GREENHOUSE TECHNIQUES IN FORAGE CROPS RESEARCH

U. S. Regional Pasture Research Laboratory

Crops Research Division

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GREENHOUSE TECHNIQUES IN FORAGE CROPS RESEARCH [1]

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This manual describes general greenhouse management and special techniques that have proven advantageous in experimental work during the past 20 years at the U. S. Regional Pasture Research Laboratory in State College, Pa. Except for a brief description of greenhouse facilities, their design and construction[2] will not be treated. Emphasis primarily is placed on techniques useful in growing plant material for experimental purposes.

GENERAL CONSIDERATIONS

To provide good natural light and to reduce shading to a minimum, the greenhouses are placed south of the Laboratory building and with their sides facing east and west. The headhouse is adjacent to the north ends of the houses and provides working space for preparing soil and plant materials before moving flats or pots into the greenhouses.

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[1] Submitted for publication . A contribution of the U. S. Regional Pasture Research Laboratory, Crops Research Division, ARS, USDA, State College, Pennsylvania, in cooperation with the 12 Northeastern Agricultural Experiment Stations.

[2] Kentucky Progress Report 28, 1955, Purdue Ex. Bul. 411, 1956, and a release by Raymond Sheldrake, Cornell University, 1957, indicate satisfactory use of clear plastics for greenhouses. While visible light transmission by plastic is similar to glass, ultraviolet and infrared transmission is greater. A personal communication 1957, from N. L. Taylor, University of Kentucky, indicated greater moisture retention in plastic greenhouses unless ventilators were installed, and that damage from diseases may be greater. The useful life of many plastics usually is from September to June.

There are bins for soil storage, a floor area about 8 x 10 feet for mixing soil, and a steam sterilizer. The sterilizer mounted horizontally is a strong iron cylinder with a hinged door at one end and the other is closed. A track within it enables a loaded iron cart to be pushed in before sterilization and then easily removed when the process is completed. Work benches are provided for transplanting, seeding, making up nutrient solutions, mixing spray materials, and other miscellaneous jobs. Several small cupboards provide easy access to essential tools and numerous small items used in greenhouse studies.

In addition, the headhouse has a small and well equipped woodworking shop, a room for threshing individual heads of grasses or legumes, a room for threshing and cleaning small lots of seed, and a laboratory for soil moisture studies. The attic is used for storage where high temperatures are not harmful to materials and high humidities may be avoided.

HEATING

Low pressure steam provides heat for the greenhouses and two types of radiators have been used. One house is heated by banks of 2-inch iron pipe placed along the outside walls, and steam to them is thermostatically controlled with modulating valves. The other houses are heated with air taken from near floor level, and circulated over small continuously heated copper coils mounted about 6 feet high. The operation of the fan for each coil is controlled by a thermostatic switch.

There are several advantages and disadvantages with the two methods of heating. The system using the pipe radiators provides a more constant heat, with only 2° or 3°F variation between "off" and "on". Where forced circulation of air is used the variation in air temperatures is about twice as great and there is more variation between ends of the same bench. Also uneven evaporation occurs where heating is by means of the forced air circulation. In all cases the row of pots next to an outside wall during the winter is cooler than other rows on the bench, except where pipe heating coils are also adjacent to this outside wall. In all cases a row of empty pots placed along the outside edge of the bench minimizes this difficulty. An advantage of the circulating air heater is the lower installation cost and the smaller maintenance requirements.

VENTILATION

Greenhouse ventilation is designed primarily to prevent overheating on clear days. Radiation from the sun passes through the glass as visible light and as relatively short wave infrared heat, but within the greenhouse radiation is absorbed by plant, bench, and pot surfaces and converted to longer wave infrared. This energy is trapped because glass is opaque to these longer wave lengths and heat must be removed by circulating cooler outside air.

For best manual operation of ventilators, the relative amount of radiant heat and heat losses should be anticipated. Thus experience is essential in suggesting the best amount of ventilation and the time when it will be required. On clear days, the top ventilators should be opened slightly before there is much increase in air temperature, and if temperatures rise further the top vents should be opened wider. Opening the side vents facilitates circulation and allows the warmer air to escape more rapidly through the top.

Equipment used for automatic ventilation control operates only the top vents. Side vents are operated manually. At night, during the spring and fall, side vents should be closed or left open only 3 or 4 inches, and top vents set to remain open about an inch. During cold months all vents normally should be closed. Responsibility for setting thermostatic controls is delegated to one person and temperature readings from properly placed thermometers or thermographs, not personal opinions, determine whether a house is too hot or too cold.

