual growing season is very limited, and because of this the experiment was begun by using artificial light.

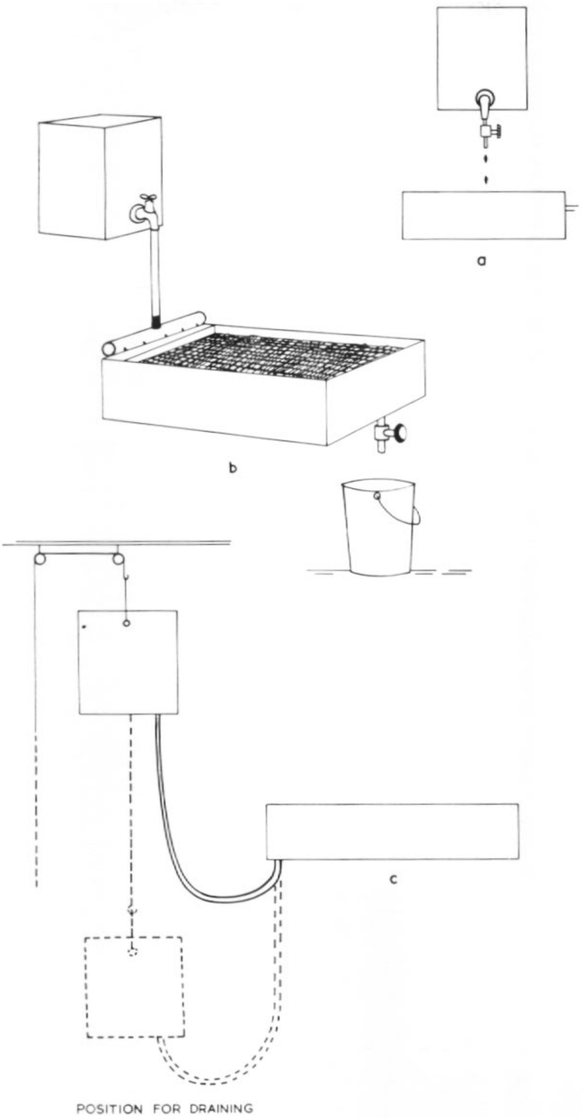

Fig. 1. Methods of applying nutrient solution.
a. Drip-feed method.
b. Sub-irrigation (bucket emptied back into top tank daily).
c. Modified sub-irrigation system used in outside greenhouse.

Although much work has been done recently on the use of artificial light on plant growth (Canham, 1962*a*, *b*, 1963, 1966), in 1961 information on the subject was limited and controversial. The information available to the author at that time showed that for normal growth both the intensity and the colour of the light were of prime importance, whilst the duration of lighting must also be satisfactory. The optimum light intensity was said to be about 1,000 W./sq. yd. (1,196 W./m.^{2}) of growing area. With regard to the colour of the light, it was known that tungsten lamps were generally unsuitable because of their radiation in the far red of the spectrum, and that this caused undesirable formative effects in many plants (including the ones grown), in particular excessive stem elongation. (Much of their radiated energy is not light but heat; only 6 per cent of the total output is visible light.)

Fluorescent tubes appeared to be much more suitable. They are available in a number of colours, depending on the fluorescent coating used, and of these the "warm white" was recommended as giving the most suitable spectral distribution of light. Fluorescent tubes also have a much more satisfactory heat : light ratio. Fortunately, fluorescent light units were available, though limited, at the Halley Bay station and by a careful re-arrangement and substitution of light fittings it was possible to acquire two 4 ft. (1·2 m.), 40 W. light units and two 40 W. "warm white" tubes for the purpose.

Beginning work in mid-May 1962, racking made from "Dexion" was fitted into one corner of the radio office, a lower rack to carry the growing trays and an upper rack to carry the lighting units and their control gear. This upper rack could be raised or lowered to vary the lighting to plant distance as required (Figs. 2 and 3). The maximum height of the lighting was 2 ft. (0·6 m.) above the surface of the growing trays, and manual switching of the lamps provided a "day length" of 16 hr.

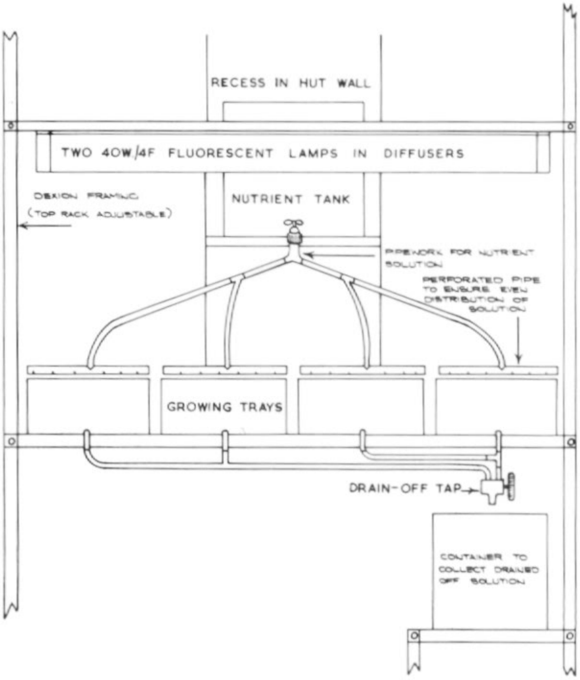

Fig. 2. Diagram of indoor installation at Halley Bay in 1962.

Work indoors (*Phase* 1)

After overcoming several problems experienced with the irrigation system, a sowing of lettuce (May Queen) was made. The seeds were sown thinly over the surfaces of the trays, the lighting rack was at its maximum height and the gravel/vermiculite growing medium was kept moist by flooding (as described above) with water to which no nutrients had been added. Germination was good after 3 days and at this stage feeding by nutrient solution began. The plants continued to grow well after thinning out but at 2 weeks they were becoming noticeably drawn, and at 3 weeks they were 4 in. (10 cm.) high and very much drawn and "leggy". Two other attempts with the lighting rack lowered to 12 and 8 in. (30 and 20 cm.), respectively

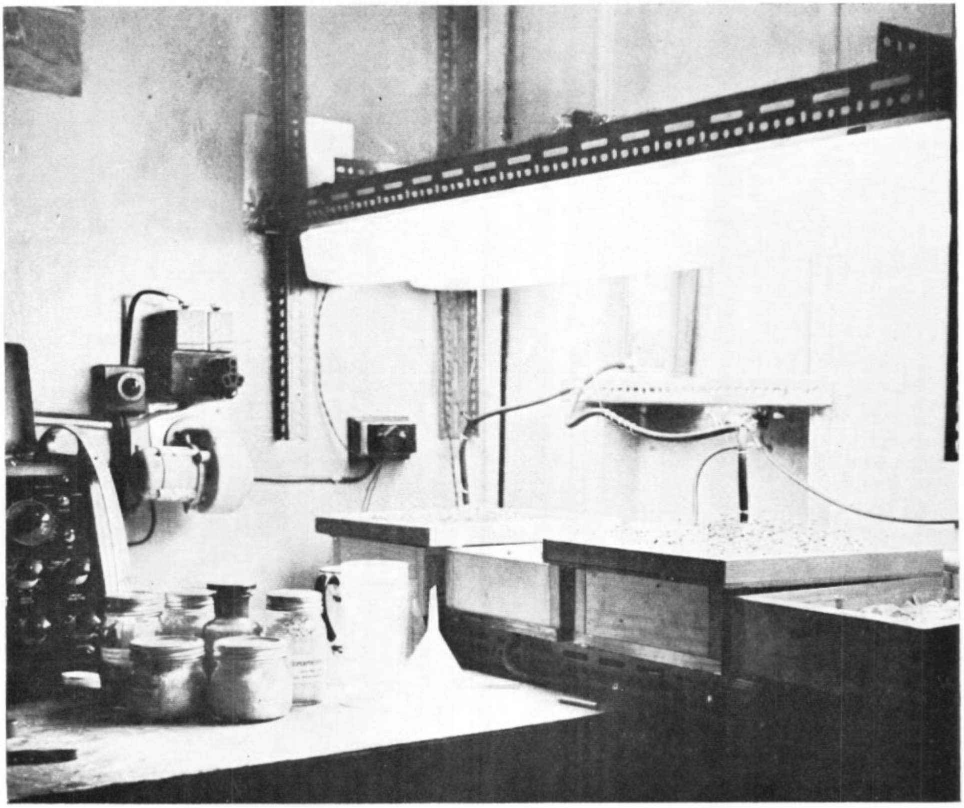

Fig. 3. Indoor installation at Halley Bay in 1962.

