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Using photoselective films to enhance the profitability of leafy salad production in Wales

Final Report

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GENERAL NOTES

Title: Using photoselective films to enhance the profitability of leafy salad production in Wales

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Date:	20/08/21		

About EIP-AGRI

The European Innovation Partnership for Agricultural productivity and Sustainability (EIP-AGRI) was launched by the European Commission in 2012. It aimed to foster a competitive and sustainable agriculture and forestry sector that "achieves more from less". It contributed to ensuring a steady supply of food, feed and biomaterials, and to the sustainable management of the essential natural resources on which farming and forestry depend, working in harmony with the environment.

EIP Wales

Menter a Busnes delivers the EIP Wales scheme on behalf of the Welsh Government and has received funding through the Welsh Government Rural Communities – Rural Development Programme 2014-2020, which is funded by the European Agricultural Fund for Rural Development and the Welsh Government.

For Welsh farm and forestry businesses to remain competitive, profitable and resilient, they will need to work on a continuous programme of improving both business and technical practices. The aim of EIP Wales was to solve common agricultural and forestry problems by bringing people from practical and scientific backgrounds together. It was an opportunity for farmers and foresters to put their ideas into practice by testing new technologies or techniques.

Photoselective films are relatively new products that can potentially improve the colour and nutritional value of crops and improve overall growth rates. The project sought to assess the benefits of spectra modifications to provide small scale growers with evidence relating to the use and best-practice approach of integrating this innovative technology into their businesses. Tunnels were skinned with three films. A range of cultivars were trialled, and crop performance was monitored to quantify the effects of production compared to conventional film.

EIP Operational group

The businesses represented in the operational group are:

Organisation	Name	Farm/Location	Role
	Phil & Deb Handley	Mostyn Kitchen Garden Mostyn Hall Holywell Flintshire CH8 9HN	Lead Farmers & principal contact
	Hootons Homegrown	Gwydryn Hir Brynsiencyn Anglesey LL61 6HQ	Grower
	Owen Lane	Owen Lane XL Horticulture Ltd 01404 823044 owen@xlhort.co.uk	Specialist on films for polytunnels

Other members of the project

Organisation	Name	Location	Role
RSK ADAS Ltd	Chris Creed	ADAS SCW ADAS Rosemaund Preston Wynne Herefordshire HR1 3PG	Horticultural Specialist
RSK ADAS Ltd	Ewan Gage	ADAS SCW ADAS Boxworth Battlegate Road Boxworth Cambridgeshire CB23 4NN	Senior Consultant, Horticulture
RSK ADAS Ltd	Aldwyn Clarke	ADAS SCW Canolafan Enterprise Park Llanafan Ceredigion SY23 4AY	Senior Scientist Field crop assessments
RSK ADAS Ltd	Lynn Tatnell	ADAS SCW ADAS Boxworth Battlegate Road Boxworth Cambridgeshire CB23 4NN	Principal Research Scientist- Weed Biology
RSK ADAS Ltd	Will John	ADAS ALM Henstaff Court Business Centre Groesfaen Cardiff CF72 8NG	Innovation Broker

EXECUTIVE SUMMARY

Innovations in plastic formulation have developed new materials for skinning polytunnels which offer potential benefits to growers. Manipulation of the light spectrum reaching a crop can include enrichment of certain portions of the spectrum such as blue-enrichment to modify plant development, or blocking UV light to reduce pest and disease development. Light direction can also be modified, increasing scatter with diffuse films to increase penetration of light into the lower canopy. Whilst many of these materials are reported to offer a broad range of benefits, there is a scarcity of practical experience and evidence as to their benefits, particularly given that responses are likely to be highly crop specific, and may change between seasons depending on the condition of the crop and local climates.

Leafy salad crops can be essential crops for mixed horticultural growers with high yields and short cropping cycles. However, the demand for high quality means these are best cultivated under protection, making them well placed to exploit innovations in growing approaches to improve quality and nutrition of crops, whilst potentially reducing the impact of pest and disease development.

This project was set up to test for the benefits of photoselective plastic use in leafy salad production in Wales. Targeted trials over three years at two commercial sites were used to illustrate the potential benefits of plastic use. Grower mentoring was provided over the course of the trial to support growers in adapting to protected cultivation.

These trials have demonstrated that different plastic treatments can impact both yield and produce quality, although these effects will vary between different cultivars. Higher value varieties to Lollo Bionda shows improved quality when grown under diffuse plastic due to improved head shape and density, whilst Lollo Rosso showed lower pigmentation of the leaves under UV-blocking plastic. Conventional green lettuce varieties such as Green Oak Leaf showed a more consistent response with plastic treatment, although material which block UV light may offer an opportunity to reduce pesticide applications.

These trials have demonstrated that photoselective plastic use can offer a range of benefits, but variation between variety and time of season should be taken into account when using them. Furthermore, given that polytunnels may be used for the production of a broad range of different crops, growers would be advised to consider the needs and responses of all likely crop types when choosing a polytunnel covering. This trial was undertaken using small 1x3m homemade tunnels, demonstrating that this approach can be used on both the large and micro scale depending on business needs.

Trial results showed that the light-modifying properties of plastics were stable, at least over a three year period, and whilst plastic use does have an environmental impact, other environmental benefits such as improved water/fertiliser use and reduced pesticide needs may compensate for this, coupled with industry recycling schemes to reduce the environmental impact of plastic use.

It can be concluded that protected cultivation can offer a range of benefits for growers in Wales, and this can be developed further through the use of photoselective plastics as a way of increasing produce value, and the productivity of their holdings as a whole.

CONTENTS

1 INTRODUCTION AND AIM

Leafy salad crops are a key horticultural product, which can be produced for a large portion of the year and with high yields, short cultivation cycles and low inputs can offer good returns for growers. While some varieties like iceberg are low value, high volume products, others such as coloured leaf or baby leaf salad can be sold at a premium – particularly when a range of varieties are grown together and sold as a mixed salad product. These are also relevant to the typical Welsh food supply chain whereby growers produce small volumes of a wide range of products which are sold directly to consumers, giving a short supply chain enabling produce to reach customers with a high quality and long shelf life.

However, to achieve target prices these must be grown to a high-quality standard which can be difficult to achieve under open field conditions. Therefore, the use of plastic polytunnel protection can offer a way of achieving target quality and yields, as well as extending the season by allowing early spring and late autumn plantings. These are low-cost alternatives to glass, as well as enabling growers to exploit new technologies.

Developments in plastic materials have enabled new types of polytunnel covering to be developed. These includes plastic which transmit only certain wavelengths of light such as creating a blue-enriched light spectrum or blocking UV frequencies from reaching the crop. The direction of light can also be modified, with diffuse plastic creating a high degree of scattering to improve the penetration of light further into the canopy to improve leaf quality in tight head crops like lettuce. These materials can be used to improve product quality, reduce the impact of pest/disease damage (and so reduce the need for chemical pesticide application) as well as potentially enhancing nutrition and flavour profiles. Whilst a considerable body of research has been developed using the approaches with LED lighting, photoselective plastic use enables growers a low-cost, low-carbon way of accessing these benefits.

The novelty of this approach, however, means that there is limited information available as to the benefits, risks and costs associated with using these materials in small-scale horticultural production. To address this knowledge gap, and to develop an evidence base for growers in Wales to utilise photoselective plastics in their production, trials were carried out at two grower sites in Wales across three seasons. Targeted assessments on crop performance, as well as ongoing mentoring for the host growers in the use of protected cultivation, were used to develop the evidence base for cultivation of leafy salad crops in Wales.

1.1 Introduction to the Field Sites

The farmers were keen to host the field trial sites and provided fields suitable for leafy salad production. Each farmer was actively involved in the project and contributed to steering meeting discussions and planning. Both sites sell produce directly to customers – Hootons Home Grown operates a farm shop selling a range of fruit and vegetable products grown on the farm, whilst Mostyn Kitchen Garden operates a community-focused growing business working with local volunteers, selling produce through a veg box scheme. Both sites grow a wide range of products, and the ability to grow a broad range of high-quality salad products would complement both site's offerings to their customers.

1.1.1 Site 1: Hootons Homegrown

Gwydryn Hir is a mixed farm situated on Anglesey (**Figure 1**). Annual rainfall for the area taken from Manner NPK is 1,001 mm per annum. The site location is 45 metres above sea level. Soil type from maps indicates that the fields are of the East Keswick Association, a deep well draining, fine loamy soil. Aspect is south-easterly, with a flat profile. At the start of the

trial the site had P and K index of 3 and 2+ respectively, with a soil pH of 6.5 and 4.8% organic matter with a high stone content.

Plate 1. Aerial imagery of Hootons Homegrown Farm.

1.1.2 Site 2 Mostyn Kitchen Garden

Mostyn Kitchen Garden is situated in a protected location near the North Wales coast (Figure **2**). Annual rainfall for the area taken from Manner NPK is 851 mm per annum. The project location was 80 metres above sea level. Soil type from soil maps indicates the area to be dominated by the Brickfield 2 Association, a seasonally wet deep loam. At the start of the trial the site had P and K index of 5 and 3 respectively, with a soil pH of 6.8 and 9.7% organic matter as a result of several years of compost addition. The site is within a historic walled kitchen garden, giving a sheltered aspect.

Plate 2. Aerial imagery of Mostyn Kitchen Garden

2 METHODOLOGY

2.1 Experimental design and implementation

The project set out to test a range of photoselective plastics at two sites in North Wales (Mostyn Kitchen Garden, Holywell, and Hootons Homegrown, Anglesey) over the course of three partial growing seasons representing spring (2022), summer (2021) and autumn (2020). Due to delays with the onset of the Covid-19 outbreak a single planting was achieved in 2020 and 2022, but multiple successive plantings were carried out in 2021 to test the impacts of plastic use over multiple seasons.

The different plastics used in the trial are summarised in **Table 1** below. These were chosen on the potential to achieve a variety of affects, alongside the inclusion of a clear plastic and a bare ground control to allow comparisons to be made with typical production methods. These plastics are commercially available and were obtained from an industry supplier to ensure that other growers can easily adopt this approach on their sites.