During the winter months, temperatures are more easily controlled, but snow accumulation during a storm presents a problem. To remove snow air temperatures should be increased enough to melt the snow touching the glass and thus allow it to slide off. If the vents are frozen, temperatures also should be increased, until the ice is melted.

Control of greenhouse temperatures is particularly difficult on bright days and when the air outside the greenhouse is warm. To minimize overheating, the glass may be sprayed on the outside with a white shading compound that reflects as well as absorbs part of the sunlight. Shading compounds are available commercially with directions that include suggested rates of application. Inasmuch as the shading should be removed by October or before, a last application in early August should not be too heavy. Since most shading compounds are washed off only gradually by rain, an application too heavy, or too late in the season, may require scrubbing to clean the glass.

Another shading technique involves spraying the inside of the roof glass with ground walnut shells or other material. While this may be easily washed off with a spray of water at any time, a disadvantage of spraying the inside of the glass is that light and heat are absorbed within the greenhouse rather than being reflected or absorbed by the outside surface. Trials on sunny days using 4-foot cubical glass boxes indicated that application of shading compound on the outside resulted in cooler air temperatures than the application of shading on the inside. Another advantage of external shading is that benches and greenhouse equipment are protected from the shading compound while it is being applied or removed.

Greenhouses may also be satisfactorily shaded on bright days with curtains, made from cypress strips, that can be rolled up on dark days, but the initial cost of these is high.

In the spring, as greenhouse temperatures become too warm (above 75°F - 85°F except for short periods) the plants should be moved outside. For starting plants to be transplanted into the field, or for temporarily holding plants to be used in the greenhouse during the winter, cold-frames or benches outdoors are useful. Moderate fluctuations of outdoor temperatures are not harmful to most forage plants. Material for spring planting should be started during late winter. When plants are arranged in the flats or pots in accordance with the field planting plan, they can be easily moved to the locations where they will be planted.

In those greenhouse sections used for legume breeding, all vents should be screened. Even in late winter or early spring when clover, alfalfa, and trefoil are brought into bloom, occasional warm days may stimulate bees to fly.

GREENHOUSE BENCHES

The type of bench selected depends upon its expected use. Wooden benches are probably most common and least expensive. For all benches, solid footing is essential to support the weight of soil and pots. Cypress is probably superior to other kinds of wood because of its natural resistance to decay. Hemlock or fir are also satisfactory but should be treated to prevent rotting if it will come into contact with moist soil.

The permanence of concrete benches is a decided advantage but the initial cost is high. These benches are especially useful where subsurface watering is to be used, either with gravel and nutrient solution, or with soil. Benches made of transite supported by metal frames have been widely used and found to be satisfactory.

GREENHOUSE SOIL FOR PLANT PROPAGATION

Good potting soil is a medium to provide water and nutrients for plant growth and it should be firm enough to support the plants and yet sufficiently friable that removal of a plant and its roots is not difficult. The function of soil for the physical support of a plant is fundamental whether growth is in a bed, a flat or a pot. Pots are used primarily when the plants are to be moved from place to place. In breeding studies, it may be necessary to move plants from one greenhouse bench or section to another for cross pollination. Movement of plants may also be necessary when environments are to be varied in physiological, soil fertility or pathological studies.

The physical structure of soil is a factor in the absorption of moisture following watering and in its relatively uniform supply to the plant. As a result of puddling, the surface of a clay soil tends to become impervious to the water applied by sprinkling. While clay holds more water than sand, a smaller proportion of it is available to the plant. The addition of fine sand and partially decomposed organic matter (humus) to clay or silt improves the physical condition of soil and makes it more receptive to water. The improved texture also facilitates removal of roots and other below-ground parts from the soil.

To provide potting soil with good structure, it is advisable to maintain a compost pile with alternate layers of top soil and plant refuse. After several years of outdoor weathering, the organic matter will have largely decayed and the soil can then be screened through 1/4-inch hardware cloth to remove objectionable debris. With most soils, it is advisable after screening to mix 2 shovels of sand and 1 shovel of well-rotted manure to 4 shovels of soil. In experiments where plant roots are to be washed free of soil, manure should be omitted from the potting mixture.

The lime requirement of a soil should be met by thoroughly mixing with it enough finely ground limestone to bring the soil reaction to nearly neutral, pH 6.5-7.0. The amount of lime necessary to meet this requirement is based upon soil tests. To determine for greenhouse use the amount of lime to mix with a known weight of soil, it is assumed that the plow depth (about 6 inches) of an acre of soil weighs about 2,000,000 pounds.

