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Using a Greenhouse for Controlling Plant Growth©

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INTRODUCTION

Greenhouses protect the plants from adverse conditions and enable the grower to control the growing conditions. Good control helps achieving a high yield, good quality, uniformity, and precise timing of delivery. A wide range of crops is grown in greenhouses; the end product can be leaves, roots, bulbs, tubers, flowers, fruit, seed, young plants, mature plants (herbs, salad plants, bedding plants, pot plants, garden plants), and more.

Controlling the growing conditions requires technology, primarily for heating and venting, and optionally also for root-zone heating, cooling, fogging, misting, CO_2 enrichment, shading, assimilation light, day-length extension, black-out, and more. Greenhouses come in degrees of sophistication: from uncontrolled plastic tunnels to completely automated and robotised plant factories. Simple greenhouses can be manually operated, but advanced greenhouses with a lot of technology require a good control computer. In New Zealand, most greenhouses used for plant propagation are relatively basic compared to some highly specialised greenhouses overseas.

This paper looks at using greenhouses for plant propagation and plant growth. The main growth factors are identified and the three main factors are described in some detail: light, temperature, and humidity. We discuss how they influence plant growth, and the principles of how they are controlled. The presentation will discuss these aspects as well as show examples of advanced greenhouse technology.

GROWTH FACTORS

The main environmental factors affecting plant growth are:

1) Light or photosynthetic active radiation (PAR).
2) Temperature.
3) Humidity.
4) CO_2.

In addition, plant growth can be influenced by:

1) Root-zone temperature.
2) Irrigation (frequency and volume of watering, average wetness of root zone).
3) Electric conductivity (EC) or conductivity factor (CF) in the root-zone.
4) Concentration of particular nutrients in the root zone.

LIGHT (PAR)

Light or PAR is the driving force for plant growth. Effects include:

1) More light → more photosynthesis → more biomass → more yield.
2) Low light level at high temperature → elongation (stretching) of plants.

3) More light → further opening of pores (stomata) in the leaves. Combined with more solar radiation → higher plant temperature → more transpiration.
4) Day length → photoperiodic effects such as flower initiation (related to certain wavelengths only, namely red and far-red light).

The Value of Light. Without light, green plants don't grow. An old rule of thumb is: 1% light equals 1% production. The effect is less drastic in some conditions, and therefore we quote a more conservative version of this rule of thumb, namely: 1% light equals 0.75 % growth (or yield).

This rule demonstrates the effect of light loss. In a greenhouse, natural light is inevitably lost due to shading by construction parts and cladding. More light is lost due to poor cladding or dirt on the roof, e.g., a bit of soot on the cladding can easily cause 10% light loss, which causes 7.5% yield loss. Some greenhouses are so old or dirty that they catch only 25% of the outside light. In comparison, a modern glasshouse can catch 85% of the outside light. By missing 60% light that could have come in, the yield will be 45% lower than it could be. Such dark greenhouses can't be economic. If they are heated, they cost more than they produce.

Solar Radiation Versus PAR. Light is only a part of the solar radiation, roughly about 45%–50%. The rest is heat and a very small percentage is UV radiation. Light is characterised by wavelength 400 to 700 nanometer (nm). Light in relation to plant growth is often called PAR. Ideally it should be measured by a PAR meter, and expressed in watt or joule (e.g., intensity in $W \cdot m^{-2}$ and light sums in $J \cdot cm^{-2} \cdot d^{-1}$). However, simple controllers and small computers mostly use a luxmeter, which produces readings in Lux or kiloLux (kLux).

Screening (Shading). First we considered natural light only. Sun light is a given and can only be lost by shading of the greenhouse structure (see above) or tempered by screening, shading, etc. Solar radiation contains about 50% to 55% heat (radiation with a longer wavelength than light). In addition, a large part of the light caught in the greenhouse is converted to heat as well. As a result, high levels of natural light in a greenhouse are accompanied by high temperature. This is undesirable and therefore screening can be applied during strong sunshine to avoid damage caused by too high a plant temperature. Screening is especially required for young plants with little roots (seedlings, cuttings), because young plants cannot take up enough water to cool themselves. Sometimes screening is meant to temper the light level, for example some ornamental pot plants need screening to maintain their typical leaf colour or other particular features. A simple form of shading is by white washing the roof. This is cheap, but the disadvantage is that it blocks light and causes yield loss at all times. Another method is installing a fixed screen or shade cloth. But this has the same disadvantage of permanent light loss. The ideal way would be installing a screen installation or shutters on the outside of the roof, which can be opened and closed as required. Shutters outside would block any radiation before it enters the greenhouse, so heating up would be avoided. Outside screens can be damaged by wind, so the practical solution is a controllable screen or curtain inside the greenhouse. It can be closed when required, and can be opened during dull weather. Screens can also be used for energy saving in winter. However, energy-saving screen requires high light transmission (instead of low light transmission of a shade screen) and a high insulation factor. There are screen materials available aiming at combining both functions (dual purpose screens). They are a compromise and achieve only half the energy saving that the specialised energy saving screen materials achieve.