Each plastic was used to skin individual low polytunnels with 1x3m footprint and a 1m maximum height (**Figure 3A**). These were designed to be mobile to allow for soil cultivation and planting, along with liftable sides to provide ventilation and provide access for watering. Three tunnels skinned with each plastic (or equal area of bare ground) were used at each site in a randomised block design to provide statistically viable results (**Figure 4**). In 2021 and 2022 bare ground plots were covered with chicken wire mesh to prevent rabbit damage.

Three typical leafy salad cultivars were planted under each tunnel at typical commercial densities of 9 plants/m^2 in a replicated block pattern (**Figure 3B**). Lollo Rosso (curled red leaf), Lollo Bionda (curled yellow) and Green Oakleaf (open head) were chosen as representative commercial cultivars which showed a range of quality indicators that were likely to be impacted by the plastic treatment such as leaf pigmentation, canopy shape and shelf life.

Table 1. Photoselective plastics used in the trial. A clear plastic and a bare ground treatment was included for comparison as a control.

Plastic	Properties	Proposed Benefits
Clear	Conventional clear plastic.	Microclimate modification, high light transmission.
Diffuse	High light scattering.	Increased light penetration into closed canopy, improved older leaf condition.
Blue	Absorbs red and green portion of the spectrum, transmitting blue light.	Compact habit and enhanced colour development in pigmented leaves.
UV Blocking	High transmission light transmission but UV blocking.	Enhanced pest and disease control.
Untreated	Bare ground	N/A

Figure 1. A - Example tunnel at harvest. The tunnels were designed to have retractable sides to allow access for watering and harvest. **B** – Replicate block planting of Lollo Bionda, Green Oakleaf and Lollo Rosso taken from a bare ground control plot.

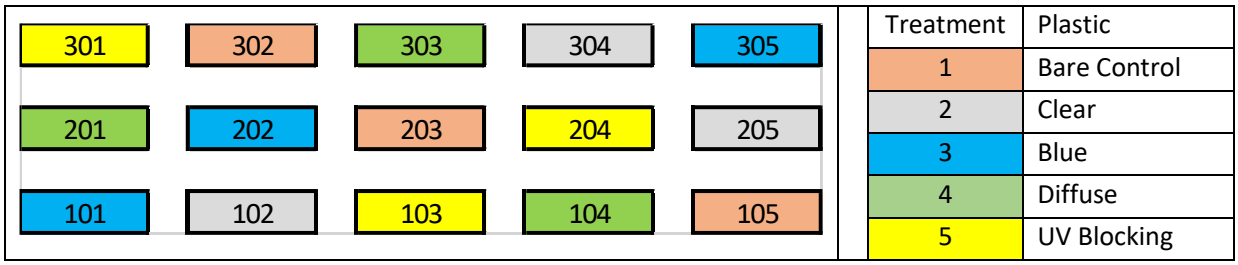

Figure 2. Trial area layout replicated at each site. Each tunnel had a 1x3m footprint.

Following germination and establishment in trays, plug plants of each cultivar were planted in September 2020, May, July and October 2021 and March 2022 with harvests taken c. 6 weeks after. Trials in the 2020 season were delayed as a result of the COVID-19 epidemic, but due to late autumn planting it was still possible to achieve five replicate trials over the course of the project.

Plots were examined for plant damage (e.g. slug/rabbit), pest/disease incidence and for the provision of agronomic consultancy and training to the host growers every two weeks until harvest. After harvest, individual plant height and marketable weight and diameter, leaf number and condition were assessed. Leaf colour and area were also recorded. After the final harvest in March 2022 samples collected from each site were placed in refrigerated storage for five days and marketable condition tracked on a daily basis to examine postharvest quality declines.

3 RESULTS AND DISCUSSION

3.1 Experimental year One (2019)

3.1.1 General Summary

Good harvests were achieved at both sites in all treatments, with marketable produce being harvested from all treatments. Representative photographs of plots at harvest are given in **Appendix 1**. Clear differences were present between the bare ground treatment and those under plastic, where smaller, more compact plants were produced most likely as a result of the cooler temperatures seen without plastic. Growth responses were relatively comparable between the clear, diffuse and UV-blocking plastics, although the blue plastic treatment produced slightly smaller and more compact plants compared to other treatments. Pigmentation differences were evident, particularly in the Lollo Rosso, with the strongest colour seen in the bare ground treatment, although this may have been linked with the reduced plant development seen in open field growth. The pigmentation of the Lollo Rosso was generally reduced in the plastic treatments, more significantly in the blue and UV blocking films. However, generally marketability of the crops was good across all treatments and the plastic use did not show any significant detriment to production.

There was no significant statistical difference across the samples at either site for any of the parameters measured, so measurements were pooled and treated as a single sample for analysis. Due to the small number of heads planted, and the impact of pest damage in the control plots, treatments were analysed on a per head basis rather than per m^2 to minimise the impact of this effect on the trial. It should be noted that this analysis was based on a limited number of assessments (three heads per plot, or 18 heads per treatment in total) and so carried significant margins of error, although this would be addressed with the multiple plantings planned for the 2021 and 2022 seasons.

3.1.2 Yield Response

Bare ground gave the lowest marketable head weight compared with the plastic treatments, although the blue plastic treatment also gave reduced overall yield (**Figure 3**). Greatest yields were seen in the Green Oak Leaf in the clear, UV blocking and diffuse plastics, with a marginally greater yield in the latter. Average yields for Lollo Rosso and Lollo Bionda were greatest under the UV blocking plastic, although these differences were not significant compared with the clear and diffuse plastics.

Head diameter for Green Oak Leaf was greatest in the UV blocking, diffuse and bare ground treatments (**Figure 4**), although there were no significant differences between these averages. The Green Oak Leaf variety showed significant differences under the clear and diffuse plastics compared with the other two varieties – this is likely to have been due to varietal differences, particularly head density which is much more open in the green oak leaf compared with the denser heads of the Lollo varieties. There were no significant differences in head diameter between the treatments, including the bare ground control. There were no significant differences in the marketability of crops between the treatments.

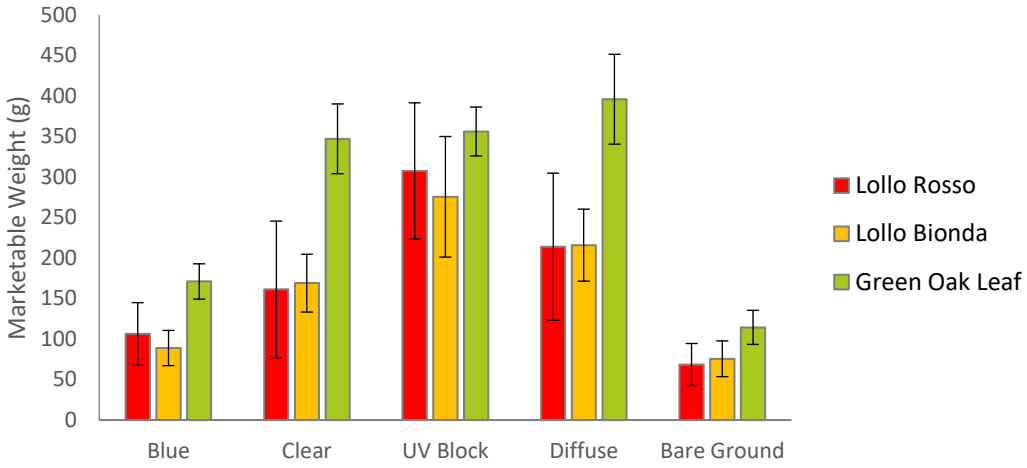

Figure 3. Average individual head weight at each harvest averaged across both sites.

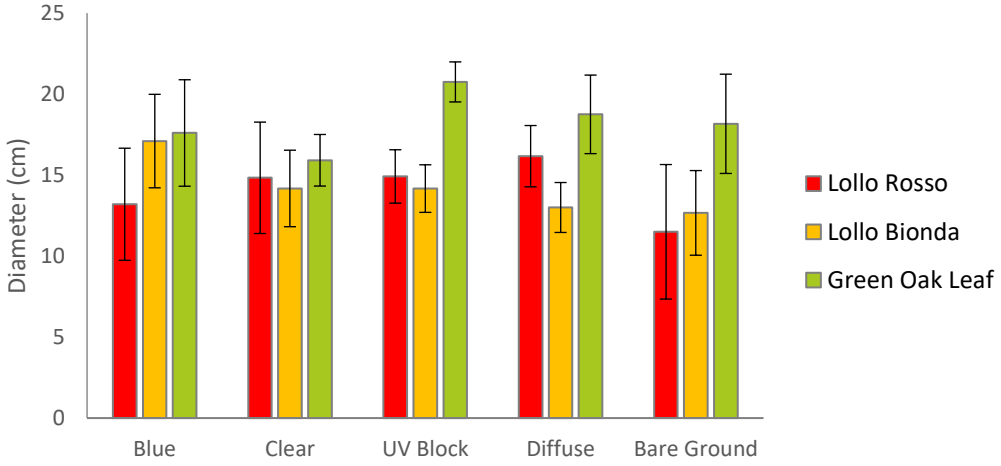

Figure 4. Average head diameter at harvest, averaged across both sites.

In terms of overall impact, plastic protection has a beneficial impact on yield. For the Green Oak Leaf, there were no significant differences between the clear, UV blocking and diffuse plastics, which may indicate that the benefits of protection may be linked primarily with the microclimate modification as opposed to light manipulation specifically. However, both Lollo

varieties gave a greater (although not statistically significant) marketable weight in the UV blocking and diffuse treatments compared with the clear plastic. The curled nature of these varieties leads to a more compact head compared with the Green Oak Leaf, so the increased scatter of the diffuse plastic may be beneficial in aiding light penetration into the head.

