DEVELOPMENTS IN PLASTIC STRUCTURES AND MATERIALS FOR HORTICULTURAL CROPS

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ABSTRACT

The availability of improved greenhouse structures and plastic films gives growers greater opportunities to overcome climatic limitations. Advances are still being made in the design of films suitable for greenhouses, direct covers and mulches, and further progress is inevitable.

INTRODUCTION

There was a belief after the 1939-1945 war that the production of out-of-season crops would no longer be viable. This view was influenced by rapid improvements in air and sea transport and by moves to liberalize trade. Instead, the production of crops under protection has grown dramatically in many countries, as a result of the increasing demand for high-quality fresh produce (Garnaud 1988). This development has been encouraged by many factors but, on a world scale, the introduction of plastic technology was undoubtedly a major influence.

Despite the dominant position of glass as a covering for protected structures in northwest Europe, improvements in glass technology are occurring only slowly. Glass remains inflexible, heavy and expensive. Consequently, the acreage of glasshouses on a world basis has remained static (at around 30,000 ha) during the last 25 years. In contrast, the amount of plastic used for greenhouses, direct covers and mulches is increasing rapidly.

The area of plastic greenhouses expanded from zero in the early 1950s to 60,000 ha in 1976. It now approaches 200,000 ha and is still increasing. Many factors indicate that further progress is inevitable. These include:
• the versatility of plastic;
• the development of new uses for plastic coverings;
• improvements in structural design.

Initially the rapid swing towards crop production under plastic in the Mediterranean area resulted from the availability of simple, cheap structures. These were used mainly to increase winter temperatures, and to protect crops against wind. In these areas, plastic greenhouses are considered by growers to be the best and cheapest insurance against climatic injury. In northwest Europe there is a tendency for plastic greenhouses to replace cold frames, glass cloches and single span glasshouses, but not heated glasshouses.

In contrast to glasshouses, little information was available on suitable design criteria for plastic structures during the 1960s and 1970s. The plastic clad tunnel was based on the principle of low-cost, do-it-yourself construction, with wood often used for the structural framework. These low-cost greenhouses frequently suffered from structural failure.

In addition to wind damage, other risks incurred by users of cheap plastic structures without environmental control were low temperatures during winter, high daytime temperatures, unsatisfactory ventilation, high humidity at night, and a deficiency of CO₂ in closed greenhouses during the day.

While unsophisticated structures gave many European growers their first experience of protected crops, they were not good enough to provide the high quality or precise crop planning required for present-day markets. Consequently, several strong influences are currently interacting in the horticultural industry. There is greater awareness that plastic structures need to be designed for specific regions. Moreover, advances at the plastics manufacturing level in such areas as coextrusion and the production of speciality polymers and additives, are resulting in the availability of plastics with improved characteristics. At the same time, consumers are increasingly demanding high-quality fresh produce, grown with little or no use of pesticides. As a result, growers are looking for more sophisticated green-
houses and plastic coverings which give improved control of the microclimate, pests and pathogens.

Much of the development work with films and structures has taken place in temperate and Mediterranean countries. Light and temperature are often limiting in temperate regions and, in contrast to the tropics, production is not possible throughout the year without protection. Although the problems facing growers in the humid tropics are different, plastic structures could help to overcome some climatic limitations in these regions also, e.g. torrential rain during the rainy season.

**PLASTIC FILMS**

Plastic film can be used to aid crop production in many ways. Polyethylene and other materials can be formulated to control or utilize more effectively the heat and light energy from the sun, and also heat energy radiated from the soil. These forms of energy are part of the electromagnetic spectrum and differ only in their wavelength. By using different polymers and additives, it is possible for films to transmit, absorb or reflect different wavelengths preferentially. It is possible, therefore, to create a wide variety of microclimates by using different types of film, either as covers over crops or as a mulch on the soil surface.

The main wavelength ranges are shown in Table 1.

<table>
<thead>
<tr>
<th>Energy</th>
<th>Wavelength</th>
<th>nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultraviolet (UVA) Light</td>
<td>300-400</td>
<td></td>
</tr>
<tr>
<td>Visible Light</td>
<td>400-700</td>
<td></td>
</tr>
<tr>
<td>Near infrared (IR)</td>
<td>700-2,100</td>
<td></td>
</tr>
<tr>
<td>Mid infrared (IR)</td>
<td>2,100-30,000</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Main wavelength ranges of plastic films

Photosynthetically, active radiation is close to the visible range (400-700 nm), but different plants respond differently to light of different wavelengths, especially red or blue light.

