THE ARK PROJECT
R. R. #4, SOURIS, P. E. I.

MANAGEMENT OF SOLAR GREENHOUSES

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ABSTRACT

The positive and negative effects on plant growth of environmental conditions in the Ark solar greenhouse have been monitored. The lower light levels, wide temperature fluctuations, low winter temperatures, high relative humidity and possibly low CO_2 levels compared to conventional greenhouses have been problems that have been solved to varying degrees. Plant variety selection, revised bench design and the addition of a heat exchanger are used together to provide optimum conditions within the solar design.

INTRODUCTION

The commercial greenhouse industry exists because crops can be grown at a profit within a protected environment. It is well known that the energy cost of maintaining the artificial interior climate is an increasingly vital factor in the viability of the industry. The growing necessity to conserve energy has brought about investigations into solar greenhouse design, energy-saving retrofitting, and low-energy cropping methods. Although research is currently being carried out elsewhere to determine tolerable minimum soil and air temperatures, energy-saving temperature regimes and minimum light levels (1), there is still a relatively narrow range of temperature and environmental conditions that must be provided for plant growth. Extremes of cold (below 10°C) and heat (above 30°C) may not kill the plants but will certainly reduce their productivity. In designing the solar greenhouse the economic factors such as capital cost, labour, maintenance and energy use must be considered in conjunction with the specific environmental requirements of the crops to be grown. For every crop and economic situation, there is a balance to be struck between energy input and cash return from the crop. Assessing this balance is a complex process. For instance, it may not be necessary to install a back-up heating system in a solar greenhouse if one accepts night-time minimums below 10°C in early spring. If tomatoes are being grown however, the sterile flowers resulting from the cold nights may ruin enough fruit clusters that the crop loss will be substantial. Scheduling the crop to mature later may avoid that problem--but will bring tomatoes into market when prices are lower. As has been quickly discovered, the most efficient use of solar design is not always the best for the culture of crops. For example, a solar design with an annual heat storage system may be the most efficient when the summer drop in soil temperatures. Basically, however, for very little maintenance energy (approximately 500 kwh/month for the rock storage fan) the greenhouse maintains adequate production temperatures from February through November.

Soil temperatures in the deep soil beds have been adequate during the same ten months of the year for crop production but there was one major problem in their design. The soil level was so low that in December the front half metre of these beds was shaded from the sun by the shallow soil benches along the south wall. Nothing could be grown in this area for a month before and a month after the winter solstice. The original soil benches in the commercial and domestic greenhouses were suspended wooden trays 20cm deep, and filled with soil. This presented several problems: the soil was too shallow to provide adequate thermal mass in winter and it dried out quickly and made adequate irrigation a problem in summer. The amount of watering necessary was hard on soil structure, leached out nutrients and caused salt toxicity symptoms in plants that were stressed by dry soil part of the day.

The humidity levels in the greenhouse were good in the summer and there was no need to humidify the air on hot days. High relative humidity, however, became a problem by November when it was necessary to keep the vents closed to maintain air temperature. Condensation and stale, still air threatened crop health in December and January when botrytis fungus seriously damaged the lettuce crop. Conditions again improved in March when it was possible to ventilate to the outside. Although no data was collected on the CO_2 concentration during this time, levels may have been inadequate while the greenhouse was closed up to conserve heat.

DESIGN MODIFICATIONS

In an attempt to provide better growing temperature during the winter of 1978-79, an interior skin of 2 mil polyethelene plastic was installed in November against the purlins. A Tedlar skin was planned but was not immediately available and since the new plastic should have had virtually the same light transmissivity, it was temporarily substituted. It was clear, even when walking from covered to yet uncovered sections of the greenhouse while it was being installed, that the plastic was cutting down heat loss. Subsequent problems with the plastic skin, however, gave a good indication that the permanent Tedlar may not be worth installing. A heavy layer of condensation formed on the inside of the plastic as well as between the plastic and the Rohaglas glazing. This resulted in two layers of condensation instead of one. The light levels were drastically lessened and even on a sunny day in January, the interior level of solar radiation measured on the horizontal was twenty percent of what was striking the building exterior. Physiological problems with the lettuce crop were observed and the symptoms were typical of those seen when lettuce is grown under inadequate light levels. As plant metabolism increases with warmer temperature, the requirements for light and CO_2 also increase proportionally.

