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Project leader:	Dr Catherine Eyre, ADAS Horticulture
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[The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.]

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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CONTENTS

GROWER SUMMARY

Headline

There are viable alternatives to peat for use in the vegetable propagation industry. Fine composted bark is a very promising new material, but availability may be an issue. Blocking is more challenging that modules. More work is required by growing media producers to develop and bring these peat alternatives to market.

Background

Government targets along with retail, environmental and public pressures are all pushing towards the reduction and eventual elimination of peat from horticulture. In August this year the Government announced that the sale of peat to amateur gardeners in England is to be banned by the end of 2024. The Government is also encouraging the transition to peat-free alternatives in the professional horticulture sector, with a ban on peat to follow at some point in the near future.

A great deal of effort has been put in to developing peat-alternatives. There are some specialist areas, however, that turn up particular challenges. One of those is vegetable propagation. In vegetable propagation, very small containers are filled mechanically with substrate. A single seed is planted in each container where it then germinates. The seedlings are raised under glass before being mechanically planted out in open fields at high speed. There are multiple issues here, in addition to 'simply' identifying a basic peat-free or peat-reduced substrate. Firstly, the substrate must be able to flow into small containers, or be formed into small substrate 'blocks'. Secondly, the substrate must be suitable for seed germination. Finally, the small substrate bolus and seedling must be able to survive mechanical planting in a field.

If the transition to peat-free is to be respected then peat-alternatives for vegetable propagation must be found. If not, the sector is threatened. Since vegetable propagation is an important contributor to high-efficiency food production and food security this cannot happen. Workable solutions must be found.

In search of solutions towards this goal this project considered the transition to peat-reduced and peat-free substrates in three different vegetable propagation methods: blocking, modules and ellepots.

In 'blocking', moistened substrate is mechanically compressed into a slab then cut by a square grid of blades to create a set of individual 37.7 x 36 x 36 mm cubic blocks. Blocks are created a tray at a time, with 176 blocks per tray. A set of dibbers makes a small depression in the centre of each block ready to receive a seed. In the blocking method the substrate must be self-supporting and the block must be capable of sustaining mechanical handling without any container support, though once the seedling has developed there is root support for the substrate. Because blocks are self-supporting their creation conventionally relies on special sticky ‘blocking peat’.

‘Module trays’ are plastic trays with arrays of cells to receive substrate. Each cell has a 25 by 25 mm opening and a depth of 43 mm, giving a cell volume of 15.5 cm^3. There are 345 cells per tray. Modules are filled by flowing substrate into the cells row by row. Rotating brushes press the substrate into the cell and remove excess material. The substrate plus subsequent seedling is supported by the material of the tray. However at planting-out time the seedling plus substrate and root ball must retain its structural integrity without relying on the module tray for support.

The third and final technology is the ellepot system. Substrate is fed under suction to a continuous paper-wrapping stage. Every few centimeters the continuous emerging ‘sausage’ of paper-wrapped substrate is sliced into separate cylinders which are then stored vertically side by side in trays ready for sowing and planting out. Significantly, the cylinders are open top *and* bottom. Like modules, the ellepot system relies on a relatively free-flowing substrate. Each ellepot cylinder is typically 33 cm^3 (diameter 29 mm, depth 50 mm). At planting out, the substrate plus seedling is supported by the paper sleeve which relieves the need for so much structural integrity from the substrate. The paper sleeve is biodegradable.

At the growers request, this project considered both peat-free *and* peat-reduced options, the latter being a step towards the ultimate peat-free objective and potentially easier to achieve. Crops that featured in this work were lettuce, celery, tenderstem broccoli, kale, cauliflower and spring greens.

There are three disparate threads to this project.

1. Existing commercially available peat-reduced and peat-free blends were trialled in various combinations with the three propagation technologies.

2. Growing media producers supplied small quantities of promising prototype materials. These were assessed via laboratory measurements of their physical characteristics. The results were compared with a reference dataset of a range of raw materials, leading to the selection of the most promising of the prototypes on offer. Other factors such as material chemistry, availability and flow properties were also considered, leading to a final selection of peat-free and peat-reduced (50:50 blends of peat and prototype peat alternative) that were assessed for block, module and ellepot creation and seedling growth.

3. Mechanical assessment of substrates using laboratory compression testing. The objective was to assess the substrates' mechanical handling properties, an important aspect of their suitability for vegetable propagation, especially for blocking. The impact of binders, additives whose intended role is to provide additional cohesion to the substrate, was also investigated. Thread two, which investigated prototype materials for filling and growing, likewise considered substrate options containing binders.

