Physical Principles of Row Covers and Grow Tubes with Application to Small Fruit Crops

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ABSTRACT. Protected cultivation has been used to modify the microclimate to advance maturity, increase yields, and expand areas of production for many horticultural crops. Ancillary benefits of protected cultivation can include reduced numbers of pests and lower disease pressure. This discussion will limit the term "protected cultivation" to row covers, low tunnels, and individual plant shelters ("grow tubes"), addressing their applications in the production of small fruit. The foremost biological response of crops grown under protected cultivation is an increase in growth rate, induced primarily by elevated soil and air temperatures within the shelter and around the plant. The protected environment often has lower vapor pressure deficits between crop and atmosphere, resulting in less plant stress. Although many reports detail the biological responses of crops grown under protected cultivation, few include measurements of environmental variables within plant shelters. Understanding the physical principles governing microclimate modification by row covers and grow tubes is essential for effective use of these materials. The optical properties of a covering material and its porosity largely determine the cover's influence on plant growth and development. Optical properties and cover porosity will be discussed in terms of heat transfer between the crop and its environment. The benefits of row covers and grow tubes have been most dramatic in cool or maritime climates where their use can extend the growing season or make possible the production of warm-season crops. Technological advancements in plasticulture

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Small Fruits Review, Vol. 1(3) 2001

could lead to 'prescription' plastics, where covers with specific optical properties and ventilation characteristics are made available for site- and crop-specific applications, particularly small fruits.

KEYWORDS. Optical properties, boundary layer, plasticulture, row cover, grow tube, microclimate

INTRODUCTION

Historically, horticulturists have attempted to modify the plant microclimate to accelerate growth, increase yield, or advance maturity. Various techniques under the umbrella of "protected cultivation" can be used to increase air and soil temperatures, increase humidity around the plant, reduce insect and disease pressures, and/or reduce water stress (e.g., Kjelgren, 1994; Pollard and Cundari, 1988; Wells and Loy, 1985). Protected cultivation includes, but is not limited to, hot caps, floating row covers, low tunnels, and individual plant shelters or "grow tubes." Research has elucidated the effects of row covers and grow tubes on various crops, particularly vegetables and tree seedlings. Unfortunately, much of this research has failed to describe the physical environment within the shelter. It is important to understand the physical mechanisms of microclimate modification for the development of new materials and so that growers use row covers and grow tubes appropriately and effectively. The objective of this paper is to review seminal research on row covers and individual plant shelters, to explain the physical principles governing microclimate modification by these techniques, and to propose applications for the production of small fruits.

Row covers, which have been used predominantly in vegetable production, are flexible sheets of translucent materials such as extruded polyethylene or spunbonded polypropylene that cover one or more rows of a field-grown crop (Hall and Besemer, 1972; Wells and Loy, 1985). The degree of opacity of a cover depends upon the material used. Row covers may be supported by wire hoops (low tunnels) or by the crop itself (floating row covers). Tree shelters or grow tubes, which were developed initially to protect new forest plantings from herbivory, are manufactured from semi-rigid materials like plastics and cardboard. All commercially available grow tubes share the common feature of encircling a single, young plant, usually a perennial, with a semi-rigid material of low porosity. Most variation among grow tubes lies within a narrow range of optical properties.

