Grower Summary

CP 147

Optical coatings to increase the yield and quality of protected salads, fruit and ornamental crops

Final 2015

Disclaimer

The results and conclusions in this report may be based on an investigation conducted over one year. Therefore, care must be taken with the interpretation of the results.

Use of pesticides

Only officially approved pesticides may be used in the UK. Approvals are normally granted only in relation to individual products and for specified uses. It is an offence to use non-approved products or to use approved products in a manner that does not comply with the statutory conditions of use, except where the crop or situation is the subject of an off-label extension of use.

Before using all pesticides check the approval status and conditions of use.

Read the label before use: use pesticides safely.

Further information

If you would like a copy of the full report, please email the AHDB Horticulture office (hort.info.@ahdb.org.uk), quoting your AHDB Horticulture number, alternatively contact AHDB Horticulture at the address below.

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GROWER SUMMARY

Headline

This report describes a review of the state of the art for optical coatings and spectral filters that might be used in greenhouse crop cultivation. Key technologies are now becoming mainstream, including diffuse glass. For other technologies, such as near infra-red (NIR) filters more effective materials are required. UV active or blocking materials have great potential but for many applications further research on whole crop responses to UV is needed.

Background

Optical coatings or spectral filters for both glass and polyethylene greenhouses have been seen for many years as a key technology which may bring about increased yield, changes to pest and disease behaviour and improvements to crop quality. The technology is environmentally passive and may have significant potential to drive improved economic returns, for example EU funded studies suggest a payback for combined diffuse and anti reflective (AR) glass of c. 4 years based on a demonstrated c.10% yield gain for rose crops (Montero *et al*., 2012). The uptake of the technology has though been slower than many anticipated and this review examines the state of the art, where applications are becoming mainstream and some of the key challenges to further develop these technologies. The review considered both the material technology *per se* and its state of the art and also the biological know how which is required to establish confidence in the technology

Summary

Light is the primary driver of crop growth and yield. Optical coatings or spectral filters offer a passive means to drive productivity and potentially reduce pest and disease incidence across a wide range of protected crops. This review examined the key technology underpinning optical coatings and also the underpinning biology of many of the responses. It also sought to understand where further materials innovation and biological knowledge is needed to optimise and underpin the approach.

High Light Transmission Materials

Over the last ten years there have been a number of key innovations to increase the total light transmission of glazing materials, notably glass. These are of interest as a 1% increase in light transmission equates to a 0.7 to 1% increase in the yield of multiple, especially high wire, greenhouse crops. A key innovation has been the wide scale availability of anti-reflective (AR) glass. These are coated on one or both sides with nano scale deposits which reduce the reflection of light from the glass surface. Light which would have been reflected is transmitted through the pane. They exploit an optical "interference" effect and coatings include compounds such as MgF_2. Data from Wageningen (WUR) suggests they can increase light transmission by up to 5% and therefore worthy of investment assessment given the long term and passive potential impacts on yields. However, growers need to understand the actual performance of the material prior to investment decisions and also the materials long term durability. Furthermore, in terms of long term decisions it should be noted that AR glass can only be cleaned with water based systems, the use of acids and chemicals may damage the coating.

Anti-reflective paints are also now entering the market. The manufacturers claim a 2% increase in light transmission via the use of these materials but we are aware of no independent data which confirms this performance. If the claims are proven, AR paints could be of significant interest and worthy of monitoring going forward.

Low-iron glass has been shown by tests at WUR to have a higher total light transmission by 1 to 2% compared to conventional float glass. These materials are now widely available on the market and the cost benefit can be estimated from the likely long term yield gain. They can be cleaned using conventional systems.

Diffuse Light

The use of light diffusing materials is now gaining wide scale adaptation across the global horticulture industry and with a wide range of cladding systems including glass, polyethylene and ETFE media. Within the soft fruit industry, the largest user of polyethylene materials in the UK, light diffusing films are now standard and have been used for the last 15 years. Light diffusing films are seen by the industry as helping to improve yield and provide a more uniform light environment across the greenhouse. This uniform environment is considered to help improve product consistency and quality. The use of diffuse glass for high wire crops is now being widely adopted in new build glasshouses within Europe. This is a consequence of 10 years of intensive studies on high wire and pot plant crop responses to diffuse light, mainly carried out by Wageningen in the Netherlands. They have shown that light diffusion, which creates a "haze" level of up 75%, can increase yields of tomato and cucumber crops by between 5 to 7%. This is an entirely passive means to increase yield. Substantial benefits have also been seen on flowering and foliage pot plants, typically manifested by increased leaf area and overall plant quality.