Summary

- The objective of this project was to explore peat-reduced and peat-free candidate substrates for vegetable propagation using blocking, modules and ellepots. We have confirmed that finding candidate substrates for blocking is the most difficult.
- Commercially available candidates, both peat-reduced and peat-free, are available for modules and ellepots.
- A 15% peat-reduced commercially available candidate for blocking exists
- Prototype materials were supplied by growing media manufacturers. These formed the basis of test substrates, though in some cases additional processing was required. Amongst these test substrates, viable peat-reduced and peat-free candidates were identified for modules and ellepots, but not for blocking.
- Among the new materials trialled, fine (0-2 mm) composted bark, a material not routinely available, was found to be of particular merit.
- Growing media producers struggle to supply substrates of adequate quality, or novel substrates in significant amounts. The supply of substrates is a pinch point on the path to peat-reduced and peat-free vegetable propagation.
- Mechanical testing of hand-formed substrate blocks showed that water content strongly influences their strength, and that some materials apparently gave rise to blocks sufficiently strong for mechanical blocking. This conflicts with subjective assessment of the materials as blocking candidates.
- Binders may have a role in substrate block strength, in the water content required to achieve that block strength, and in the growing success of the crop, but our data is not comprehensive enough for a definitive overview.

The objective of this project was to explore peat-reduced and peat-free candidate substrates for vegetable propagation using blocking, modules and ellepots. Vegetable propagation is a demanding system: substrates need to support germination, seedling growth and the creation of small growing units. In addition those small growing units – blocks, modules and ellepots – must be able to sustain mechanical handling.

For modules and ellepots there already exist peat-reduced (50% and 70%) and peat-free substrates that, according to this project, are viable solutions: modules and ellepots can be created, seeds germinate and develop, and planting out is successful. Further, two different peat-free blends were studied, one of which performed satisfactorily and one of which performed poorly. An additional organic peat-free substrate was trialled for modules, but its growing performance was disappointing and it was not sent for planting out.

For blocking, a single 15% peat-reduced substrate was available to the project (a second 30% peat-reduced material was defective and was abandoned). This was successful, though the blocks were inferior to those made with the peat standard, highlighting the challenge facing the creation of blocks with alternative materials.

Of the prototype materials contributed by the growing media manufacturers, many were confidential even from members of the project team. With regard to three key physical parameters, AFP (air filled porosity), D_b (dry bulk density) and AW (available water), comparison with a reference library of raw material values saw five prototype materials excluded. Others materials were dropped on the basis that, even at a 50% blend with peat, some chemical properties might remain problematic. Other materials were simply unavailable. In summary, the project generated a list of eight materials (comprising six prototype materials) to carry forward. Two of these materials were peat-free. The remaining six were peat-reduced at the level of 50% peat and 50% non-peat. In all cases there were severe limitations on the availability of materials that impacted directly on project outputs – some materials were available in only a few litres in an industry where cubic metres are necessary to fully test the entire production process. Also, some materials required specific processing by the supplier, whilst others required in-house sieving to remove over-sized material.

The non-peat materials used were wood fibre, coir, composted bark (0-2mm) and two unidentified materials. Both the peat-free options were 100% composted bark (0-2mm). Where sufficient material was available, 'with binder' versions were also created. Counting the no-binder and with-binder versions as distinct, in total fourteen substrates were carried forward for limited assessment.

For modules, two substrates (plus the binder version of one of these) gave a superior performance in terms of both filling and seedling growth. One of these substrates was peat free, composed of composted bark (0-2 mm). Several other substrates gave useful outputs. Some were compromised by the presence of woody fragments, which interfere with module filling. These fragments should not be there, and suggest that one improvement for module filling lies with improved quality control of substrates to ensure disruptive fragments are absent. Of this second tier of substrates, one was peat-free, composed of composted bark (0-2 mm), and another was a 50:50 blend of this bark with peat. A third tier of substrates, a single candidate plus its binder partner, failed to grow.

All the experimental substrates bar this final one gave modules that could be extracted from the module tray, an essential prerequisite for field planting. In conclusion there are several viable candidates amongst the prototype substrates for use in modules. The choice is governed to some extent by the compromise between mechanical handling and seedling growth. Both peat-reduced and peat-free candidates exist.

For ellepots, two peat-reduced blends and their with-binder partners gave overall superior performance. Two other substrates and their with-binder partners gave a weaker performance. One of these tier-two materials was a peat-free composted bark (0-2 mm) material that caused filling problems due to the presence of woody fragments but which gave good seedling growth. The same material that failed for modules also failed for ellepots. For the other materials, though planting out was not explicitly trialled no problems were anticipated as the finished ellepots were satisfactory. Fewer substrates were available for ellepot trials due to the shortage of materials. Overall, the conclusion for ellepots mirrors that for modules –there exist viable peat-reduced and peat-free candidates, even better with improved quality control.

