AHDB HORTICULTURE

Grower Summary

FV 398b

Practical evaluation of carrot field storage alternatives

Final 2017

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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.

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Before using all pesticides check the approval status and conditions of use.
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Project title:	Practical evaluation of carrot field storage alternatives
Project number:	FV 398b
Project leader:	Dr S J Roberts, Plant Health Solutions Ltd
Report:	Final Report, Nov 2017
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Key staff:	Dr S J Roberts (PHS) James Howell (VCS)
Location of project:	VCS, Wellbeck; PHS, Warwick; Trial sites in Norfolk, Aberdeenshire, Yorkshire.
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Date project commenced:	01 Aug 2015
Date project completion due:	30 Sep 2017

GROWER SUMMARY

Headline

- All of the reduced-straw and non-straw alternatives provided adequate frost protection for field-stored carrot crops during the winters of 2015-16 and 2016-17.
- Cellulose fibre or similar materials could be a realistic alternative to conventional straw if suitable prices can be negotiated.

Background

Current UK industry practice is to store carrots for winter/spring marketing *in-situ* in the field, typically covered with a thick layer of straw (with or without an additional layer of polythene below) to provide insulation against frost damage during the winter and to prevent warming and re-growth in the spring. However, field storage using straw is becoming increasingly problematical and challenging as a sustainable technique. This is largely due to the high cost and volatile availability of straw, but also due to agronomic issues such as nutrient lock-up from the decomposition of incorporated straw after carrot harvest, and the potential for introduction of problem weed seeds with the straw. Supplies of straw are likely to become both more expensive and erratic in future years due to the continued development of straw-fired biomass plants; increasing pressure on cereal farmers to re-incorporate organic matter rather than remove it as straw; the volatility of the cereal market; and the effects of climate change. In addition, landowners have a major concern that importing straw may introduce blackgrass seeds into fields which have been previously free. Although not considered a severe problem on sandy (carrot) soils, there is a fear that once present on a farm it could move on to other fields with heavier soil.

There is therefore a demand to examine alternative options for in-field storage of carrots which do not rely on the use of large quantities of straw: either through reduced quantities of straw or non-straw alternatives. A previous project, FV 398a, (Roberts & Lacey, 2014) primarily a theoretical desk-based study, investigated:

- heat transfer principles involved in field storage
- the theoretical insulation value of current methods
- the cost and issues involved in using alternative insulation materials

The project identified inefficiencies (in terms of insulative value) in the current straw-based systems, some possible misconceptions, and alternative systems and materials that could have equivalent or better insulative value to the current system. However, estimates of insulative value of alternative systems were theoretical.

This project aims to:

a) Validate the theoretical insulative values for alternative materials and their impact on crop quality; and

b) Investigate practical implementation of alternative systems.

This final report summarises the results of both years of the project (2015-16 and 2016-17).

Summary

Field trials were established in commercial strawed crops of cv. Nairobi. Six treatments (untreated control plus five others) (Table 1, Figure 1) were examined at three different locations (Norfolk, Scotland and Yorkshire) and with two harvest dates over two winters (2015-16 and 2016-17). Each plot was 6 to 8-beds wide by 10 m long. Soil temperature and moisture sensors were inserted into each plot at depths of up to 50 cm and relayed hourly data records via the mobile-phone network.

Table 1. Treatment codes and details.