Recent studies at Wageningen (WUR) have shown that diffuse glass materials work by creating a more even light environment in both the horizontal and vertical plane. In the horizontal plane the irradiance is more uniform across a leaf surface. This enables a higher rate of leaf photosynthesis since there are fewer high intensity spots of light on the leaf surface which may have been saturated in terms of their photosynthetic response (the photosynthetic response to light intensity saturates at relatively low light levels). Diffusing materials also create a more uniform vertical light distribution, driving the light deeper into the canopy. The middle layers of the canopy can then contribute a higher level of photosynthetic output. WUR also showed that the temperature profile of the canopy is more uniform and that the leaves in the middle canopy layers adapt to the diffuse light source, with thicker cells and therefore a higher potential photosynthetic capacity.

The technology to create a diffuse light environment is now well established. In polyethylene materials the approach is to use fine particulates within the material to scatter light. For glass the surface properties are typically altered, either by “roughening” it or creating specific and usually prismatic or groove shapes to disperse light. The group at WUR have developed a new way to characterise the diffusing capability of different materials, called the F Scatter. This measures varies from 0 to 1, and materials with an F scatter close to one scatter light very widely, low scores indicate that they only scatter light over a narrow range of angles. It is not clear how F scatter affects crop performance but intuitively (it has not been proven experimentally) a high F Scatter should be advantageous. The work at WUR has shown existing materials have very significantly different F-scatter performances. It is critical therefore that before going ahead with large scale capital spends, a proposed glazing materials F-scatter performance should be obtained and understood.

A number of diffusive paints are also coming onto the market; these show a high level of diffusion in dry conditions with a reduced performance when wet. There are few independent studies of their performance, in particular whether they compare well to diffusive glass, whether they can be cleaned and how they affect total light transmission. Ongoing work at the AHDB pot and bedding plant centre at Bagington is currently examining some of these questions and the results will be available by the end of 2016.

In Holland, diffusing glass is now being deployed on a large scale on new builds (T. Dueck, pers comm). It is clear that material advances can still improve the performance of these materials, for example we need to understand how to improve the proportion of light scattered and also how to manipulate the scattering cone (F-scatter). We also need to understand the long term durability of the materials. Given that the glass materials have their surface properties adjusted we need to understand how they can be cleaned and whether they are sensitive to the long term build-up of dirt and other deposits. Further work is required to test diffuse material performance on a wider crop range to underpin confidence in the technology and to establish how changes in the scattering cone (direction of scattering) can be exploited to further increase the response of crops.

In terms of investment decisions for glass glazing systems, growers are clearly faced with a multitude of opportunities. Any investment decision must be made solely by the grower, using costs provided by suppliers. However, as a guide Montero *et al.,* (2012) provided some indicative costs (provided to them by Hogla, NL) of different diffuse and AR coated glass solutions, shown below;

Glass type	**Investment (euro/m^2)**
Horticultural glass, not tempered	3.5
Horticultural glass, tempered	6.5 to 7
Diffuse and tempered glass	11 to 12
Diffuse, tempered and AR coated glass	16 to 18

They concluded the payback of diffuse / AR glass on a cut rose crop with a yield gain of 10% would be 4 years compared to standard horticultural tempered glass. We are aware of no other published pay back analyses on other crops, but these are indicative of decent returns, assuming the materials keep performing over extended periods.