As early as the 1940s, row covers were investigated for use in vegetable production (Emmert, 1955); commercial use expanded during the late 1950s and early 1960s (Hall, 1971). Floating row covers, introduced in the late 1970s with the development of lightweight, spunbonded fabrics, furthered the popularity of row covers because of their relatively easy installation, reduced labor requirement, and greater potential for reuse (Loy and Wells, 1982). Row covers have been shown to advance maturity (e.g., Hemphill and Mansour, 1986; Motsenbocker and Bonanno, 1989), increase early and total yields (e.g., Farias-Larios et al., 1998; Gaye and Maurer, 1991; Gaye et al., 1992), and exclude various pests (e.g., Ghidiu et al, 1986; Hough-Goldstein, 1987; Natwick et al., 1988; Wells and Loy, 1985). They are used principally in areas with short growing seasons or long, cool springs (Loy and Wells, 1982; Motsenbocker and Bonanno, 1989; Patten and Wang, 1993; Poling et al., 1991; Wells and Loy, 1985). In small fruits, floating row covers have been used successfully to increase early yields and to advance the maturity of strawberries (Pollard and Cundari, 1988; Pritts et al., 1989), blueberries (Wildung and Sargent, 1989), raspberries (Pritts et al., 1992), and cranberries (Patten and Wang, 1993; Stang et al., 1991). Row covers may also provide a small measure of frost protection depending on the type (convective vs. radiative) and severity of the frost (Hochmuth et al., 1993; Poling et al., 1991; Turner et al., 1992). Grow tubes used in forestry, pomology, and viticulture have increased growth rates and plant heights (Applegate and Bragg, 1989; Due, 1990, 1996; Tuley, 1983, 1985). However, accelerated growth occurs only while the growing tissue is inside the structure; once the plant exceeds the height of the tube, growth rates decrease to the rates observed among unprotected plants (Applegate and Bragg, 1989; Tuley, 1983, 1985). Correct installation of grow tubes is essential. One should seal or berm the bottom of the tube with soil, decreasing ventilation rates, and thus, convection. Grow tubes that are not sealed at the base are less effective plant shelters because of greater convection and consequently less temperature increase above ambient (Due, 1990; Frearson and Weiss, 1987).

PHYSICAL PRINCIPLES

To better understand the physical principles governing microclimate modification by row covers and grow tubes, the "energy balance" of our system (e.g., Tanner, 1974; Tarara, 2000) must be considered. A surface energy balance is an accounting system for the fluxes of energy to and from a surface, including that of a crop, soil, or row cover.

$$R_n + G + H + LE = 0 \qquad [1]$$

where R_n is net radiation, or the sum of incoming and outgoing long-and shortwave radiation; G is heat transfer by conduction; H is heat transfer by convection between the crop, soil, or row cover and moving air; and LE is the transfer of latent energy by evaporation (or condensation) from the surface, all in $W \cdot m^{-2}$. By convention, energy fluxes towards the surface are assigned positive values, while fluxes away from the surface are negative. Of primary interest for our discussion are R_n, H, and LE.

Net radiation is comprised of two components. Shortwave or solar radiation (R_S; 0.2 to 1.4 μm) includes the visible and photosynthetically active radiation (PAR) wavebands. Longwave or terrestrial radiation (R_{LW}; 2 to 50 μm) is emitted by all objects, including crops, soils, and row covers, according to the object's temperature. This relationship is described by the Stefan-Boltzman Law (Campbell and Norman, 1998). During the day, R_S is the primary input of energy into the system and the crop or soil has a positive R_n. This energy is dissipated from the crop surface by H and LE and from the soil surface by H, LE, and G. From a dry row cover or grow tube material, R_n is dissipated by H. When a crop is transpiring (evaporating), LE is negative; energy is transferred away from the crop surface (i.e., evaporative cooling). When the crop or soil is warmer than the air, energy is transferred by convection away from the surface (H = negative), warming the air. Conversely, if the surface temperature of the crop or soil is less than that of the air, H becomes positive–the crop, soil, or row cover surface is warmed by the surrounding air. Rates of H and LE are affected by wind speed and the thickness of the boundary layer at the crop or soil surface (Campbell and Norman, 1998).

Under protected cultivation, the observed responses of plant growth and development result primarily from increased temperatures within the covers or grow tubes (e.g., Brown and Osborn, 1989; Edge and Gerber, 1984; Hemphill and Mansour, 1986; Wells and Loy, 1985; Wolfe et al., 1986). In early spring, higher soil temperatures accelerate root growth and water uptake (Raleigh, 1941; Taiz and Zeiger, 1991). While the cover is in place, air temperatures are elevated during the day in relation to ambient solar radiation and the optical properties of the cover. At night, with no solar radiation input, air temperatures within the protected environment return to near ambient (Kjelgren, 1994; Rendle, 1985). Under high solar radiation and low wind speed, air temperatures may exceed a crop's optimum. For example, flower abortion and delayed ripening were observed in tomatoes and peppers grown under clear polyethylene and spunbonded polypropylene covers (El Ahmadi and Stevens, 1979; Gent, 1990a; Gerber et al., 1988; Wolfe et al., 1989); hence the predominant use of row covers and grow tubes is during the early, cool part of the growing season. This increase in temperature under row covers can be influenced by the crop size or the fraction of soil surface area covered by the canopy. Small plants or plants grown under wide spacings allow a larger proportion of R_S to be absorbed by the soil surface, which can act as a heat reservoir. By contrast, large plants that cover the soil surface will absorb most of the available R_S. Air temperatures beneath the cover in a closed canopy crop may actually be cooler than ambient air temperature because of increased latent heat flux (LE).