There was no clear pattern of the impact of binders on the creation of modules and ellepots. However, there is a hint of some impact on growth. For two substrates in ellepots, the binder version gave superior top growth. In a third substrate the binder version displayed better germination. The evidence is not robust but the impact of binder on top growth is likely worth further investigation.

In the case of blocking, according to subjective assessment none of the substrates carried forward in this project were likely to produce adequate blocks. This, together with only one commercial 15% peat-reduced blend suitable for blocking, confirms that finding candidate substrates for blocking is the most difficult of the three.

Compression testing of hand-made blocks of substrate gave readings for the load required to induce their fracture. These values we have termed the ‘strength’ of the substrate block. Water content of the material was found to be important – too much and too little both gave weaker blocks. The impact of the binder on the overall strength of the substrate blocks was unclear.

Mechanical testing allows comparisons between blocks made of different materials with a block made of black Baltic peat, a material which can itself be used as a blocking substrate. Therefore, even if the absolute values of ‘block strength’ do not have a directly accessible meaning, the hypothesis is that a *comparison* between a block made of a material of interest and with one made from black Baltic will be relevant. On this basis, all of the blocks tested are broadly comparable in strength with the black Baltic peat. Two (plus a binder partner of one of these) appear stronger and might be considered candidates for blocking substrates. However, this does not agree with the subjective assessment of the suitability of these substrates for blocking. Proper testing of candidate materials – with sufficient quantities (in the cubic metre range) to run through real blocking equipment – would resolve the issue. It is also possible that the mechanical testing regime is not measuring the block mechanical properties in a way that is wholly relevant to blocking. It is clear this is an area requiring more investigation.

A theme throughout this project is the availability or otherwise of substrate materials. The basic limitations are well-known: the key sustainable raw materials are coir, wood fibre, bark and green compost. Green compost is distrusted by the professional horticulture sector: the growers in this project would not even consider its inclusion, and some growing media producers will not supply it. Coir is a fine substrate but is in limited supply and must be imported from the tropics. With wood fibre and bark it is worth emphasising that a given substrate is in fact a result of *both* the fundamental raw material *and* the processing it is subject to. There are other candidate materials but currently all have serious limitations. The vegetable propagation sector would benefit from a fresh look at processing of known materials, at improved quality control of existing materials, and the introduction of wholly new materials.

Financial Benefits

This project attempts to preserve a key industry sector through the transition to a peat-free operation.

Action Points

- For modules and ellepots peat-reduced and peat-free candidates clearly exist. Propagators need to conduct trials sufficient to identify substrates that work on their sites and with their crops to give the confidence to make the transition from a peat-based operation.
- Blocking needs additional effort focussed entirely on the search for new blocking substrates in tandem with laboratory-based substrate assessment methods, especially mechanical assessment. It is the mechanical issue with blocks that is the real problem.

- Substrate providers need to improve quality control, particularly with regard to removing fragments from wood-based products.
- Substrate producers need to explore further the development and supply of fine (0-2mm) composted bark, since this project shows that this material performs well in the vegetable propagation environment.

SCIENCE SECTION

Introduction

Government targets along with retail, environmental and public pressures are all pushing towards the reduction and eventual elimination of peat from horticulture. A Defra-funded project overseen by AHDB and undertaken by ADAS set out to examine ways in which sustainable materials might be used as peat alternatives (‘Transition to Responsibly Sourced Growing Media Use Within the UK’, CP138, 2015-2019). By focusing on sustainable materials, which in practice translates into plant-based materials such as coir, bark, wood fibre and green compost, that project developed a strategy for *designing* substrate blends. In particular, three physical parameters, air-filled porosity (AFP), dry bulk density (D_b) and available water (AW) were used to describe materials and blends in a unifying strategy that moves away from conventional recipe-based descriptions of blends. Candidate raw materials and blends are then easily identified via their position relative to known high-performing substrates in the three-dimensional AFP – D_b – AW space.

That project, and other researchers and commercial players in horticulture, have formulated useful peat-reduced and peat-free blends. However there are some specialist areas that bring additional challenges. One of those is vegetable propagation. In vegetable propagation, very small containers are filled mechanically with substrate. A single seed is planted in each container where it then germinates. The seedlings are raised under glass before being mechanically planted out in open fields at high speed. There are multiple challenges here, in addition to ‘simply’ identifying a basic peat-free or peat-reduced substrate. Firstly, the substrate must be able to flow into small containers or be formed into small substrate ‘blocks’. Secondly, the substrate must be suitable for seed germination. Finally, the small substrate bolus and seedling must be able to survive mechanical planting in a field.