3.1.3 Leaf Colour

Leaf colour was measured through two routes: i) SPAD value, as a measure of the total leaf chlorophyll content (depth of green) and ii) Colour Index, a quantitative expression of leaf colour on a transition from red (positive) to green (negative). SPAD value was greatest in the blue and bare ground treatments, with only marginal differences in chlorophyll content seen between the clear, UV blocking and diffuse plastics (**Figure 5**). Similarly, there was also a significant impact of treatment on leaf colour index, particularly for Lollo Rosso (**Figure 6**). The greatest depth of red colour was seen in the bare ground treatment, with the plastic treatments showing weaker pigmentation and increased proportion of green. This was most pronounced in the blue plastic treatment, where the average colour index for Lollo Rosso was approaching that of the Lollo Bionda and Green Oak Leaf varieties.

As a general response leaf colour is the inverse of that seen in overall yield – the deepest green colour was seen in the blue plastic and clear ground treatment, alongside the lowest yield. The increase in colour may be due to a variety of effects. Firstly, smaller more juvenile plants with less expanded leaves may show increased pigment content, especially if these are grown in colder conditions – this may also result in the increased red pigmentation in Lollo Rosso grown under bare ground.

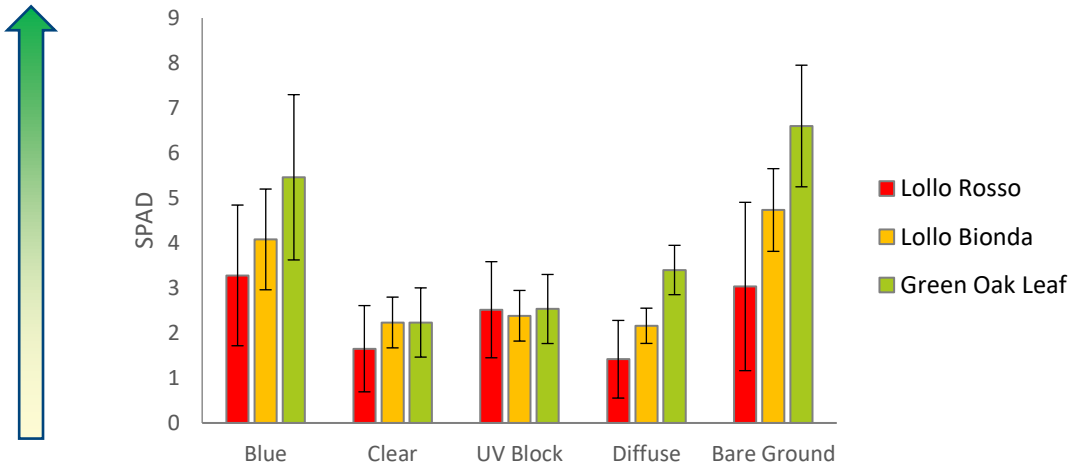

Figure 5. Average SPAD value across plastic treatments. A greater SPAD value indicates increased chlorophyll content, giving a greater depth of green to the lead material.

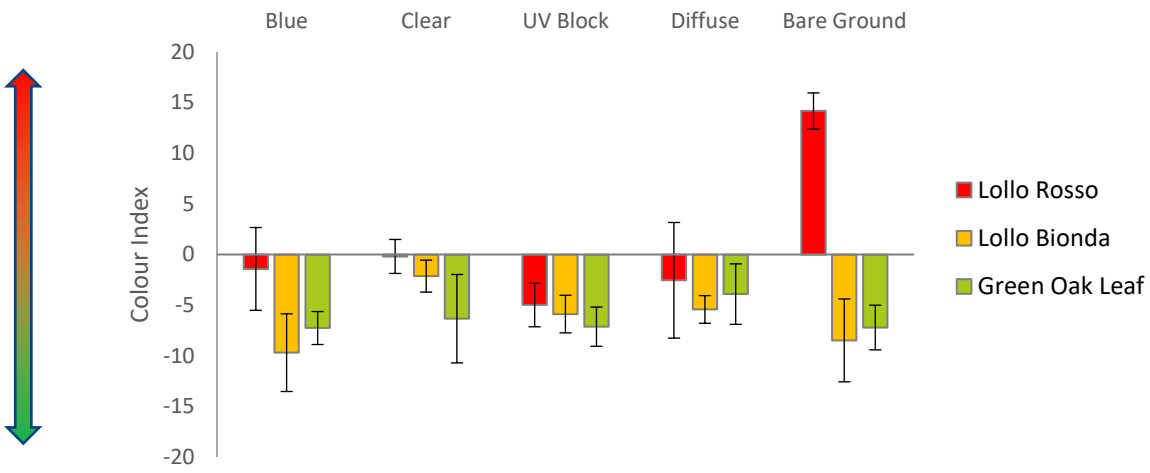

Figure 6. Average colour index values for each variety grown under plastic treatments. A more positive value indicates a deeper red, whilst a lower or negative value indicates increased greenness.

Other areas of agronomic focus were also identified during the trial. Tunnel use provided a suitable protection from larger pests like birds and rabbits, as the bare field treatment did see some damage. This was addressed in the next season using netting to prevent pest access after planting. Conversely, there was an increased incidence of slug damage under plastic protection, mostly likely as a result of the more humid environment. This necessitated the increased use of slug pellets to limit damage, although the use of ferric phosphate slug pellets is compatible with organic production and does not carry the environmental problems of conventional metaldehyde pellets. There were no significant pest/disease issues seen in this trial, although these are liable to be more of a concern in later plantings as temperature and humidity within the tunnels are likely to increase in the summer period. Growers would need to respond to this with careful control of the tunnel vents and control programs to mitigate any increased risk.

3.2 Experimental year Two (2021)

3.2.1 General Summary

Despite delays associated with the COVID-19 epidemic, three trials were run over the 2021 season at both sites. Good establishment was seen at both sites, along with more uniformity between treatments, particularly between the bare ground control and the plastic treatments. This was due to overall warmer conditions in the spring and summer period over which the trials were carried out in 2021 compared with the cooler autumn period used for trials in 2020. This is most likely to be due to improved climate around the plant achieved by the summer weather reducing differences in temperature-limited growth between the protected and open plots. Besides yield, there were more pronounced differences in quality between the varieties, corresponding with findings from the 2020 season.

3.2.2 Yield Responses

Total head weight was relatively consistent between treatments, with no significant differences between plastics or open ground for all three varieties (**Figure 7**). Overall yield per head was lower than in the 2020 trials, most likely as a result of reduced time to maturity. Longer daylength in the summer will promote bolting, so it is necessary to take earlier harvests to avoid lettuce acquiring a bitter taste as it begins to bolt which can lead to lower

head weight. Whilst this can be managed commercially by agronomic mechanisms (e.g. variety choice, planting density) these aspects were kept consistent between years to ensure comparability of results. There was a minor (but not significant) increase in yield for the Green Oak Leaf under clear plastic relative to the other treatments. This was in contrast to the results from 2020, whereby the blue and bare ground treatments gave significantly smaller yields compared with the clear, UV blocking and diffuse plastic. However, given that greater light and temperatures were seen in the summer months and plants harvested before bolting it is likely that the warming benefits of plastic and differences in total light transmission were less pronounced. However, there were small differences in head diameter between treatments, particularly with the blue plastic giving smaller, more compact heads compared with the other plastics, whilst the clear plastic gave larger heads, although these were not statistically significant (**Figure 8**). Head quality was reduced for the Green Oak Leaf variety across all plastics treatments (**Figure 9**) although this was largely due to increased propensity for bolting compared with the other two varieties leading to a reduction in overall quality scores.

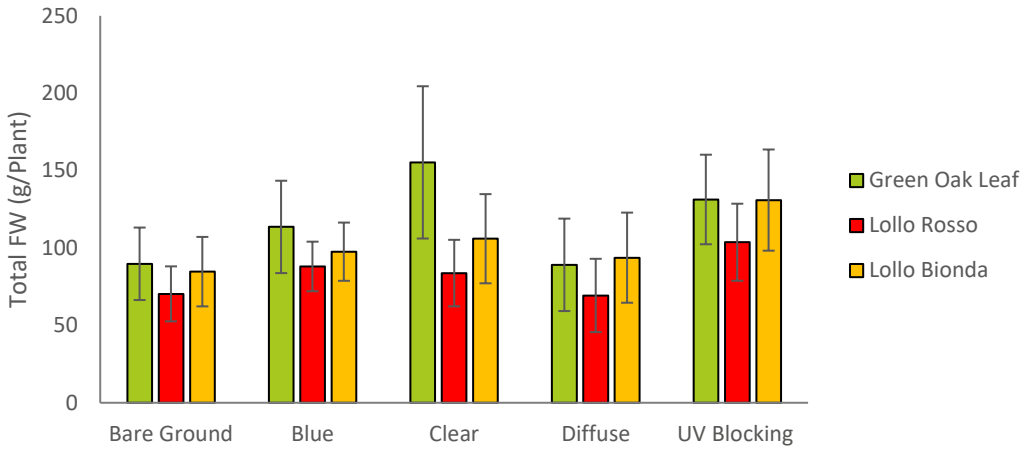

Figure 7. Average individual head weight at each harvest averaged across both sites.

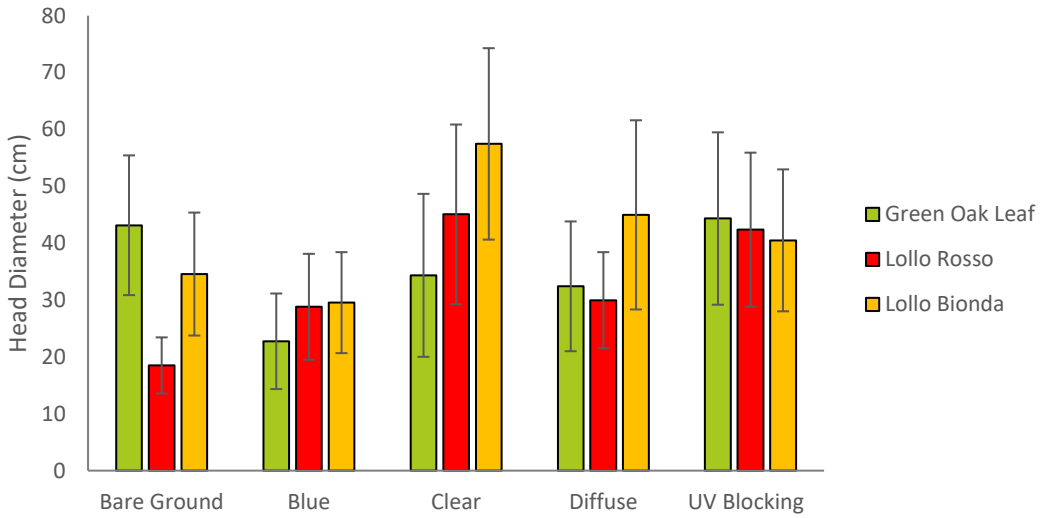

Figure 8. Average head diameter at harvest, averaged across both sites.