produced only slightly better results (Fig. 4) and on no occasion was it possible to get the lettuce to "heart-up" (for a possible explanation see p. 61). Throughout this work a day length of 16 hr. was given: 08.00 to 00.00 hr.

A variety of dwarf pea (Meteor) was sown and it grew quite well, initially under the lamps at a height of 8 in. (20 cm.). As the plants increased in size, the lighting rack was raised to 2 ft. (0·6 m.) when the plants attained their maximum height of 14 in. (36 cm.) (at 12 weeks), flowered and produced small- to medium-sized well-packed pods.

Cucumber plants (Yates Improved Telegraph) were grown in 5 in. (13 cm.) plastic pots containing vermiculite and "plunged" in the growing trays. These grew well and flowered at 12 weeks, setting fruit at 14 weeks (Fig. 5). Unfortunately, the plants were killed off at 15 weeks by toxic fumes resulting from a broken stove chimney.

All except one of six tomato plants (Amateur) which were in the seedling stage when this unfortunate accident occurred also succumbed. This single plant was grown on and again the lighting rack was raised as the plant increased in height. At 14 in. (36 cm.) the plant was "stopped" (by having the growing point nipped out) and at 14 weeks it produced flowers on its single truss. Due to the dry air conditions inside the hut, the truss did not set well; only one fruit grew to maturity and on picking it was 1·5 in. (4 cm.) in diameter, weighed 1 oz. (28 g.) and was divided and eaten with great relish by eight people!

During this time several trays of mustard and cress were grown successfully, some under the fluorescent tubes (as an intercrop with the cucumbers and tomatoes) and some under tungsten lights, using a simple drip-feed method of applying the nutrient solution. That grown under fluorescent lighting had a better colour but there was little to choose between the rates of growth under either condition.

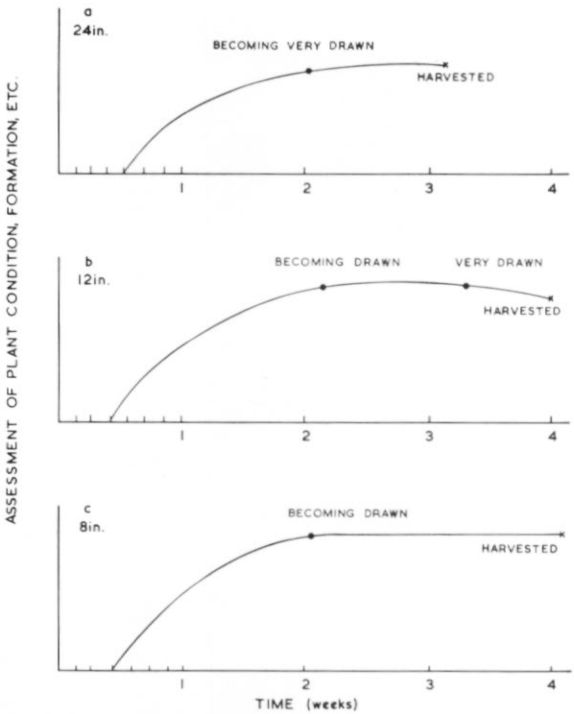

Fig. 4. Performance of lettuce (May Queen) under 80 W. fluorescent light at three different light-mounting heights. 16 hr. "day" at a continuous temperature of 65° F (18° C).
a. 24 in. (60 cm.) height.
b. 12 in. (30 cm.) height.
c. 8 in. (20 cm.) height.

Fig. 5. Cucumbers grown under fluorescent light at Halley Bay in 1962.

All work up to that date had been done in completely artificial conditions. The hut at this stage was about 30 ft. (9·1 m.) below the surface of the snow outside, and for most of this period there had been complete darkness during the winter months. The average temperature inside the hut was generally about 65–70° F (18–21° C), and particularly in the radio office, because of the presence of the radio equipment, the humidity was low (40–50 per cent). The hut was not equipped with any form of forced-draught ventilation but in spite of this there was some air movement, cold air coming down the entrance shafts and warm air leaving by the ventilator cowls, and also by air being used up in combustion by the coal-burning stoves.

To improve the air circulation around the plants a blower motor was installed, taking air from near the growing trays and blowing it out into the workshop next door. Shallow trays of water placed between the growing trays helped to improve the level of humidity.

In September 1962, 12 tomato seeds were germinated successfully using a simple propagator. This was made from a shallow tin tray filled with vermiculite. The seeds were sown on this and kept moist with plain water by a drip-feed system, and the tray was enclosed in a box covered by a sheet of glass. This was done to maintain a steady temperature and to retain a moist condition during germination in an effort to improve the vigour of the seedlings.

The 12 seedlings were pricked out into empty "50" cigarette tins (with drainage holes punched in the bottom) filled with vermiculite. These were then grown on under the fluorescent light (Fig. 6). The tins containing the plants were stood in a shallow tray and fed by the drip-feed method, as the equipment made for sub-irrigation was about to be installed in the outside greenhouse.

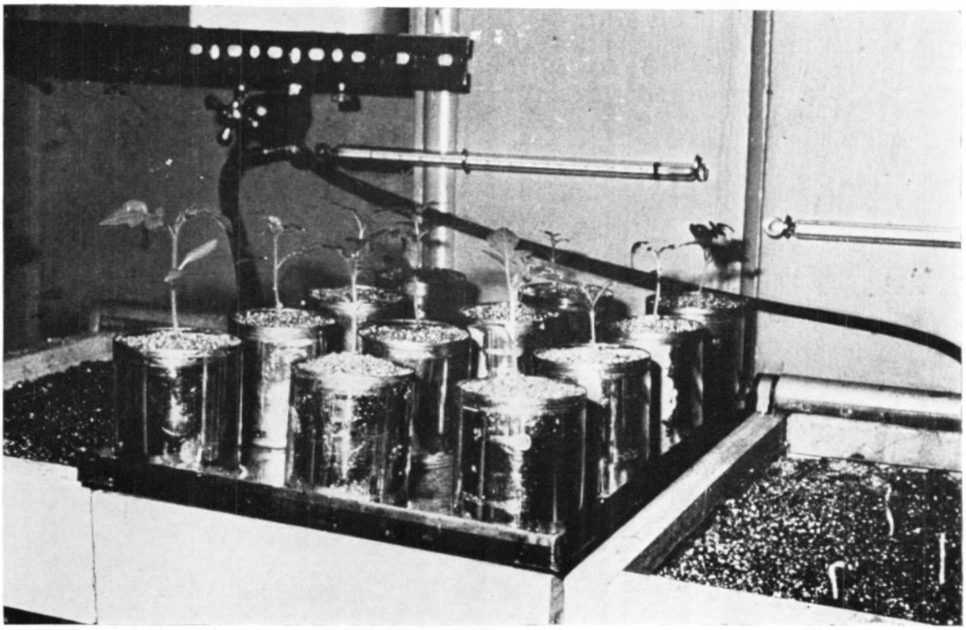

Fig. 6. Tomato seedlings growing in cigarette tins under artificial light.