The current project addresses these problems against a backdrop of a parameter-based description of substrates. Participating growers expressed interest in both peat-free and peat-reduced substrates, for which reason both are considered here. In addition, the project has two distinct phases. In the first, commercially available substrates are trialled as candidates for vegetable propagation. In the second, prototype materials and blends that are currently unavailable on the open market are explored. A novel element of this project is the direct mechanical testing of substrates as a way of assessing their suitability for machine handling. This project has benefitted from the collaboration of scientists, commercial substrate producers and commercial vegetable propagators and growers.

Materials and methods

Three propagation technologies were considered. In ‘blocking’, moistened substrate is mechanically compressed into a slab then cut by a square grid of blades to create a set of individual 37.7 x 36 x 36 mm cubic blocks. Blocks are created a tray at a time, with 176 blocks per tray. A set of dibbers makes a small depression in the centre of each block ready to receive a seed. In the blocking method the substrate must be self-supporting and the block must be capable of sustaining mechanical handling without any container support, though once the seedling has developed there is root support for the substrate. Because blocks are self-supporting their creation conventionally relies on special sticky ‘blocking peat’.

‘Module trays’ are plastic trays with arrays of cells to receive substrate. Each cell has a 25 by 25 mm opening and a depth of 43 mm, giving a cell volume of 15.5 cm^3. There are 345 cells per tray. Modules are filled by flowing substrate into the cells row by row. Rotating brushes press the substrate into the cell and remove excess material. The substrate plus subsequent seedling is supported by the material of the tray. However at planting-out time the seedling plus substrate and root ball must retain its structural integrity without relying on the module tray for support.

The third and final technology is the ellepot system. Substrate is fed under suction to a continuous paper-wrapping stage. Every few centimeters the continuous emerging ‘sausage’ of paper-wrapped substrate is sliced into separate cylinders which are then stored vertically side by side in trays ready for sowing and planting out. Significantly, the cylinders are open top *and* bottom. Like modules, the ellepot system relies on a relatively free-flowing substrate. Each ellepot cylinder is typically 33 cm^3 (diameter 29 mm, depth 50 mm). At planting out, the substrate plus seedling is supported by the paper sleeve which relieves the need for so much structural integrity from the substrate. The paper sleeve is biodegradable.

Two principle vegetable propagators were involved in the project. 1. Crystal Heart Salads in Yorkshire, which uses blocking and ellepots. 2. Sheepgate Nursery in Lincolnshire, which uses modules.

It is helpful to clarify the terminology of the field planting stage. A fully automatic planter takes entire trays and removes individual plants for placing in the ground: the operator supplies whole trays. In semi-automatic planting, a group of operators on the planter remove individual plants from trays and place them in carousels from where the machine then transfers them into the ground. Manual planting is planting by hand.

Growing-on in fields was undertaken by G’s Growers, Cambridgeshire, Farringtons in Lancashire and Elsoms in Spalding.

Trial plants

Crops that featured in this project were lettuce (cv. Challenge and Elizium), celery (cv. Victoria), tenderstem broccoli (cv. Inspiration), kale (cv. Reflex), winter cauliflower (cv. Cartagena and Isadora) and spring greens (cv. Winter Supreme and Verve).

Commercial substrates

Three companies, ICL, Sinclair Pro and Klasmann-Deilmann, supplied both commercially available substrates and prototype substrates. Table 1 summarises the commercial materials supplied to the project. For the open field trials using commercial substrates, some were assessed in detail as set out below. Others were assessed subjectively via trial photographs to gauge the success of the crop planting out and establishment.

Table 1. Commercial blends and propagation methods

Trial type	Substrate	Site
Blocking trial	15% peat-reduced	Crystal Heart
Blocking trial	30% peat-reduced	Crystal Heart
Modules trial	15% peat-reduced	Farringtons
Modules trial	30% peat-reduced	Farringtons
Modules trial	15% peat-reduced	Sheepgate
Modules trial	30% peat-reduced	Sheepgate
Modules trial	100% peat-free organic	Sheepgate
Modules trial	100% peat-free conventional	Sheepgate
Ellepots trial	50% peat-reduced	Crystal Heart
Ellepots trial	70% peat-reduced	Crystal Heart
Ellepots trial	100% peat-free	Crystal Heart

Prototype substrates

The three participating substrate companies supplied a total of 20 materials in addition to the commercial materials listed above. These are anonymous for commercial reasons. The selection included composted bark, wood fibre and coir, and in addition some materials that are totally novel. At least three materials were peat-based.