Plastic film can be used in crop production as covers for greenhouses and low tunnels, or as direct covers. These vary greatly in size and cost, but one important factor is common to all. The film entirely covers the crop and so has an influence on the total plant environment. The ideal properties of the films used for these very different growing systems in temperate regions is essentially the same (Gilby 1990a). These are:

1. A film lifespan suitable for the end use. This will vary from a few months for direct covers to three or four years for greenhouses.
2. Suitable visible light energy transmissions with a wavelength range from 400 nm to 700 nm.
3. Good transmission of solar heat energy (near infrared wavelength range 700 to 2,100 nm).
4. Low transmission of black body radiated heat energy (wavelength in mid infrared range from 7,000 to 14,000 nm).

Given these basic characteristics, many different types of film are used because of the wide range of crops produced and the diverse climates where they are grown.

In both northern and southern Europe, polyethylene (usually 150-180 micron) is the main plastic used for greenhouses. Other materials, such as PVC, EVA and glass-reinforced polyester sheeting, are also used in Europe, but in relatively small amounts. In Japan, plasticized polyvinyl chloride (PVC) is the most commonly used film. This film has good heat retention, but is not much used in Europe because it is difficult to process into large sheets, is expensive and attracts dust particles.

**Polyethylene**

In Europe, low density polyethylene (LDPE) has a number of advantages, including cheapness, availability in large sheets, high light transmission...
and light weight, but it has also important disadvantages. It is short-lived (2-3 years at most) and has poor heat retention, allowing some 60-80% of radiant heat (mid infrared) to pass through.

As one of the main requirements of plastic films in Europe is low transmission of radiant heat, this is a major defect, as any heat generated under the film by the action of sunlight on plants or soil will be rapidly lost through the film at night. The heat-retention properties of polyethylene can be greatly improved by the incorporation of a suitable filler to produce infrared polyethylene (IR PE). A large number of substances have strong absorption bands in the mid to far infrared, but commercial, physical and toxicological limitations reduce the choice to a few inorganic fillers (Hancock 1988).

Of a number of materials tested, including calcium carbonate, talc and china clay, calcined clay was the most effective, giving the strongest absorption in the mid to far infrared. This thermal barrier film retained over 70% energy and gave the greatest heat retention. It also increased the yields of a number of crops and extended the growing period (Hancock 1988).

Although films with inorganic fillers retain a greater proportion of radiated heat at night, they have the disadvantage of reducing visible light transmission and heat energy gain during the day. This has tended to limit their use in areas where winter light levels are low (Gilby 1990a).

**Ethylene Vinyl Acetate**

Films based on ethylene vinyl acetate (EVA) copolymers contain 14-18% vinyl acetate, and have been widely used as an alternative to polyethylene, both unmodified and with the addition of heat absorbing fillers. EVA copolymers are transparent to visible light, and allow all those wavelengths essential for photosynthesis to pass through (Desriac 1988). In addition, they have good heat retaining characteristics to an extent which depends on the vinyl acetate content.

In general, increasing levels of vinyl acetate result in the changes seen in Table 2.

<table>
<thead>
<tr>
<th>An increase in:</th>
<th>A reduction in:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• tensile strength</td>
<td>• rigidity</td>
</tr>
<tr>
<td>• elongation at break</td>
<td>• hardness</td>
</tr>
<tr>
<td>• impact strength</td>
<td>• yield strength</td>
</tr>
<tr>
<td>• low-temperature impact strength</td>
<td>• fusion temperature and softening point VSP (0 C)</td>
</tr>
<tr>
<td>• flexibility, elasticity</td>
<td>• resistance to extensibility</td>
</tr>
<tr>
<td>• transparency</td>
<td>• permeability</td>
</tr>
<tr>
<td>• resistance to splitting</td>
<td></td>
</tr>
<tr>
<td>• weldability</td>
<td></td>
</tr>
<tr>
<td>• adhesion properties</td>
<td></td>
</tr>
<tr>
<td>• compatibility with mineral fillers</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Changes in plastic from increasing levels of vinyl acetate