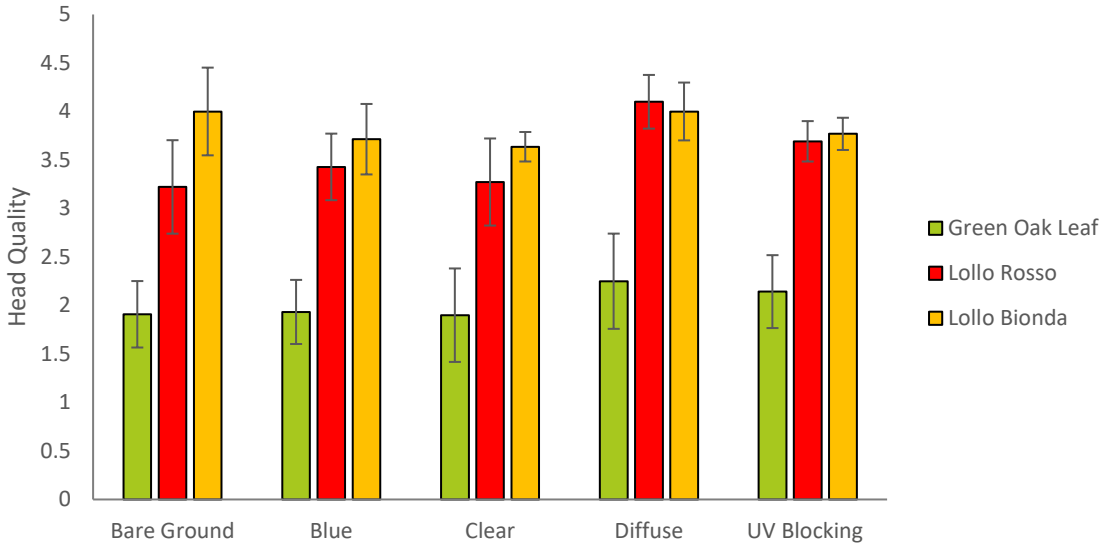

Figure 9. Average head quality (scored 1 – 5, with 5 being greatest) at harvest.

In terms of overall impact, plastic protection had a beneficial impact on yield. For the Green Oak Leaf, there were no significant differences between the clear, UV blocking and diffuse plastics, which may indicate that the benefits of protection may be linked primarily with the microclimate modification as opposed to light manipulation specifically. However, both Lollo varieties gave a greater (although not statistically significant) marketable weight in the UV blocking and diffuse treatments compared with the clear plastic. The curled nature of these varieties leads to a more compact head compared with the Green Oak Leaf, so the increased scatter of the diffuse plastic may be beneficial in aiding light penetration into the head.

3.2.3 Leaf Colour

Leaf greening (as examined through chlorophyll content, assessed through use of a SPAD) showed relatively consistent chlorophyll content in the Green Oak Leaf between plastic treatments, with no significant differences (**Figure 10)**. However, for the yellow Lollo Bionda there were significantly lower SPAD values recorded for the blue, clear and diffuse plastic treatments. However, given that yellow pigmentation is a desirable market characteristic this is not considered a negative output.

Red colour development in the Lollo Rosso was stronger across all treatments compared with trial assessed in the autumn of 2020, mostly likely as a result of strong light and dry soils over the summer period (**Figure 11**) In 2020 the blue and diffuse plastics gave the strongest pigmentation of the plastic treatments, and similar results have been seen in the 2021 season.

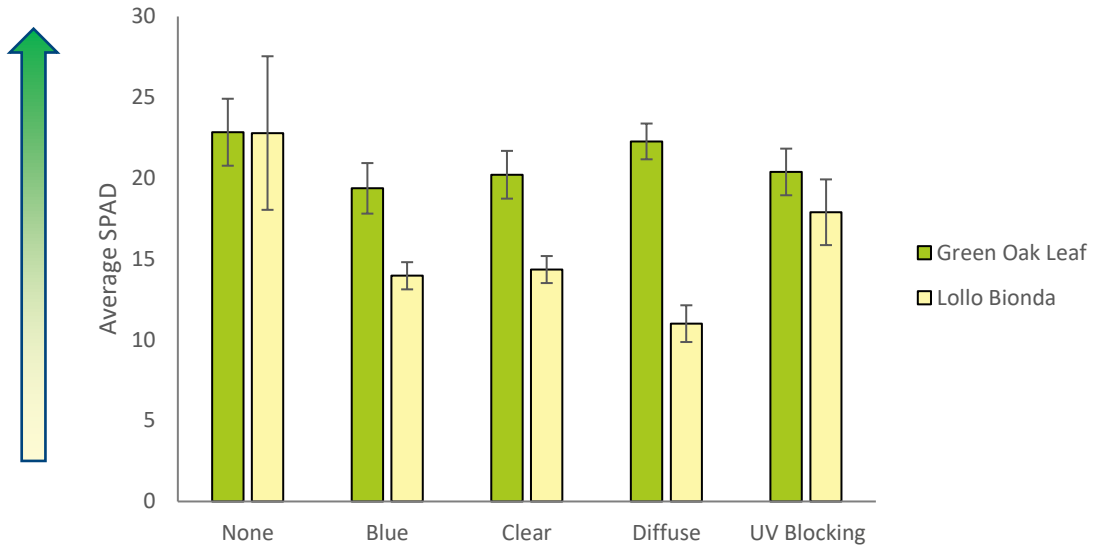

Figure 10. Average SPAD value across plastic treatments. A greater SPAD value indicates increased chlorophyll content, giving a greater depth of green to the lead material.

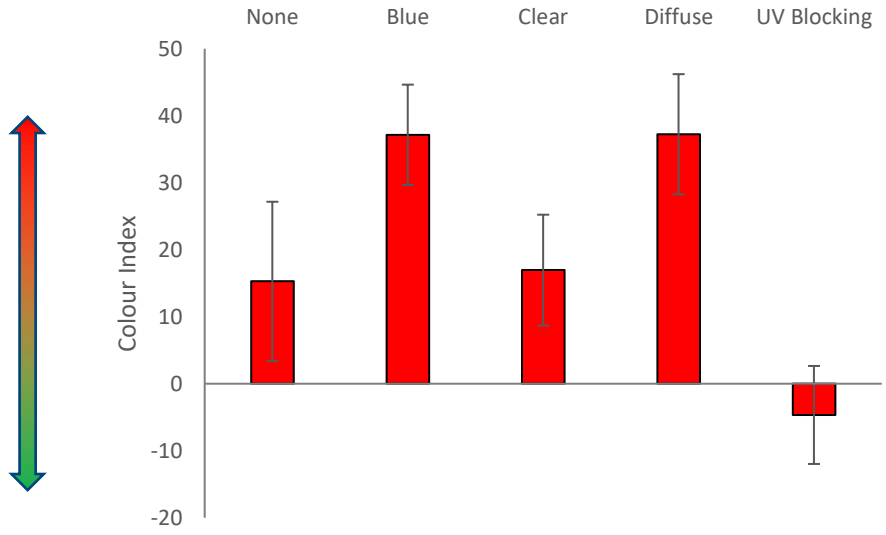

Figure 11. Average colour index values for the red Lollo Rosso variety grown under the plastic treatments.

3.3 Experimental Year Three (2022)

3.3.1 General Summary

Plug plants were planted at both sites on the 23 March 2022. Site 1 (Hootons) was harvested on 12 May, and site 2 on 04 May. Planting was delayed to limit the risk of frost damage as whilst this would be somewhat mitigated by protected cultivation, the inclusion of a bare ground control necessitated a delayed to ensure the comparable crops could be produced. Plant establishment was good at both sites, although there were a small number of transplant failures. Site 2 (Mostyn) showed more consistent establishment although there were some reductions in establishment in bare ground, most likely as a result of increased exposure during early rooting.

3.3.2 Yield Responses

Plant vigour was significantly reduced in bare ground at both sites (**Figure 12**), and across all varieties most likely as a result of suboptimal climate conditions in the early season outside of protection. At site 1 vigour between the plastic treatments was relatively consistent, although the Lollo Bionda varieties showed reduced vigour under blue plastic treatment. At site 2, however, vigour was more variable between treatments although was generally improved in the UV Blocking for all three cultivars.

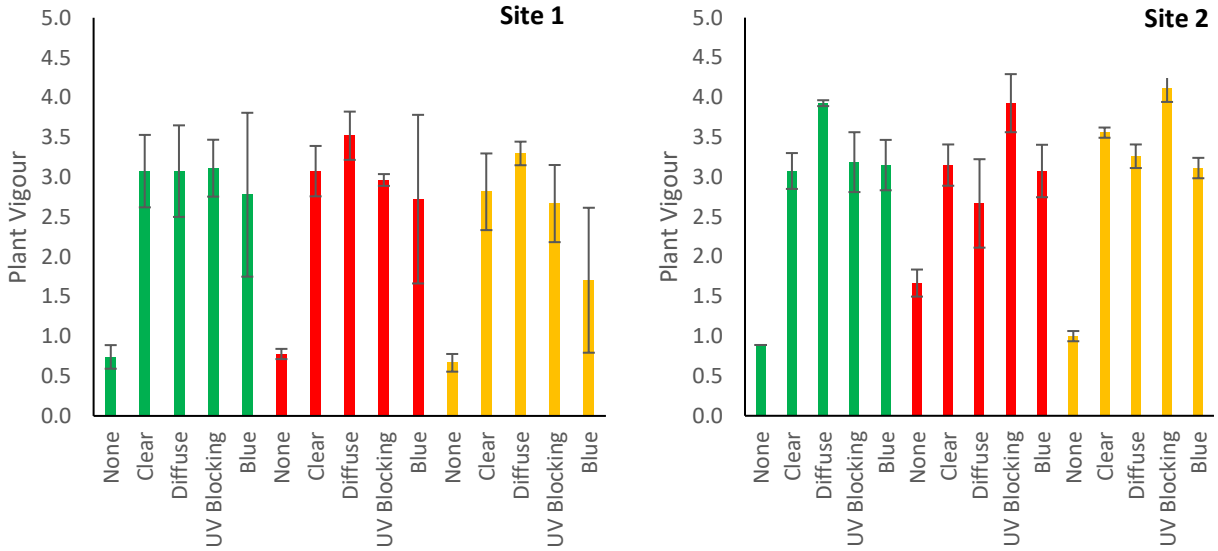

Figure 12. Average plant vigour score (1-5) at harvest for Green Oak Leaf (Green), Lollo Rosso (Red) and Lollo Bionda (Yellow).