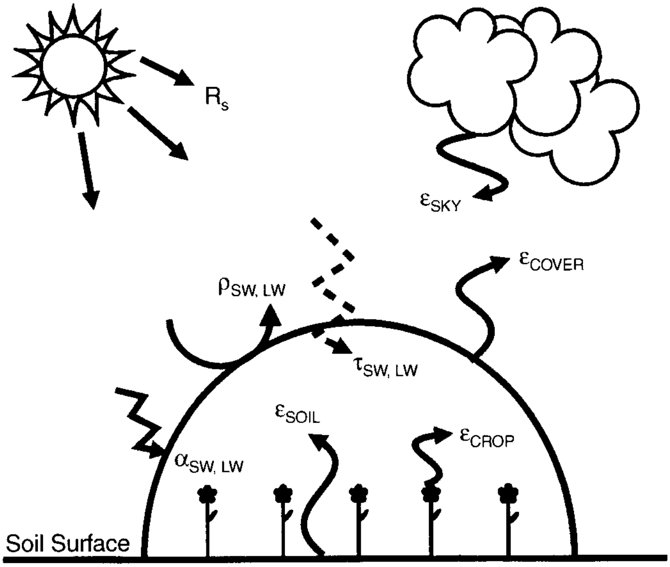
The observed increases in temperature under row covers and grow tubes are functions of the canopy size, the extent to which the cover modifies the boundary layer of the crop, and the optical properties of the cover material. The primary mechanism by which row covers and grow tubes increase soil and air temperatures around the crop is by increasing the crop's boundary layer, thus reducing convection (Okimura and Hanada, 1993; Pollard et al., 1987; Wells and Loy, 1985). The boundary layer is the thin layer of air immediately adjacent to a leaf, crop, or soil surface in which air velocity is slowed and the fluxes of heat, mass, and momentum are reduced. The boundary layer induces a resistance to heat and mass transfer to and from the plant or soil surface. Its thickness varies with wind speed, turbulence, and the area of the surface. Row covers and grow tubes increase the thickness of this relatively still layer of air around the crop.

The optical properties of a material are its transmittance (τ), reflectance (ρ), and absorptance (α) in both shortwave ($_{SW}$) and longwave ($_{LW}$) spectra, where

$$\tau + \alpha + \rho = 1 \qquad [2]$$

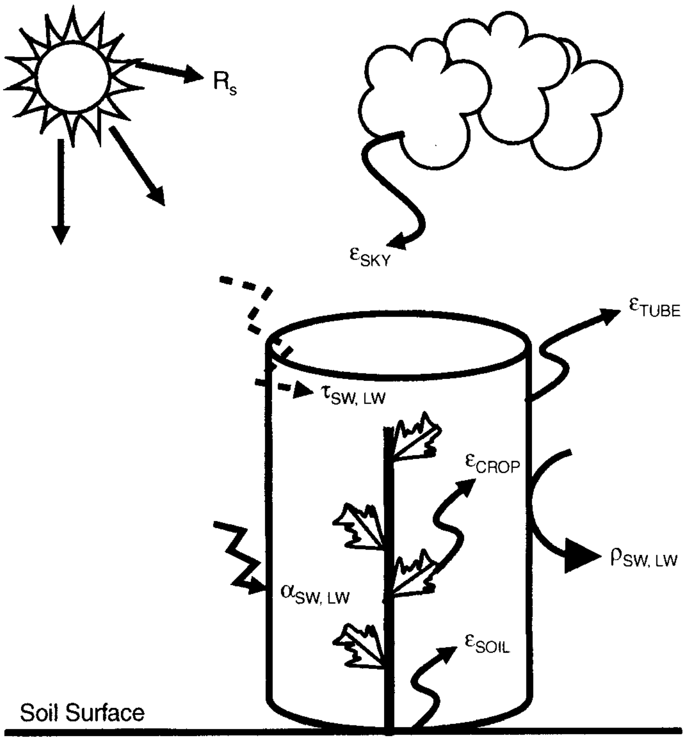
Energy not transmitted through the cover or tube can be absorbed by the material or reflected back into the atmosphere (Figures 1 and 2). Longwave emissivity (ε; $\varepsilon = \alpha_{LW}$) is the fraction of radiation emitted