Outside "greenhouse" (*Phase* 2)

As the daylight and day length increased (September–October 1962), plans were made to build a small greenhouse outdoors but there were many problems to be overcome:

i. Drifting snow burying any structure on the surface, or of that structure causing a drift to form thus covering entrances, chimneys, ventilators, etc.

ii. Maintaining an optimum temperature within the structure, complicated by the necessity for most of its surface to be of glass, and also that of temperature losses due to opening a door for access.

iii. Temperature control was further complicated by the problem of ventilation within the structure.

However, these problems were resolved and the design shown and discussed in Appendix B was eventually arrived at.

During October 1962 I was away from the Halley Bay station on a depot-laying journey and the building of this "greenhouse" was of necessity delayed. On my return the 12 tomato plants were still growing under completely artificial conditions; they had been cared for by a colleague during my absence and were thriving, and though there was some unevenness average plants had reached a height of 5 in. (13 cm.) 7 weeks from seed sowing (Fig. 7). At 8 weeks the six best plants were selected and transplanted, two into each of three new growing trays which had been made up from empty cereal tins and filled with the 60 per cent gravel/40 per cent vermiculite mixture. The trays had the same dimensions as before, 18 × 12 in. (45 × 30 cm.), but they were a little deeper to allow for better root development. After transplanting, these six plants continued to grow under artificial light for a further 10 days.

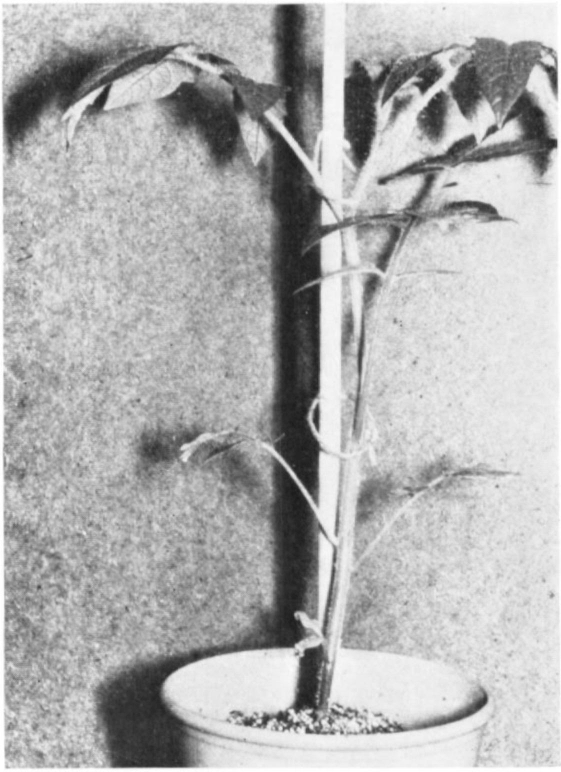

Fig. 7. Tomato plants grown to a height of 8 in. (20 cm.) under inside conditions, then grown on in outside greenhouse at Halley Bay.

During this time the outside greenhouse was constructed in sections in the carpenter's shop, and each section was hoisted up through an entrance shaft and assembled over the hatchway as described in Appendix B. After completion several days were spent in recording temperature gradients inside the greenhouse and checking these against outside temperature and weather conditions (see Appendix B).

Because these tests were satisfactory, the trays containing the tomato plants were moved from their completely artificial environment and placed in the natural light of the outdoor greenhouse. The plants, at this stage 9½ weeks, averaged 9 in. (23 cm.) high and though a little pale in colour they were quite good plants, comparable to any early sown plants grown in the poor but natural light conditions of an English winter and early spring.

Problems

My previous limited glasshouse experience was of little use during much of this work, and this was especially true of this phase of the work in the "roof-top greenhouse". New methods and strange conditions required a whole new learning and the adoption of completely new techniques. For example, because of the continuous daylight at this time of the year, it was necessary to fit shutters over the glass during part of each 24 hr. period to give the plants a night period. (Further inquiry has shown that this was probably unnecessary, as tomatoes are grown north of the Arctic Circle. This problem has been studied (Kristoffersen, 1963) and it has been claimed that tomatoes will tolerate continuous light from fluorescent tubes if the air temperature is reduced from 68 to 59° F (20 to 15° C) for 6 hr. in each 24 hr.) This is a topic for further study under conditions of natural as well as artificial light. The shutters were fitted in order to give an average simulated day length of 16 hr. but this was gradually increased until there was a day length of 18 hr. during early January (Table I).

Table I. Weekly temperature, humidity and other data for the outside greenhouse at Halley Bay

	1962				1963			
Week ending	8 Dec.	15 Dec.	22 Dec.	29 Dec.	5 Jan.	12 Jan.	19 Jan.	26 Jan.
Inside temperature (° C)								
Average	18	19	17	18	19	18	18	19
Minimum	14	13	12	14	16	16	16	17
Maximum	26	26	24	24	23	23	24	23
Outside temperature (° C)								
Average	−8	−7	−6	−7	−5	−4	−5	−7
Minimum	−19	−15	−14	−17	−7	−6	−15	−14
Maximum	−4	−2	−2	−2	−2	−1	−1	−1
Average humidity (per cent)								
Outside	72	69	74	67	68	74	79	67
Inside	61	51	49	46	61	57	55	51
Ventilation	x	*	*	*	x	*	*	*
Shade	N	M	M	H	N	N	N	H
Hours of light given								
Average/day	16	16	16	17	17	18	18	20
Hours of sunlight								
Total	23	94	57	19	—	8	—	—

Ventilation * Maximum. x Half.
Shade N. None. H. Half. M. Maximum.

A further problem was that of maintaining a sufficiently high level of humidity but this was never completely solved. Broad wicks, suspended amongst the plants with their ends in trays of water, helped a little and twice daily spraying later on improved conditions slightly. Because of the design of the greenhouse, temperature control did not present such a problem as had been anticipated, except for one period of about a week of high wind when it was found that cold air was being blown in through the hut loft below. Normally, warm air rising from the hut kept the temperature up to the optimum; to supplement this a 200 W. tubular heater was fitted and connected through a thermostat set to switch in when the temperature dropped below 68° F (20° C). On the contrary, keeping the temperature down was by far the greater problem. The greenhouse had been designed with very little facility for ventilation and it was found that the strong sunlight experienced on many days during the summer caused the temperature inside the greenhouse to soar to over 90° F (35° C) in spite of outdoor temperatures never rising above 29° F (−1·5° C) (Table I). Shading had to be used and an additional sliding ventilator was fitted to the back of the structure.

Results in Outside Greenhouse

The six tomato plants set out in the outside greenhouse on 2 December 1962 matured rapidly in their new environment. Feeding was by the modified sub-irrigation method and twice-daily flooding was later carried out on sunny days when the trays showed signs of becoming too dry. With the low humidity, transpiration from the leaves was quite rapid and wilting occurred very quickly if the growing medium became too dry. At 11 weeks the plants were stopped at just under 2 ft. (0·6 m.) but several strong side shoots were allowed to grow on to form a bushy plant (Amateur is a bush variety normally grown outdoors in England).