Possible side effects of screening (shading) include:

1) Loss of growth and production. If 70% of the radiation is blocked by shading, then also 70% of PAR is excluded, reducing photosynthesis and growth by roughly 50% in that period.
2) Shading makes plants lush, soft, and vulnerable. In a shaded greenhouse, the roots and water transport systems of the plants are not challenged to withstand harsh radiation. Then, if the plants are accidentally exposed to high radiation or low humidity, their water uptake capacities will be too low and the plants will wilt and burn.
3) Shading stretches the plants. Low light level makes plants elongated. High temperature during day-time stimulates stretching even more (see below under temperature). Due to reduced photosynthesis under the shade screen, there is little biomass to give any substance to this stretching. Hence the warmth and dark conditions under a screen may result in soft, floppy tall plants.

Artificial Lighting. Overseas it is common practice to increase the light level by using artificial light, in two ways:

1) ***Assimilation Light.*** Addition of extra PAR can increase plant growth and production. However, a very high intensity is required to have any effect. This is extremely expensive in investments and running costs. This is only cost effective in countries with long dark winters, and/or low electricity costs.
2) ***Photoperiod Light.*** The photoperiodic effect or day-length sensitivity is brought about by red and far-red radiation. A low level radiation from simple incandescent lamps (cheap) is sufficient to create this effect. It can extend the day length to stimulate flowering in long-day plants, or prevent flowering in short-day plants. Black-out screens can be used in other periods to shorten the day.

TEMPERATURE

Effects on Plants. In the range of roughly 10 to 30 °C, temperature has the following effects:

- Higher temperature stimulates the rate of development (rate of appearance of leaves and flowers).
- Higher temperature increases the rate of respiration (burning of assimilates) → less biomass → less yield.

In Fruit Crops Such as Tomatoes:

- Higher temperature favours distribution of assimilates to the fruit → higher fruit yield.
- Higher temperature speeds up fruit ripening → stimulates earliness.

Day-Time Temperature:

- Higher day-time temperature strongly stimulates cell expansion → stretching → increased plant length and leaf area.

Night-Time Temperature:

- May affect fruit set (e.g., in capsicum optimum fruits set at 18 °C night temperature).
- May affect fruit growth.

Other Effects:

- Too low or too high temperature reduces the success rate of germination.
- Reversed temperature (higher night than day temperature) results in shorter, more compact plants. DIF is used to indicate the difference between day and night temperature. Negative DIF indicates reversed temperature. It is used in some greenhouse climate control computers.
- At very low or very high temperature (say below 4 °C and over 35 °C depending on species) plant processes stand still and/or plant cell organs get damaged. Close to these temperatures the plants don't perform very well.

Temperature Control. Temperature control is based on utilising solar radiation and applying heating and venting and optionally cooling.

Heating devices can be hot-air heaters, hot-water pipes, hot-steam pipes, possibly infra-red radiators, and for root-zone heating the main options are pipes, tubes, and mats. Overseas the use of heat exchangers for greenhouse heating is being trialled.

Hot-Air Heaters. These are a cheap form of air heating. It's often sufficient when only little heating is required, but they have some disadvantages. Many hot-air heaters release the flue gases directly inside the greenhouse. Although this can have the positive effect of CO_2 enrichment, it has more risks than benefits. The heaters are often used at night when there is no photosynthesis, and hence no need for CO_2 enrichment. So the CO_2 accumulates to an extreme level. Moreover, the flue gases often contain traces of harmful gases (carbon monoxide, ethylene, nitrous oxides), which accumulate when the greenhouse is not vented. Other disadvantages include uneven heat distribution. Also, hot-air heaters release the heat in the top of the greenhouse, so that quite a bit of heat is lost through the roof before it reaches the plants.

Hot-Water Pipe Heating. A central boiler is the best controllable and most efficient way of heating. The number of pipes per area can be adjusted to the heating requirements and climatic zone. In crops such as tomatoes and capsicums, the heating pipes are positioned on the ground and used as tracks for internal transport systems and for trolleys to work on.

The position of the heat source relative to the plants is important:

1) Below the plants (close to the ground, on or under a bench) → stimulates root activity → increases transpiration (e.g., guttation at night).
2) Between the plants (tubes or pipes) → stimulates roots and shoots, and keeps the plants dry (reducing fungal infections).
3) Overhead → warm shoots → stimulates shoot growth but leaves roots cold.
4) Separate nets below the plants and overhead → root growth and shoot growth can be influenced separately, which gives best control.