Potting soils for general use should contain liberal amounts of mineral fertilizers such as phosphorus and potassium. Soil tests and the previous use of a soil provides a good indication of the requirements for these elements. In many soils, available phosphorus is apt to be low. Generally an ounce of triple superphosphate should be thoroughly mixed with each 50 pounds of screened and limed soil and this then mixed with about 25 pounds of sand and 12 pounds of manure. When small lots of potting soil are to be prepared, it is convenient to mix 10 grams of triple superphosphate with 3 shovels of soil and then mix this with 2 shovels of sand and 1 shovel of manure.

While most soils contain sufficient potash and nitrogen for growth of small plants, as the plants become larger, more potash and nitrogen is required. This may be applied in solution and daily watering will distribute it well within the soil. Minor elements are usually not deficient in greenhouse soils but where a deficiency may exist a small amount (1 or 2 grams) of salts supplying boron, copper, manganese, zinc, or molybdenum should be added to the soil and well mixed.

After the soil, sand, manure, and fertilizer have been mixed by repeated shoveling, the mixture should be heated with steam in an autoclave to kill any seeds, plant disease organisms, and insect pests. Metal pans about 4 feet square and 5 inches deep are filled with the soil and each pan then moistened with 2 or 3 quarts of water. The pans are then stacked, separated by wooden strips, onto the iron cart and pushed into the steam sterilizer. Between 4 and 6 pounds of steam pressure should be maintained for about 6 hours. Fewer and shallower pans will require less time. Over-sterilization may be avoided by maintaining high temperatures only long enough to kill seeds and pathogenic organisms. If observations of previous steaming procedures, or the first use of a steamed soil suggests that over-sterilization may have occurred, the amount of superphosphate used may be doubled or, as a corrective measure, soluble phosphorus may be applied in solution to the soil surrounding an established plant. This procedure may not be effective with all soils, but it has proven satisfactory on the Hagerstown silt loam used at the Pasture Laboratory.

SOIL FERTILITY STUDIES

In all soil fertility experiments, care must be taken to reduce all sources of contamination to a minimum. While the small lots of soil used in plant propagation work and preliminary nutrient studies may be mixed within the headhouse, the larger quantities of soil used in soil fertility studies should be mixed out-of-doors where the dust is blown away. Another method of reducing contamination and to obtain thorough mixing of soil and fertilizer ingredients is to place them all in a small motor-driven cement mixer. By this method the uncertainties and variabilities of manual shoveling are eliminated.

Greenhouse pots, particularly those made of porous clay, are frequent sources of contamination. Glazed pots are probably best, although glass, plastic, or metal containers may be used.

In the State College area, a frequent source of contamination is the calcium or magnesium dissolved in the tap-water. Thus for soil nutrient studies, only distilled water should be used for watering the plants. Similarly where sand, humus, or other substances are mixed with soil, it should be certain that contaminants are not thereby introduced.

POTTING PROCEDURE

Types and sizes of pots used in a greenhouse will vary with the experiment and the expected size of plants, but, irrespective of the type of pot or plant, it is essential that the soil be well settled. Satisfactory settling is accomplished by filling a pot level-full and then jarring it three or four times on a firm surface. If the pot is to be planted with seed, the soil surface should be smoothed. When rooted cuttings are to be planted, holes may be made with a dibbler or wide knife blade to receive the plant. After the cutting is placed in the hole, the soil is firmed around the roots with the fingers.

For most purposes, porous clay pots are used which are inexpensive and are available in graded sizes from 2 to about 14 inches in diameter. the 3-, 4-, and 6-inch sizes are most common. A clay pot can be easily emptied by tapping the top edge of it on a wooden block while the pot is inverted.

Clay pots have several disadvantages. Because water is evaporated from the moist outside of the pot, soil dries rapidly and requires frequent watering. Plant nutrients dissolved in the water, accumulate in the pot and the availability of nutrients to the plant is not uniform. In soil fertility studies this contamination is a serious problem. Painting clay pots with water-proof paint decreases water loss. Since roots tend to adhere to an inside painted surface and break when the soil is jarred loose, it is advisable to paint the pots mainly on the outside, and on the inside, only above soil level.

Glazed crocks, with a glass like surface, have the advantage of being impervious to water. Because there is no water loss by evaporation through the pots, small plants may be overwatered unless care is used. Most glazed pots have holes near the bottom, but these should not be considered as drain holes to compensate for overwatering. If water appears in a hole, it has either passed between the soil and the crock or the soil is saturated. The hole serves primarily as a means to observe the moisture in the soil at the bottom of the pot, and to release air as water is applied. When glazed crocks are used, plant nutrients remain well distributed in the soil and nutrient contamination is eliminated. Disadvantages of glazed crocks are their cost and the fact that they cannot be stacked inside one another for storage. Several sizes are available ranging from about 2 qts. to 2 gals. Unless plants are very large, the 2-qt. and 1-gal. sizes are suitable.

