Grower Summary

FV 398a

Field storage of carrots: identifying novel techniques

Final 2014

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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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Further information

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Headline

In the short-term, the most cost-effective means of reducing straw usage would be to move to a poly-over-straw system, with potential savings of £2000 per ha on straw costs.

Background

UK industry practice is to store carrots for winter and spring marketing *in-situ* in the field, typically covered with a thick layer of straw (with or without a layer of polythene underneath). The aim is to provide insulation against frost damage during the winter and to prevent warming and re-growth in the spring. However, the sustainability of field storage using straw is becoming increasingly challenged – largely due to the high cost and volatile supply of the large quantities of straw required.

Consequently, carrot growers urgently need to examine and evaluate alternative options to current *in-situ* field storage practice.

This project aims to provide the initial step in meeting this need. Novel techniques with similar insulating and light exclusion properties to straw will be identified from a wide range of sectors (including agriculture, construction and chemical industries). All techniques will be evaluated for viability and will be presented to the carrot industry for selection for future testing in 2014.

Summary

The literature on mass heat (energy) transfer in the soil, in insulation layers, and between the soil surface and atmosphere was investigated. The temperature of the soil surface is dependent on the rate of heat/loss or gain from the surface to the atmosphere and the rate of heat transport up and down the soil profile. The deeper layers of the ground/soil act as a reservoir of heat energy. Adding a layer of straw to the surface acts as an insulation layer reducing heat loss during colder periods in the winter and reducing heat gain in the spring. The principles are well understood for the soil/air systems and there is a lot of information on the theory of insulation from the fields of building and engineering. The insulation properties of materials are usually characterised using one or more of the following terms:

- k-value in W/mK is the intrinsic thermal conductivity of a material
- R-value in m^2K/W is the thermal resistance of a material, taking into account its thickness
- U-value in W/m^2K is the thermal transmittance of a system, taking into account all components

Good insulators have low k- and U-values and high R-values.

Characterising the current system is complicated due to the dynamic and thermodynamically unstable nature of the system. Most studies of the insulation values of materials have been done in the context of building and engineering, with measurements under stable conditions. These values do not necessarily provide a good indication of the actual insulation value of straw in the field in the current system. There are three main aspects of the current system that have significant impact on the efficiency of the straw layer as insulation:

Density: as the density of the straw layer decreases, the effective k-value (conductivity) increases, so the insulation value decreases. This means that having a light fluffy layer of straw is less effective as insulation than the same depth of a denser layer of straw.

Forced convection: as the straw layer is not sealed, moving air can penetrate into the surface layers, this air movement increases heat loss, and so the effective k-value increases with increasing wind speed and the insulation value decreases. This effect will also be greater for less dense straw coverings.

Moisture: the presence of moisture in the straw increases the effective k-value and decreases the insulation value. This results from the higher conductivity of water and from the movement of water vapour. Moisture contents of up to 286% were measured in straw samples from field crops. Given that in the UK straw is likely to remain relatively wet throughout most of the winter, the overall insulation value of the straw layer is considerably reduced.

Using soil temperature data, logged at hourly intervals and every 10 cm in the top 40 cm depth of soil under three different surface coverings, we estimated the amount of heat lost from the soil surface on one of the coldest nights (minimum air temp -1.8°C). The total net heat lost from uncovered soil was around 2.25 MJ/m^2 or 39 W/m^2, compared to 3.1 and 2.1 W/m^2 under 10 cm of dense straw and 20 cm of less dense straw. The resulting estimates of the thermal conductivity (k-values) of the straw layers were consistent with those predicted from values in the literature for straw mulches with forced convection.

The role of the polythene layer in the current system is not clear cut. Growers perceive that light-exclusion is important for longer-term storage and discount the insulation value it provides. Apparently, the use of polythene came about as a result of previous ADAS work. There appears to be no information on the effects of light on carrot re-growth, which seems to be mainly temperature dependent. Calculations indicate that insulation value of the polythene sheet may be equivalent to 3 to 5 cm depth of straw. Thus, it may be that the improved storability achieved with polythene may be due to the greater insulation value of the system as a whole.

Another factor reducing the overall insulation value is the effect of the wheelings. When grown on a conventional bed system, wheelings account for approximately 16% of the area. Wheelings are not actively covered with straw, so the incidental covering with straw is thinner. If we estimate that the depth of straw in the wheelings is about half that on the beds, this means that the rate of heat loss will be double for 16% of the area. This thermal bridging effect increases the potential overall heat loss for a field compared to spreading the same amount of straw evenly over the whole area. The resulting surface undulations may also create localised 'frost-pockets'.