Year	**Code**	**Treatment**	**Details/Notes**
1 & 2	A	Uncovered control	Untreated control.
1 & 2	B	Straw alone	Standard covering of straw (commercial standard). All sites in year 1, one site in year 2.
1 & 2	C	Straw over polythene	Straw with a single layer of black polythene below (commercial standard). All sites in year 1, two sites in year 2.
1	D	Reduced straw polythene sandwich	Reduced (~1.5kg/m^2) amount of straw with layer of black polythene below and layer of black polythene over the top. Year 1 only, modified for year 2 → J.
1	E	Cellulose fibre polythene sandwich	Cellulose fibre, approx. 5 cm depth, 1.75 kg/m^2 with a layer of black polythene below and a layer of white polythene over the top. Year 1 only, modified for year 2 → H.
1 & 2	F	Closed cell PE Foam	Natural/white coloured, closed cell polyethylene foam, 7.5 mm thick, with a layer of white polythene over the top to provide anchorage. All sites in both years, material stored and re-used in year 2.
2	G	Cellulose fibre	Cellulose fibre, approx. 5 cm depth, 1.75 kg/m^2. Blown onto beds. Year 2 only.
2	H	Cellulose fibre with polythene cover	Cellulose fibre, approx. 5 cm depth, 1.75 kg/m^2. Blown onto beds, then covered with black polythene. Year 2 only.
2	J	Reduced straw with polythene cover	Reduced (~1.5 kg/m^2) amount of straw covered with black polythene, plus straw in wheelings to anchor. Year 2 only.