Pots made of plastic have the advantage of no water loss through the pot, no nutrient contamination, and are easily stacked for storage. Present disadvantages are the higher cost and the flexibility of the larger sizes that may result in soil compaction when they are moved during use.

SOLUTION CULTURE

Supplying plant nutrients at specific concentrations may employ any of several solution culture methods to support the growing plants. One method is to use quartz sand for the plant roots to grow into and then applying the nutrient continuously to the top of the sand. This has the disadvantage of encouraging growth of algae on the sand.

The technique found most satisfactory at the Pasture Laboratory has been the gravel culture method. With this method watertight benches, or glazed crocks with holes near the bottom, are filled with coarse gravel in which cuttings or rooted seedlings are placed. The nutrient solution is forced upward by air pressure every few hours from storage bottles below. The air pressure and the time it is applied is adjusted so that the solution reaches almost to the top of the gravel but does not cover it. The pump is then automatically turned off to allow drainage back to the bottle with the resulting aeration of the roots. Sufficient solution is retained by the gravel so that transpiration losses are not a problem. Algal growth in the glass storage bottles has been practically eliminated by covering all glass surfaces with aluminum paint.

Numerous solution culture formulae have been suggested. One found satisfactory for general growth includes potassium nitrate, calcium nitrate, potassium dihydrogen phosphate, and magnesium sulfate. Stock solutions of these chemicals are made up in one-tenth molar concentrations by dissolving separately in a liter of distilled water the following: Potassium nitrate (KNO_3) 10.1 grams, calcium nitrate ($Ca(NO_3)_2$) 16.4 grams, potassium dihydrogen phosphate (KH_2PO_4) 13.6 grams, and magnesium sulfate ($MgSO_4 \cdot 7H_2O$) 12.0 grams.

Minor elements are prepared separately. Iron stock solution may be made by dissolving 2.4 grams of ferric phosphate pearls in 2 liters of warm water. This does not keep well and is best made up the day it is used. A stable stock of the other minor elements may be made by dissolving the following in 3 or 4 liters of water: Manganese chloride 2.66 gm., zinc sulfate 0.30 gm., and copper sulfate 0.48 gm. Two hundred ml. of 4 percent boric acid solution should be added and the entire solution then made up to 6 liters.

Nutrient solution for use either with gravel, sand, or as a solution culture may be made as follows: To about 12 liters of distilled water add one-tenth molar stock solutions in the following amounts: 180 ml. potassium nitrate, 225 ml. calcium nitrate, 54 ml. potassium dihydrogen phosphate, and 90 ml. magnesium sulfate. Then add 90 ml. of the minor element stock solution and 90 ml. of the iron solution. Bring the mixture to 18 liters with distilled water and the nutrient is ready for use. It has a pH value of about 6.5 . When the plants are small the nutrient solution will need to be changed in about two weeks, but as the plants become larger changes weekly may be advisable. Water losses should be checked and replacement with distilled water made when the total volume of the solution has been reduced by about a quarter or a third.

PLANT ESTABLISHMENT

Plant materials used for cytogenetic, pathological, physiological, and soil fertility studies may be started from seed, cuttings, tillers, or plants brought in from the field. Methods of establishment, whether in clay pots, glazed crocks, flats, or greenhouse benches are fundamentally similar.

ESTABLISHMENT FROM SEED

Before a study is begun, the percent germination of the seed should be determined if not already known. To carry out the germination test two or three 50-seed samples from the seed lot are placed on moistened filter paper in Petri dishes. The filter paper should be kept moist, but standing water should be avoided, and for most seed a room temperature of about 70°F is satisfactory. Freshly harvested seed may sometimes be dormant--it may absorb water but not germinate. To stimulate germination of such seed, daily alternation of temperatures is usually helpful. The Petri dishes may be moved to 50°F temperatures for half days and back to 75°F the other half. Light is not essential for germination tests of most forage species.

To obtain vigorous grass or legume seedlings, the soil should be managed to favor close contact of the seed with moist soil and also maintain such soil physical conditions that the first leaves can readily emerge. Seed should be placed on firm, moist soil and covered with about one-fourth inch of fine sterilized soil. This soil should then be watered carefully to avoid puddling. In bright weather and especially when evaporation is rapid, drying may be retarded by shading the pots or flats with a layer of cheese cloth laid on top of them. At intervals the soil should be examined and moistened as necessary, and after most of the seedlings have emerged, the covers may be removed. For the following week or 10 days, and especially during bright weather, it is important to check the cultures frequently to maintain proper moisture. Light watering may be required several times daily on clear days, but overwatering should be guarded against, particularly in cloudy weather. These procedures are applicable for one or two seedlings in a pot, several rows in a flat or for a uniform stand over a larger area.

