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PLASTIC-COVERED RAINSHELTERS FOR VEGETABLE PRODUCTION IN THE TROPICS

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Abstract: Many tropical locations with an otherwise favorable climate for vegetable production receive high rainfall. This contributes to high disease incidence, reduced pesticide efficiency, physiological diseases associated with uncontrolled moisture conditions such as radial cracking, reduced fertilizer efficiency due to leaching of nutrients and reduced worker efficiency. Rainshelters generally consist of structural wood, plastic or metal frames covered with transparent polyethylene film or rigid plastic panels on the top to intercept the rainfall and, possibly, screen on the sides and ends of the structure to act as a wind and insect barrier. Rainshelters typically do not have electrical power nor contain active heating or cooling devices. Quonset-style tunnels or arched structures are the most common configuration, but gable and temporary tent structures are also prevalent. Rainshelters range in size from single-row covers to gutter-connected multi-unit structures. Daytime temperatures rise above ambient in rainshelters and this is advantageous for growing warm-season crops like tomatoes at cooler, upper elevations and disadvantageous for many vegetables at warmer, lower elevation locations. Passive rainshelter cooling issues include structure size and height, air exchange, roof and side vents, screen mesh, orientation according to wind direction, shading, irrigation type, relative humidity and transpiring crop surface. Growers converting from open field to growing in rainshelters may need to change irrigation, fertilization and pest control practices and may be confronted with new problems such as high soil salinity and insufficient pollination of some crops. Insect and disease control strategies include growing the same crop of the same age in an individual rainshelter, decreasing the time that a crop is in the rainshelter and decreasing the planting density. A unique problem solved by rainshelters in Hawaii was caused by an active volcano which contributed to acidic and pollutant-containing rainfall such that no marketable tomato yield was produced from unprotected plants, but those under a polyethylene-covered rainshelter grew normally and produced 5 kg/plant of marketable fruit.

Introduction

Many tropical locations receive from 80 to 500 cm of rainfall per year (1). This contributes to high disease incidence on vegetables, and pesticides applied to combat these diseases are often washed from the plants. Physiological diseases such as radial cracking and splitting of tomatoes are often associated with uncontrolled moisture conditions. Fertilizer efficiency is low, because rainfall leaches nitrogen and potassium from the root zone. These problems are reduced by growing crops in rainshelters. Worker efficiency improves in rainshelters, because work can be scheduled and harvesting can be conducted on a predictable schedule. Intensive container-culture and hydroponic systems should be protected from rain. Thus, rainshelters can convert low-priced land with high rainfall, but an otherwise favorable climate and location into very productive properties.

Discussion

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Structures. Rainshelters generally consist of a structural frame covered with polyethylene film or rigid plastic panels on the top of the structure and possibly screen on the sides and ends. Rainshelters usually do not contain active heating or cooling devices and do not have electrical power, but an irrigation source is available. Lumber and metal are the most common framing materials. In addition, plastic materials such as PVC pipe and locally available materials such as bamboo and guava have also been used as framing materials.

Similar to protective structures in the northeastern U.S. (16), quonset-style tunnels or arched structures are the most common configurations, but gable and temporary tent structures are also prevalent. Rainshelters may be home-made or numerous styles may be obtained from commercial vendors. Rigid coverings such as fiberglass and polycarbonate are more expensive and durable than uv stabilized polyethylene films which are commonly used. Vendors of the various coverings gladly communicate advantages of their products with emphasis on cost, ease of covering a structure, lifetime of the covering and plant responses to the light which passes through these coverings. In the case of films, it is important to use only uv stabilized films specifically manufactured for greenhouses and rainshelters as compared to construction grade polyethylene which will fail within 6 months of exposure to sunlight. Direct contact of some pesticides and wood preservatives may adversely affect the lifespan of the polyethylene film.