At harvest, the smallest gross yield was recorded in the open ground controls, with plants averaging less than 17g at both sites (**Figure 13**). Greatest gross yields for the Green Oakleaf were seen under UV Blocking plastic at site 1 (192g), whilst clear and diffuse plastics were comparable (166g and 148g respectively) and blue plastic produce the smallest gross yield (128g). Similar patterns were seen at site 2 where UV Blocking plastic produced the greatest gross yield (207g), while clear and diffuse plastic were comparable (141g and 132g respectively). Blue plastic produced the smallest gross yield at site 2 (110g).

This pattern of responses was seen also in the Lollo Bionda variety. At site 1, average UV Blocking plastic gross yield was 180g compared with 129g/158g (clear/diffuse), with the lowest yield under protection seen for the blue plastic (83g). At site 2 diffuse and UV Blocking

plastics gave comparable gross yields (183g and 184g respectively) compared with 156g under clear plastic. Blue plastic again gave the lowest yield for protected plastic (131g).

Lollo Rosso gave the greatest gross weight under diffuse plastic (175g) compared UV Blocking and clear plastics (104g and 156g respectively). At site 2, gross yields were relatively comparable between clear, diffuse and UV Blocking plastics (157g, 132g and 148g respectively).

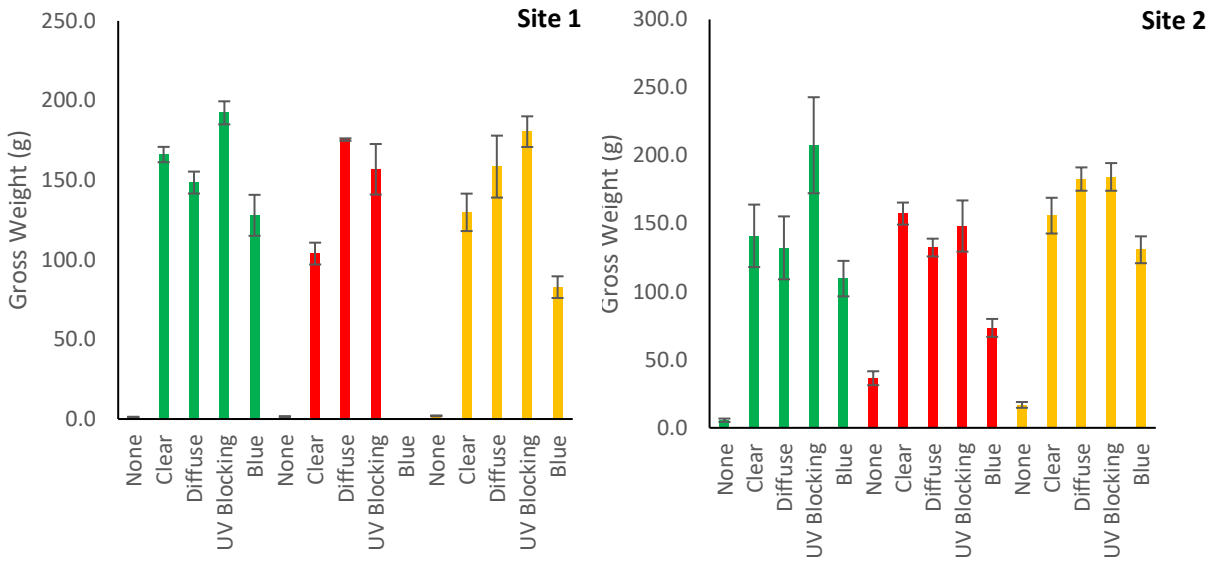

Figure 13. Gross weight at harvest for Green Oak Leaf (Green), Lollo Rosso (Red) and Lollo Bionda (Yellow).

Marketable yield at harvest followed similar trends (**Figure 14**). At site 1, marketable yield in Green Oak Leaf was greatest in UV Blocking (192g), although the greatest Lollo Bionda and Lollo Rosso marketable yield was seen in the diffuse plastic (147g and 151g). However, the proportion of marketable yield for both Lollo Rosso and Lollo Bionda was significantly reduced under all plastic types compared with Green Oak Leaf (83% and 74% respectively compared with 93%), although the greatest proportion of marketable yield was achieved in the diffuse plastic and UV Blocking plastics. Marketable yields at site 2 followed a similar trend with the greatest marketable yield, although high variability, showed no significant difference between plastic treatments, however clear plastic showed the smallest yields for Lollo Rosso (72g) and blue plastic the smallest yield for Lollo Bionda (130g).

Overall, the greatest marketable yield at both sites was seen in Green Oak Leaf, grown under the UV Blocking plastic. Lollo Rosso and Lollo Bionda were most consistent between plastic treatments, although the blue plastic coverage gave particularly lower marketable yield for the Lollo Rosso variety.

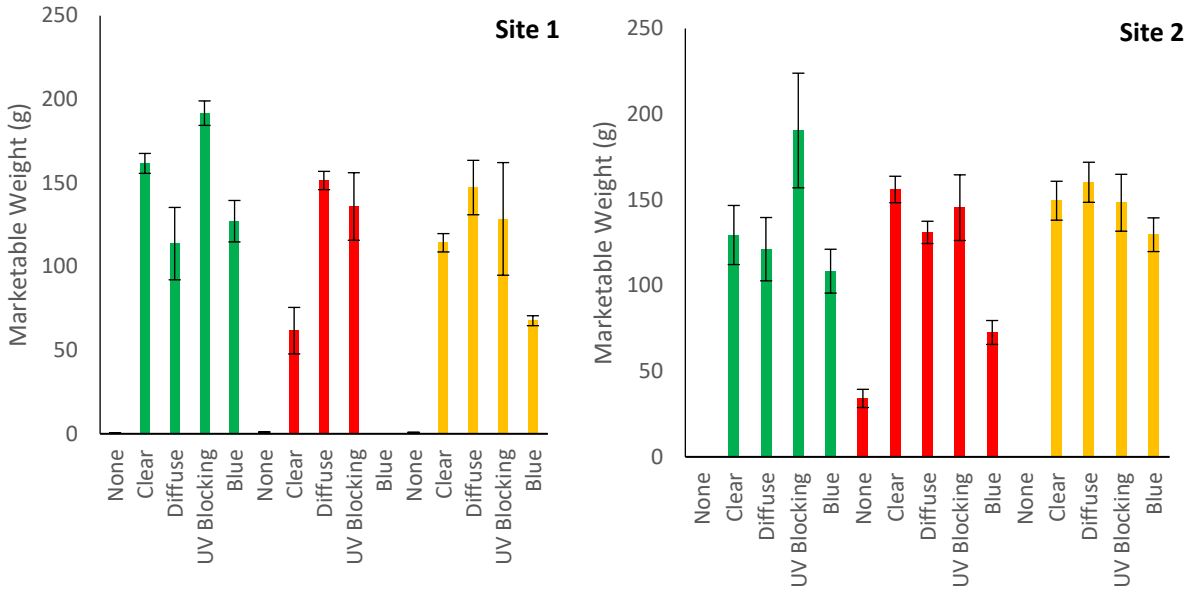

Figure 14. Marketable yield at harvest for Green Oak Leaf (Green), Lollo Rosso (Red) and Lollo Bionda (Yellow)

Plant size and shape was most variable in Green Oak Leaf, with Lollo Rosso and Lollo Bionda forming shorter, dense heads overall (Figure 15, Figure 16). Height was relatively consistent in Green Oak Leaf but diffuse and UV Blocking plastics gave the greatest width at Site 1, whilst both height and width were relatively consistent between treatments at site 2. Both Lollo Rosso and Lollo Bionda followed similar trends, with the greatest plant width achieved similarly in the diffuse and UV Blocking plastics. Overall, plastic treatment did not have a significant impact on plant height or width at either site, outside the significant increase between protected and open treatments.

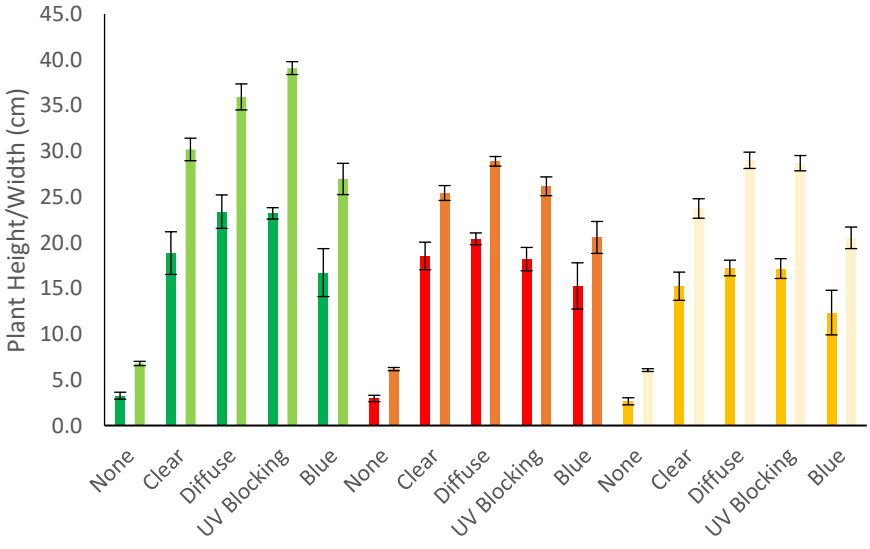

Figure 15. Average plant height (dark) and width (light) for Green Oak Leaf (green), Lollo Rosso (red) and Lollo Bionda (yellow) at site 1.