EVA copolymers have good light transmission and thermal characteristics, but some have the defects of being liable to excessive stretching and tackiness. Because these properties are influenced by the vinyl acetate content, the final use for the film will determine the type of EVA copolymer required. Films for greenhouse covers should have good resistance to stretching at high temperatures. Otherwise, on warm, windy days the film will stretch and flap on its supports and this may result in damage to the structure. For greenhouse covers, therefore, the vinyl acetate content should be less than 15% (Desriac 1988). A long life is also required for films used to cover greenhouses. Special formulations are available with UV stabilizers which give films a life of at least three years.

Long life and resistance to stretching are less important with films for low tunnels. However, for this type of structure, a film that does not stick to itself is essential, as ventilation is provided on hot days by folding back the film over the supporting hoops. Again, sticking is more likely to occur where high levels of vinyl acetate are used, but for low tunnels, an upper limit of 18% is possible in practice in a specially formulated non-stick film.

No one single layer film possess all the
properties required for covering greenhouses. Each manufactured film is a compromise between properties such as longevity/cheapness, high light transmission/good retention of heat, and mechanical strength/resistance to stretching.

**Coextrusion Technology**

The shortcomings of single layer films are now being overcome as a result of the extension of coextrusion technology into wide film manufacture, supported by the continuing development of special purpose polymers and additives (Gilby 1988).

Co-extrusion enables the desired properties of different polymers to be combined, and can be used to compensate for their negative effects. In this way, a final polymer can be made with all the desired properties at an acceptable price for some markets (Daponte 1987). For example, the co-extrusion of EVA as a middle layer with polyethylene as the two outside layers can overcome the weaknesses of both materials. Thus coextruded films can be made with good light transmission plus heat retention properties, and with little deformation under wind or snow loadings (Table 3).

Coextrusion is also helping to improve the technology involved in the UV stability of films. For example, by supplying the absorber to the outside layer only, less UV is removed from the spectrum, which is beneficial for photosynthesis of aubergines, strawberries and other crops. Coextrusion also facilitates the economic addition of an appropriate anti-fogging additive into the layer placed inside the greenhouse. Gilby (1990a) reports that this enables high light levels to be maintained during periods when condensation on untreated films reduces light levels by 15%.

Coextruded films are more expensive than monolayer films, but there is evidence that in those European countries with a well developed plasticulture industry, such as Spain and Italy, the demand for more sophisticated plastics is increas-

<table>
<thead>
<tr>
<th>Film type</th>
<th>Visible light transmission (%)</th>
<th>Mid-infra red transmission (%)</th>
<th>Creep (%-CEMP method)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional LDPE</td>
<td>88-90</td>
<td>&gt;65</td>
<td>7</td>
</tr>
<tr>
<td>IR PE (Thermic film)</td>
<td>81-85</td>
<td>&lt;20</td>
<td>7</td>
</tr>
<tr>
<td>EVA copolymer</td>
<td>89-91</td>
<td>&lt;20</td>
<td>&gt;30</td>
</tr>
<tr>
<td>Modern coextrusion</td>
<td>86-88</td>
<td>&lt;20</td>
<td>14</td>
</tr>
</tbody>
</table>

Source: Gilby 1990a

Double Cladding

With energy costs rising again, there is renewed interest in temperate regions in the use of double-cladding with polyethylene for energy conservation. Heat loss can be reduced by about 30% by separating two coverings by air pressure maintained by a small continuously running fan. In temperate countries such as Britain and Ireland, this type of house is a cheaper alternative to a glasshouse for long-season production with heat of high-value crops such as tomato and cucumber. A simple double clad house with thermal screen and side wall ventilation has been designed in Germany to provide favorable temperatures in summer and winter without heating (von Zabeltitz 1989).

Double cladding is frequently used on multispan houses, but large, fully automated, single span houses are also being erected for specialized purposes. With laminated timber supports, these can have a span of 25 m, so that a house 100 m long can cover a quarter of a hectare and, with heating,
ventilation, lighting and irrigation equipment, may cost over US$400,000.