Physical parameter assessment

Substrates were physically characterised in terms of three parameters, AFP, D_b and AW. The AFP, air filled porosity, is the proportion of air-filled pores following gravity-induced drainage of the substrate. Dry bulk density, D_b, is the density of the substrate matrix free of any water. The available water, AW, is the amount of water that can be extracted by plants from the substrate while respecting the competition between plant and capillary pressure. AW measurements were taken at a pressure of 5 kPa. The physical parameters were measured in-house according to a published protocol (Mulholland et al, 2016). The physical parameters of the commercial materials were not assessed. The prototype materials were assessed via duplicate measurements.

Chemical assessment

Materials were sent to NRM for routine chemical analysis using the H001 Compost Suite (for growing media). Chemical analysis was undertaken for both the commercial materials and the prototype materials.

Mechanical testing

Blocks of substrate for mechanical testing were created four at a time using a simple hand-held compression and cutting machine, Figure 1. Each cell was overfilled with substrate then pressed down, to emulate the substrate compression that occurs in a mechanical block-making machine.

Figure 1. The upper panel shows the simple hand-held block making machine. The lower panel shows a typical set of four blocks produced in this way.

Mechanical testing was performed using a high-accuracy compressive-force measuring machine. A contact element provided the interface between the force measure machine and an individual block. Blocks were tested to destruction. Each compressive load measurement was determined three times on three different blocks from a given substrate.

Results

Commercial Materials

Blocking

Propagation trials using blocks made from commercial blends were carried out at Crystal Heart Salads from June to July 2021. Two peat-reduced blends (15% reduced and 30% reduced) were supplied by one growing media manufacturer. The 30% reduced blend was unusable due to a manufacturing fault that left too many large wood fragments in the blend that threated the block-forming blades.

The 15% reduced product was run through the machine on 24 June 2021 (week 25) to fill the trays and create the blocks, Figure 2. Blocks were created successfully. The trays were then used to create two trials, one on lettuce (cv. Challenge) and one on celery (cv. Victoria). Seeds were sown using the seeding machine and the trays were placed on the floor under glass and grown alongside the nursery peat standard product for comparison. Irrigation was overhead by automatic boom. A data logger was placed with the trial to collect temperature and humidity data during propagation.

Figure 2. Blocks created using 15% peat-reduced media

Once the plants reached planting size, a sub-sample of trays were sent to G's Growers, Cambridgeshire, for planting in the field. The lettuce was planted into two large demonstration plots on 14 July 2021 (week 28) using a semi-automatic planter. Trays of nursery peat standard and 15% peat-reduced lettuce plants were also sent to ADAS Boxworth for assessment. Young plants were assessed for height (mm), quality (0-3 scale), fresh weight and dry weight. In addition, 25 blocks per media were dried in the oven at 80°C for 48 hours and dry weight recorded, along with block volume, so that bulk density could be calculated.

The celery blocks were planted on 27 July 2021 (week 30) using a smaller semi-automatic planter. As with the lettuce, plants were planted into two large demonstration plots and trays of young plants were sent to ADAS Boxworth for assessment, using the same assessment criteria.

Once the lettuce field crop had reached maturity, Figure 3, 30 heads from each demonstration plot were harvested by hand (03 September, week 35) and sent to ADAS Boxworth for assessment. Heads were assessed for head weight, head diameter and internal core length.

For the celery field crop, ADAS were notified by G's in the first week of November that the crop was not going to mature further and so was due for destruction. ADAS harvested 10 plants per plot and assessed the plants for stick length, stick weight and stick number per plant.

Figure 3. Lettuce blocks planted in the field in week 28 (left) and at harvest (15% peat-reduced) in week 35 (right).

In Figure 4 the upper panel bar chart compares crop heights for block-grown lettuce and celery using either peat standard or 15% peat-reduced. The lower panel is the corresponding fresh weights. There is little in the data to suggest any difference in heights for the two blends; for weights the mean values in the 15% peat-reduced case exceed those of the peat control but there is insufficient statistics to confirm significance.