Polyethylene tends to fit loosely when it covers gable or straight structural members and must be secured with battens to prevent flapping. However, polyethylene forms snugly to arched members when attached tightly at the top and bottom. Thus, quonset and tunnel structures only require that the plastic needs attachment at the ends and sides, such that no battens are needed. In windy areas, hold-downs of rope or drip irrigation tape may be placed every 8 m to prevent large waves from generating in the plastic. If arches are spaced too far apart, the polyethylene may sag slightly if it has not been applied tightly, and water may pond on the flat area on top of the rainshelter. This may be remedied by placing a PVC pipe midway between the arches and supported by the top and adjacent purlins. Structural arches and other members which directly contact transparent plastic should be painted white, because this will prevent heat build-up which accelerates aging of the plastic covering.

Polyethylene film should be applied to rainshelters on a sunny day, because the heat causes it to stretch and then shrink somewhat when it cools, thus causing a nice tight cover. Pulling the plastic over the rainshelter is accomplished by having several ropes attached to perimeter polyethylene which is wrapped over tennis balls or similar spheres. This helps to prevent tearing of the plastic. Often the plastic hangs up on the purlins and must be pushed from underneath with a long pole. Alternatively, the new cover may easily be pulled over the previous plastic cover, but it becomes very difficult to remove the old cover which becomes trapped under the newly installed cover. It may be useful to start attaching the plastic film from the middle of the rainshelter and work outwards because this will help to avoid wrinkling of the polyethylene. There are a variety of commercially available devices which attach the polyethylene to the rainshelter including plastic clips, metal extrusions and ‘wiggle wire’ inserted into a metal channel.

Narrow (4.4 m) tunnels have been constructed with 1.9 cm Schedule 40 PVC pipe covered with 6 mil polyethylene and they are useful for non-windy locations (1,4,8). PVC pipes are simply pushed about 30 cm into the soil or placed over 1.2 cm reinforcing rods which have been pounded into the soil. They require a 2.3 m high center support which usually consists of wooden posts attached to 3.8 x 8.9 cm lumber which also can support trellis wires. A cable may be used as a center support if a clear-span is desired. Absence of a center support may cause ponding on top of the structure and even collapse of the structure in extreme cases. Applying white latex paint to the PVC pipes may reduce deterioration of the polyethylene which directly contacts the pipe as well as increase the life of the pipe. A 9.2 m wide PVC pipe structure was unsuccessful because even a moderate wind caused excessive deflection of the pipes.

Narrow rowcover structures have been designed to protect only one row, bed or tank and the crops must be accessed from outside of the structures, since there are no interior aisles. In plots receiving 89 cm of rainfall during the growing period, salable tomato yields from soil beds under 0.8 m wide rainshelters were 13 and 19 per cent greater than from unprotected plots and grade 1 yields were 31 and 95 per cent greater from the protected plots when 2 tomato cultivars were grown, respectively (9). More fruit cracking occurred in tomatoes from the unprotected plots. There was a 0.7 m wide vent area between these rowcovers. Air temperatures under the rowcovers and between the rowcovers were similar except near the top of the rowcover which was 2.3^{o}C higher. In another experiment, salable tomato yields in hydroponic pots and tanks were reduced 100 and 55 per cent, respectively, when there was no rain protection from 158 cm of rainfall as compared to plots covered by a rowcover (13). Temporary fiberglass-panel rainshelters were placed over onion beds which experienced only 25 per cent onion spoilage as compared 69 per cent spoilage in unprotected plots (3). Rain protection for onions is needed in the final 1 to 2 months before harvest. Hydroponic lettuce tanks (1.2 to 1.8 m wide) were covered with an arched rainshelter having a 0.5 m roof overhang which was somewhat higher than the grower's height. The sides and ends were screened, but the side screens were held down by a weighted PVC pipe filled with sand which could easily be raised and lowered, thus, allowing easy access to the tanks.

The upright and bench support members of a 6 m long x 1.5 m wide seedling bench rainshelter was constructed with PVC pipe filled with concrete and reinforced steel in Taiwan (10). The top PVC support members were not reinforced so they could easily break away during a severe typhoon leaving the reinforced upright and bench members intact, and thus, greatly facilitate reconstruction after a storm.