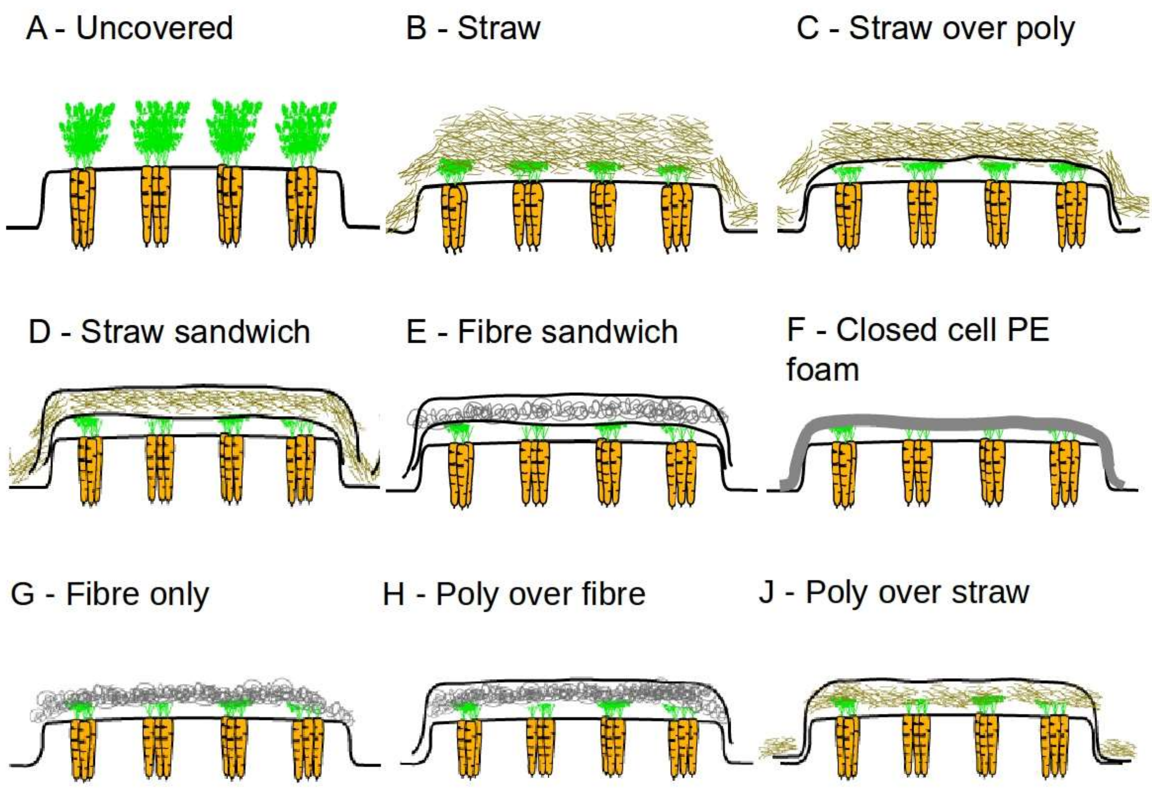

Figure 1. Diagram demonstrating each of the treatments

All of the treatments provided effective frost protection during both winters. The only significant frost damage occurred in the uncovered control (A). Based on experience in 2015-16, some of the treatments were modified for 2016-17 to make them more practical for application on a commercial field scale. For brevity only results for the second year are presented in the grower summary. The levels of total damage in 2016-17 (frost-damage and crown-rots) are shown in in Figure 2. The average U-values (measures of insulation value) are shown in in Figure 3 for 2016-17 for both heat loss and heat gain by the soil.Descriptions and comments on each of the treatments examined in 2016-17 are given below:

Uncovered (Treatment A)

This treatment was included as a negative control in both years and at all sites. Inevitably the harvested carrots had significant levels of frost damage, and reduced marketable yields compared to the covered plots.

It would be expected that levels of frost damage would be correlated with how cold each site was, and this was the case in 2015-16 where the most severe damage occurred at the coldest site (Aberdeenshire). In 2016-17, this was not the case; the coldest site was again Aberdeenshire, but there was no frost damage at the first harvest (end of January) and damage was still at a relatively low level at the second harvest, with the most severe frost damage seen at the Yorkshire site. The most likely reason for the difference was that at the

Scottish site, the crowns were not exposed and were generally at or below the soil line, whereas at the Yorkshire site (with large roots destined for processing) crowns were exposed and often 1 cm above the soil line. In addition, (although not measured) it was perceived that there was a greater mass of foliage at the Scottish site, which could in itself reduce the rate of heat loss from the soil surface. This suggests that simply ensuring that crowns are covered with soil (e.g. by choice of variety or by cultivating between rows to ensure they are covered) could eliminate the need for, or reduce, the amount of straw required for earlier harvested crops.

Straw alone (Treatment B)

This treatment was included as a positive control and commercial standard, and to obtain baseline data for current practice. It was included at all sites in 2015-16 and at one site in 2016-17. Growers tend to use straw alone for shorter term crops, or when the crop may be processed and some damage to crowns is acceptable. This treatment provided slightly less insulation than straw over polythene (treatment C). The straw remains wet at the bottom (but not as wet as treatment C), and based on moisture contents at the final harvest the water content was equivalent to up to 8 kg/m^2. This has two effects: providing a thermal mass effect (dampening of temperature fluctuations, and the water in the straw will freeze before the soil/crop) and evaporative cooling. It is likely that both the thermal mass effect and the protection resulting from release of latent heat when water in this layer freezes is an important aspect of the protection provided. In 2015-16, the soil in the beds was wetter in this treatment than the others which all had a covering of polythene, but this was not the case in 2016-17.

Straw over poly (Treatment C)

This treatment was included as a positive control and a commercial standard, to obtain baseline data for current practice and to understand more about the role and benefits or otherwise of the polythene layer. It was included at all sites in 2015-16 and at two sites in 2016-17. Growers planning long-term field storage of crops generally use straw-over-poly system. The introduction of a polythene layer provides additional insulation through surface resistance to heat transfer, and so overall provides slightly greater insulation than straw alone (treatment B). However, the most important effect of the polythene was that the straw remains much wetter than straw alone (up to twice the moisture content), and often with free water on the surface of the polythene. Based on moisture contents of the straw at the final harvests the water content was equivalent to as much as 14 kg/m^2. This larger amount of water provides a greater thermal mass and greater potential for evaporative cooling. Thus, not only does this mean that the crop is more protected from freezing, but also heats up less slowly in the spring (i.e. is kept thin a narrower temperature range than the other treatments). Hence treatment C appeared to be the most effective insulation against incoming heat.

In the previous project (FV 398a) growers often reported that the main benefit of the polythene under straw was light-exclusion to prevent re-growth. There is no evidence for this. We conclude that the beneficial effect of the polythene perceived by growers is primarily a result of the greater thermal mass, and evaporative cooling effects, which in turn maintain soil and carrots at a lower temperature in the spring.