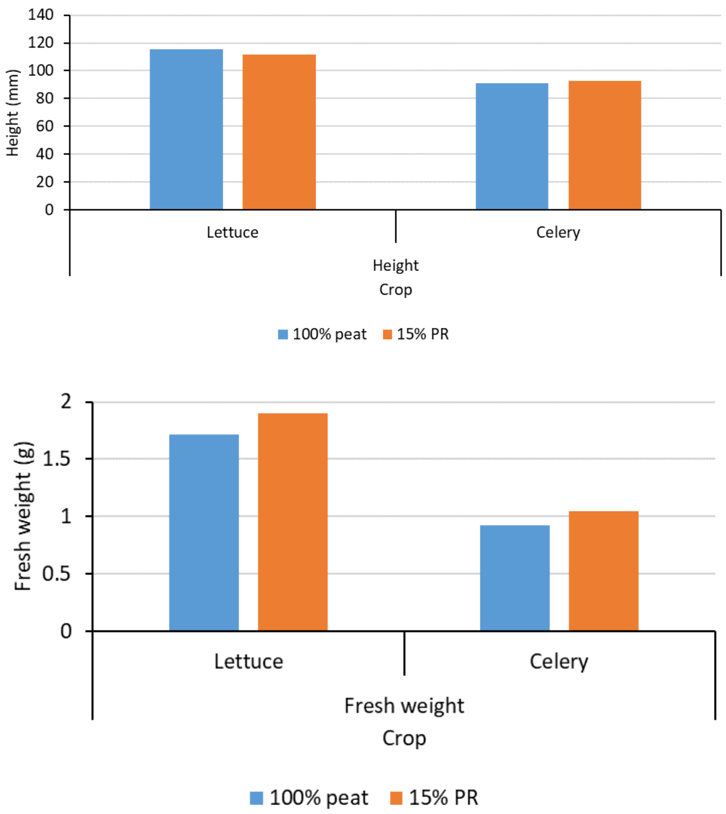

Figure 4. Block-grown lettuce and celery, peat versus 15% peat-reduced. The upper panel records the height of young plants prior to field planting at G's. The lower panel records the fresh weights

Harvest – Lettuce

Table 2 shows that in blocking trials the 100% peat had slightly higher averages across the weight, diameter and core length categories compared to the 15% peat-reduced.

Table 2: Blocking trials, lettuce, average weight, diameter, and core length of the harvested lettuce, peat control versus 15% peat-reduced substrate.

	Average lettuce weight (g)	Average lettuce diameter (cm)	Average lettuce core length (cm)
100% peat	689.31	15.78	4.71
15% PR	665.43	15.43	4.10

A closer inspection of the lettuce weights, in which they are ranked by weight within each substrate, shows a detail missed when using only averages, Figure 5. At lower weights

(<600g) there is a group of plants in peat-reduced substrate that have in some cases dramatically smaller weights that those grown in peat: the peat-reduced case shows a 'tail' of small plants absent in the peat control case.

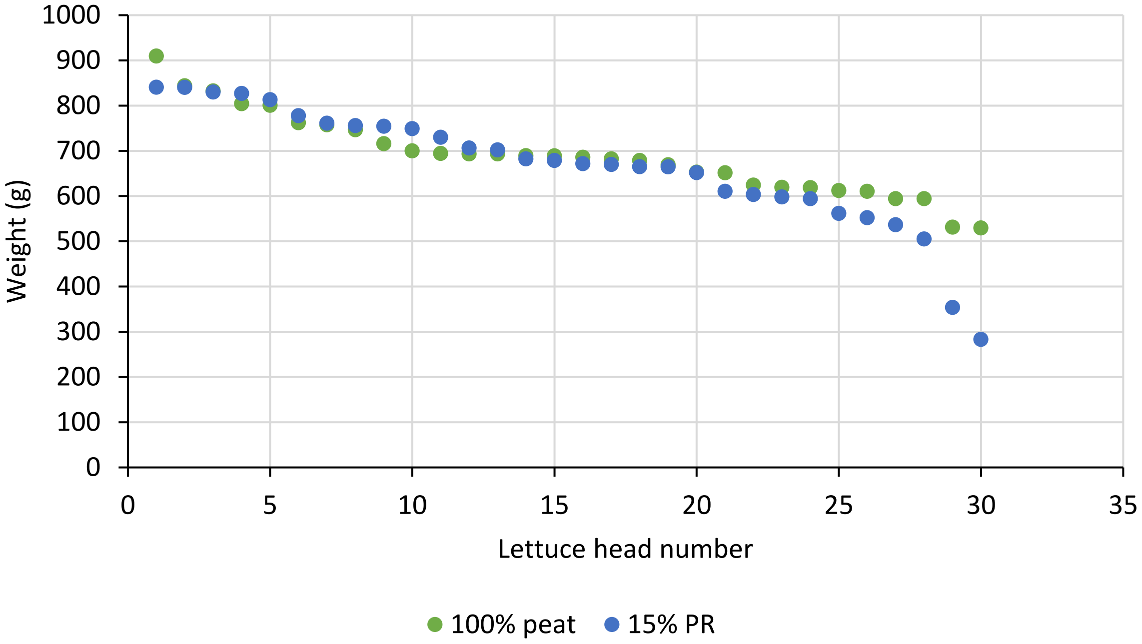

Figure 5: Block-grown lettuce, weight versus lettuce head number, with data ranked by weight for each of the two growing media types.