Root-zone heating is often used for ornamental pot plants, bedding plants, young plants, and nursery stock plants. They are often grown in heated beds, on heated floors or on benches with under-bench or in-bench heating. Heating tubes, mats, or pipes are located close to the roots. Root-zone temperature inside the bed or pot can be 23–26 °C (or even higher depending on species and conditions). The pipes must be placed in a fairly fine grid and must run at a moderate temperature in order to achieve even temperature distribution without burning nearby plants. Because root-zone heating may dry out the pots and cause low air humidity, the watering needs to be adjusted. In cold conditions, root-zone heating alone can lead to growth problems and diseases. Root-zone heating responds slowly to a change in temperature setting. In these cases additional air heating may be necessary. Root-zone heating is then the base-load heating, which is controlled on the basis of temperature measurements in the beds or pots. The additional heating is controlled on the basis of temperature near the top of the plants.

Heating Control. It can be done in many ways: manually or by a simple thermostat, analogue controller, digital controller, or advanced computer. The following applies primarily to heating the greenhouse air, and sometimes to root-zone heating.

In its basic form, the controller strives to maintain a certain set-point for air temperature, e.g., a thermostat does the on/off control of a heater (e.g., hot-air heater). With heating pipes, the controller steers a mixing valve for mixing hot water with cold return water, so that a certain pipe temperature is achieved. This is not on/off control but proportional control.

Advanced computers do the same: maintaining a certain set-point for air temperature. But in addition a computer first calculates what the best set-points are for temperature, humidity, CO_2, etc. The computer can optimise the performance of the whole system by controlling the boiler, heat storage, venting, and other devices.

Venting. Venting is needed when the greenhouse gets too hot and/or too humid. Vents can be opened either manually or by a thermostat, controller, or advanced computer. A setting in the computer called a P-band is used to determine how far the vents should open depending on temperature inside the greenhouse. If it is way too hot or humid inside, it seems appropriate to open the vents very wide. But if the outside conditions are cold, wet, or windy, a small vent opening is sufficient. Hence the P-band must be modified depending on the outdoor conditions. Simple controllers only have a fixed P-band, so the grower has to adjust the P-band between seasons or when the weather changes. Advanced computers have all sorts of modification and safety measures in place, including modifications of P-bands and limitations. The simple forms are frost protection, rain protection, wind protection, but they do much more. Venting is also used a lot for humidity control.

In winter conditions, it is best to open the vents on the leeside only, to avoid influx of a large volume of cold dry air. In milder weather conditions, first the vents on the lee-side are opened, and those on the wind-side follow when more venting is needed. In hot conditions both sides need to be opened wide.

Cooling. This is meant here in the sense of active cooling or evaporative cooling (some computers use the word cooling for just opening vents). Evaporation (water changing from liquid to vapour) requires energy, so it removes heat from the surroundings. Plant leaves evaporate water and thereby cool themselves. Leaf temperature can be several degrees below air temperature, and a greenhouse with plants is a lot cooler than a greenhouse without plants. If plants have no water available for evaporation they will get hot and they "burn." Evaporative cooling in a greenhouse can be achieved by pad and fan, fogging, misting, or roof sprinklers.

Roof sprinklers are underrated in New Zealand. It is a simple but effective system with irrigation lines or sprinklers on the roof of the greenhouse. In hot conditions they spray a film of water over the roof. The hot air makes the water evaporate, thereby heat is absorbed and moisture added to the air. This creates a cool fresh breeze into the greenhouse (the vents are meant to be open). It works especially well in conditions of low outside air humidity. The effect can be a temperature drop of as many as 10 °C. Roof sprinklers require a stream of clean water, but this water can be recollected. Water sprayed on the roof should not contain iron, as that will stain the glass and cause light loss.

Solar Energy. Solar energy is used in greenhouses in New Zealand only passively, the sun heats the greenhouse (and if it gets too hot the surplus heat is vented out). In the Netherlands some large-scale trial greenhouses make active use of solar energy. They catch an excessive amount of heat in summer, while special heat exchangers transfer the surplus heat to cold ground water that is pumped up. The then luke-warm ground water is pumped back into underground aquifers. Half of a year later, the luke-warm water is pumped up from the aquifer and used for heating in winter. The surplus can be so great that a number of houses can be heated from a 1-ha glasshouse. Unfortunately this is unlikely to happen in the near future in New Zealand, due to extreme costs and resource management issues.

AIR HUMIDITY

Effects of Humidity. For seeds, seedlings, and cuttings:

- High humidity is needed for seed germination and for avoiding water loss from seedlings or cuttings.

In established plants, including garden plants and ornamental pot plants:

- High humidity reduces transpiration, and hence reduces uptake of certain nutrients (e.g., calcium).
- High humidity may stimulate leaf stretching and makes plants lush and soft.
- High humidity increases fungal infection which increases the risk of moulds, rots, and diseases.