Poly over reduced straw (Treatment J)

This treatment was examined in the second year only, and was a modification of the reduced-straw polythene sandwich of the first year, simplified by omission of the polythene layer below the straw and using a minimal amount of straw in the wheelings to anchor the polythene.

The omission of the lower layer of polythene made little difference to the insulation values whilst reducing costs and making it more practical for field scale deployment. Whereas in the first year the top layer of polythene was anchored using staples and bags of soil, in the second year the polythene was anchored by dropping a relatively small amount of straw in the wheelings (1 kg per m). This proved largely successful; on the few beds and occasions when the straw became partially exposed only, this tended to occur from the anchor points at the ends (held by bags of soil) rather than the sides (which would not be an issue on a field scale) or towards the end of the trial in the spring when the straw dried out at one of the sites.

This treatment could feasibly be implemented by using a wider polythene sheet (2.5 m) and with modifications to existing straw laying machinery: setting up so that the polythene unrolls over the top of a reduced quantity of straw and redirecting a small proportion of the straw on top of the polythene to provide anchorage.

Closed-cell PE foam (Treatment F)

The treatment was included as a non-straw alternative. This treatment consisted of a single 7.5 mm thick natural/white closed-cell polyethylene foam laid directly over the crop and secured with a wider layer of white polythene. The material is relatively expensive and would only be cost-effective if re-used. It is available in different thickness, but thicker versions increase cost, we therefore examined the thinnest version with a view to using it on its own for earlier harvests or as an adjunct to other materials. The great advantage of this material is that the closed-cell nature (i.e. air is trapped in closed-cells) means that its insulation properties are unaffected by moisture. Based on the theoretical predictions it was expected that this treatment would have the lowest insulation value, and this proved to be the case, nevertheless it still provided adequate protection at all sites in both years, and we were able to recover it intact for re-use at the end of each year.

One aspect of this treatment not anticipated was that both it and the polythene cover were translucent, this meant that unlike in all the other treatments, the crop foliage remained green throughout, although this did not have any noticeable/measurable direct effect on crop quality either way. There was a perception that the presence of green foliage encouraged a higher slug population at one of the sites in 2015-16, but this was not seen in the 2016-17 trial.

The more translucent nature may also have contributed to a 'greenhouse' effect contributing to the relative higher increase in incoming U-value compared to the other treatments.

Fibre only (Treatment G)

This treatment was examined in the second year, and envisaged as the simplest way to make use of the cellulose-fibre on a commercial field scale. The product was loosely broken up and then blown onto the crop using a petrol leaf blower with a flexible outlet. The rate used (1.75 kg/m^2) was the same as used in the other fibre treatments, and intended to give a 5 cm depth of material. There was concern that the material would not stay in place on the crop without a cover, this proved to be unfounded. The carrot foliage trapped the initial fibres, and there was very little drift off the target bed. In addition, once the surface had been wetted by the first rain or dew following the initial application, the top layer of material formed a crust, and stayed locked in place for the duration of the winter until harvest.

In terms of frost protection, the material was equivalent to the field standard (straw over poly or straw alone) with a comparable outgoing U-value. Most of the winter the product remained quite wet and when temperatures were coldest, a frozen layer developed in the top 1-2 cm. The material is not quite so effective at preventing warm-up in the spring compared to the field standard. We presume this is because the overall mass was lower and therefore the maximum water content was also lower. Measurements in the first year indicated that the fibre can absorb up to 600% of dry weight in water when saturated, but at harvest was down to 27 to 75% depending on site.

Although not quantifiable, the crowns of the roots from under the fibre, had a better visual appearance than roots from the other treatments. We suspect that this may be due to its relative water absorbency, and freedom from micro-organisms.