Two different films are sometimes used in more conventional houses. For example, in Spain an internal EVA copolymer film on the greenhouse roof is being increasingly used below polyethylene film to reduce heat loss at night (de Pedro 1989). Rigid plastic, such as twin-wall structured sheets, e.g. polycarbonate or acrylic, or single layer sheets such as glass reinforced plastic or fibre glass, can also be used (Noble 1988). Some of these materials give considerable energy savings compared with glass (Table 4). However, none combine energy saving with high light transmission. Consequently, these new energy efficient, cladding materials, which promised much to growers in northwest Europe in the 1970s, have not been adopted to any extent. The decrease in light and hence yield has exceeded the value of the fuel saved.

**Table 4. Light transmission and energy requirements of greenhouses covered with different materials, relative to a glasshouse**

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Relative Light Transmission (%)</th>
<th>Energy Saving (Relative to Glass) (%)</th>
<th>Cost (£/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single glass</td>
<td>100</td>
<td>0</td>
<td>33</td>
</tr>
<tr>
<td>Double glass</td>
<td>85-80</td>
<td>34</td>
<td>47</td>
</tr>
<tr>
<td>Double polycarbonate</td>
<td>62-83</td>
<td>38</td>
<td>51</td>
</tr>
<tr>
<td>Double acrylic</td>
<td>88</td>
<td>42</td>
<td>54</td>
</tr>
<tr>
<td>Varilgaze</td>
<td>93</td>
<td>*</td>
<td>52</td>
</tr>
<tr>
<td>Glass + Melinex, 75 microns (μ)</td>
<td>88</td>
<td>37</td>
<td>34</td>
</tr>
<tr>
<td>Tedlar + Melinex, 75 microns</td>
<td>94</td>
<td>*</td>
<td>56</td>
</tr>
<tr>
<td>Double polythene, 180 microns</td>
<td>75</td>
<td>25-35</td>
<td>13</td>
</tr>
</tbody>
</table>

* Depending on air gap
Source: R. Noble1988

any region will have an influence on greenhouse design and construction, as well as on the covering material used.

**Design and Construction Standards**

In the last 30 years, much research on design and construction standards has been conducted at centers in Europe such as AFRC Engineering (Silsoe, United Kingdom), and the University of Hannover in Germany. This work has done much to improve greenhouse construction, particularly with regard to light transmission and robustness. Baille (1989) summarizes available information on the shape and orientation of glasshouses for Mediterranean countries in the northern hemisphere as follows:

- East-west orientation gives higher light transmission in winter than north-south orientation, and lower light transmission in summer;
- Single span structures provide better light levels than multispan structures;

**GREENHOUSE STRUCTURES**

Plastic covered structures were developed initially as a cheap substitute for glasshouses, often in temperate areas of the world where protection from cold was essential and poor light often a limiting factor. Rapid expansion and modification took place in Mediterranean areas, where simple greenhouses helped greatly in the winter production of vegetables. Subsequently, plastic greenhouses have been developed for tropical desert conditions and, more recently, for humid tropical regions.

Production under plastic is more expensive than in the open, but is often economically viable because it enables limitations of the climate to be overcome. The constraint limiting outdoor production may be low winter or nocturnal temperatures, excessive heat, wind, hail, snow, rain, or some other climatic factor. Obviously, the prevailing climate in
Asymmetric shapes with the lower slope roof oriented towards the south give better transmission of diffuse light; An arched roof shape with high radius curvature gives improved light transmission.

Wind pressure loads on plastic-covered structures are complex. Under windy conditions, plastic cladding is able to transfer load from where it is sucked clear of the frame to where it is still in contact with it (Richardson 1988).

Apart from stability, there is now greater awareness that the method of construction also has a major influence on ventilation, humidity control, light transmission, heating, cooling and the collection of rainwater for irrigation. Von Zabeltitz (1988) emphasizes the importance of designing greenhouses to suit prevailing climatic conditions, and has defined design criteria of plastic greenhouses as follows:

- Avoidance of film destruction by making sure the covering does not flap against the structure
- Simple methods of changing the covering film which require little work
- Insulation of those parts of the structure which are in contact with the film and which are heated up by solar radiation
- Effective ventilation
- Tightness of structure to avoid heat loss on cold nights
- Minimizing condensation problems by correct choice of roof slope and covering material
- Vertical sidewalls to facilitate machinery use and the production of tall crops.