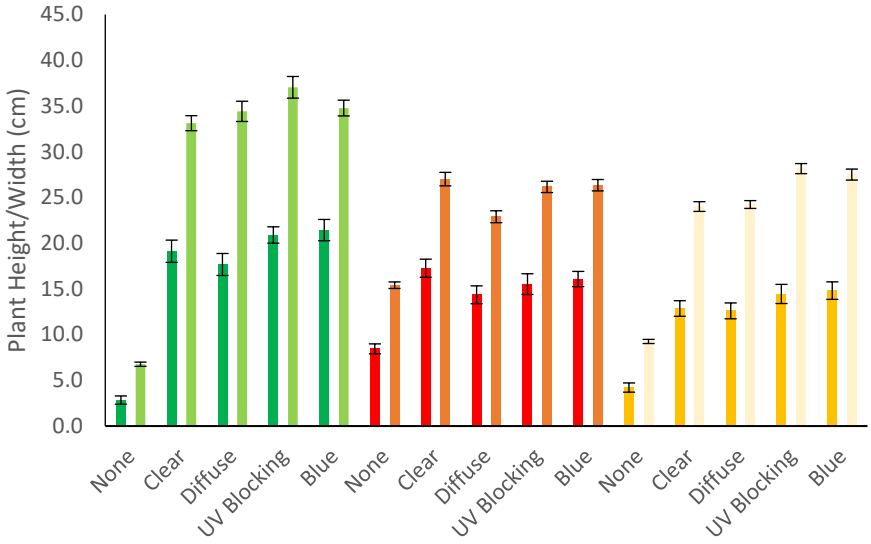

Figure 16. Average plant height (dark) and width (light) for Green Oak Leaf (green), Lollo Rosso (red) and Lollo Bionda (yellow) at site 2.

3.3.3 Leaf Colour

Plant colour showed a strong response to plastic treatment between cultivar (**Figure 17)**. For the Green Oak Leaf colour was strongest in the diffuse, UV Blocking and blue plastic at both sites, although bare ground covering gave the strongest colour in Lollo Rosso.

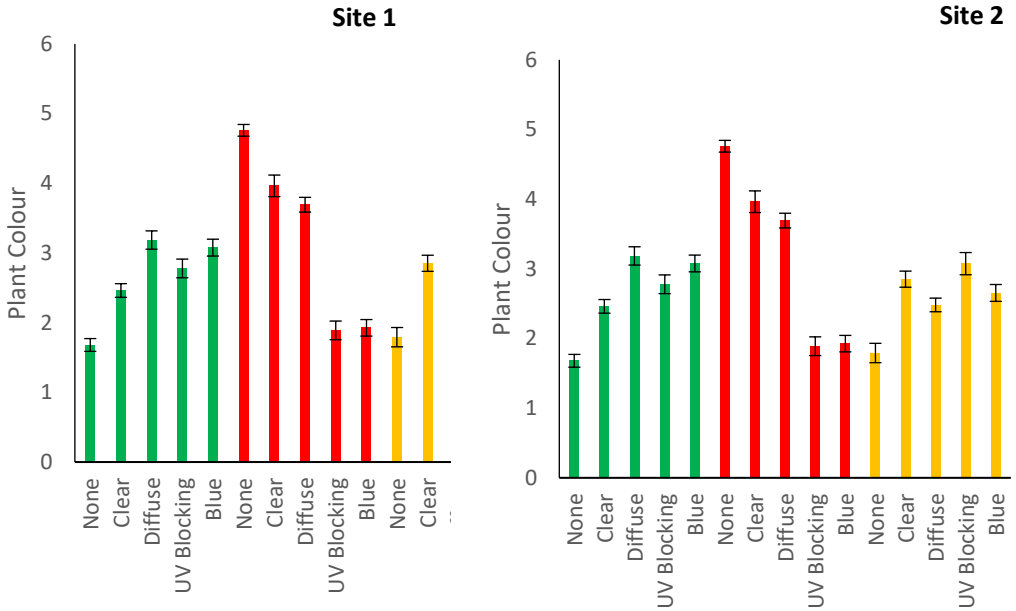

Figure 17. Average plant colour score (1-5) for Green Oak Leaf (green), Lollo Rosso (red) and Lollo Bionda (yellow).

Other quality issues varied between site and varieties. Significant tip burn was only seen in Lollo Bionda at site 2, which was present across all treatments although was significantly elevated in plants grown under the UV Blocking plastic compared with the clear, diffuse and blue. Some pest damage was seen at site 1, but this largely associated with specific tunnels rather than any significant correlation between cultivars or treatments.

3.3.4 Trial Summary 2022

General results from the 2022 trial have demonstrated the benefits of protected salad production in the early season. At both an exposed and more protected site, May harvests of leafy salad crops would not be feasible due to poor establishment of the crops, whilst marketable yields could be achieved under protection.

Whilst no significant differences were seen between treatments, the UV Blocking plastic gave marginally greater yields compared with the other treatments in some instances. However, strong performance was seen under the clear control plastic, indicating there may not be much additional benefit compared with conventional plastics in the early season.

Besides marketable yield, plastic treatment did not have a significant impact on other quality characteristics, including head shape or colour. The strongest colour in Lollo Rosso was seen under bare ground, but this is most likely as a result of increased stress due to colder conditions for this variety when grown without protection in the early season.

Overall, whilst the benefit of protected cultivation in the early season was demonstrated, there was no significant difference between plastic treatments. However, as many of the reported benefits of light quality modification are unlikely to be tangible in the early season (such as high humidity, temperature and disease pressure) observed benefits may be reduced within the trials undertaken in this project.

3.4 Postharvest Behaviour

Postharvest testing was performed from samples collected from both sites in 2022. The postharvest behaviour of samples from each plastic type are given for the four-day period following harvest for site 1 (**Figure 18**) and site 2 (**Figure 19**). Protected samples far outlasted the bare ground samples at both sites, with the majority of bare ground samples becoming almost completely unmarketable within 2 days of storage (except for Lollo Rosso samples at site 2). However, this is more likely a reflection of the poor condition of the bare ground samples at harvest due to unsuitable weather in the early season.

Between plastic treatments, there was generally no significant difference between plastic types, with general declines in marketability across all treatments. However, the UV Blocking treatment showed marginally greater declines in produce quality for Green Oak Leaf and Lollo Rosso at site 1, and all varieties at site 2. For example, Green Oak Leaf samples from site 2 were only 30% marketable on day 3 compared with 45-58% of the other treatments.

Conversely, the clear and blue plastics showed stronger retention of marketability, with produce remaining of greater marketable quality for longer. For example, Lollo Rosso samples from site 2 were 70% marketable on day 3 compared with 30-53% in other plastic treatments.

It should be noted that the majority of marketable failure was due to a reduction in leaf integrity, wilting and general head shape rather than disease development. There is potential that the UV Blocking treatment would have shown greater benefits under conditions of higher disease pressure (e.g. *Botrytis*). Furthermore, conditions at harvest can have a significant impact on postharvest life. Site 1 samples were harvested under good weather conditions, whereas site 2 samples were harvested under conditions of light rain and damp soil conditions. Whilst all samples were immediately collected onto ice, differences in field heat and surface moisture can impact postharvest longevity.

Overall, these results would suggest that plastic treatment does not have a significant effect on postharvest behaviour. However, it should be noted that this is based on a single trial in the early season, and more significant differences may be seen under mainstream production in the summer.

Postharvest quality responses in lettuce, and the relationship with light quality, is a complex issue. One of the main features which demonstrates a response to pre-harvest light quality is the proportion of ascorbic acid (vitamin C) present in the tissue, and its deterioration rate after harvest (e.g. Ntsoane *et al*., 2016) although this will also be impacted by variety, light levels and temperature (Sivakumar *et al*., 2018). In addition to the nutritional profile, vitamin C (and associated antioxidant content) is important in reducing browning of the cut end of head lettuce. Whilst vitamin C quantification was not possible as part of this trial, this could represent an interesting extension to photoselective plastic trialling. Similarly, there are other postharvest aspects of quality which could also be impacted by light quality, for example, nitrate concentration (for which maximum levels are set for human heath perspectives) have also been impacted by light quality (Matsumoto *et al*., 2010).