Therefore, it would appear that the polyethelene layer aggravated the physiological stress in the lettuce by simultaneously causing lower light levels and warmer temperatures. In any case, it is certainly questionable whether the added layer should be a permanent addition. Since the tomato variety (Tuckqueen) selected for low-light conditions produced the best in the greenhouse in 1978, it is felt that the light at plant level was already reaching economic minimums and adding another permanent layer could only make this worse. Since the problem is how to cut down night-time heat loss without impairing daytime light levels, the use of a night curtain may be the solution. A night curtain of aluminized material was sewn but not hung due to considerable design problems with installation which finally culminated in a long wait for back-ordered hardware. It is expected that the curtain will raise the average night-time temperature a couple of degrees centigrade, but the real value of it under operating conditions will have to be judged next winter.

To provide better soil temperatures for roots, the deep soil beds in the commercial greenhouse and the soil benches in the domestic greenhouse were redesigned in the summer of 1978. The soil benches in the commercial greenhouse were reconstructed in 1979. Plant productivity is adversely affected by low soil temperatures, but soil temperatures that fluctuate rapidly are even more stressful than consistently cold soil. At some times of the year--especially February on P. E. I.--the solar greenhouse air temperatures were subject to wide fluctuations. During the course of a sunny winter's day, the temperatures would often rise to 18°C yet the minimums at night would often drop to 7°C. With such a wide variance, the soil in the shallow wooden benches is also subject to a wide range of temperatures in the course of a day. To help correct this (and the shading problems mentioned previously) in the soil beds, the beds were reconstructed. The deep soil beds in the commercial greenhouse were built up from the original 20 cm to a height of 40 cm. This has been adequate and growth has improved. The soil benches were removed and beds were built with field stone underneath the soil to provide thermal mass. The soil depth was increased to 40 cm (see Fig. 1). A problem with this design (and the one it replaced) is that the cold air falling down inside the glazing has nowhere to flow. Plants closest to the glass are caught in frost pockets on cold February nights. The chilling problem was not noticed in the commercial greenhouse, undoubtedly due to the air circulation forcing upwards against the glazing from the rock storage system. In greenhouses where this feature is not present, however, thought should be given to designing a space between bench and sill for the downward flow of cold air under the bench.

Problems with the air quality in the greenhouse--high humidity, stale air and low CO_2--led to changes in the use of the rock storage fan and the addition of an air-to-air heat exchanger. The rock storage system fan in the commercial greenhouse was initially intended to operate only in cold weather and only during the warmest part of the day while storing heat, and the coolest times to discharge it (regulated by timers switching the fan off and on). However, since moving air is an absolute necessity in a greenhouse of any size, especially when planted with a tall, lush crop such as tomatoes, the fan is now run continuously. This prevents a film of stale air from forming around each leaf and enables CO_2 to be absorbed. It also helps to inhibit fungus spores from germinating in the high humidity of leaf surfaces. A smaller fan than the 1½ hp rock storage fan would suffice to move air but the simplicity of running the one system continuously is an important consideration. The rock storage system is now used year around to provide heat in winter, circulate air and cool the greenhouse in summer. With the ridge vents left open at night and the fan drawing cool air into the rocks, the system helps cool the greenhouse during the day. The rock storage fan solved the air circulation problem but did nothing towards providing the frequent changes of fresh outside air necessary in a greenhouse. The necessity for fresh air with its low relative humidity can be appreciated when one realizes that condensation on glazing seriously cuts down interior light levels and that stale, moist air also presents a serious disease hazard. The need for CO_2 replenishment also becomes apparent when one realizes the high CO_2 requirement of a crop on a sunny day. For example, maintenance levels of CO_2 in an average productive greenhouse requires eleven air changes per hour on a sunny day. If artificial enrichment is not used, infiltration and ventililation account for the CO_2 maintenance in conventional glasshouses. In the solar greenhouse with well-sealed glazing and doors, infiltration is considerably less. At the Ark, much of the warmed air is drawn into the rock storage system and re-used instead of being vented outside when temperatures rise. Some venting on the sunniest days in winter is possible at the ridge but the lower vents allow a direct stream of icy air across the bench and are not used. However, if the ridge vents are open on a sunny February day, the rock storage fan then has to be switched off at the best time to collect heat to prevent it from drawing in cold air at the duct inlet. With more efficient heat storage systems, the problem is even worse as the greenhouse, theoretically, would never need venting in the winter months to dump heat. Artificial CO_2 enrichment only solves half of the problem--the other half being humidity. It is a relatively simple matter to humidify a dry greenhouse but dehumidification requires either a good fresh air flow or a dehumidifier. The installation of an air-to-air heat exchanger in the greenhouse has been the best solution to both problems so far. This heat exchanger was adapted to greenhouse use by A. Caffell from plans by R. W. Besant (3). A small internal fan in the exchanger ducts draws cold, dry, outside air between alternating layers of polyethelene while another fan drives the warm, moist, CO_2-depleted air from the greenhouse through the alternating membranes. The heat in the air is exchanged across the polyethelene membrane yet the humidity and CO_2 levels do not appreciably change. While in theory, the exchanger was capable of retaining up to ninety percent of the heat in the air, this has not been measured. Preliminary estimates of efficiency taken at the time of installation indicated about fifty percent of efficiency. In actual operation, running the exchanger on very cold nights did not seem to affect the temperatures in the greenhouse. The relative humidity which was a hundred percent before installation of the heat exchanger, began to drop as low as fifty percent during the day after installation . At the same time, botrytis infections in the lettuce slowly disappeared. The heavy layer of condensation on the inside plastic skin began to clear up and on many days was almost gone between 10 a.m. and 3 p.m. In short, quantitative observations indicate that the heat exchanger appears to be a good solution to the atmospheric problems in this greenhouse.