FIGURE 1. Illustration of the optical properties of a row cover where R_s is global irradiance, τ is transmittance, α is absorbance, ρ is reflectance, and ε is longwave emissivity of the sky, cover, crop or soil. The subscripts $_{SW}$ and $_{LW}$ represent shortwave and longwave radiation respectively. In the shortwave spectrum, $\tau + \alpha + \rho = 1.0$. In the longwave spectrum, $\varepsilon = \alpha_{LW}$, and $\varepsilon + \tau + \rho = 1.0$.



from a surface relative to that emitted by a perfect emitter ($\varepsilon = 1.0$) at the same temperature. Organic materials, including plant leaves, typically have high ε (e.g., 0.95-0.99; Gates, 1980). Clear row covers with high τ_{SW} allow more absorption of R_S by the soil or plant surface, while white or opaque covers with low τ_{SW} and high ρ_{SW} decrease R_S available to the plant or soil surface. Typical τ_{SW} for row covers range from 0.82 for clear polyethylene to 0.77 for spunbonded fabric materials, with even lower values for opaque materials (Avissar et al., 1986; Dubois, 1978; Ham et al., 1993; Loy and Wells, 1982). Opaque grow tubes, such as those made from cardboard have lower τ_{SW} than translucent tubes, and thus have a smaller temperature increase during the day. White translucent tubes can reduce τ_{SW} to 0.70, while brown colored translucent tubes can reduce τ_{SW} to 0.50 (Kjelgren et al., 1997). The optical properties of any cover will shift with cleanliness and age (Avissar

FIGURE 2. Illustration of the optical properties of a grow tube where R_s is global irradiance, τ is transmittance, α is absorbance, ρ is reflectance, and ε is longwave emissivity of the sky, cover, crop or soil. The subscripts $_{SW}$ and $_{LW}$ represent shortwave and longwave radiation, respectively. In the shortwave spectrum, $\tau + \alpha + \rho = 1.0$. In the longwave spectrum, $\varepsilon = \alpha_{LW}$, and $\varepsilon + \tau + \rho = 1.0$.



et al., 1986; Kluitenberg et al., 1991). Colored grow tubes that are not stabilized for ultraviolet radiation (UV) can degrade over time, changing the optical properties in certain wavebands (Due, 1990; Evans and Potter, 1985; Tuley, 1985). Typical τ_{LW} for row cover materials range from 0.71 for clear polyethylene to 0.12 for transparent PVC (Dubois, 1978). Minimizing τ_{LW} is important for minimizing temperature declines at night from underneath covers (Pollard et al., 1987).

Protected cultivation can modify humidity and vapor pressure deficits (VPD) around the crop. The largest increases in humidity have been measured inside solid plastic grow tubes and nonperforated row covers (e.g., Bergez and Dupraz, 1997; Potter, 1988; Wolfe et al., 1989). These materials maintain thicker boundary layers, thus limiting convection to a greater extent than perforated or spunbonded covers (Hamamoto, 1996). Less convection results in lower fluxes of water vapor to the outside environment; consequently, rapidly transpiring plants under row covers or in grow tubes often experience lower VPD than unprotected plants (Brown and Rosenberg, 1971; Kjelgren and Rupp, 1997; Tanner, 1974). Plants grown under low VPD generally suffer less water stress (Taiz and Zeiger, 1991). In some cases, water vapor from transpiration can condense on the cover or inside the tube and fall to the soil, recycling water that would otherwise be lost to the atmosphere (Bergez and Dupraz, 1997; Burger et al., 1992; Kjelgren, 1994; Morison et al., 1989; Savage, 1980). One type of grow tube has an internal "collection cuff" to trap condensation and rain (Applegate and Bragg, 1989). Water in the cuff evaporates throughout the day, thereby increasing humidity in the tube and reducing VPD. One drawback of nonperforated covers is the potential for more severe incidence of certain diseases in the warm, humid environment if disease inoculum is present before the cover is installed.