Not all these criteria apply to tropical areas, where different climatic conditions require a different approach to greenhouse design.

Von Zabeltitz (1988) lists the main needs of plastic-covered greenhouses in the humid tropics as:

- Protection from rain, with a covering which should be as cheap as possible
- Very good ventilation efficiency
- Film life of at least one year
- Rainwater collection during the rainy season to provide water during dry periods.

Tropical greenhouses have a major cost advantage over those in other regions in one important respect. Seasonal and nocturnal temperatures are such that ventilators need never be closed, so that complicated movable ventilators and fans are unnecessary. Nevertheless, the ratio of ventilation opening to area covered should be as high as possible.

Von Zabeltitz (1988) describes a simple greenhouse built with round timber and designed for humid tropical conditions in Kenya (Fig. 1). Good ventilation is provided by openings in the sidewalls and gables, and at the ridge. The necessary top ventilation is provided by arranging for the roof sections on each side of the ridge line to meet at different levels. The film from the sidewalls extends over the ground so that the rainwater from the roof can be collected in a storage reservoir.

A multispan structure in Kenya, also built from timber, (von Zabeltitz 1988) is 6.4 m high at the ridge to provide efficient ventilation (Fig. 2). Large ventilation openings are provided at gutter and ridge, and a penthouse is added to the sidewall on the windward side to provide protection from rain.

Rault (1990) also emphasizes the importance of good ventilation for greenhouses in the tropics, because of the significant temperature rise under polyethylene during the day. His research showed that investment in movable sidewall or roof ventilators could be justified in Martinique, where ventilators must always be open. He reports on the successful use in the French West Indies, of a ‘chimney effect’ tunnel, which has performed well in comparison with other structures (Fig. 3).

This tunnel has a plastic cover/soil surface ratio of 128%, and a ventilation opening/covered surface of 35%. Side ventilation is provided by stopping the plastic cover 1 m from the soil surface at each side. In addition, there is a continuous opening of 0.35 m on each side of the ridge. A rigid transparent PVC gutter is carried under the opening to collect rain. This static ventilation system gives excellent air movement and an increase of only 0.4°C in average diurnal temperature, compared with outside conditions.

This ‘tropical’ tunnel has the advantage of simplicity, as other kinds of structure can be easily adapted to conform with the basic design. It is also robust, as the internal gutter is well sheltered from wind (Rault 1990).

**Ventilation**

Although movable ventilators may be unnecessary in the humid tropics, they are an essential feature of plastic structures in other areas. The type of ventilation system used depends, not only on the climatic zone, but also on the crops grown, the length of the greenhouse, and the amount of available capital. Ventilation may be provided simply by separating overlapping film sheets to create openings on each side of the house or on the whole round
arched surface. More elaborate structures with side and top ventilation are becoming popular in many areas (von Zabeltitz 1988). Research at the Lee Valley Experimental Horticulture Station in United Kingdom showed that ventilation along both sides of tunnels was advantageous for a number of vegetables and watercress, since it improved the control of temperature and humidity compared to tunnels ventilated by opening only the ends (Allen 1981).

Fans can be used to supply high air exchange rates, and so maintain inside temperatures at levels only slightly higher (1-2°C) than those outside (Baille 1989). However, fan ventilators need electric energy, and their efficiency is low in long houses.
Fan and pad cooling systems are useful in hot desert situations and enable a reduction in temperature of up to 12°C where the relative humidity outside is around 15%.

**Multispan Houses**

Where a single crop is to be grown in an area of 1000 m² or more, multispan greenhouses are normally used instead of separate tunnels. The inner spans of multispan houses usually range in width from 4.4 to 8 m. Multispan houses are expensive, but have many advantages over single tunnels. Land and labor can be used more efficiently, environmental conditions are better as the greenhouse volume is larger, and machinery, heating and fan ventilation can operate more effectively.

**LOW TUNNELS, DIRECT COVERS AND MULCHES**

**Low Tunnels**

About 50,000 ha of low tunnels are used in southern Europe for the production of salads, strawberries and many other crops. In Spain, low tunnels are used inside greenhouses for the protection of crops such as muskmelon and watermelon planted in January.