COMMERCIAL CROP PRODUCTION

A vital aspect of management only beginning to be explored is the adaptation of crops, varieties and planting schedules to the solar greenhouse environment. The greater temperature stress and, in this greenhouse, low light and high humidity are environmental conditions that plants must be selected for while keeping in mind their value for commercial production. As an example, kale grows well but is not a popular winter vegetable on P. E. I. Therefore lettuce is being investigated. Leaf lettuce grows well but is difficult to market because it wilts easily and is an unfamiliar crop to consumers. Head lettuce is easy to market, but very difficult to grow being particularly susceptible to fungus diseases and requiring well controlled environmental conditions. We have settled for the Dutch-type loose head (or Boston head) lettuce which is a marketable, reasonably trouble-free type of lettuce. Tomatoes are currently being researched for the warm season crop because of their marketability and high return per square metre. As may be expected, variety trials are showing large differences in cultivar performance. The commercial seed houses in North America and Holland are not selecting for solar greenhouse performance but continued testing at the Ark of available varieties is identifying some that perform particularly well (and some that do particularly poorly!)

Along with identifying suitable varieties, working out appropriate cropping schedules is essential. The following timetable is an example of crop scheduling within the parameters of the Ark greenhouse environment. Greenhouse tomato varieties are seeded at the end of January and grown on a small bench with 23°C bottom heat for two months and artificial lighting for the first month. They are hardened off to the greenhouse temperature (by this time the soil is above 13°C - 14°C at 8 cm depth) and set out at the end of March in slightly raised hills. Usual management practices for pollination and trellising are carried out. In August, the crop is high enough above the ground from the continuous removal of senescent leaves and ripening fruit that lettuce can be planted under the vines. In two months, the lettuce is harvested and another crop is planted among the tomatoes. This lettuce is harvestable when the tomato vines are pulled out in December. The beds are then closely planted to lettuce. (Broccoli varieties have been tested and grow exceedingly well but have a lower yield per square metre than lettuce.) This lettuce is harvestable by March 1st and another crop is set out between the intended tomato sites. It will have three to four weeks to mature after the tomatoes are set out before the vines shade them too much. Tomato yields from the 1978 crop were around 19.5 kg/square metre --equal to Ontario glasshouse yield for the same time period and it is expected that yields will be substantially higher in 1979 due to intensive pruning methods. Lettuce production is also comparable to what can be expected in conventional commercial greenhouses.

FUTURE DIRECTIONS

From the foregoing experiences with crop and systems management, it should be apparent, first of all, that yields as high as those from conventional systems are possible from a one hundred percent solar greenhouse. It should also be obvious that problems with atmospheric conditions and low winter temperatures have to be solved before it is possible to assure commercial success and economic returns from solar designs. Finding solutions must be approached both from the aspects of better building and systems design as well as that of selection and management of appropriate crops. Seed houses must be encouraged to select and breed cultivars adapted to solar greenhouse environments. Crop research should go beyond the usual vegetables in commercial production into investigation of grape culture, fruit production and nursery stock propagation as well as the less usual but promising vegetables such as the oriental cole crops. Profitable cropping systems based on greenhouse operation ten months of the year can be developed , making the capital costs of heat storage systems considerably lower. Crop systems could be developed for entirely passively heated structures. An example would be the culture of table grapes combined with a bedding plant operation or a nine-month tomato production. Grapes require cold dormancy but can be planted along the north wall and trellised out of the way of annual crops. The greenhouse could be producing vegetables from March to November with good passive design or minimum of back-up heat and the added income from specialty table grapes combined with the savings from not operating in the coldest months could make a profitable enterprise. Methods of providing solar start-up soil heating for such a greenhouse system should be developed and can be cost effective in as little as one year according to one study (4). The potential for the development of solar greenhouse systems is enormous and the possibilities are just beginning to be realized. The reasonable success of the solar experiment at the Ark gives us confidence that the greenhouse industry which is beginning to flounder in the face of escalating energy costs can be revitalized by the widespread use of good solar designs.