Elevated concentrations of atmospheric carbon dioxide (CO_2) have been measured under row covers and in grow tubes (Dupraz and Bergez, 1999; Frearson and Weiss, 1987; Hartz et al., 1991; Mayhead and Jones, 1991; Rendle, 1985). Increased CO_2 within covers and tubes can reduce transpiration rates and conserve soil water (Bremer et al., 1996; Ham et al., 1995). Similar observations have been made of tree seedlings in grow tubes, where higher CO_2 has been correlated with both increased growth and higher water use efficiency (Kjelgren, 1994; Teskey and Shrestha, 1985). This is known as the 'chamber effect' (Bremer et al., 1996; Ham et al., 1995). An increasing gradient of CO_2 from top to bottom has been observed in grow tubes and is likely the result of vertical gradients in carbon fixation, low rates of air circulation, and soil respiration (Applegate and Bragg, 1989; Burger et al., 1992; Evans and Potter, 1985; Mayhead and Jones, 1991). High rates of net photosynthesis and concomitant depressions in CO_2, especially under clear skies, have been measured (Brown and Rosenberg, 1971; Dupraz and Bergez, 1999; Morison et al., 1989). There is no published information on the effects of shelters on photosynthesis in small fruits or grapevines.

Light transmission by the row cover or grow tube material influences potential CO_2 concentration via photosynthesis. Some materials transmit only 25 to 70% of R_S (Kjelgren, 1994; Kjelgren et al., 1997), potentially depressing rates of photosynthesis (Teskey and Shrestha, 1985). In grow tubes, observed increases in CO_2 were attributed to low amounts of PAR and low rates of carbon fixation by the plant (Dupraz and Bergez, 1999). One would expect increased temperatures to increase respiration, elevating CO_2 within shelters (Taiz and Zeiger, 1991). However, reduced rates of gross photosynthesis may be observed if temperatures beneath the cover exceed optima (Bergez and Dupraz, 1997).

Limited research exists on the potential of row covers as passive means of frost protection (e.g., Hochmuth et al., 1993; Moore et al., 1993; Poling et al., 1991). The common hypothesis was that row covers increase the crop's boundary layer, decrease convection, and thus insulate the crop or maintain a portion of the temperature increase gained during the day. Greater than a 1 to 2°C increase in air temperature above ambient at night, and less on windy nights should be expected (Albright et al., 1989; Gent, 1990a; Wolfe et al., 1986; Wolfe, 1992). On still nights with high risk of radiative frost, row covers should not be used for frost protection unless the material itself transmits little longwave radiation. For example, clear polyethylene, the most common material for row covers, has a longwave transmissivity (τ_{LW}) of 0.82; therefore, 82% of the longwave radiation emitted by the crop or soil surface is "lost" to space (Avissar et al., 1986; Dubois, 1978; Hanson, 1963). Unfortunately, the optical properties of row cover and grow tube materials are infrequently reported. Longwave transmission can be decreased by a small amount by condensation forming on the underside of the cover. This thin film of water slows heat loss because of its high heat capacity and absorption of nearly all of the longwave radiation (α_{LW}, ε = 0.99) from the crop (Albright et al., 1989; Pearson et al., 1995; Savage, 1980; Waggoner et al., 1960; Walker and Walton, 1971; Wells and Loy, 1985). In blueberries, nonwoven polypropylene row covers used in conjunction with microsprinklers afforded a small degree of protection from frost; however row covers alone did not protect berries from frost damage (Norden, 1990).