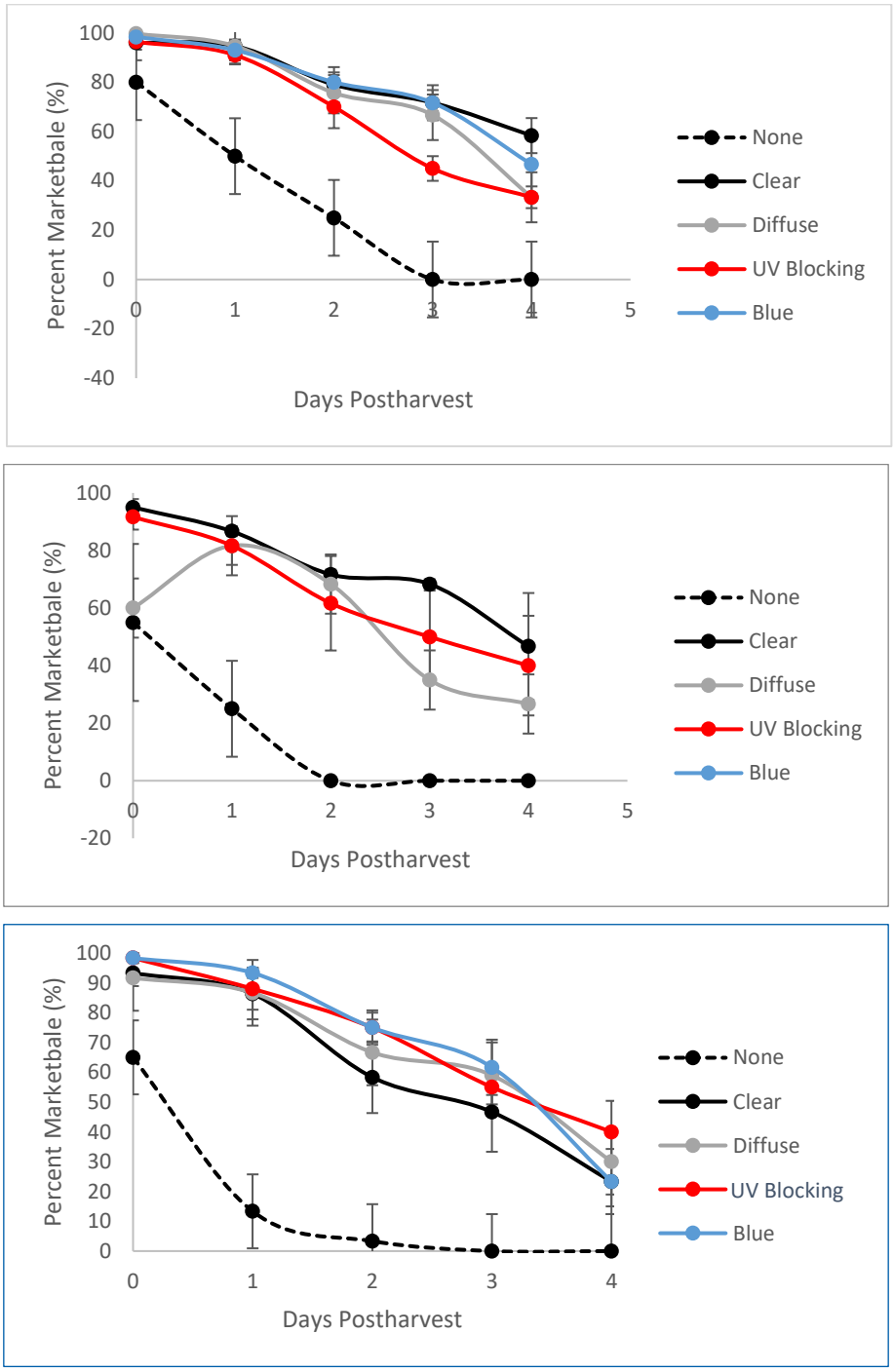

Figure 18. Postharvest responses of Green Oak Leaf (top), Lollo Rosso (Middle) and Lollo Bionda (bottom), site 1.

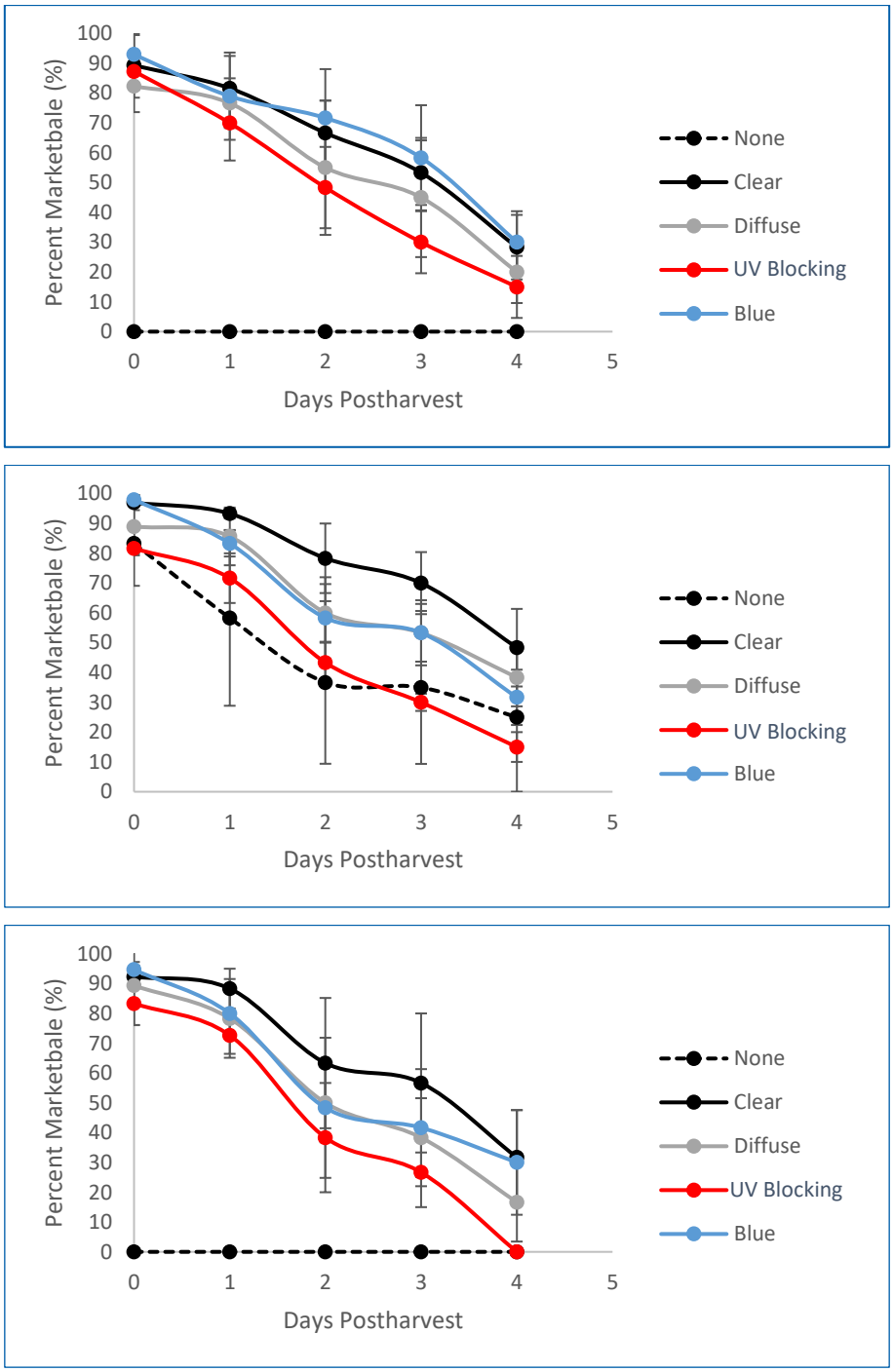

Figure 19. Postharvest responses of Green Oak Leaf (top), Lollo Rosso (Middle) and Lollo Bionda (bottom), site 2.

3.5 Plastic Condition

At the end of the trial in early summer 2022, plastic samples that had been used for three seasons were collected from Site 1, as this site was the most exposed, it was considered that plastics used here would show the greatest extent of weathering compared with Site 2. Transmission curves are given in **Figure 22** (it should be noted that as these were collected using sunlight as a light source). Whilst this ensures that achieved irradiance measurements correspond to what plants would experience under natural conditions (unlike artificial light sources) it is not possible to ensure constant irradiance input between recording but only constant light quality. Therefore, the obtained graphs should only be interpreted for relative changes in irradiance rather than total irradiance achieved.

Overall, there is little indication of a decline in plastic qualities with use, at least over a 30-month period. There is a minor reduction in transmission below 400nm level for the diffuse plastics with age, but given this is outside of the photosynthetically active radiation (PAR) range (400-700nm) this is unlikely to impact crop productivity. Similarly, the UV Blocking plastic sample showed reduced transmission above 700nm. However, as this plastic is used to control UV transmission (300-390nm) changes at longer wavelengths are unlikely to impact the potential activity of tunnels covered with this plastic. The used clear plastic sample showed a minor reduction with age in the 500 – 700nm which could potentially impact productivity as this falls within PAR range, but without more accurate testing with a constant light source it is not possible to test this aspect fully. However this is likely to represent typical weather of the plastic under field conditions.

Based on this evidence, the longevity of the plastics under field conditions is considered to be good. Typical manufacture's specifications are for eight or more years of life expectancy, with at least five years of UV manipulation. Whilst these timeframes are outside of the range of this project, measurements taken after 30 months of use show little to no degradation which may support these projections. There is no notable decline in photoselective performance with use, supporting growers in the uptake of these materials.