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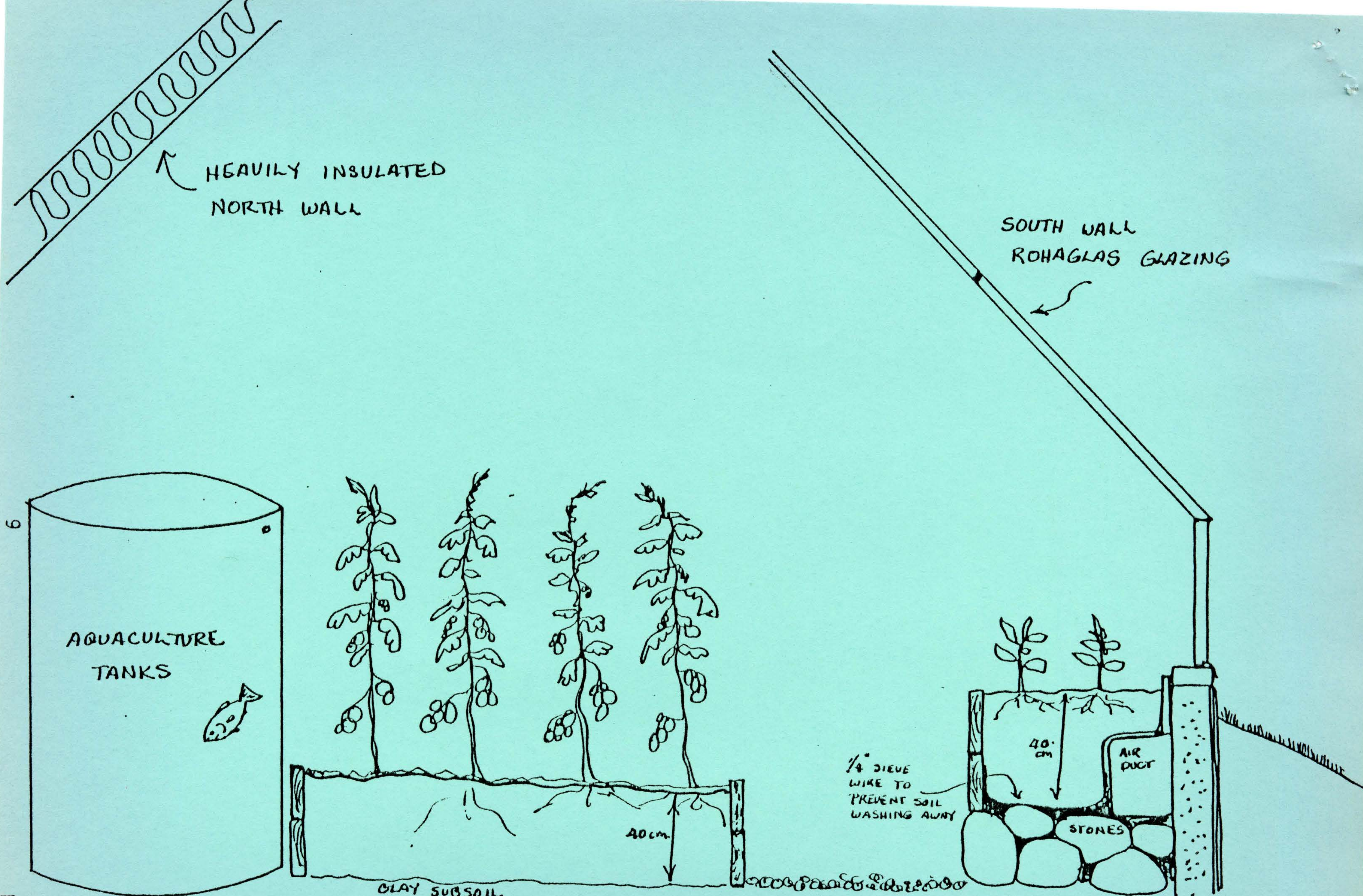

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Figure 1: CROSS SECTION - EAST END COMMERCIAL GREENHOUSE

ARK PROJECT - SPRY POINT, P.E.I.