Carrot Field Storage
The appliance of science

HDC Projects FV 398a/b

05-Nov-2015

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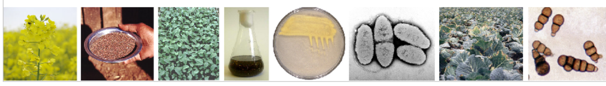
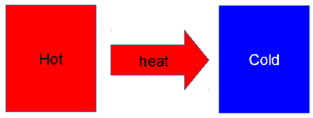
PHS & VCS



Now the science bit…

- **First law of thermodynamics**
  - Conservation of energy
  - Energy can transferred from one form/state to another but cannot be created or destroyed
- **Second law of thermodynamics**
  - Heat will flow from a hotter body to a colder body



Outline

- **Characteristics of current system**
  - **Trying to figure out how what's happening**
- **Possible alternatives**
  - **Upcoming field trials**

Warning ! – nearly all info presented is theoretical

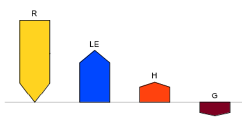
- **Frost doesn't penetrate**
- **Heat is lost**

What are we aiming for ?

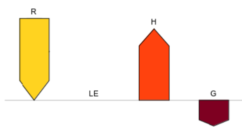
- **Base temp. for carrot growth ~1°C**
  - Ideal storage temp 0-2°C
- **During winter**
  - Prevent freezing
  - Freezing point of both soil and carrots will be below 0°C (depression of freezing point by solutes)
- **During spring**
  - Keep as cool as possible
  - Prevent/reduce re-growth
- **Keep costs down**
- **Minimise environmental impact**

Soil surface energy balances

Day, moist surface



Day, dry surface



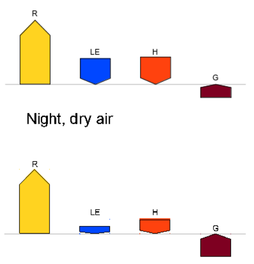
R = Net radiation (in minus out)
LE = latent heat (evaporation)
H = Sensible heat (air movement, conduction
G = Soil heat flux (conduction)

R + H + LE + G = 0

Soil surface energy balances

AHDB

Night, moist air



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It's complicated !

AHDB

- **More complex and dynamic than first imagined**
- **Lots of over-simplification...**
- **Soil**
  - below about 1 m v. little temp variation
  - net energy gain in the day/summer, net loss at night/winter
  - soil type and soil moisture affect k and D values
  - sand > clay > peat; moist > dry
  - ground is a big reservoir of heat energy (cf. ground source heat pumps)
  - to stop surface temperature dropping/freezing at night/cold days....
    - need transfer heat upwards at the same rate as being lost ...
    - and/or reduce heat loss with a layer of insulation....

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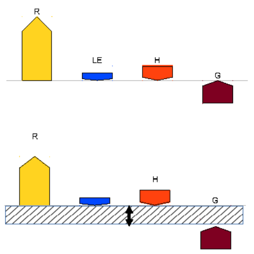
Soil surface energy balances

AHDB

Night, dry air



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By adding a layer of insulation, we hope to reduce the rate of heat transfer from the soil surface to the atmosphere

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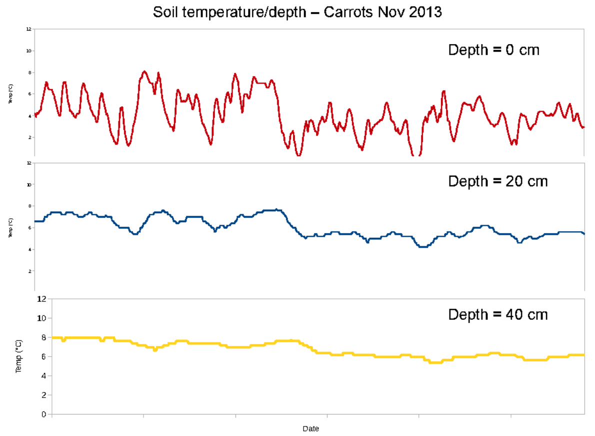

Characterising current system

AHDB

- **It's complicated !**
- **Mass heat (energy) transfer**
  - In the soil
  - In the insulation layer
  - Between surface and atmosphere
- **Need to understand different heat transfer methods**
  - radiation, conduction, convection, latent heat
- **Principles well understood for soil/plant/air**
- **Lot of info/theory of insulation from buildings**
- **Very little info. for layers of straw !**