Using less straw

Table 1. Comparison of U-values for poly-over-straw vs. straw and straw-over-poly. The moisture content and straw depth represent the measured straw moisture content in a typical strawed crop.

System	Bales per ha	Depth (cm)	Moist. (%)	U-value (W/m^2K)	Material cost ($£/m^2$)
Dry straw	90	15.5	0	1.42	0.31
Dry straw + poly below	90	15.5	0	1.17	0.36
Moist straw	90	15.5	286	1.97	0.31
Moist + poly below	90	15.5	286	1.52	0.36
Poly top + straw	29	5	0	1.09	0.15

Calculations suggest that making more efficient use of straw by keeping it dry, and eliminating forced convection, would have a major impact on the amount of straw required. This could be achieved by covering the top of the straw layer with a layer of polythene. Results indicate that a 5 cm layer of straw covered with polythene would provide the equivalent insulation to 28 cm of uncovered, wet straw, or 20 cm of uncovered, dry straw. Thus it would seems that potential savings in the amount of straw used of up to 75% could be achieved by covering the straw with a layer of polythene. It should be noted that these are theoretical calculations, so it is vital that they are tested experimentally, before wide scale adoption in practice. A further benefit of using less straw would be less N lock-up for subsequent crops. Other aspects that would also need to be examined experimentally are:

(i) whether there would be a need for, or the relative importance of also having a layer of polythene beneath the straw to minimise moisture levels in the straw;

(ii) the influence of the emissivity (reflectivity) of the covering layer, particularly for longer-term storage into the spring, i.e. does the cover need to be white or reflective to minimise heat gain in the spring ?

It is likely that there would be two main challenges to a poly-over-straw system compared to the current system: (a) anchoring the polythene in place (b) avoiding physical damage/breeches in the polythene that would reduce the insulation value of the covering. There are perhaps a number of approaches to (a):

(i) Apply a second layer of straw over the top of the polythene, this would mean that reduction in the amount of straw used would be lower, but even if the overall amount of straw used was only reduced by a third, this would still achieve potential savings of around £1000 per ha. It is likely that this approach would also deal with (b) by providing direct protection and an insurance layer.

(ii) Cut the polythene into the soil at the time of laying as used in current plastic mulch/film covering equipment.

(iii) Specifically apply an additional thick layer of straw to the wheelings to cover the polythene edges.

(iv) Apply the polythene cover across multiple beds with manual anchoring at the edges.

In addition to dealing with (b) by (i) above, there may be a need to use thicker polythene than the 40 µm thickness commonly used at present. This would of course increase costs. Alternatively, provided it is relatively not too great, some loss could be allowed for by increasing the straw depth.

Given the potential savings that can be made in the amount of straw used, it seems that these are likely to more than offset any additional costs of laying and polythene disposal Reduced amounts of straw could also be combined with other systems, e.g. frost-tolerant varieties with deeper crowns, but experimental data would be needed to quantify the the relative impacts of system components.

Alternative insulation materials

A wide range of alternative materials have the potential to achieve equivalent insulation values to straw, especially if they can be kept dry.

Table 2. Calculated U-values and material costs for selected alternative field storage options.

System	t/ha	Density (kg/m^3)	Depth (cm)	kg/m^2	k-value (W/mK)	U-value (W/m^2)	£/m^2	Notes
Moist straw (90 bales/ha)	45	28.6	15.5	4.43	0.31	1.97	0.31	Current system
SF19 (multifoil)	6.9	-	3.8	0.69	-	0.42	5.00	Exceeds insulation needs.
TLX Gold (breathable)	9	-	3.3	0.90	-	0.91	1.50	Price indication from manufacturer
Poly + Rockwool + poly	5	10	5	0.50	0.044	0.70	2.00	

Poly + 2 layers Vattex + poly	7.5	94	0.8	0.75	0.037	1.96	2.40	
Poly + 1 layer Vattex + poly	3.8	94	0.4	0.38	0.037	2.49	1.20	
Closed PE foam	2.6	35	0.75	0.26	0.037	2.89	1.46	Most easily re-used, with longest life.
Closed PE foam	7.0	35	2	0.70	0.037	1.46	3.68	
Poly + Excel fibre + poly	17.5	35	5	1.75	0.044	0.70	0.80	Cheapest realistic alternative.
Poly + PAS100 GW + poly	200	400	5	20.0	0.060	1.02	0.07	Would exceed N limits
Poly + starch peanuts + poly	3.25	6.5	5	0.325	0.040	0.65	1.72	Difficult to handle
Poly + wood shavings + poly	80	160	5	8.0	0.065	0.94	0.72	Issues with N-lock up
Poly + Bark	107	213	5	10.7	0.060	0.89	1.10	Issues with N-lock up
Foil/Bubble			0.4		n/a	3.75	1.49	
Poly alone		0	0		n/a	6.67	0.05	