At 13 weeks the first trusses flowered and, helped by regular spraying, about 90 per cent of these set fruit. Unfortunately, it was later noted that most of these first fruits were affected by blossom end rot, a physiological disorder caused by insufficient moisture being available to the plant during the early development of the young fruit, and they had to be removed. (It had not been appreciated just how high the water loss due to transpiration and evaporation from the growing medium had been, and it was at this stage that twice daily flooding on sunny days was begun.)

However, blossom end rot is not an infectious disorder and the second and third trusses flowered well and their fruit had set at 15 weeks. At 16 weeks there were 120 visible maturing fruit of which only about 5 per cent were affected by blossom end rot. In the good light conditions (bright sunlight and/or reflected light from the snow surface) together with a day length of 18 hr., and later for a short period of 20 hr., the fruit ripened quickly (Fig. 8). Of the first picking, the average weight per fruit was about 1½ oz. (42 g.); they were uniform in size (Figs. 9 and 10), clean and of good flavour. (The plants subsequently carried between five and seven large fruit trusses each, and a total of 40 lb. (18·2 kg.) of ripe tomatoes were picked.)

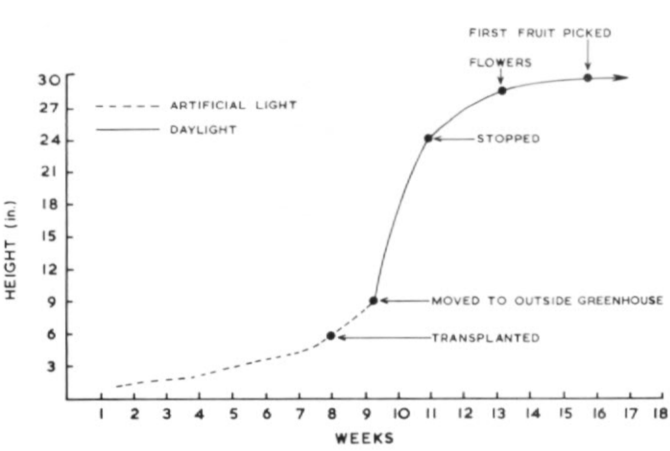

Fig. 8. Growth rate of tomato plants at Halley Bay in 1962. A 16 hr. "day" given under artificial light indoors; the details of exposure to daylight are given in Table I.

Fig. 9. Tomatoes, many of them ripe, growing in the outside greenhouse at Halley Bay in January 1963.

Fig. 10. Tomatoes, many of them ripe, growing in the outside greenhouse at Halley Bay in January 1963.

An intercrop of lettuces and radishes (seed sown on 8 December 1962) grown in the trays along with the tomatoes was picked on the 25 January 1963 (7 weeks), and together with several tomatoes they made the basis of a nice salad! The radishes (Early French Breakfast) were crisp and well flavoured. The lettuces too were crisp and good, but even in natural daylight they again failed to heart up satisfactorily.

Work at Halley Bay—Conclusions

It must be realized that this work at Halley Bay was undertaken purely as something of a hobby and, considering the often make-shift facilities together with my own inadequate knowledge, the results obtained were pleasantly surprising and encouraging.

By the use of hydroponics, a controlled rate of feeding and of ideal growth conditions was ensured, and root-development problems and the usual soil troubles were not experienced. Although there were other unforeseen problems, that of pests and diseases did not arise—in spite of warnings to go well armed with insecticides and fungicides! The growing medium, which was completely inert to begin with, contained no harmful organisms, and because of the climatic conditions further harmful organisms did not occur at the station. The possibility of some fungoid growths, such as *Botritis cinerea*, had been expected but apart from finding a mild infection of this on a number of hyacinth bulbs (not referred to here) which flowered under artificial light, the infection did not arise again. The bulbs and the medium in which they had grown were disposed of outdoors.

The nutrient solution formula used proved to be satisfactory and total cost for the salts used came to about 3*s*. 7*d*. The formula used is given in Appendix A. Other formulae are available and these are referred to in Appendix A.

For the continuous growth of plants, i.e. to maturity, the light intensity used indoors was not really adequate. Equivalent to less than 50 W./sq. yd. (60 W./m.^{2}) this was considerably less than the intensity of 1,000 W./sq. yd. (1,196 W./m.^{2}) which had been recommended as necessary by two sources before leaving the United Kingdom. The single tomato which was reared to maturity under this low intensity should be regarded as something of an "accident". And yet the peas grew and matured under this light—but they are not really a practicable crop under these conditions. The cucumbers too had reached a well-advanced stage prior to their loss by outside factors. Although the lettuces became very drawn and never hearted at all, this condition still obtained even in natural daylight, and it is suspected that the choice of variety was probably at fault (see p. 61).

The choice of tomato variety (Amateur), normally grown outdoors as a bush, seems highly satisfactory and it was chosen for several reasons:

i. It was assumed that as an outdoor variety it would have certain characteristics of hardiness, resistance to fluctuations in temperature and so on which are absent in the normal greenhouse types.
ii. Its habit of growth, a bush some 12–18 in. (30–45 cm.) high, seemed to lend itself to the sort of accommodation in which it was to be grown, and it was understood to be a fairly prolific producer of good flavoured fruit.

The use of a time switch in the indoor lighting circuit would have been a great help, and a small pump also actuated by a time switch would have made the irrigation system more automatic. Some method of maintaining a higher level of humidity is necessary and the kind of equipment used for mist propagation could probably be used.

The design of the outdoor greenhouse proved to be quite suitable, though size was a limiting factor; had it been larger many more plants could have been grown. The construction of double walls filled with fibreglass and double glazing of approximately half of its total surface area maintained a suitable temperature inside whilst still admitting sufficient light. The ventilation was not satisfactory and this presented something of a problem because of drifting snow. This could probably be solved by using opposite facing vents fitted with gravity louvres, plus a drift-tight inner door. The shading used on sunny days was very make-shift but proper green plastic roller blinds would solve this. The fitting of shutters to give a "night" period proved to be effective and they were sufficiently light-tight even in mid-summer when the light intensity outside varies very little throughout the 24 hr. Open ventilators during this "night" period would admit light but fortunately when the radiation from the sun is excluded the temperature inside the greenhouse falls and all ventilation can be shut down.

After the initial outlay—and for the work described here this was very little but it would increase as the system became more sophisticated (with a proportionate increase in yield)—running costs were quite low. Reference has already been made to the cost of nutrient solutions. The only other item which can be counted against running costs is that of electricity for heating and lighting. In the indoor installation the plants were grown at normal room temperature and no additional heat was required. The lighting, which would have been used for normal room lighting anyway, though not separately metered, can be considered to have consumed 192 units (80 W. × 16 hr. × 150 days). In the outside greenhouse, warm air rising from the living hut below plus heat from the sun maintained the optimum temperature, and the 200 W. heater came on only for intermittent periods, say 30 units (200 W. × 2 hr. × 75 days).

Phase 2 of the work was probably the most practicable and economical method, and plants could certainly be grown first in completely artificial conditions and later planted out into specially constructed greenhouses or existing ones (as at the Antarctic Peninsula stations) to continue growing. This effectively gives a longer growing season. The use of artificial light to supplement natural light, i.e. for raising seedlings in otherwise poor daylight conditions or for extending day length at the end of the growing season, is accepted horticultural practice in the United Kingdom and other countries in high latitudes, and it could be put to good effect especially at the Antarctic Peninsula stations. However, at Halley Bay the problems are somewhat more complex and would require special consideration.

The methods used, hydroponics, artificial light, etc., are not in themselves new, but it is believed to be the first time that such methods have been used in Antarctica. On the basis of the work reported here, it is believed that these techniques could be applied to provide Antarctic stations with a limited supply of fresh salad vegetables, which, so far, are not available in tins!