Ultra violet modifications

Recent work suggests that multiple crops have a very high sensitivity to the spectral quality and also quantity of ultra violet light. Manufacturers are now marketing both polyethylene transmitting and also absorbing (opaque) materials. Research is now showing the magnitude of some of the responses. Research at Reading in the UK used a series of UV waveband cut off materials to assess the impacts on lettuce. This showed that the biomass increased as more wavebands of UV light were cut out, up to 400nm, i.e. heaviest yields occurred when all UV was removed. However, removing UV also dramatically reduced the quantity of phenolic and anthocyanins produced. UV is also known to impact the essential oil content and flavour of many crops. We also now know many responses are crop specific. The responses are biologically quite impactful and this is clearly an area where further work is required to understand where the commercial balance for a material for a grower lies. For some crops it is likely that no UV at all may be beneficial, for others a total transmission may be optimal and for others a balance of some UV may be preferred.

Ultra-violet light has a profound impact on many crop pests and diseases, as well as insect pollinators. Bees for example require UV in order to find flowers. Other insect pests require UV to target plants and also for mating. Therefore, systems which remove UV may have advantages in terms of reducing insect pests, as long as they do not impact pollination or other agronomic aspects. Likewise, for key diseases such as Botrytis UV stimulates sporulation, so removing the waveband may be a way to reduce disease pressure. UV is also needed to degrade pesticide so any application must be considered in light of potential impacts on food pesticide residues.

The impacts of UV are therefore quite considerable but highly complex. For a grower the use of these materials must be underpinned by further crop specific research which elucidates the financial benefits of UV opaque or transmission films. Elucidation of financial benefits (higher yield / less disease / better quality) where there are conflicting impacts of UV on the whole cropping systems is key.

Near infra-red reflection

It is often harder to control greenhouse heat levels in the summer, than to heat a glasshouse in the winter. The reflection of near infra radiation, that comprises 45% of the incoming solar radiation offers a passive means to reduce greenhouse temperatures and ventilation rate. This should enable a higher level of CO_2 control, lower water use and a more controlled crop in terms of temperature. Here we reviewed a number of NIR materials and work to date suggests they do not yet have a materials performance (reflection of NIR) which is sufficiently impactful to drive meaningful responses for growers. However, this area is worthy of monitoring, since if more effective materials can be developed they have considerable potential to impact yield and increase greenhouse temperature control.

Action Points

There are now a number of key optical coatings or spectral filters on or about the market.

- Anti-reflective glass (AR) is now widely available and test at WUR show it can increase light transmission by c. 5% of conventional glass types. These systems have Nano thick coatings which increase light transmission, but they can only be cleaned with water based systems. They should be considered in an investment appraisal since for multiple crops a 1% increase in light transmission equates to 0.7 to 1% increase in yield. New anti-reflective paints are coming onto the market but these need further independent evaluation. The manufacturers suggest they increase light transmission by c. 2%.
- Low iron glass is now well proven and increases light transmission by c. 1 to 2%.
- Diffuse glass installations are now increasingly common in the Netherlands and should be seriously considered within new build glass installations. Yield gains of between 5 to 7% are possible depending on the material and crop. Prior to installing diffuse glass growers should ensure that have full technical information on the diffusive performance of the

material and how far it throws light (F-scatter). We do not yet fully understand whether these materials are easy to clean. Diffusive paints are now available as an alternative to new glass in old installations. These show promise but there is little comprehensive independent knowledge underpinning their performance and crop responses. They should not be dismissed and are worthy of further testing.

- Paybacks for diffuse and AR glass look promising, with published reports of returns within 4 years for cut roses crops with a yield gain estimated at 10% per annum. These are based on rose crops only and growers need to assess the likely returns in view of the potential yield gains from the technology described in the literature. However, these published data suggest the technology has commercial potential.
- Crops are highly sensitive to ultra violet radiation, and considerable impacts can be achieved by either filtering of transmitting UV radiation. Some of the responses can be conflicting, for example on lettuce yield is maximised by removing UV but this impacts total phenolic content of the lettuce. Bees require UV for pollination, but removing UV reduces insect pest pressure. With these strong and often opposing impacts, UV active materials should be selected on the basis of understanding the likely economic impacts of +/- UV on the whole cropping systems. Further work is required to determine these impacts for multiple UK crops.
- Near infra-red materials have potential to reduce greenhouse ventilation rates, water use and to passively drive crop yield. Our review suggests that for many crops the existing materials on the market are unlikely to have a sufficiently meaningful biological impact to justify investment. However, material technology advances are likely to be rapid within this space and if new materials come onto the market they are worthy of further investigation.