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Important insulation terms

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- **k-value (intrinsic property of a material)**
  - thermal conductivity, W/m.K
  - low → good insulator
- **R-value (accounts for k and thickness)**
  - thermal resistance, m²K/W
  - takes account of thickness = l/k
  - high → good insulator
- **U-value (used for a system as a whole)**
  - thermal transmittance, W/m²K
  - $1/(R_1 + R_2 + R_3)$, combines R values for all components
  - low → good insulator
- **D**
  - thermal diffusivity
  - ratio of thermal conductivity, k, to volumetric heat capacity, c
  - determines speed of temperature change

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Typical insulation values

Material	k-value W/mK
Still air	0.024
Water (0°C)	0.563
Water (20°C)	0.596
Snow	0.05 to 0.25
Ice	~2
Sand (dry)	0.29
Sand (40%)	2.2
Peat (dry)	0.06
Rockwool insulation	0.04
Straw bale 75 kg/m3	0.052

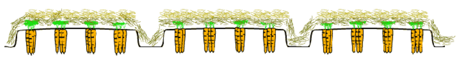
Low k = good insulator
<u>Still</u> air is a very good insulator
Many insulation materials work by trapping pockets of still air:
- air pockets must be small to prevent convection ;
- must be no continuous air gaps (cf. draft proofing);

Dry straw and wind

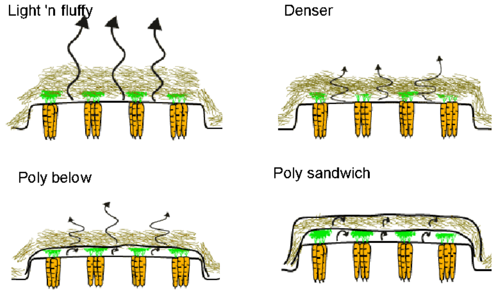
(van Donk, 2000)

Straw insulation

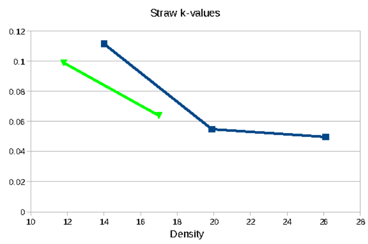
- **Current system is very inefficient**
  - but it works ! (Mostly ?)
  - might be a good thing ? !
- **k-values are variable**
  - open surface layer → affected by wind speed
  - moist/wet → conduction, latent heat
  - low density → continuum of air space



Straw convection



Dry straw and density



Blue line = Danish data, Green = van Donk 2000. Both steady state conditions.

Some measured density values (kg/m3):
Fresh fluffed-up: 12   Fresh rotary combine: 26   Old settled: 21 to 28

Straw and moisture

- **Moisture content of straw layer: ~250% w/w**
- **All insulation values in the literature based on dry straw**
- **Moisture will increase conductivity (reduce insulation value)**
- **Also increases thermal mass (stored heat)**
- **Evaporative conditions → increased heat loss**
  - cooling benefit in the spring ?
- **Freezing conditions:**
  - initially may reduce rate of downward movement of ~0°C isotherm
    - water has to freeze in each layer first
    - latent heat of fusion (334 kJ/kg) >> specific heat capacity (4.2 kJ/kg.K)
  - but once frozen ice is a better conductor than water (~4X)
- **On balance better to maximise insulation by keeping dry**

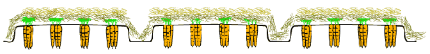
Polythene (below straw)

- **Light exclusion ?**
  - No evidence or research on effects of light on storage/re-growth.
  - Temperature is main driver of re-growth.
  - May affect physiology, plant hormone levels ?
- **Little intrinsic insulation value BUT...**
  - traps an air layer, prevents evaporation
  - provides surface resistance to heat transfer
  - cf. survival bags work !
- **Potentially equivalent to about 3-5 cm of *dry* straw.**
- **Effects on gas exchange: CO_2↑ O_2 ↓ ?**

Straw alternatives

- **Based on comparison of insulation values**
- **Using realistic k-values for straw**
- **Compare systems using U-value (low = good)**
- **Ideal requirements:**
  - equivalent/better insulation than current systems
  - no more expensive than current system
  - bio-degradable or re-useable
  - similar or lower transport costs (lower bulk)
  - can be laid as quickly, with similar labour to current
- **Ideal insulation would give a continuous cover with no gaps (thermal bridges)**
  - but where would the water go ?