From the practical perspective, this treatment is the most feasible non-straw alternative, providing equivalent frost protection to conventional straw, requiring less mass, and so less potential for nitrogen lock-up, better visual quality of the roots, and no risk of weed or disease introduction. It is likely that there could be several options for field application, depending on the form of delivery, and ease of adaptation of machinery. Different application methods would likely result in subtle differences in the structure of the layer, therefore additional trials would be appropriate to look at the influence of different application methods on performance.

Poly-over-fibre (Treatment H)

This treatment was examined in the second year and was essentially a modification of the poly-fibre sandwich (treatment E) from the first year, modified by removal of the bottom layer of polythene, as it was found that due to the smooth surface of the polythene, the fibre tended to fall off the shoulders of the beds, resulting in an variable depth or absence of insulation material in places. Removing the bottom layer resulted in improved and even coverage. The polythene over the top was intended to (a) keep the material in place, i.e. preventing it blowing away and (b) keep the material drier than in the fibre-only treatment (G), and this was indeed the case.

In terms of frost protection, the material had a slightly higher outgoing U-value than the field standard (straw over poly or straw alone) or fibre-only. This is probably a result of the lower moisture content providing less thermal mass and protection via latent heat. The material is not quite so effective at preventing warm-up in the spring compared to the field standard, with similar incoming U-values to the fibre-only and poly-over-reduced-straw.

Given that that this treatment did not provide any insulation benefit compared to the fibre-only, and that the fibre-only stayed in place without a cover, there is no justification for the additional cost and extra complication of covering the fibre with a layer of polythene.