Condensation and disease outbreak is a real risk in any greenhouse. In an unheated greenhouse condensation is almost inevitable. In heated greenhouses there are always cold spots where condensation occurs too, especially at night and in early mornings. At sunrise the plants slowly warm up, but more massive plants parts (e.g., stems and fruit) are very slow to warm up. These are cold bodies that will attract condensation and will stay wet for much longer. Spores of fungal diseases, such as botrytis, are ever-present in the greenhouse, and wet plants offer the perfect conditions for spore germination and infection. The incidence of fungal diseases can be reduced by avoiding very high air humidity.

Humidity Control. Increasing the humidity can be required in very hot dry summer conditions when plants are under stress, or in winter in frosty conditions when the relative humidity of the air is low. Humidity can be increased in summer by fogging, misting, roof-sprinklers, (sometimes by screening) and in winter by screening, reducing venting, or keeping the vents shut. For seeds, seedlings, and cuttings, high humidity can be maintained in small enclosed environment (e.g., under plastic).

Lowering the humidity can be achieved by heating and venting. Heating for humidity control can be complicated because heating affects humidity and temperature. Moreover, relative humidity (RH) is strongly linked to temperature. The linkage is that RH is the moisture content of air as a percentage of the maximum moisture content of air at a certain temperature. Warmer air can hold much more moisture than cold air. Heating obviously increases the temperature, and since warmer air can potentially hold more moisture, the relative humidity drops (assuming that no moisture is added). This is a very effective way of reducing the RH.

However, after some time, the lower RH will stimulate plant transpiration. This will then increase the humidity. Then the vents have to be opened. The warm and now humid air will be replaced by cold dry air (cold air is by definition drier, since cold air can only hold a limited amount of water vapour). Continued heating and venting will result in lower air humidity, while plant transpiration is higher than without heating. Temperature control and the location of heating pipes (under the tables, overhead, etc.) can have significant effect on humidity and plant transpiration.

MISCELLANEOUS

Stretched Plants Under Screens. Shading may result in floppy plants because under shade it is dark and warm (although not as hot as without shading). Higher day-time temperature strongly stimulates stretching. Due to shading, photosynthesis is reduced, so there is little biomass to give any substance to this stretching. Low light level also makes plants stretch. Hence the combination of warm and dark conditions under a screen may result in very floppy tall plants.

Making Plants Compact by Using Reversed Temperature. Plants can be made more compact by reversing the day and night temperature, i.e., giving higher night temperature than day temperature. This is only possible in winter and shoulder seasons, and is hard to achieve in milder climates and on sunny days. But the plants can be kept fairly compact by having little difference between day and night temperature, giving a bit of heating at night and keeping temperature low during the day.

Advanced Climate Control Computers. Some advanced greenhouse climate computers determine the optimum temperature, humidity, and CO_2 level, based on plant requirements, season, time of the day, light level, and other factors. Some computers can also consider the weather forecast. Most modern computers have facilities to strive for energy efficiency. They try to optimise the performance of the whole system by controlling all devices in an optimal way: burner speed, boiler temperature, pump speed, pipe temperature, heat storage, heat retrieval, vents, cooling, screening, CO_2 unit, and more. This can never be done manually, partly because the weather conditions always change. Obviously such computers are expensive and very complicated. Although greenhouse climate control computers have become very powerful, the grower is still in control, but indirectly. The grower chooses the settings that the computer programme needs for the calculations and control actions. These settings can stay the same for months (many growers leave them for years) but it is wise to review the settings every season. In this way the growers keep up their understanding of the (complicated) computers and can put in place new insights.

Fuel and Energy Saving. Energy is required for heating to control temperature and humidity in hours with insufficient solar radiation. Most commonly used fuels are gas, coal, and oil, and less common are diesel, LPG, propane, butane while a few greenhouses are heated by geothermal energy. Electricity is rarely used for greenhouse heating in New Zealand as it is too expensive. Since energy prices are rapidly rising, it is becoming increasingly important to employ energy-wise control strategies. There is a wide range of energy-saving measures that growers can implement. Some require investments, while others are cost-free energy-saving actions, such as improved control. Advanced control computers offer many options for optimising plant growth as well as energy efficiency.

Crop Recording. A way to learn more about climate control and its effect on plants, and about growing more efficiently, is to do crop recording. This is doing certain observations and using a specially designed spreadsheet for recording input factors, such as climate, irrigation, fertiliser, energy and output such as crop growth and production. By recording and studying the tables and graphs produced by the spreadsheet, the grower can discover links between input and output. It can help find out which conditions give the best results in terms of yield, quality, uniformity, timing, and efficiency.