Current Work

Since returning to the United Kingdom further inquiry and work on this method of growing plants has been carried out, and there has been further success using similar techniques. Reference to both published and unpublished work on the growth of plants under artificial conditions, visits to various Departments of Horticulture and so on, have convinced me that the further application of this method of producing a supply of fresh salad vegetables at Antarctic stations is by no means outside the realms of possibility.

With the use of two simple "growing cabinets", further work on the growth of plants in an artificial environment is at present being carried out. The purpose of this work is to discover just how "simple" these growing cabinets can be, i.e. how inexpensive they are to construct and equip, and how simple and uncomplicated they are in operation. Growth cabinets and growth rooms are in use in several universities and other research establishments concerned with the study of plant physiology, but in general they are highly sophisticated pieces of equipment and very expensive and complex to construct and to operate (Lawrence and others, 1963; Morris and Carpenter, 1964; Carpenter, 1966). My present interest is in the design of a compact, inexpensive growing cabinet or room that requires a minimum of equipment, does not make large demands on the electricity supply and is capable of being used by anyone able to follow a few simple instructions.

Growing cabinets in use at present

The prototype growing cabinets in use now, and built at Chorley College of Education, are in the form of two large "cupboards" each measuring 4 × 4 × 4 ft. (1·2 × 1·2 × 1·2 m.) (Fig. 11). Each cabinet contains two growing trays, each 3 × 2 ft. (0·9 × 0·6 m.) and 6 in. (15 cm.) deep. Both cabinets are supplied with nutrient solution from a common supply tank and pump, and the sub-irrigation method is in use. The pump circulating the nutrient solution is operated by a time switch and it floods the growing trays three times each day. Drain-off is by gravity return to the supply tank. Experiments with two different light sources have been carried out, one cabinet being fitted with fluorescent tubes (MCF/U) and the other with a

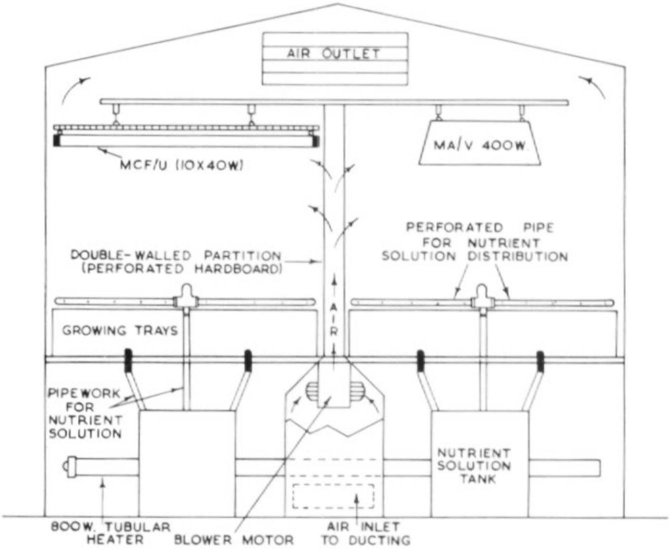

Fig. 11. Diagram of Chorley cabinets.

mercury vapour lamp (MA/V) of the type used by commercial growers as a source of supplementary light (Lawrence and Calvert, 1954). The MA/V lamp is rated by the manufacturers at 400 W. and, in order to have two light sources of matching rated intensity, the fluorescent light unit consists of ten 40 W. "warm white" tubes mounted in a bank at 2 in. (5 cm.) centres. This tube size and arrangement is not ideal (p. 63) but it was chosen because it was the combination best suited to give an area of illumination similar to that of the MA/V lamp, and it was therefore used to standardize the experiment.

Initially, trouble was experienced with temperature control; during warm sunny days the cabinet temperatures became too high. There is a high correlation between light intensity and air-temperature requirements for normal plant growth. Low light intensities must be balanced by low temperatures, and the increase of one cannot compensate for a deficiency in the other, though it is generally accepted that under artificial light higher temperatures can be used than are practicable in natural light of corresponding intensity (Canham, 1962*a*, *b*, 1963, 1966).

In many growth chambers an elaborate system of refrigeration is used (Morris, 1957) but refrigeration equipment is outside the scope of this present experiment and has not been used. The problem of temperature control, i.e. preventing a rise or fall in temperature above or below a predetermined level, has been partially taken care of by using a fan, blowing in air from outside and working in conjunction with a thermostatically controlled heater. Because the cabinets are not adequately insulated, fluctuations in temperature inside still occur but these variations are tolerable and during the winter months they will not vary too much from the required range.

In the humid atmosphere of south Lancashire, where the present work is being done, control of humidity is much less of a problem than it would be in Antarctica, but a system of wicks similar to that used at Halley Bay has been installed in the cabinets. The wicks are of fibreglass ("Cosywrap" pipe-wrap), which retains moisture very well, and the water level in the containers is maintained by capillary action from a supply tank. Suspended in the flow from the air intake fan, they have proved to be more than adequate.

Air is drawn in through a ducting at floor level, passed over a thermostatically controlled heater and is then blown up between a double-walled partition between the two cabinets (Fig. 11). This double partition is made from perforated hardboard and so the blown air is fairly evenly distributed into the two cabinets. Air is removed by convection through a large ventilator fitted centrally above the two lamp units. Whilst this removal of air by convection is adequate at present, it could be much improved by the installation of an extractor fan and thermostat, thus giving a more satisfactory control of temperature inside the cabinets (Fig. 12) in conditions of high outside temperatures.

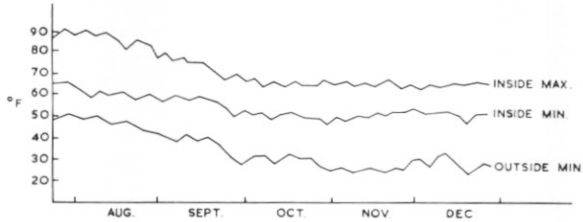

Fig. 12. Record of temperature at Chorley, 23 July—30 December 1966.

Preliminary results from present cabinets

Early work with these cabinets was not satisfactory because of the problem of temperature control but subsequent and present trials have been encouraging.

In order to study the distribution of light intensity within each cabinet, cress was sown thickly in each growing tray so that the total surface of the growing area was covered. Germination was good under the fluorescent lamps and growth was good and fairly even with some fall-off at the outer edges, especially below the ends of the lighting tubes. This was as expected and the fall-off at the edges can be corrected by using a reflecting surface on the walls of the cabinet. Work on the choice of reflecting materials for growing cabinets has been carried out by the National Institute of Agricultural Engineering (Carpenter and others, 1965), who found that aluminium foil gave the best results.

Under the mercury lamp germination was poor, due to excessive heat directly below the lamp, and germination was restricted to the areas of the trays not in the direct radiated light of the lamp. Poor growth in these areas was caused by low light intensity (shading by the lamp reflector).

Hearted lettuces have been grown under fluorescent light, using varieties recommended by Miss W. M. Dullforce of Nottingham University. These are Cheshunt 5B and Proeftuins "Blackpool", two winter glasshouse varieties used by Miss Dullforce for experimental work carried out in growth rooms to evaluate choice of winter lettuce varieties (Dullforce, 1962, 1963). Of the two varieties used, Cheshunt 5B hearted up in the shortest time but Proeftuins "Blackpool", though later, produced the largest lettuce and the heart was not as firm as that of Cheshunt 5B (Fig. 13) (cf. Dullforce, 1962, 1963). This aspect of the work to date has shown that the failure to get this crop to form a heart at Halley Bay was due to using what has now been shown to be an unsuitable variety and not to environmental factors alone.