There has been a progressive reduction in film thickness (from 75 microns to 25 microns) and hence in the quantities used per hectare. There is also a tendency for polyethylene to be replaced by other films with better thermal properties, such as EVA. Where very high light transmission coupled with excellent heat retention is required, e.g. for early strawberry, plasticized PVC is often the preferred material.

A coextruded film has been produced recently which has given good agronomic performance when used for strawberry (Gilby 1990a). Although the coextruded film is more expensive, it has a number of advantages over PVC, including greater mechanical strength, lower density, and less likelihood that it will stiffen and become dirty during use. It handles easily, and can be readily used for another crop or a second season.

Despite these developments, the use of low tunnels is expected to decline in popularity as a result of the ease of mechanization of direct covers.

**Direct Covers**

The use of plastic sheets laid directly over horticultural field crops and supported by the crop as it grows, is increasing rapidly in many European countries. These covers are used mainly for the early production of field crops such as potato, carrot and salad vegetables. In addition, with the growing demand for pesticide-free produce, direct covers are also being used to protect crops from insect pests such as cabbage fly.

The uptake of direct covers is occurring more strongly in northwest Europe, where farm units tend to be larger, than in the Mediterranean area. Further expansion is likely in view of its low cost.
compared with other protection techniques, and the ease with which laying the covers can be mechanized.

The most commonly used film is polyethylene perforated with 500-1,000 holes/m² and weighing 30-50 g/m². Agrotextiles weighing 8-20 g/m², either nonwoven polypropylene or polypropylene and polyamide mesh that is UV stabilized, are also used (Christensen 1986). All these materials are marketed in widths varying from 0.75-12.8 m. Wide covers can be used more efficiently, giving greater uniformity of production, and now represent about 80% of the market. Although non-woven materials are much more expensive, they do not burn or chaff crops as readily and allow some penetration of water, while maximum temperatures beneath the plastic are lower.

Plastic covers raise soil and air temperatures compared to those in the open field, and protect crops from rain, hail, snow and wind. In addition to promoting earlier crops and providing protection against insect pests, they have other advantages including improvements in seed bed conditions, seed germination, higher yields and improved crop quality (Antill 1988). Initially, plastic covers were used mainly by small-scale growers, but with improved mechanical methods of laying and lifting the film, their use is extending to large open fields.

Mulches

Developments in plastic technology have led to the availability of a greater variety of mulching materials (Gilby 1990a). As with plastics for greenhouses and direct covers, it is now possible to formulate plastic film to control or utilize more effectively the heat and light energy from the sun and also the heat energy radiated from the soil. In addition, plastic mulches have the advantage, in many situations, of retaining moisture in the soil.

In contrast to films used as coverings for greenhouses, plastic mulches mainly influence soil conditions and have a relatively small effect on the atmospheric environment surrounding the crop. However, in the design of films for mulching, there are additional requirements that do not arise with films for cladding. These are:

- Visible light should be reflected back towards the crop by the film and so aid photosynthesis.
- The surface temperature of the mulch should not rise so high as to cause crop injury.

Among the range of monolayer mulching films currently available are clear, black, white, black/white and thermic brown and blue films. The properties of these films in comparison with uncovered soil is shown in Table 5 (Gilby 1990b).

Clear polyethylene film (15-50 microns) is used in Europe to warm up soil in early spring and enhance seed germination. This practice is most popular in Mediterranean countries, but is gaining popularity in northwest Europe now that the process of laying plastic has been completely mechanized. Further improvements are expected in combining mechanical laying of plastic mulch with other operations such as seeding, planting and the placing or irrigation pipes (Castillo Prados 1987).

While clear film is used to increase soil temperatures in temperate and Mediterranean countries, black/white film with the white side uppermost may be useful in tropical countries to mitigate the effects of high soil temperatures. At the same time, weed growth would be suppressed and the exposed surface of the white film would remain relatively cool.

Experiments are in progress in Britain with blue ‘thermic’ mulching film. This reflects photosynthetically active light at the blue end of the spectrum which is believed to be beneficial for strawberry (Gilby 1990b).