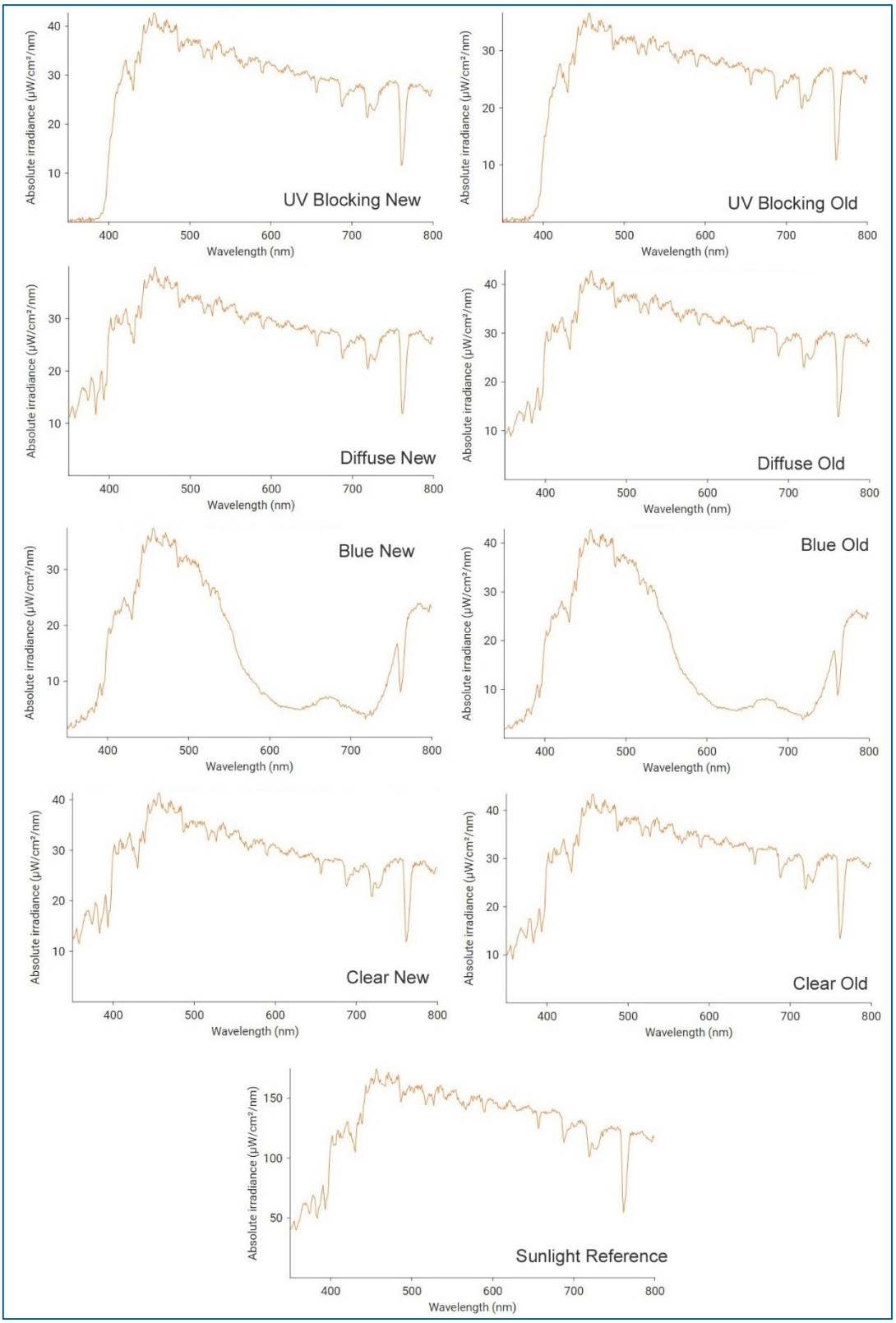

Figure 20. Transmission spectra of plastic samples taken from new (unused) plastics and plastics that have been used for three seasons. A reference spectra for sunlight is present. NB. As a non-constant light source (sunlight) absolute irradiance should not be compared between samples – these are presented for comparison of the *shape* of the curve not the achieved irradiance.

4 CONCLUSIONS

This project has demonstrated a number of trends relating to the use of different types of plastic use for leafy salad production. One clear trend is the benefits of protected cultivation compared with bare ground cultivation. For example, Green Oak Leaf marketable weight was 347g under protection compared with 114g with bare ground on average in 2020. Differences were less pronounced in the 2021 season, but as this period covers the summer months the benefits of protected cultivation are likely to be less pronounced. This was particularly evident in the spring trial at the start of 2022 where practically no yields were achieved from bare ground cultivation at either site compared plastic treatments. General results from the early 2022 trial have demonstrated the benefits of protected salad production in the early season. At both an exposed and more protected site, May harvests of leafy salad crops would not be feasible due to poor establishment of the crops, whilst marketable yields could be achieved under protection.

Besides the benefits of protected cultivation in general, there are a number of trends relating to light modifying plastic seen demonstrated in the trials. In 2020, the UV-blocking UV Blocking plastic gave strong increase in head weight for both Lollo Rosso and Lollo Bionda, whilst the diffuse plastic can drive an uplift in yield for Green Oak Leaf. Whilst no significant differences were seen in the summer trials of 2021, UV Blocking plastic also gave an increase in yield in the spring 2022 trials. Increases in individual head weight may not necessarily translate to increased profit, however, especially where produce may be sold on a per unit basis rather than on a per weight basis. Therefore, changes in quality may be more relevant, particularly if produce is being marketed at premium direct to customers through a farm shop or veg box scheme, a typical marketing model for Welsh sites. Head colour was most significantly impacted by plastic treatment, although this was linked with variety choice.

Green Oak Leaf – In the autumn 2020 trials the UV Blocking treatment gave marginally more open heads compared with the other treatments, whilst the blue plastic treatment gave the strongest chlorophyll concentration implying the greatest depth of “green” although in 2021 there was no significant difference between treatments and leaf colour.

Lollo Rosso – Head diameter was not impacted by plastic treatment, suggesting that the dense, close head which is required for marketing was not impacted by plastic treatment. Head quality was marginally increased in the diffuse plastic treatment in 2021, where increased light penetration into the closed head achieved with diffuse treatment is likely to have improved development of the inner whorls of leaves. A strong depth of red colour is desirable for this variety, and this was significantly impacted by plastic treatment. In 2020 all plastic treatments gave weaker colouring compared with bare ground production, but this may be a result of the greater stress that unprotected plants were under compared with the plastic treatments. In the 2021 trials the strongest pigmentation was seen in the blue and diffuse plastics, with the UV Blocking plastic giving the weakest colour.

Lollo Bionda – Similarly, head diameter was not impacted by plastic treatment, although quality was marginally increased with diffuse plastic use in 2021. Lighter coloured leaves are more desirable for this variety, and this was seen in the clear, UV Blocking and diffuse plastics in 2020, and with the blue, clear and diffuse plastics in 2021 as indicated by lower chlorophyll levels.

Overall, plastic choice is likely to impact both yield and head quality, although achieved impacts may change between years and between different points in the season. Given that different varieties respond in different ways to plastic treatment, it would be advisable to choose a plastic based on intended cultivar ranges. For the Lollo-type varieties the diffuse plastic gave a marginally improved head quality in terms of shapes and overall structure, without having major impact on pigmentation. The UV Blocking plastic may reduce quality (particularly in terms of colour) for both varieties, as well as reduced postharvest longevity. Green Oak Leaf performed relatively well under all plastic treatments, and so plastic choice may have less of an influence on marketability. However, one of the

reported benefits of UV Blocking plastic which is improved ability to control pest and disease incidence could not be fully explored in this trial due to relatively low pest and disease pressure. However over routine cultivation it is possible that pest and disease pressure would be more relevant. Furthermore, UV Blocking plastic use did give marginally greater yields under some conditions which might be of benefit for conventional lettuce varieties where bulk volume is more important than individual head quality.

Overall, whilst the benefit of protected cultivation in the early season was demonstrated, the more nuanced differences between plastics may preclude easy judgment of their use under commercial conditions. However, as many of the reported benefits of light quality modification are unlikely to be tangible in the early season (such as high humidity, temperature and disease pressure) observed benefits may be reduced. This may be particularly relevant to the UV-blocking film as reducing UV light in the growing environment can impact insect pest flight and navigation to potentially reduce the need for pesticide use in control infestations, as well as impacting fungal disease sporulation and spread (Desani *et al*., 2007). It should also be noted that the conditions used in this trial were slightly different to conventional practice in order to accommodate experimental design. The scale of tunnels used were considerably smaller than those seen under general circumstances, with much lower ground clearance. Reduced airflow and higher humidity as a result of this, particularly in summer, may have impacted crop growth responses, and so yield and quality.

From an economic perspective, plastic choice will have cost implications as well as an effect on crop responses. Typically, specialist plastics will cost c. 15% more than standard clear plastic, and this would need to be taken into consideration when choosing speciality plastics over conventional clear plastic. Furthermore, the differences in responses between different cultivars (and most likely between different crop types) should also be borne in mind. A large number of small-scale holdings in Wales follow a mixed-cropping paradigm, where a variety of different products are grown for marketing direct to the consumer. Therefore, a polytunnel is likely to be used for a variety of crops and different purposes e.g. raising seeds for transplanting in the early spring followed by different main crops including fruit (and potentially flowers) in the main season. Plastic choice will not only impact different crops in different ways, but those which also require pollinator activity (e.g. strawberry, tomato) will also be impacted by plastic choice, particularly the blue and UV-blocking given the potential impact of these materials on insect flight. Therefore, growers would be advised to think carefully about what demands are likely to be placed on a polytunnel over an 8+ year-lifespan to make sure they can maximise the benefits of their investment.

Growers may also be concerned about the additional use of plastics impacting the environmental sustainability of their production. The long lifecycle of these plastics coupled with the use of available industry recycling schemes will means the materials can be used in a sustainable way. Plastic use will also have a range of additional environmental benefits such as reducing the need for irrigation by providing reducing soil evaporation in the summer, and potentially offer reductions in agrichemical use.

Feedback from Owen Lane, specialist on films for polytunnels, was that the results from the project were broadly similar to those of other research projects he has been involved with, and that while the plastic treatments show some benefits, the coloured plastics are partially shading so it is understandable that they did not perform as well as higher light transmitting films. Owen also felt that the research clearly shows that it is beneficial to have some plastic covered structures for salad production in Wales, and that some careful thought should be given to the light transmission properties of the covering used.

Overall, this project has demonstrated that protected cultivation can offer a range of benefits to growers in Wales, however photoselective plastics will need to be chosen carefully to take into account specific crops, varieties and what characteristics will be of greatest relevance to their customers. Feedback from the host growers were positive, and one of the growers has shown strong

interest in continuing the use of plastics as part of their normal cultivation approaches. It would be preferable for any future trials to test the performance of these materials in large scale tunnels, and on mixed cropping systems, to test how these materials can be exploited in a mixed production system.

5 REFERENCES

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Matsumoto, T., Itoh, H., Shirai, Y., Shiraishi, N., & Uno, Y. (2010). Effects of light quality on growth and nitrate concentration in lettuce. *Journal of Science and High Technology in Agriculture*, *22*(3), 140-147.

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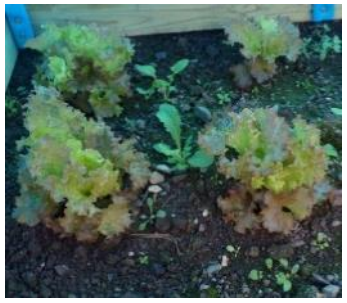
APPENDIX 1 – GENERAL TRIAL PHOTOS

	Untreated Control	Clear	Blue	Diffuse	UV Blocking
Green Oakleaf					
Lollo Rosso					
Lollo Bionda