When only one established seedling in a pot is desired, 3 or more seeds may be planted and the plants later thinned to one good seedling. If the seed supply is limited, seed may be germinated on moist filter paper or blotters in Petri dishes and then carefully transplanted into fine damp soil when roots are between 1/4 and 1/2 inch long. The cotyledons or first leaves should remain above ground and the soil carefully watered to insure close contact between the roots and soil. Partial shading for the first few days is again desirable. Legume seedlings are particularly susceptible to damping-off both before and after emergence. This problem will be discussed later.

ESTABLISHMENT FROM CUTTINGS

In many cytogenetic and plant breeding studies it is desirable to use plant material having the same gene base. Similarly in experiments where effects of light, temperature, nutrients, and responses to pathogenic organisms are being studied it may be desirable to use genetically uniform material. Such plants may be started from cuttings of new clones or those that have been maintained from previous years.

Grasses

Grass tillers usually root more easily than legume stems. Under field conditions new roots arise from the very short stem near the nodes at about soil level. To obtain rooting of clonal pieces, the leaves and stems are cut off about 4 inches above ground level and all soil below the crown is removed. The tillers may then be pulled downward, broken from adjacent material, and old or dead material stripped away. Remaining roots should be trimmed off because old parts of roots do not initiate new growth. Tillers for rooting may be placed in moist sand, gravel or soil, but it has been found better practice to put tillers in about 2 inches of tap water in glasses set in the light. The water should be changed daily in cool weather and 2 or 3 times a day when it is warm. When many tillers are being rooted they may be supported in groups by chicken wire over a shallow tray through which tap water is slowly circulated at a depth of about

1-1/2 inches. When new roots become evident, in about a week, the tillers may be planted. It is advisable to plant tillers while the new roots are from 1/8 to 1/2 inch long. Although tillers with longer roots may grow satisfactorily they are likely to be damaged during transplanting. Broken roots usually die and new ones must develop.

Legumes

While legumes root more slowly than grasses, a similar procedure is usually effective. Plants from which cuttings are to be made should be vigorous and free of diseases and insects. It is good practice to sterilize cutting tools in 75 percent ethyl alcohol to prevent the transfer of virus from one plant to another. Cuttings usually root more certainly and rapidly if younger parts of the stolon are used, and these should include 1 or 2 nodes with vegetative buds, not flower buds.

Under field conditions, roots of white clover usually develop on the stolon near the nodes. The stolon cuttings of white clover should, therefore, be placed in sand, vermiculite, or soil, maintained moist, and placed at an angle with the cut end about 1/2 inch below the surface and the rest on the surface. Small leaves should not be covered. Roots will usually develop within 3 weeks, and the stolons may then be transplanted into pots or flats. Again they should be set nearly prostrate to obtain good soil contact with the new roots, and the growing tip of the stolon should be above the soil.

Alfalfa, birdsfoot trefoil and red clover cuttings root from the ends of cut stems. Alfalfa stems from which cuttings are taken are best made at the early flower-bud stage. From such stems, tissue of intermediate maturity rather than the most mature basal portion or the youngest tip is best for making cuttings. Red clover stems from young crown shoots are satisfactory. Alfalfa and red clover cuttings should include 1 or 2 nodes with healthy leaves. These should be placed in moist sand, vermiculite or peat moss, or in a glass of water with the water changed twice a day and protected from high temperatures and direct sunlight. Cuttings placed in coarse sand and flushed each hour with a dilute nutrient solution have rooted especially well. This procedure provides moisture plus aeration.

Legumes root more slowly than grasses, usually in several weeks, and as soon as roots are visible, the cuttings may be planted. New cuttings of both grasses and legumes should be maintained at air temperatures between 65° and 70°F, and shaded from bright sun for 2 or 3 weeks.

The use of root-promoting substances applied in water, or as a dust with talc before the cuttings or tillers are placed in sand, vermiculite, or peat moss has sometimes been advised. Trials at the Pasture Laboratory, however, have indicated that rooting of perennial grasses and legumes was satisfactory without hormones, and that hormones did not promote rooting if either moisture or aeration were inadequate.

Rooted grass or clover cuttings should be planted directly into the pots or flats in which they are to be used. Where greater uniformity is essential, it may be advisable to plant the cuttings or tillers into flats of soil. Then after several weeks' growth, the most uniform plants should be selected and transplanted into pots. Another method of obtaining greater uniformity of material is to plant cuttings directly into pots and provide an excess number of pots so that those most uniform may be selected for the experimental treatments.