Plant-based, straw or straw-like materials are likely to have similar insulative properties to straw if they can be applied at sufficient depth and at sufficient bulk density. However, in most cases they are unlikely to be more efficient than straw, in terms of either volume or biomass required per ha. Also, they would all have the same issues with moisture and forced convection, and N lock-up for subsequent crops. Nevertheless if alternative fibrous materials can be obtained locally at low cost, they may be worth investigating as to the amounts needed to achieve sufficient depth and density to replace straw.

At present, most of the non-straw alternatives are likely to be more expensive than straw, so only become feasible if they can be re-used several times or if the price of straw increases further. It should also be considered that costs of some materials could come down if purchased in the bulk quantities that would be required for carrot field storage. Nevertheless some of these non-straw alternatives would still be worth investigating to have on hand as back-up or additional or supplementary options in case of problems with straw availability.

The cheapest non-straw alternative examined was a layer of PAS100 composted green-waste sandwiched between polythene. However the amount required (up 200 t/ha) would preclude its use due to nitrogen application limits. Bark or wood-shavings sandwiched between polythene are also amongst the cheapest alternatives considered, but the amount required to achieve adequate depth (80 to 100 t/ha) would have much greater impact on N lock-up than straw. Possibly the two effects could be combined, e.g. a mix of green-waste and wood-shavings would counteract each other and effectively provide long-term slow release of N into the soil. However, the dynamics of N release and availability in such a system would likely need further study to ensure there were no detrimental cropping and environmental impacts.

Although relatively expensive initially, closed-cell PE (polyethylene) foam, is worthy of further consideration. This is the material typically used in outdoor sleeping mats and as frost protection for freshly laid concrete. It has the major advantage that, unlike most other materials (including straw), its insulation value is unaffected by moisture. It is robust and would have the potential to be re-used for several years, and would not require covered storage. We could envisage that this could be most readily used in the short-term as a replacement for the polythene layer under a reduced straw layer for later crops. Key factors for its widespread uptake would be the number of times it can be re-used, and the cost of the cost of re-cycling or disposal.

Excel fibre (http://www.excelfibre.com/) in a polythene sandwich is another alternative that could become feasible as a single-use option if straw costs increase. This is an industrial 100% re-cycled cellulose-fibre type product similar to one that has been developed as loft insulation (Warmcel) and with similar insulation properties.

Conclusions

- The insulation properties of straw are affected by bulk density, moisture content, and forced convection.
- The current carrot field storage system of straw or straw-over-poly make inefficient use of the potential insulation value of straw.
- Spreading the same amount of straw evenly across the entire field (including wheelings) may be more efficient than just applying to beds and reduce overall heat loss by around 6%.
- The insulation value of the polythene in straw-over-poly is not negligible, but its value for light exclusion has not been established. This needs to be investigated.
- In the short-term, significant reductions in straw use (possibly up to 75%) can theoretically be made by covering the straw with polythene to keep it dry and prevent forced convection. This needs to be confirmed experimentally.
- A range of potential alternatives to straw have potential to provide equivalent or better levels of insulation than the current system.
- The material costs for most non-straw alternatives are higher than the current cost of straw and only become cost-effective if they can be re-used or if straw prices increase significantly.
- At least two non-straw alternatives are worth practical experimental investigation: closed-cell PE foam and Excelfibre in a polythene sandwich. Respectively, these are highly re-usable and at the lower end of the cost scale.

- Closed-cell PE foam could be used as a supplement in the current system if straw is in short supply.
- Some non-straw alternatives could possibly be combined to improve their feasibility.

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.

Theoretical calculations of the insulation values achievable indicate that a reduction in straw usage of up to 67% could be achievable by moving to 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.

Action points for growers

This project was predominantly a desk-study to evaluate potential options, therefore the main action point is to consider funding further work to validate the theoretical calculations and demonstrate the options with the most potential:

- Growers should consider funding experimental work to (a) validate the theoretical calculations reported here; (b) to confirm the potential of the most feasible alternatives so the information is readily available in case of straw price increases or supply issues; (c) understand the effects of light and light-exclusion on spring re-growth and quality; (d) evaluate the effect of pre-conditioning (pre-chilling) prior to covering; (e) develop a model that can be used to accurately predict insulation/straw requirement for different situations.