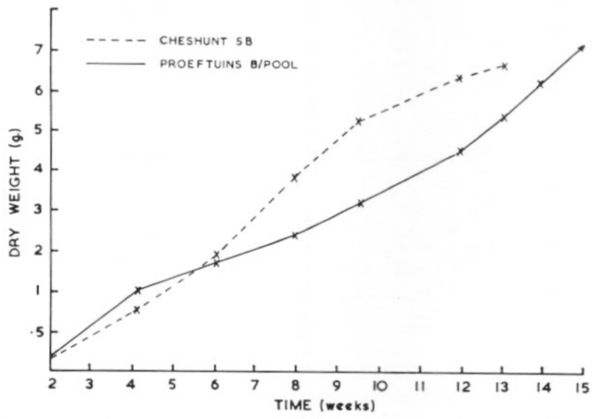

Fig. 13. Growth rate of lettuce (Cheshunt 5B and Proeftuins Blackpool) at Chorley under 400 W. fluorescent light, 16 hr. day length and temperature of 62–55° F (17–13° C).

A crop of tomatoes (Amateur) is now being grown, using both mercury and fluorescent light, and in the sixteenth week their fruit have set well, with many over 1 in. (2·5 cm.) in diameter. The growth-rate graph (Fig. 14) shows that initially those plants under the mercury lamp did better, making larger plants, producing flowers and setting fruit well in advance of those under the fluorescent light. However, subsequent results and observations show a marked fall-off in this initial gain and these plants are now showing excessive stem elongation, flower bud dropping, uneven development of fruit trusses and severe defoliation of the lower leaves. The plants under the fluorescent light are at present quite compact sturdy plants with large fruit trusses fairly evenly spaced. Sample plants removed from each cabinet at 15 weeks showed much better root development on that grown in fluorescent light and a higher leaf area: dry weight ratio.

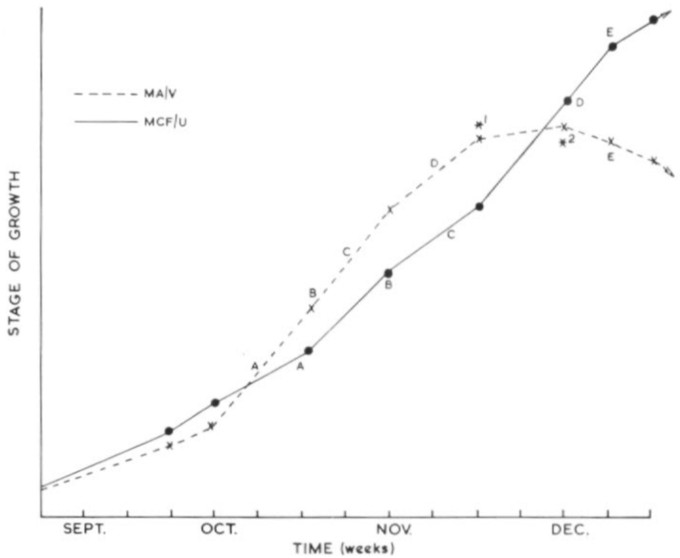

Fig. 14. Growth rate of tomato plants (Amateur) at Chorley under artificial light. "Stage of growth" was assessed from leaf count and size, flower formation, fruit formation, and overall plant size and shape.

A. First flower buds formed.
B. First flower buds opened.
C. First fruit set.
D. First fruit over 0·5 in. (12·5 mm.) in diameter.
*1. Lower leaves drying off.
*2. Severe defoliation and bud drop.
E. Dry weight of sample plants:
MA/V. 9·6520 g.
MCF/U. 19·3937 g.

Of the two light sources used, the best results have been obtained with the fluorescent light, as others have previously shown (Boodley, 1963; Canham, 1962*a*, *b*, 1963, 1966).

Choice of lamps for continuous growth

For continuous growth in artificial light, the fluorescent tube, in spite of its comparatively low light output for its physical size, offers the best spectral characteristics, since the radiation contains practically no near or far infra-red. The very low level of the latter radiation means that the lamp radiates very little heat and therefore causes a smaller increase in leaf-tissue temperature than does the MA/V lamp (Fig. 15), resulting in less transpiration from the plant and reduced moisture loss from the growing medium. Near infra-red (or far red as it is more usually called) is responsible for stem elongation in plants, and for many plants too high a level is a distinct disadvantage, though for some it is necessary for normal growth (Friend and others, 1959; Canham, 1962*a*, *b*, 1963, 1966).

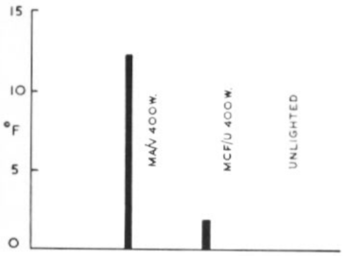

Fig. 15. Comparative increase in leaf temperature with lamps at 3 ft. (0·9 m.) mounting height above plants. The mean temperature difference between lighted and unlighted plants was used as a control.

It is said that the addition of a small percentage of tungsten light to that of fluorescent improves the spectral characteristics by providing the necessary far red radiation which the fluorescent light lacks, but for the plants being considered, i.e. mainly tomatoes and lettuces, this lack of far red is in fact an advantage, producing in these plants a desirable short-jointed habit of growth. Conversely, cucumbers would probably benefit from the addition of tungsten light, as this plant grows in a compact form under fluorescent light alone, and normal stem elongation does not take place (Fig. 5) (cf. Canham, 1962*a*, *b*, 1963, 1966).

Although 4 ft. (1·2 m.) 40 W. tubes have been used previously and are being used now, this has been due to circumstances and not from choice. The most suitable tube size, and that generally in use in growing rooms and cabinets, is the 5 ft. (1·5 m.) 80 W. "warm white" tube. Quite a wide choice of different types of lamps is available and some of them are also suitable for plant growth. But when total efficiency, spectral quality, growth response, light output and light depreciation, temperature control and ease of handling are considered, the 5 ft. (1·5 m.) 80 W. fluorescent tube appears to be the best.

A fluorescent tube with a built-in reflector (MCFR/U) is available but trials with these tubes have shown their light output is slightly less than normal non-reflectorized tubes. A bank of normal tubes (MCF/U) backed by an external reflector gives better results. An external reflector made from perforated hardboard painted gloss white provides adequate reflective qualities and facilitates cooling, and is in use in the cabinets at Chorley. The tubes used at Halley Bay were mounted in the manufacturer's housing and covered by the standard plastic "diffuser", but in fact these reduce light output and it would have been better without them.

In the original report (Hill, 1962) it was stated that the use of artificial light as the sole light source for growing plants was possible but not practicable because of the high intensities necessary. Information available at that time suggested this and that light intensities of 1,000 W./sq. yd. (1,196 W./m.²) were necessary. Subsequent inquiry has shown that this is not so and that much lower light intensities can be used. Trials carried out by A. E. Canham of Reading University, under light intensities of 160 and 200 W./sq. yd. (192 and 240 W./m.²), produced tomatoes earlier than control plants grown in an outside greenhouse (cf. Germing, 1963). As previously stated, the relationship between light and temperature is of prime importance and at low light intensities the temperature needs to be correspondingly lower. By way of example, in one of the trials referred to above, at a light intensity of 200 W./sq. yd. (240 W./m.²) temperatures of 78° F (25·5° C) (day) and 68° F (20° C) (night) were used. In my own current trials with Amateur tomatoes, temperatures of 62° F (16·5° C) (day) and 55° F (13° C) (night) in a light intensity of approximately 100 W./sq. yd. (120 W./m.²) are being used.