Screens are recommended on the sides and ends of rainshelters to act as a windbreak and also to exclude some insects. A 2 m high perimeter fence (with no polyethylene rainshelter top) of Typar fabric on a 6 x 7 m area reduced both fruit fly damage and mosaic viral symptoms on zucchini squash (15) by excluding insects from ground level to 2 m height. A polypropylene screen fence on the perimeter of a similar plot effectively reduced fruit fly damage, but viral symptoms appeared. Presumably, aphids were able to pass through the screen. It is likely that a polyethylene top cover would have increased the exclusion of insects from this structure.

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Varied opinions on the orientation of a rainshelter are based upon access to the structure, maximum light distribution and prevailing wind direction. In a tropical climate, one opinion is that the structure should be oriented based upon prevailing wind direction, because detrimental effects of high temperatures to crop production overcome positive effects of orientation for optimum light interception. Although large gutter-connected rainshelter complexes promote labor and other efficiencies, larger structures can become too hot in tropical environments, especially since passive cooling systems are usually employed. Smaller structures have more perimeter area and can better take advantage of prevailing breezes.

Passive Cooling of Rainshelters. Solar radiation passing through a polyethylene roof is absorbed by inside surfaces and emitted as long wave radiation which does not pass back through the roof and is captured as heat (5). The maximum temperature in rainshelters typically occurs on a sunny day from noon to 2 PM. Cooling by fans is expensive, but fortunately there are passive strategies for cooling the structures. Firstly, shading will reduce incoming radiation, but it may decrease production or quality, but there are instances of improved growth by shading (17). White colored objects are very reflective and thus, contribute to cooling a rainshelter. For example, fresh white snow has an albedo of 0.80 whereas typical green fields have an albedo of 0.20 which means they reflect 80 and 20 per cent of incident light, respectively (14). Growers can increase reflectivity by placing white-colored fabric or film on walkways, cover beds with white mulches, place white covers on hydroponic tanks or utilize white bags for bag culture and paint trellis posts and structural members white. Evapo-transpiration causes cooling and is related to the type and amount of foliage, the relative humidity of the air and the water supply to the plants. Misting of the plants can also contribute to cooling, but misting too late in the day may contribute to plant diseases.

Air exchange is the most common method of cooling a rainshelter. For example, 1 air change per minute was calculated to maintain temperature 5.6^{o}C above ambient in a tomato rainshelter, but only 0.4 air change was needed if misting also occurred. A 29 m long rainshelter which was half obstructed with crops required a 2.2 mph breeze to exchange the air every minute. The end screens can greatly impede air flow such that more than a 5 mph breeze through a 35 per cent shade screen with 2.5 mm openings would be needed to generate a 2.2 mph breeze in a structure which needs to pass through incoming and exit screens. Finer screens might be useful to restrict more insects, but they greatly restrict air movement. Reducing the length and width of the structure and increasing the height of screen on the sidewalls will contribute to air exchange. Tall structures provide a reservoir of hot air above the crop because hot air rises and, thus, these structures are cooler for the plants. Top-vented structures exhaust the warmest air from the structure, thus reducing the required air exchange rate. Maintaining a grassy space between rainshelters also contributes to cooling, whereas large, gutter-connected complexes contribute to excessive heat problems.

Culture and Management. Many types of crops may be grown in rainshelters, but the added costs of the structure dictates that these must be high value crops grown in an intensive manner. Crops may be grown in soil beds, in various types of containers and hydroponically. Crops require irrigation which is most commonly delivered by micro-irrigation and drip irrigation systems with an option for fertilizer injection. Transplanting crops is recommended whenever possible, because the grower may plant extra seedlings and select the best plants for transplanting plus it allows more crops per year in the growing structure. For example, hydroponic lettuce may be transplanted immediately after harvesting and cleanup of the previous crop. Thus, 50 per cent more crops may be grown when 14-day-old seedlings are transplanted followed by a 28-day grow-out period in the rainshelter as compared to a 42-day growing period for a direct-seeded crop.