P L A N T   M A I N T E N A N C E

Obtaining normal plant growth under the artificial conditions of a greenhouse poses several problems. These will be discussed in the following sections.

WATER

Adequate moisture is one of the most important factors in providing for the good growth of plants in a greenhouse. The amount of water in a pot or bench is small compared to the relatively large amounts of water held by the soil under field conditions. Also, evaporation is often more rapid in the greenhouse than out-of-doors. Since all water for greenhouse plants is applied artificially, the amount, rate, time, and frequency of watering must be carefully considered.

Perhaps good watering is difficult to obtain in a greenhouse because it seems so easy. Watering from a can or a hose nozzle may appear to be good, but proper watering takes time and several factors are involved. The amount of water should be adequate to prevent wilting until water is applied again. This depends on the size and age of the plant, amount of soil in the pot, and type of pot used (glazed or porous clay), as well as the kind of day (cloudy or clear), the relative humidity, and the air movement. Thus each pot should be observed daily and individually treated with water applied to meet its requirements. While sufficient water is easily added to prevent wilting of certain pots, there is always the possibility of overwatering others. When the soil in the pot is saturated, aeration is poor and plant growth is inhibited. It has been found satisfactory to add enough water that the soil moisture will be at field capacity (moist to the bottom of the pot), but not so much water added that it runs out.

For most containers with soil 6 inches deep, about an inch of water on the surface is adequate and watering need not be repeated until the soil surface appears almost dry.

One result of careless watering is puddling of the soil. When water is applied with appreciable force, the soil granules are broken into fine particles that seal the surface against easy penetration of water. A good technique is to allow the water to strike one's fingers or a strip of paper placed on the soil so that the water spreads sideways onto the soil. A small stone or the crown of a plant can similarly absorb the impact of water and avoid puddling.

For seedlings, a watering can with small holes in the pouring spout held near the soil and moved back and forth will distribute the water evenly. For larger cuttings and established plants, a hose without a nozzle held just above the soil may be used when the faucet is so adjusted that the water runs out slowly and without force.

Generally, plants are watered to replace the water lost by evaporation from the soil and transpiration by the plant. Larger and more leafy plants use much water and losses are much greater on the longer, warmer and brighter days.

White salt crystals may accumulate on the soil surface of pots having only small plants, and thus are watered infrequently. Most of the salts include nitrates which have been formed by nitrification of the organic matter in the soil and usually have no deleterious effects. They may be carefully scratched into the soil again. As the plants grow and watering is more frequent, the salts will be dissolved and redistributed in the soil.

When pots are continuously wet from overwatering, algae and moss may accumulate on the soil surface. It then becomes difficult to determine when and how much water to apply because the soil itself is not easily visible. Shallow working of the soil surface at intervals and avoidance of overwatering will eliminate this condition. It is never desirable to allow all the soil in a pot to become dry; the depth to which it may safely dry will vary with the depth of root growth and the size of the plants.

During the winter, plants may be watered once a day and about mid-morning is satisfactory. Such a time and practice permits an estimation of whether the day will be bright and considerable water used or dark with less water needed. Large greenhouse plants require a quart or more of water every day, whereas small plants may not need more than a pint of water in a week. Plants should never be allowed to reach the wilting stage nor should the soil be kept wet on top. Experience in estimating water use by plants is essential in developing good watering procedures.

PLANT NUTRIENTS

The required calcium, phosphorus, and potash should be mixed with the soil after it is screened, as indicated in a previous section. These mineral elements and others, including magnesium and the minor elements do not usually become limiting during one season, except for potash which is used in large amounts during rapid vegetative growth. The amounts of potash removed may be estimated and replaced by the addition of potassium chloride in dilute solution. Where nitrogen is applied as potassium nitrate (see below) it may not be necessary to supply additional potassium.

For grasses and other nonlegumes, the amount of nitrogen fertilizer needed depends upon the amount available from the soil and the rate at which it is used by the plant. Most composted soils already contain available nitrogen in amounts sufficient for one or two months' growth of a seedling or single tiller. As plants become larger and grow more rapidly their nitrogen requirements increase. A lack of vigor and yellow-green leaves suggest limited available nitrogen. Nitrogen fertilizer should then be applied in solution every 4 or 5 weeks, and just before watering. Because greenhouse plants usually have adequate mineral fertility and water, and because leaf area exposed to light is about twice that of similar plants growing in a field sod, it was found advisable to double the amount of applied nitrogen fertilizer per pot area to make them roughly comparable with the rates of nitrogen applied in the field.