APPLICATIONS IN SMALL FRUIT PRODUCTION

Advances in protected cultivation have allowed warm season crops to be grown in increasingly northern latitudes (e.g., Bornt et al., 1997;

Gast and Pollard, 1989, 1991; Gaye and Maurer, 1991; Hemphill and Mansour, 1986). Row covers are most applicable in climates that have long, cool springs with a moderate seasonal rise in temperature (i.e., maritime climates; Gent, 1990a; Patten and Wang, 1993; Pollard and Cundari, 1988; Wells and Loy, 1985). For example, cranberries often are produced in cool maritime climates and apparently benefit from the use of row covers during establishment and beyond (Patten and Wang, 1993; Stang et al., 1991). In areas with rapid increases in seasonal temperature (i.e., continental climates) row covers may be less effective or sometimes detrimental because rapid daily temperature fluctuations can suppress growth and development (Kjelgren, 1994; Kjelgren and Rupp, 1997; Motsenbocker and Bonanno, 1989).

Most investigations of row cover use in small fruit production have been with strawberries, cranberries, and lowbush blueberries. Use of row covers with these crops is facilitated by their growth habit. Fruit with a tall upright growth habit, like raspberries or highbush blueberries may benefit less from row covers because of the large volume of air under the cover (Pritts et al., 1992; Norden, 1990). Accumulated heat units were significantly higher for raspberries under a slitted polyethylene cover than in an unprotected crop, but this increase in early-season temperature did not influence vegetative growth or yield (Nonnecke and Taber, 1989). By overwintering strawberry plants under row covers, growing degree-days were increased in early spring and harvest was advanced (Pollard and Cundari, 1988). Timing of row cover application and removal is important for some small fruits (e.g., Gent, 1990b; Austin, 1991). For example, in short-day strawberries, winter and/or spring applications were more effective than fall applications to increase yield because of the interactions of temperature and photoperiod in flower bud initiation. In early spring, row covers may raise tissue temperature enough to stimulate flower initiation (Pritts et al., 1989). Because soils are already warm in the fall, row covers may induce temperatures that are above optimal for flower bud initiation. During the winter, row covers have been used to collect snow to insulate the crop and reduce cold damage (Turner et al., 1992; Wildung and Sargent, 1988). This technique was used to insulate lowbush blueberry bushes and increase winter survival (Wildung and Sargent, 1989). This same practice could be applied to strawberries and other low-lying fruit crops in areas with consistent snow cover. Without consistent snow, the crop under the row cover would be subject to wider fluctuations in temperature, leading to a greater risk of winter damage.

Grow tubes and row covers could be used to increase growth or improve plant establishment in the spring. Grow tubes are currently being used in vineyards for establishment of both juice (*Vitis labrusca* L.) and wine grapes (*Vitis vinifera* L.; Due, 1990, 1996). Vines respond to elevated temperatures and lower VPD within the tubes with increased growth rates and a change of growth habit. Rooted cuttings grown in tubes produce fewer, but longer shoots, which growers have exploited to expedite the training of the vine onto the trellis wire. This principle could be used to establish kiwifruit, which has a similar growth habit to that of grapevines. However, if grow tubes are used during the fall, growers should not rely on the tubes for frost protection. Hardening off and dormancy may be delayed because of daytime temperature elevations. In vineyards, growers must lift the base of the tubes before winter to allow the vines to acclimate.

Intense solar radiation can cause sunscald in fruit crops (e.g., Even-Chen et al., 1981; Gatherum et al., 1997; Renquist et al., 1987, 1989). Ultraviolet radiation has been implicated in sunscald on raspberries (Renquist et al., 1987, 1989), blueberries (Kossuth and Biggs, 1978), and grape leaves (Lang et al., 1998). One potential use of highly perforated or porous row covers is as a shade cloth to reduce R_S, including UV. Plastics specifically designed to absorb UV could be applied. If used midsummer, configuring the cover to minimize the daytime temperature increase would be beneficial. For example, to avoid extreme daytime temperatures, floating row covers over cane berries should not be anchored at the soil surface. This concept has been tested in raspberries, where commercially available shade cloth reduced UV by 30% and fruit temperatures by 4°C. Spunbonded polypropylene that absorbed 25% of UV reduced surface temperatures on berries by 1°C (Renquist et al., 1989). Spunbonded covers typically are less porous than netted shade cloth. In 'Concord' grapes, the disorder "blackleaf" recently has been demonstrated to be the result of UV exposure and water stress (Lang et al., 1995; Smithyman, 1999). The use of a wavelength-selective row cover in an established vineyard may not be cost effective, but the principle of its use is the same as in the previous example.