Thermal bridging



- Heat moves horizontally as well as vertically
- Follows the path of of least resistance
- Wheelings comprise approx 16% of field area – significant heat loss
- Straw filling in the wheelings is a good thing

Reduced straw

System	Bales	Depth	Densit	Moist	k	R1	R2	U	£/m2
Dry straw	90	15.5	28.6	0	0.22	0.70		1.42	0.31
Dry + Poly	90	15.5	28.6	0	0.22	0.70	0.15	1.17	0.36
Moist straw	90	15.5	28.6	286	0.31	0.51		1.97	0.31
Moist + Poly	90	15.5	28.6	286	0.31	0.51	0.15	1.52	0.36
Poly top + straw	29	5	28.6	0	0.065	0.77	0.15	1.09	0.15
Foil + straw	29	5	28.6	0	0.065	0.77	0.34	0.90	?

- **Poly on top of straw clear benefit**
  - maximises insulation value of straw
  - potentially only 1/3rd amount of straw needed
  - challenge is to keep poly in place

Current system summary

- **Dynamic, thermally unstable system.**
- **Difficult to characterise.**
- **Dense layer more effective than fluffed-up layer:**
  e.g. 15 cm (21 kg/m3) ≡ 30 cm (14 kg/m3) [2.3 v 4.2 kg/m2]
- **But....**
  - initial 'fluffing-up' may help lock together
  - subsequent settling increases density
- **Inefficient use of straw – moisture and wind.**
- **Insulation value of poly is not negligible.**
- **Wheelings (=16% of area) → less insulation → heat loss↑**
  - thermal bridging....reduces overall insulation level
- **But it works !**

Non-straw alternatives

System		Depth	Dens	Moist	k	R1	R2	Ri	Re	U	£/m	
Moist straw	90	15.5	28.6	286	0.31	0.507				1.97	0.31	
SF19		3.8				2.21		0.11	0.033	0.42	5.00	
TLX Gold (breathable)						0.95		0.11	0.033	0.91	1.5?	*
poly-Rockwool-poly		5			0.044	1.14	0.15	0.11	0.033	0.70	2.00	*
2 layers Vattex + poly		0.8	94		0.037	0.22	0.15	0.11	0.033	1.96	2.40	
1 layers Vattex +poly		0.4	94		0.037	0.11	0.15	0.11	0.033	2.49	1.20	
Closed cell PE foam		0.75			0.037	0.20		0.11	0.033	2.89	1.46	*
Closed cell PE foam		2			0.037	0.54		0.11	0.033	1.46	3.68	*
Warmcell poly sandwich		4	40	0	0.044	0.91	0.15	0.11	0.033	0.83	1.10	*
poly-PAS100 GW		5	400		0.06	0.83	0.15			1.02	0.07	200 t/ha !!
Starch peanuts poly sandwi		5			0.04	1.25	0.15	0.11	0.033	0.65	1.72	
Foil/Bubble		0.4				0.12		0.11	0.033	3.75	1.49	
Poly alone		0	0	0	0	0.00	0.15			6.67	0.05	

- All except closed cell PE need to be dry
- Nearly all are much more expensive than current
- Need to be re-used several times to be cost effective
- Biggest challenge - to anchor down/keep in place

Field trials 2015-16

- **Validate theoretical calculated U-values etc.**
- **Six treatments:**
- **Three locations:**
  - Scotland, Yorks, Norfolk
- **Two harvest dates**
- **Data loggers recording temp at up 6 depths**

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Acknowledgements

- **Tim Lacey who got the work started at VCS**
- **AHDB Horticulture and BCGA for financial support**
- **Rodger Hobson, the grower representative, for useful discussions and insights**
- **The three growers providing us with trial sites:**
  - Hobsons
  - TBG
  - AA Carrots
- **The team at VCS for all their help and support**

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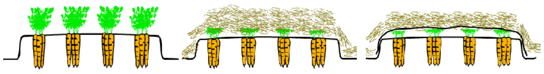
Field trials 2015-16

Uncovered Straw Straw over polythene



Straw sandwich Cellulose fibre sandwich Closed cell PE foam

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Thank you for listening

Any questions?

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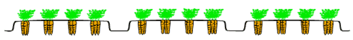

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Other things to consider ?

- **Effect of pre-conditioning prior to covering**
  - some exposure to low temperatures may increase frost tolerance
  - don't cover too soon ?
  - but there may be effects on quality ?
- **Soil moisture**
  - big effect on soil conductivity
  - if low, heat will not get to the surface as quickly
  - but high will increase risk of Pythium and other rots
- **Understand effect of light/light exclusion on re-growth/quality**

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