Open-field growers need to be aware of various cultural changes when switching to growing crops in a rainshelter. Firstly, a rainshelter makes it possible to successfully grow vegetables in high rainfall areas. The Mountain View area of Hawaii has a favorable elevation (500 $\pm$ 200m) for growing vegetables, but 350 to 500 cm of rainfall can occur annually and this causes many insurmountable production problems. At the cooler (daily low 8-15^{o}C and high 16-26^{o}C) and higher elevation (1200 m) in Volcano, Hawaii with over 200 cm rainfall, conditions are not favorable to grow tomatoes outdoors. Air temperatures in rainshelters are commonly at least 10^{o}C higher than outside for 4 to 8 hours during the midday period plus lesser, but significant increases are observed during morning and evening hours and this improves the growing conditions so that tomatoes may be successfully grown (2). Inside and outside air temperatures are similar for about 8 hours during the late evening and early morning hours in rainshelters.

It is common for field growers in rainy tropical areas to apply double, triple or more fertilizer than is actually taken up by the plants. The uncontrolled rainfall washes away much of the nitrogen and potassium from the rootzone, and the grower is forced to apply fertilizer frequently. However, in a rainshelter, excessive fertilization will cause the soil salinity to rise and decrease crop growth and yields. If the overall crop growth appears sluggish, but greatly increased growth is detected under a leak in the rainshelter roof (due to lower salinity), the grower should test the soil for electrical conductivity (salinity test) and reexamine the fertilizer and irrigation practices.

There may be poor pollination in rainshelters with enclosed screens because many plants rely on insects or air movement for pollination. This may be remedied in the case of cucumbers by choosing parthenocarpic varieties (fruits which set without pollination) or by vibrating tomato flower clusters or shaking the plant or trellis wires. In a moist climate, growers usually wait to pollinate plants until the humidity drops (usually after 10 AM), because this facilitates the shedding of pollen.

During rainy periods, a substantial amount of water can enter the soil in a rainshelter by lateral and vertical capillary water movement (11). Significantly more water enters near the perimeter of the rainshelter than in the center of the structure. If the rainshelter is irrigated, the rate along the perimeters should be lower than the center or else there will be more leaching of nitrogen and potassium from the perimeter areas. Of course, this problem is not encountered by hydroponic and container-type operations.

Some irreversibly dried soil tropical soils undergo a more or less permanent physical change when they are severely dried as when left unirrigated for a long time under a rainshelter (7). One soil changed from a well hydrated (300 per cent field capacity), muddy and sticky structure to a more porous, aggregated soil with only a 58 per cent field capacity which was easier to rototill.

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Insects and Diseases. The use of smaller, individual rainshelters quarantines insects and diseases to a particular structure rather than be free to spread throughout a larger multi-unit structure. A grower may find it affordable to program a fallow period following harvest in a small structure and this can greatly reduce insect and disease problems. One insect and disease control strategy in tropical rainshelters is to grow the same crop of the same age in an individual rainshelter. Another strategy is to decrease the time in the rainshelter where the plants are exposed to insects and disease. When seedlings are grown in a nursery and transplanted in an individual rainshelter, the cropping period may be reduced by more than one-fourth. Another strategy for tomato production is to harvest fewer clusters and increase the planting density of these smaller plants. For example, double density, 2-cluster 'Lenor' tomatoes yielded 47 per cent more salable tomatoes per m^2/day in the rainshelter than single density, 8-cluster tomatoes (12). In addition, the 2-cluster tomatoes only required 347 g of pesticide to produce 1000 kg of salable fruit as compared to 708 g for the 8-cluster tomatoes. Rainshelter growers in tropical environments might be advised to maintain a somewhat lower planting density than temperate-climate greenhouse recommendations. This discourages the buildup and spread of plant diseases and as an added benefit, encourages labor comfort and efficiency.

On the Kona side of the Island of Hawaii, a volcanic haze (vog) was apparently caused by Kileaua volcano located about 75 km away and this caused field-grown tomato symptoms of blossom drop, poor fruit set, hollow, small and almost seedless fruit and no salable fruit (6). However, plants grew normally and produced 5 kg/plant under a polyethylene-covered arched guava-stick frame rainshelter (18 m^2). This simple rainshelter intercepted the acidic rain (pH 4.0-4.4) containing 27 organic compounds in the ppb range which inhibited pollen germination and increased leaching of nutrients from the foliage and caused these deleterious effects on the tomatoes.

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