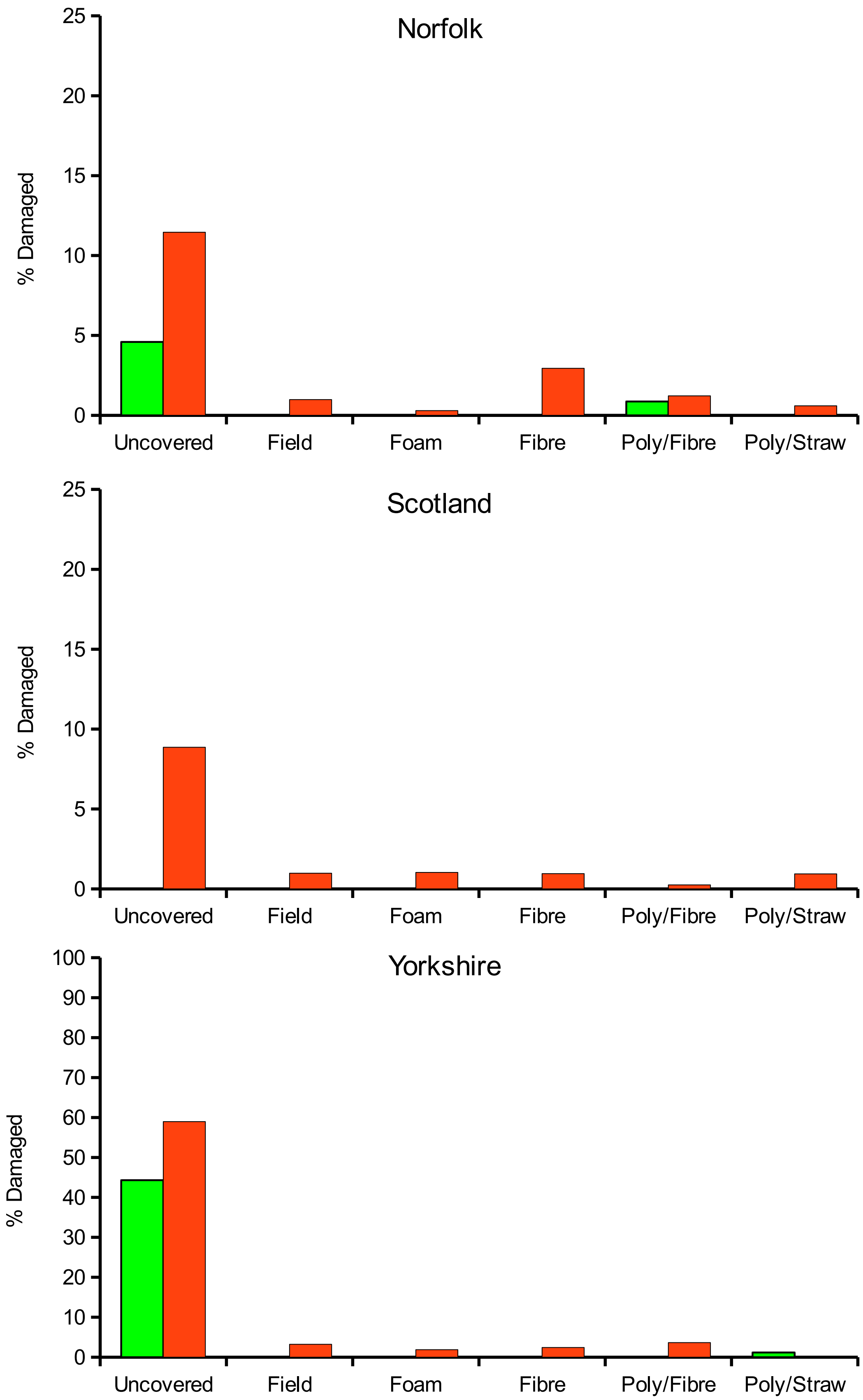

Figure 2. The percentage of damaged carrot roots at each harvest in each treatment at each site in 2016-17. Green (left hand) bars represent the first harvest, red (right hand) bars represent the second harvest.