Common stock solutions carrying nitrogen may be made by dissolving 116 grams of ammonium nitrate in 20 liters of water, or 127 grams of potassium nitrate in 10 liters of water. The addition of 40 ml. of either of these solutions to a 6-inch pot is equivalent to a field application of about 50 pounds of nitrogen per acre and should be made after the grass is well established and when it is expected that it will be grown another month or more. For large greenhouse plants a satisfactory rate would be several times that for a similar plant growing in the field. Urea or any of the common nitrates may be used as a nitrogen fertilizer.

DISEASES AND PESTS

To minimize plant diseases and insect pests on greenhouse plants, the introduction of live organisms with field-grown material should be minimized. All old leaves, stems and soil should be removed from plants before they are taken into the greenhouse, and new plants from cuttings or seed should be started in sterilized soil.

Diseases

Damping-off is a seedling disease caused by several organisms including *Pythium* spp., *Fusarium* spp., and *Rhizoctonia solani*. These fungi attack legume seedlings both before and after their emergence from the soil. Since these disease organisms are primarily soil borne, it is essential to use only soil that has been treated with heat in a soil sterilizer. Also the surfaces of flats, pots, and other equipment should be cleaned and treated, before using, with solutions containing mercuric chloride, formaldehyde, or a household bleach containing readily available chlorine. Because mycelial fragments and spores of damping-off organisms are also air borne, dust from the greenhouse or headhouse may be a serious source of infection.

Experiments have indicated that less damping-off occurs when soil moisture, temperature, and light are most favorable for the growth of the seedling. Moderate greenhouse temperatures (70^{o}-75^{o}F) and careful watering both favor seedling growth and reduce damping-off. Overwatering may favor damping-off caused by *Pythium*.

Pre-emergence damping-off may be reduced by treating the seeds before planting with a fungicide containing chloranil or thiram as the active ingredient.

Post-emergence damping-off of legumes may be minimized by spraying or dusting pots or flats immediately after the emergence of the seedlings with a fungicide containing one of the carbamates, e.g. ferbam. The careful application with a pipette, of a fungicidal solution containing ferbam, directly to the soil adjacent to emerging seedlings has markedly reduced damping-off. Starting seedlings in screened sphagnum moss has been used as another method of reducing damping-off[3].

Other common diseases on forage plants in the greenhouse include powdery mildew and leaf rust. These may be controlled by dusting a thin layer of powdered sulfur on the radiator steam pipes every day or two, or by spraying the leaves with a wettable sulfur spray. Walks and benches should be kept dry to reduce humidity in the houses.

Insects and Similar Pests

The more common insect pests include several species of aphids, mealy bugs, white flies, thrips, and moth larvae, while other pests are red mites, sow bugs and slugs. Constant watch is essential for early evidences of pests which multiply rapidly. When any are observed control measures should be begun promptly to forestall epidemics. Aphids multiply especially rapidly but may be controlled by rather simple nicofume bombs or contact sprays using nicotine sulfate or rotenone. Malathion has proven effective as a spray for the control of white flies, mealy bugs, thrips, aphids, and red

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[3] Personal communication E. A. Hollowell, ARS, USDA, Crops Research Division, Beltsville, Maryland.

mites. Sow bugs may be controlled by moistening soil with lindane and slugs may be controlled with metaldehyde and arsenic.

Fumigation with insecticides supplied as vapors from bombs have been less satisfactory than sprays. This may be due to the difficulty in small houses of obtaining satisfactory diffusion of the gas to those organisms in dense foliage near the soil surface and to those organisms slightly below the surface in gravel and coarse sand cultures.

TREATMENT FOR VEGETATIVE GROWTH

For good vegetative growth of perennials common in the northern states, greenhouse temperatures should be kept at about 75°F during the day and about 10° cooler at night. Occasional periods of 80° during bright days and 60° at night are not injurious. While detrimental effects on growth have not been observed when daily temperatures remain constant, plant growth during late spring or early fall is favored when greenhouses, that may become too warm during bright days, are allowed to cool at night.

Two plant responses to light may be expected, (1) photoperiodic responses caused by the length of the daily dark period (usually referred to as "length of day"), and (2) photosynthetic responses generally indicated by the amount of total dry matter produced.

Photoperiodic responses have usually been considered in relation to flower production and will be dealt with in more detail under that category. Observations at the Pasture Laboratory have also indicated that photoperiodic responses occur in vegetative growth. Grasses grown under long days produce longer leaf blades and fewer tillers even though they may not head.

When grown under days with short light periods, leaves are usually shorter and tillering is more abundant. In vegetative growth studies, daylength as well as temperature should be controlled to approximate the natural conditions for a desired season such as early spring, midsummer, or fall.

Natural light intensity varies with the season, usually being lower in the late fall and winter than during the summer. While plants grow better in bright weather than during dark cloudy days, in greenhouse experiments at the Pasture Laboratory only slight growth increases were obtained when supplemental light was supplied by numerous incandescent lamps on dark days.