Row cover materials can be manufactured to filter selective wavebands. Alteration of the red:far red ratio (R:FR) and differences in PAR transmission by various row cover materials have been shown to influence plant growth (Dubois, 1978; Li et al., 2000; Loy et al., 1989). For example, longer stems and petioles were measured in watermelon grown under white polyethylene and spunbonded polyester, both of which reduced R:FR (Decoteau and Graham, 1997; Friend and Decoteau, 1990). This may be desirable for establishment of horizontally growing small fruit crops such as cranberries to quickly cover the ground. In chrysanthemums and bell peppers, wavelength selective films used for greenhouse coverings were used to regulate plant height without the use of chemical growth regulators (Li et al., 2000). Grow tubes may selectively filter light in various visible wavelengths, although few reports include data on light transmission (Due, 1990; Kjelgren et al., 1997).

Exclusion of diseases and pests is a common secondary benefit to using protected cultivation. Bird damage is a concern for most growers of small fruit crops. Near harvest, one could use a floating row cover with minimal temperature lifts (i.e., low τ or high porosity) to exclude birds. Flying insects like aphids, leafhoppers, and whiteflies can be virtually excluded from the crop by a row cover (Hough-Goldstein, 1987), the effectiveness of which depends on the porosity of the material and its installation (Natwick et al., 1988). Pierce's Disease, caused by the bacterium *Xylella fastidiosa* and spread by the glassy-winged (*Homalodisca coagulata*) and blue-green (*Graphocephala atropunctata*) sharpshooters, has afflicted large acreages of *V. vinifera*, causing widespread vine death within two to three years (Goodwin and Purcell, 1992; Raju et al., 1983). Although long-term solutions are being researched, there are no effective controls at this time. However, row covers could exclude the vectors of Pierce's Disease (i.e., the sharpshooters) offering a short-term solution. Raspberries, strawberries, and grapes risk damage by spider mites (Galletta and Himelrick, 1990), which also could be excluded by a row cover. However, insects present on the crop when the cover is installed can be trapped inside, nullifying the benefit (Ghidiu, 1986; Hough-Goldstein, 1987; Millar and Isman, 1988). Row covers may also exclude beneficial insects, preventing integrated pest management practices. Using row covers in small fruits solely for protection from avian and insect damage can be prohibitively expensive. If durable row covers with applicable optical properties are used to establish a crop, they could be reused for specific applications such as pest exclusion, herbicide protection, or UV absorption. Grow tubes afford protection from directed applications of nonselective pre-and postemergence herbicides by providing a physical barrier to herbicide contact.

The physical barriers provided by row covers and grow tubes also can exclude or slow the spread of certain airborne disease inoculum. In young grapevines, grow tubes decreased the observed incidence of powdery mildew (*Uncinula necator*) by increasing temperatures above which fungal spores germinate (>36°C; Delp, 1954), reducing air movement and spore dispersal within the tube, and excluding spores blown from other vines (T. Hall and W. Mahaffee, unpublished data). Reduction of downy mildew (*Plasmopara viticola*) on grapevines was observed in South Australia and was attributed to high temperatures in grow tubes (>37°C; Due, 1990, 1996). Spunbonded row covers may only provide temporary reduction of airborne diseases because of their porosity. One risk of using row covers is that if a disease like powdery mildew does infect vegetation under the cover, it can spread quickly in the warm, moist environment and damage the crop more severely than if the crop were unprotected (Vaissiere and Froissart, 1996). Reduced pest and disease pressure with row covers and grow tubes has potential for organic growers and in those areas with pesticide restrictions (Millar and Isman, 1988; Okimura and Hanada, 1993).

CONCLUSION

Row covers and grow tubes influence the growth and development of many crops, resulting in increased yields and/or advanced maturity. Understanding how a particular form of protected cultivation modifies the crop microclimate is essential to its effective and appropriate use in the field. Row covers and grow tubes have potential applications in small fruit production to increase growth, advance crop development, and reduce both biotic and environmental stresses.

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