Harvest – Celery

Table 3 compares blocking trial results for the average number of sticks per plant, stick length and stick weight for celery grown in peat compared to that grown in 15% peat-reduced. The table shows that there was little variation in the average number of sticks between the two treatments, but average stick length was 6% higher in the peat-reduced case and stick weight was 13% higher.

Table 3. Blocking trials, celery, average number of sticks per plant, stick length and stick weight, peat control versus 15% peat-reduced substrate

	Average no. of sticks	Average celery stick length (mm)	Average celery stick weight (g)
100% Peat	15.7	540.02	28.13
15% PR	16.5	575.45	31.69

Ellepots

Propagation trials using ellepots (Figure 6) were carried out at Crystal Heart Salads from June to August 2021. Three growing media blends were supplied by two manufacturers: 50% peat-reduced, 70% peat-reduced and 100% peat-free. These were compared against the nursery standard control product (100% peat).

Figure 6. Ellepot paper sleeves containing nursey 100% peat standard substrate.

The trays were filled with media from 25 – 27 June (week 25) and the celery was sown on 26 June. The lettuce was sown on 16 July (week 28) so that both species would be ready for planting at the same time. The trays were placed on the floor under glass and grown alongside the nursery standard product for comparison. Irrigation was overhead by automatic boom. Once the plants were ready for planting, a sub-sample was sent to G's. As the ellepot planting machine was not available, plants were planted by hand into demonstration plots. Both the lettuce and celery were planted in the same field on 07 August (week 31). Some trays were also sent to ADAS Boxworth for assessment. Plants were assessed for height (mm), fresh weight and dry weight.

The 100% peat-free ellepots were not sent for planting or assessment because, following germination, the seedlings failed to grow adequately, c.f. figure 12 below.

As with the blocking, ADAS were notified by G's in early November that the celery crop was not going to mature further and so was due for destruction. ADAS harvested 10 plants per plot and assessed for stick length and stick weight and the number of sticks were counted. The lettuce plots were unfortunately damaged by a heavy frost and could not be harvested.

Plants were assessed for height and weight prior to planting out, Figure 7. The upper panel shows heights for the control (100% peat control), 50% peat-reduced and 70% peat reduced for the two crops, lettuce and celery. The lower panel shows fresh weights. Celery shows little variation in either height or weight at this stage of development. There is more variation in the case of lettuce, with the average values of height and weight for the 70% peat reduced exceeding those of the control and 50% peat reduced. The important point is that both the peat-reduced substrates gave a viable product. Ellepot trials using commercial peat-free materials supplied to the project were not successful.