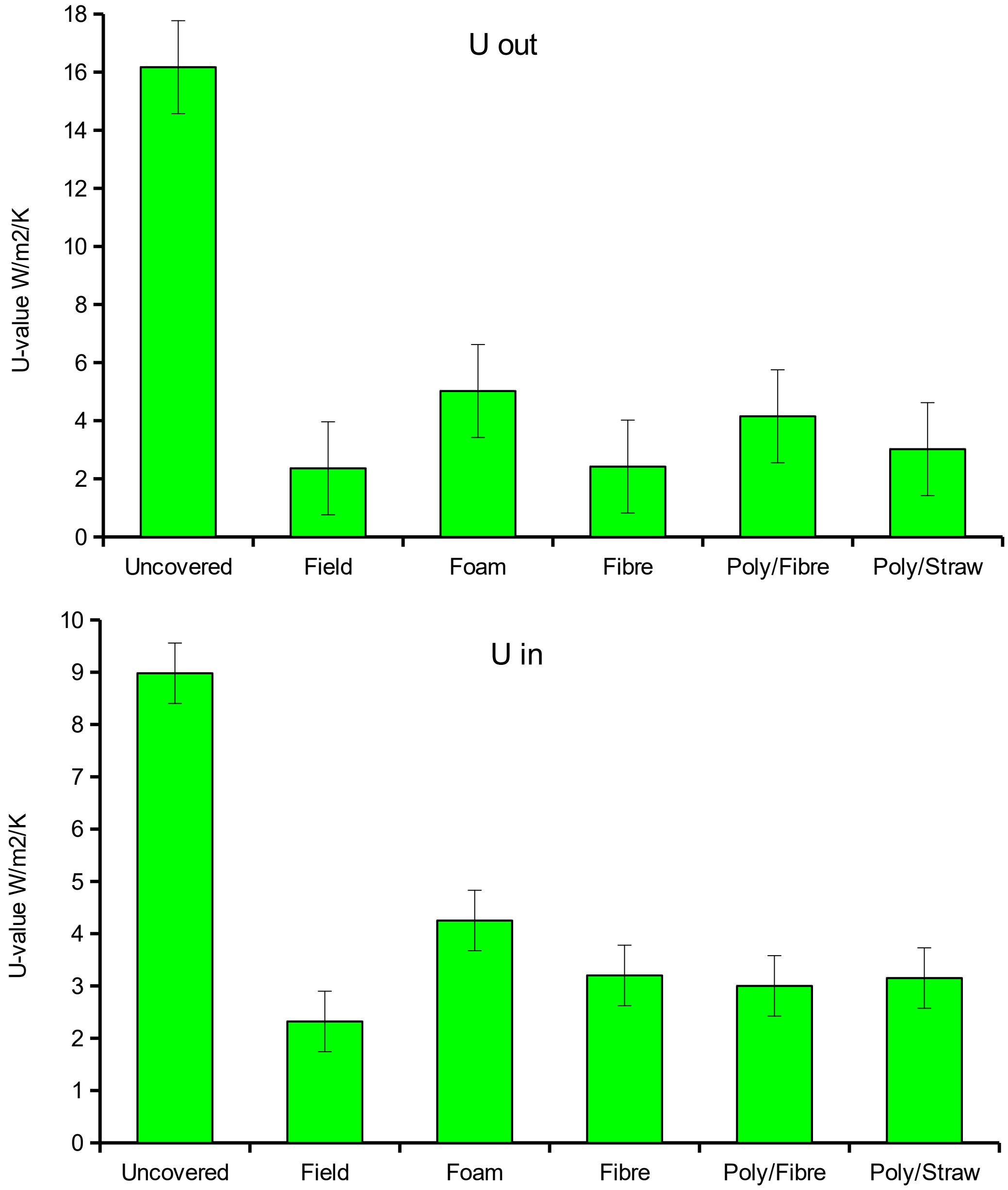

Figure 3. The effect of treatment on the estimated outgoing (soil losing heat) and incoming (soil gaining heat) U-values in 2016-17. A low U-value indicates a good insulator. Error bars represet the standard error of the mean.

Conclusions

- All treatments provided effective 'insulation' in both years of the trials (2015-16 and 2016-17).
- Although the current straw treatments are inefficient in pure insulation terms, it is likely that a significant part of the frost protection provided results from retention of water in the straw-layer. This provides a greater thermal mass (reducing temperature fluctuations) and reduces freezing due to latent heat of fusion.
- Having a layer of polythene below the straw as well as providing another layer of insulation results in greater water retention in the straw layer, increasing its thermal mass, and increasing the potential for evaporative cooling.
- There is no evidence that light-exclusion by the polythene has any impact on crop quality.
- Covering straw with polythene allows the amount of straw to be reduced by about 2/3, whilst achieving a better level of insulation.
- The two non-straw alternatives: cellulose fibre and closed-cell PE foam both provided adequate frost protection.
- Closed-cell PE foam could easily be used as a supplemental layer in the current system if straw is in short supply.
- Cellulose fibre or similar material could provide a realistic alternative to straw, with no risk of weed introduction, reduced potential for nitrogen lock-up, and good crop quality.

Financial Benefits

The area of carrots stored under straw is estimated at around 3-4000 ha per annum. Current estimates for the costs of straw-based field storage systems are around £30 per 500 kg Hesston bale (delivered to field), applied at 80-120 bales/ha. With application and removal included, the technique costs around £4000-5000 per ha on top of crop production and harvesting costs. However, almost as important as cost is the vulnerability of straw supply.

We have identified that a reduction in straw usage of up 2/3 could be achievable by using a poly-over-straw system. This could amount to a saving of £2000 per ha, equivalent to at least £6 million per annum for the industry as a whole.

Unfortunately, whilst providing a realistic practical alternative in insulation terms, the current price of the cellulose fibre used in the study (£480 per t) makes it unlikely to be economic at the present time, but there may be potential for growers to source similar materials locally at lower cost.

Action Points

- Growers wishing to reduce straw usage could consider moving to a poly-over-straw using 1/3 the normal amount of straw.
- Growers able to economically source local sources of cellulose fibre or equivalent, could consider field scale trials.