A light unit consisting of a bank of fluorescent tubes, such as is in use, has the advantage of giving a fairly uniform radiation distribution over a fixed floor area, at different mounting heights, whereas the distribution of the MA/V mercury lamp, which emits its radiation from what may be considered to be a point source, varies considerably with mounting height. The mercury lamp is of course highly recommended as a source of supplementary light for use in outside greenhouses (Lawrence and Calvert, 1954). Fluorescent tubes may also be used for this purpose although they have certain disadvantages (of shading for example, but by using MCFR/U tubes this effect can be minimized).

Conclusions and suggestions for further consideration

Cabinets of the type described here could be easily constructed for use inside any of the Antarctic station huts (including Halley Bay) and they would take up very little space. They could be used by anyone able to follow the simple instructions necessary for their management, and would be capable of providing a limited supply of fresh salad vegetables throughout the year, irrespective of the outside conditions. It is not suggested that such crops (on the scale envisaged) would replace any part of the normal diet but would merely supplement it.

In conjunction with an outside greenhouse, taking advantage of natural sunlight during the summer months, the uses of such cabinets would be increased, as was done at Halley Bay, though the use of hydroponics and not imported soil in these outside greenhouses would be strongly advocated. At some of the stations in northern Antarctic Peninsula, crops could easily be grown in existing greenhouses, again using hydroponics, by using normal supplementary lighting techniques as practised by commercial growers in the United Kingdom (Lawrence and Calvert, 1954). Maturation of crops grown by this method would of course be restricted to the summer months, thus limiting the supply to one crop of tomatoes and two, or possibly three, of lettuce. Double glazing of outside greenhouses, as was proved at Halley Bay, would overcome the problem of temperature losses.

A summary of the costs of various items of equipment is given in Appendix C. The cost of the actual construction of growing cabinets would vary according to individual stations and the choice of cabinet type. For example, a cupboard type similar to those in use at present would only require racking that could be fabricated from "Dexion", together with suitable panelling and sliding doors for access. A free-standing cabinet would require a complete box construction and would be more expensive to build, but it would have the advantage of being portable and could be prefabricated in the United Kingdom for assembly at an Antarctic station.

Ideally, a small room either specially constructed or converted and which could be walked into, would be even better than the cabinet idea but it would be more demanding of hut space. This type of walk-in growing room is of the sort used by some research establishments but it

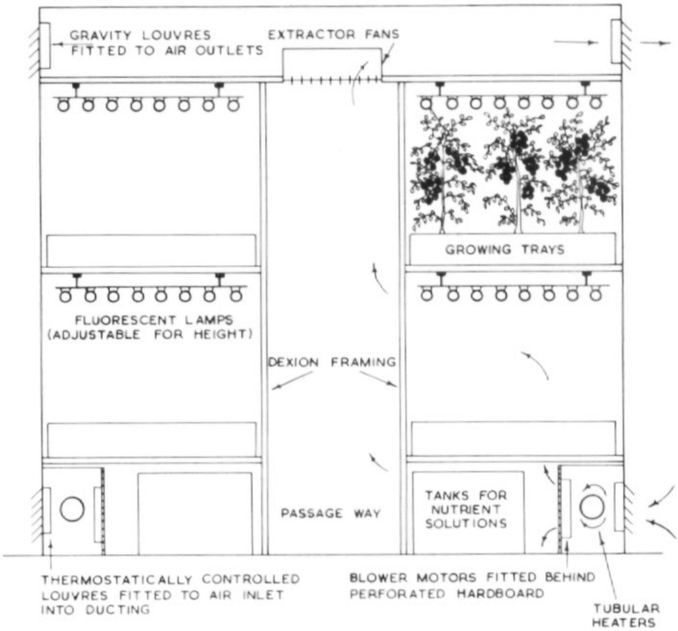

Fig. 16. Suggested lay-out of a typical growing room. This is one of several possible designs.

would not require the elaborate equipment used in most of these. For example, refrigeration equipment would not be required, as the naturally refrigerated air available at Antarctic stations could be ducted into the room as necessary. Using such a room with thermostatic control on both the heater and the air intake fan, a controlled temperature comparable to that obtained in much more sophisticated installations in the United Kingdom could be provided. If small growing rooms such as that described here were used, they would have the advantage of being capable of producing larger crops than those obtainable with the more compact growing cabinets. Fig. 16 shows a suggested lay-out of a growing room that could be used in the Antarctic.

Further work on the design of growing cabinets and/or rooms, choice of equipment, application of techniques, and suitable cropping plans and choice of varieties is continuing.

Acknowledgements

I should like to express my thanks to the Halley Bay meteorologists for the loan of instruments and for weather data, and to the physicist for the use of the heater and thermostat. John Holt kindly looked after the work whilst I was away from the Halley Bay station. The carpenters helped, advised and provided materials for building the outside greenhouse.

I am indebted to the Rural Studies Department of Chorley College of Education, who provided the facilities for the current work, to Mr. A. E. Canham of Reading University, Miss W. M. Dullforce of Nottingham University and Dr. P. Newton of Manchester University for their interest and invaluable advice. Much of the data in the latter part of this paper was kindly provided by Mr. A. E. Canham.

MS. received 7 January 1967

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APPENDIX A

Nutrient Solutions

General. A great many different combinations of chemicals may be used to make up plant nutrient solutions and full details of these have been given by Gericke (1940), Saunby (1953) and Douglas (1959).

Closer examination reveals that many of the different formulae are variations on a basic mixture. A complete nutrient solution should contain all the essential elements (in a soluble form) required for plant growth. It must be a balanced mixture so that an excess of one element is not absorbed at the expense of another and it must also be of the correct concentration to allow normal growth.

Some formulae are recommended for specific crops and some for specific climatic conditions, but for practical purposes it is generally agreed that one basic formula is suitable for practically all plants and climates. Some adjustment can be made to this basic formula to allow for different light conditions, to hurry plants along a little at certain stages, i.e. additional potash to assist with flowering and fruit formation, and additional nitrogen to increase leafiness, etc. An excess or deficiency of any element in the solution will manifest itself in easily identifiable symptoms (Appendix D and references given above). Final choice of the basic formula used must to a large extent be decided by what chemicals are available.

The basic formula used at Halley Bay was:

Sodium nitrate	6·6 g.
Superphosphate (single)	2·8 g.
Magnesium sulphate	1·1 g.
Potassium sulphate	1·1 g.

to 1 gall. (4·5 l.) of water, but the formula in use now at Chorley is:

Sodium nitrate	1 oz.	(28 g.)
Superphosphate (single)	1 oz.	(28 g.)
Magnesium sulphate	0·5 oz.	(14 g.)
Potassium nitrate	0·5 oz.	(14 g.)

to 10 gall. (45 l.) of water. "Fertilizer grade" chemicals were used, since pure chemicals are not necessary. No trace elements were added, because they are generally accepted as being present as impurities in this grade of chemicals. However, a trace of ferrous sulphate was added at one stage when iron deficiency was noted.

Rate of application. 1 gall. (4·5 l.) of solution was made up and applied to the growing trays (approximately 0·5 sq. yd. (0·4 m.^{2}) in surface area) every 2 days. After flooding, the solution remained in the trays for about 1 hr. and was then drained off. On the intervening days the solution drained from the trays was topped up to 1 gal. (4·5 l.) again by the addition of plain water, and the trays were again flooded for 1 hr. At the end of this time the remaining liquid was drained off and thrown away.

When making up solutions the salts should be added to about 1 pt. (0·57 l.) of water, thoroughly stirred and allowed to settle. Only the clear liquid is then added to make up the required amount of solution and the insoluble residue is thrown away. For the plants referred to here the solution should have a slightly acid reaction (pH between 5·5 and 6·5). The water used at Halley Bay came from melted snow (pH 7) and it was found that after the addition of the salts a suitable pH of 6 was obtained.