Coextruded combinations of black with white or silver are now available. These have similar energy transmission properties to black films, except that the soil temperature tends to be even lower (Gilby 1990a). The reflection of both light and heat results in the film remaining cool, but the plants benefit from additional reflected light. In temperate regions, this film can be used to delay the ripening of late-season strawberry varieties to further extend the season.

In addition, coextrusion makes possible the design of multilayer films in which different polymers, pigments or different additives with different wavelength absorption and transmission properties can be incorporated into the various layers (Gilby 1990a). It is possible in this way to be selective about the wavelengths that are transmitted, absorbed or reflected by the film. The ability to design a mulch to reflect light of any color is of potential importance, in view of the varying response of crops to different wavelengths.

**Mushroom Production**

**In Plastic Tunnels**

A new method of producing mushroom (**Agaricus bisporus**) in plastic tunnels has revolu-
tionized the Irish mushroom industry. In this growing system, specialist composters supply small-scale producers with plastic bags holding 25 kg of spawned compost. These bags are cropped throughout the year in structures consisting of an inner steel framework covered by a white plastic sheet (to provide good light reflection within the house), 125-230 mm of fibreglass insulation with an outer sheet of heavy gauge (200 microns) black plastic. The houses are heated by a small domestic type hot water boiler, feeding either a heat exchanger in the ventilation system or pipework along the wall of the house (Staunton 1988). As the quality of mushrooms produced in the plastic bag and tunnel system is high, this has given Irish produce a competitive edge in export markets. In addition, disease prevention and control is facilitated by having a single cropping layer only in the tunnel.

The optimum growing temperature for Agaricus bisporus is 15-18°C. In Ireland, production of good quality mushrooms throughout the year, even in summer with relatively high outside temperatures, can be achieved by the use of a heat pump for cooling and dehumidification. Good results have also been achieved experimentally by cooling tunnels with ground water at 9-10°C extracted from a borehole. The water is pumped by means of a submersible pump in the well via pipework into heat exchangers in each mushroom house (Erwin 1990).

Since the late 1970s, this new production method in plastic tunnels has completely replaced the traditional system based on wooden trays in expensive concrete houses.

CONCLUSION

In the last three decades, substantial progress has been made in the development of plastics for improving yields and quality and for extending cropping periods. Although the problems facing producers in the tropics are different from those in the temperate zone, many of the principles of protected cropping developed in temperate and subtropical regions are also relevant to the tropics. However, it is important that greenhouses, direct covers and mulches should be designed for specific regions to suit prevailing climatic conditions.

REFERENCES


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Table 5. Properties of monolayer plastic mulches compared with bare soil

<table>
<thead>
<tr>
<th>Film type</th>
<th>Herbicidal</th>
<th>Soil heating or cooling(-)</th>
<th>Heat retention</th>
<th>Film temp</th>
<th>Light reflection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear</td>
<td>- -</td>
<td>+ +</td>
<td>+</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Black</td>
<td>+ + +</td>
<td>+</td>
<td>+ +</td>
<td>+ + +</td>
<td>- -</td>
</tr>
<tr>
<td>White</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+ +</td>
</tr>
<tr>
<td>Black/white</td>
<td>+ + +</td>
<td>- -</td>
<td>+ + +</td>
<td>+</td>
<td>+ +</td>
</tr>
<tr>
<td>Thermic brown</td>
<td>+ + +</td>
<td>+</td>
<td>+ +</td>
<td>0</td>
<td>- -</td>
</tr>
<tr>
<td>Thermic blue</td>
<td>+ + +</td>
<td>+</td>
<td>+ +</td>
<td>+ +</td>
<td>+(blue)</td>
</tr>
</tbody>
</table>

+ = greater, 0 = similar, - = less,
DISCUSSION

Q. What kind of plastic sheeting would be suitable to cover plastic houses in Malaysia? Are there any relatively cheap materials?

A. A polyethylene with a good UV light inhibitor would be ideal, although it would not last long in a typhoon or storm. Polyethylene is the cheapest agricultural plastic, and its only defect is that it lets the heat out quickly, which would not matter in Malaysia. I find it surprising that PVC is used so widely, but often what is used is based on historic factors. Where a material is used in an area initially, other growers may follow suit. Light is not a limiting factor in Malaysia, and it may be possible to develop plastic which stops light coming in during the day and lets heat escape at night.