Flowering responses may be obtained at much lower intensities of supplemental light than of those essential for good vegetative growth. Thus artificial light to induce long-day growth characteristics may be provided by using either incandescent or fluorescent lamps. Intensities of 25-50 footcandles at leaf surfaces may be obtained with 150 watt incandescent lamps under white shades suspended about 3-1/2 feet above the greenhouse bench at 5-6 foot intervals along the bench. When fluorescent lamps are used 2-lamp fixtures using "white" bulbs should be hung about 4 feet above and lengthwise of the bench with about 2 feet of space between ends of the fixtures.

Since very low light intensities may induce flowering of some plants it is essential that plants which are to receive only short daylengths be shielded from any additional light. Single-thickness draw curtains of black satine give satisfactory protection. They may be supported by rings on wires installed above and between the benches, and during the day the curtains should be pulled back. Warnings should be posted to prevent turning on overhead lights at night, since only a few minutes of light during the dark period may induce undesired heading and flowering.

TREATMENT FOR REPRODUCTIVE GROWTH

Certain species, such as orchardgrass, that flower under long daylengths may be induced to flower during natural short-day periods by increasing the daylengths to 16 hours with artificial light. If many plants are to be treated the electrical load may be divided so that one portion is lighted before midnight and the other between midnight and dawn.

Many and probably all species head almost as well when they are exposed to 1 hour of light near midnight as they do to 5 or 6 hours of light just after sunset or before dawn. A short light period at 11 p.m., midnight, or 1 a.m. breaks the normal winter night of 14-16 hours into two short nights of 5-8 hours. The use of such short light periods near the middle of the night reduces electricity costs and also permits more plants to receive treatment from a limited power supply.

While conditions for obtaining good flower and seed production may vary with the species, plants should always be vigorous. To obtain such plants from seeds or cuttings, growing conditions should include air temperatures of 60-70°F with fall daylengths of 11-12 hours. Mineral fertility should be high, and available nitrogen should not be excessive but sufficient for plants to make good growth. Soil moisture should be about medium; excessive dryness or wetness should be avoided.

After the plants started in late summer are grown at 50-70°F for several months at shortening daylengths of 12 to 11 hours, the temperatures should be reduced to 50-55°F and the plants grown for 6 to 8 weeks longer as the natural daylengths continue to shorten. These periods precondition many perennials for flowering, and following it, greenhouse temperatures should be increased to 70-75° and 16-hour daylengths (or short nights) provided with artificial light. The change to a reproductive phase of growth may usually be observed in 2 to 3 weeks, and depending upon the species, flowers will begin to appear after another 2 or 3 weeks. Trials at this laboratory indicate that grasses which are difficult to bring into head, such as a few late clones of orchardgrass and many fescues, flower better when preconditioned longer at cool temperatures and short days.

The addition of nitrogen fertilizer should be delayed until it is evident that the grasses are beginning to head, and then it should be made in only moderate amounts. Legumes do not require nitrogen in a soil containing nodule-forming bacteria.

For genetic studies with legumes it may be advantageous to turn on the lights about 2 or 3 a.m. so that florets will be open by 9 or 10 a.m. and pollination procedures may be started in the morning. If crosses are desired between normally early flowering and normally late flowering plants, those of the early strain that have budded may be moved to a cooler but also lighted section to retard further growth while plants of the late strain develop further. At the proper time the early strain may be returned to the warm house for crossing. The above procedures work well for both grasses and legumes. Another technique to obtain coincident flowering of plants from known early and late strains involves providing warm temperatures and long days for the late strain a week or two before they are given to the early strain.

SUMMARY AND CONCLUSIONS

A brief presentation has been made describing some of the problems that have been encountered, and how they have been met, in growing forage plants in greenhouses during the past 20 years at the U. S. Regional Pasture Research Laboratory in State College, Pa. Procedures are discussed that have been useful in growing satisfactory plant material for various experimental purposes, but no attempt has been made to discuss comprehensively the numerous problems that arise in connection with growing plants in a greenhouse.

While there is no substitute for actual experience in growing plants in a greenhouse, the appreciation that growth is a plant's response to numerous environmental and genetic factors will be a decided aid in conducting greenhouse experiments. The environment that is discussed includes conditions of air and soil temperatures and moisture, radiation and light, soil fertility and aeration, plant diseases, and other pests. Evidence of plant responses may be either immediate or delayed and the response to a specific factor may be difficult to interpret unless all other factors are known and most of them are under control. Because it is usually impractical to control all factors, stress must be laid on items expected to be of greatest importance in the experiment undertaken.