APPENDIX B

The Outside Greenhouse at Halley Bay

The outside greenhouse at Halley Bay (Fig. 17) was built up in sections from 1½ × 1½ in. (3·8 × 3·8 cm.) timber framing, the back and two side panels being clad in ¼ in. (6 mm.) marine plywood (outside surface) and ⅛ in. (3 mm.) hardboard (inside surface). The space between was filled with 1½ in. (3.8 cm.) fibreglass insulation. The top and front panels were rebated to take the glass, which was held in place by wooden strips as shown in Fig. 18. These sections were double glazed, a 1 in. (2·5 cm.) air space being left between the glass. The sections were then taken up through the entrance hatchway and assembled over another small hatchway (previously used during darkness for auroral observations). Access into the greenhouse was through this hatch, which allowed an individual to stand on the ladder with head and shoulders inside to carry out any work.

Details of temperatures and humidities recorded in the outside greenhouse before planting out the tomatoes are given in Table II.

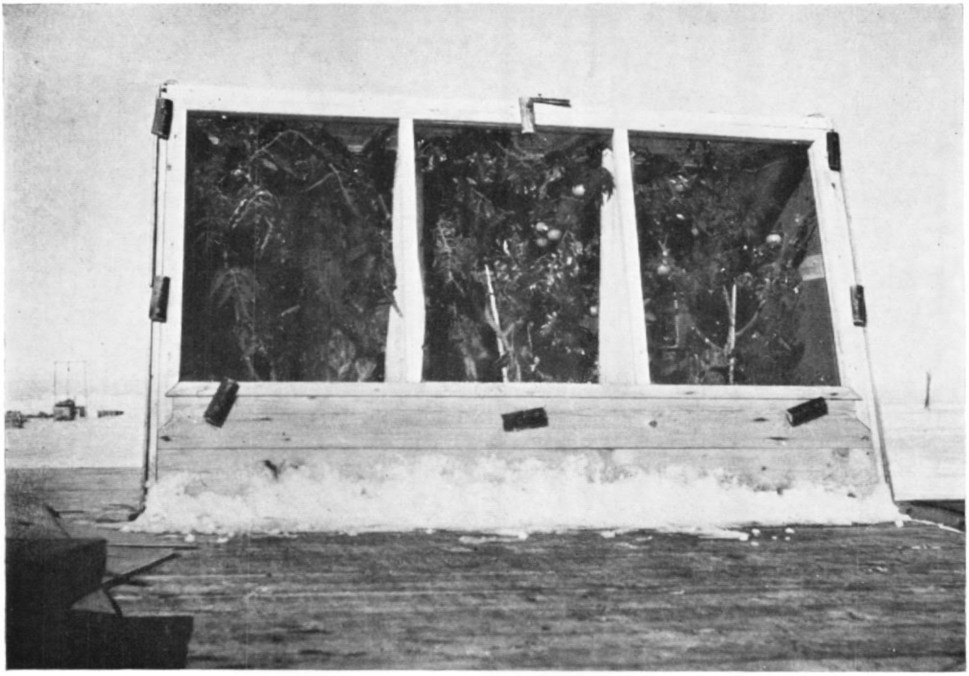

Fig. 17. Front view of the outside greenhouse at Halley Bay, showing tomatoes ripening inside.

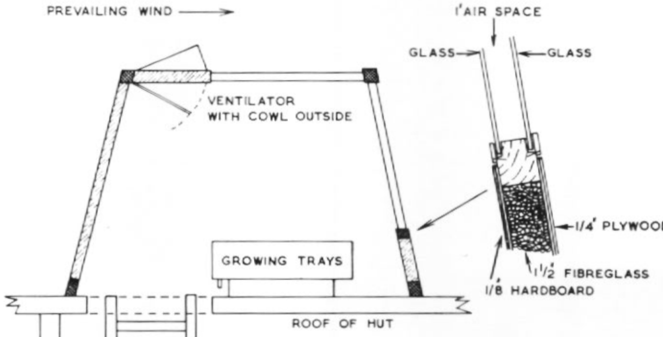

Fig. 18. End-section view showing the constructional details of the outside greenhouse at Halley Bay.

Table II. Temperature and humidity data recorded in the outside greenhouse at Halley Bay before planting out tomatoes

		Date 1962						
		25 November	26 November	27 November	28 November	29 November	30 November	1 December
Inside temperatures	Night average (°F)	54	56	56	54	56	56	56
	(°C)	12	13	13	12	13	13	13
	Day average (°F)	75	85	83	72	72	74	72
	(°C)	24	29	28	22	22	23	22
	Night minimum (°F)	52	54	52	54	54	54	54
	(°C)	11	12	11	12	12	12	12
	Day maximum (°F)	88	88	88	79	77	77	79
	(°C)	31	31	31	26	25	25	26
Outside temperatures	Day average (°F)	10	10	10	16	16	20	20
	(24 hr.) (°C)	−12	−12	−10	−9	−9	−7	−7
	Night minimum (°F)	3	3	1	1	7	13	16
	(°C)	−16	−16	−17	−17	−14	−11	−9
	Day maximum (°F)	22	22	18	18	23	23	23
	(°C)	−6	−6	−8	−8	−5	−5	−5
Humidity (per cent)	Inside	60	54	60	58	65	60	65
	Outside	75	63	74	66	75	75	78
Remarks		Day temperatures too high!	Day temperatures too high!	Additional ventilation and shading material fitted	Day maximum temperatures reduced	200 W. heater fitted	Day and night temperatures better	Day and night temperatures better

APPENDIX C

Summary of Costs for Equipment

Equipment and total cost would vary according to the type and size of the installation but a list of standard items is given here as a guide. Where quoted, prices are for single items at retail and they are average examples of reputable manufacture.

	£	s.	d.
6 80 W. (5 ft.; 1·5 m.) fluorescent tubes and control gear	24	0	0
3 Growing trays (each 3 ft. × 18 in. × 6 in.; 0·9 × 0·45 × 0·15 m.)	6	0	0
(above items suitable for growing area of up to 15 sq. ft. (1·4 m.^{2}))			
Tubular heater; 60 W./ft. (196 W./m.) of tube. (£1 10*s.* 0*d.* for first 2 ft. (0·6 m.); approximately 7*s.* for each additional 1 ft. (0·3 m.) of tube)			
15 amp rod-type thermostat	5	0	0
9 in. (23 cm.) extractor fan with gravity louvres and thermostat	16	10	0
Pump for nutrient solution	5	0	0
Time switch (new)	6	0	0
(reconditioned)	2	10	0
Reflecting material (Melinex) (per sq. ft.)		1	0
Plastic piping for solution circulation (per ft.)			6
"Tubelock" pipe fittings (various)			
Cable and electrical fittings (various)			

APPENDIX D

Symptoms Developed in Plants Indicating Deficiency or Excess of Elements

Symptoms indicating deficiency	*Symptoms indicating excess*
Nitrogen	
Poor development; small pale green or yellow leaves	Lush foliage not proportional to root system; soft stems
Phosphorus	
Abnormally dark green, or with purple leaves; stunted growth	Similar to above symptoms
Potassium	
Older (lower) leaves go yellow and later brown and dry	Stems hard, leaves dark, leaf stalks become stiff
Calcium	
Affects root system causing stunted growth; roots die	Similar to iron deficiency
Magnesium	
Yellow leaves; leaf veins stay green; flowering delayed	Leaves larger and lighter-coloured than normal
Iron	
Leaf tips at top of plant become chlorotic and later dry	Severe burning followed by complete collapse of plant