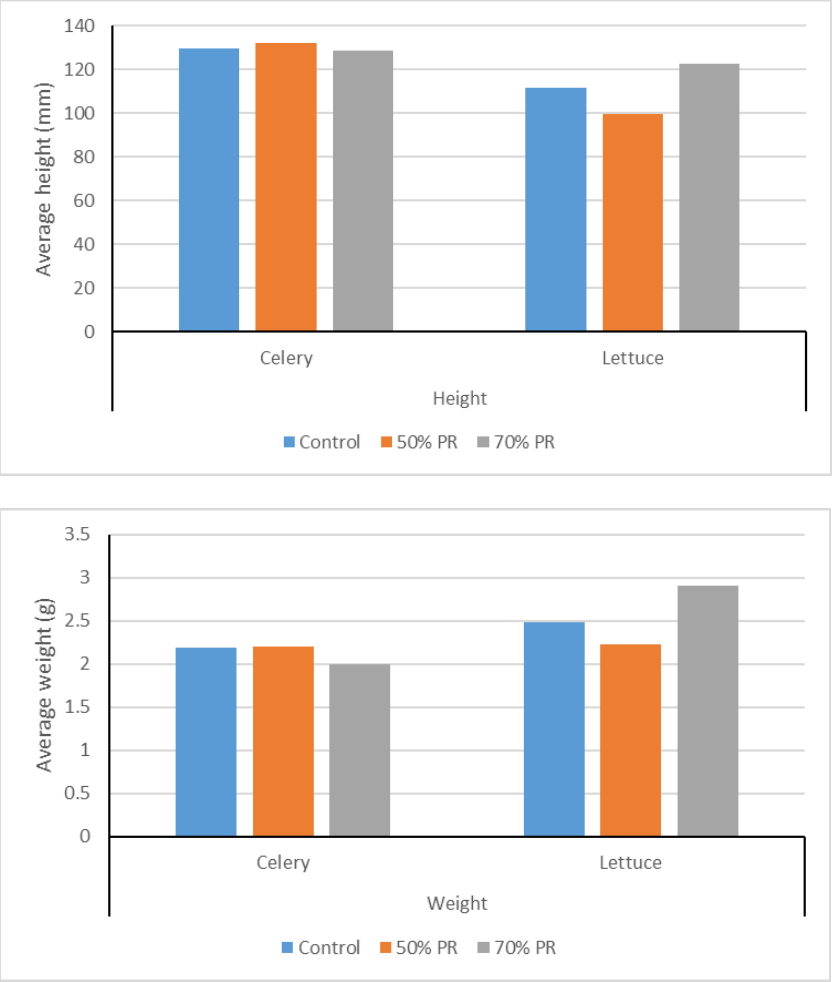

Figure 7. Ellepot-grown lettuce and celery for control, 50% peat reduced and 70% peat reduced. The upper panel records the height (mm) of young plants prior to field planting at G's. The lower panel records the fresh weights.

Harvest - Celery

At harvest the control had the highest mean stick length, while the 70% peat-reduced had the highest mean weight, Table 4. Again, the important point is that both the peat-reduced substrates gave a viable product.

Table 4. Ellepot trials, celery, average number of sticks per plant, stick length and stick weight, nursery control 50% peat-reduced and 70% peat reduced substrate.

	Average no. of sticks	Average celery stick length (mm)	Average celery stick weight (g)
Control	13.8	514.02	33.75
50% PR	14.2	502.22	32.36
70% PR	14	500.48	35.50

Harvest - Lettuce

The lettuce crop was heavily damaged by frosts and could not be harvested or assessed.

Modules

Propagation trials using modules were carried out at Sheepgate Nursery and Farringtons Nursery from June to August 2021. The set-up process was very similar in both, and the growing media blends used were the same. At each site, a 15% peat-reduced product and 30% peat-reduced product were compared against the nursery 15% peat-reduced standard substrate. In addition, at Sheepgate, a 100% peat-free conventional product and 100% peat-free organic product were used.

Module trays were filled at Sheepgate using the peat-reduced products on 24 June 2021 (week 25) and seeds of tenderstem (Inspiration), kale (Reflex) and winter cauliflower (Cartagena and Isadora) were sown. The trays were placed in the germination area for two days and then set out on upturned pots on the floor, under glass. Trays were grouped by growing media product and all were watered and fed in the same way using an overhead boom. The peat-free trays were filled and sown on 30 June 2021 (week 26). All media was run through filling machinery to fill the module trays.

The trial at Farringtons was set up on 25 June 2021 (week 25) using the same growing media products, which were run through the nursery machinery to fill the trays and sow the seed. Plant species at Farringtons were spring greens (Winter Supreme and Verve) and kale (Reflex). As with Sheepgate, trays were placed in the germination room for 2 days before moving into the glasshouse where the trays were sat on upturned pots, Figure 8. Data loggers were placed at each nursery to record temperature and humidity throughout the propagation period.

Figure 8. Trays set out under glass on upturned pots at Farringtons.

The Sheepgate trial was visited on 20 July (week 29) and Farringtons was visited on 23 July (week 29). Plants were assessed at both sites for percentage germination within a sub-sample of trays. Once the plants were ready for planting, a sub-sample of trays were collected from each site and sent to ADAS Boxworth for assessment of height, fresh weight and dry weight. The plants from Farringtons were planted in fields owned by Farringtons Nursery from 04-10 August (week 31-32). A sub-sample of Cartagena and Inspiration from Sheepgate were planted at Barfoots in Hampshire on 13 August 2021 (week 32) and a sub-sample of all four plant species from Sheepgate were planted at the Elsoms demonstrations trial ground in Spalding. All field trials were planted using a semi-automatic planter.

On 14 October (week 41), the tenderstem broccoli at Elsoms was assessed for its first pick, assessing the percentage of plants flowering per plot and the weight of stems harvested from 10 plants per plot.

Figure 9 shows module-grown broccoli assessments prior to planting out. The organic peat-free substrate shows the lowest average height and weight. The other three treatments gave an acceptable performance: the conventional peat-free material gave the highest average fresh weight.

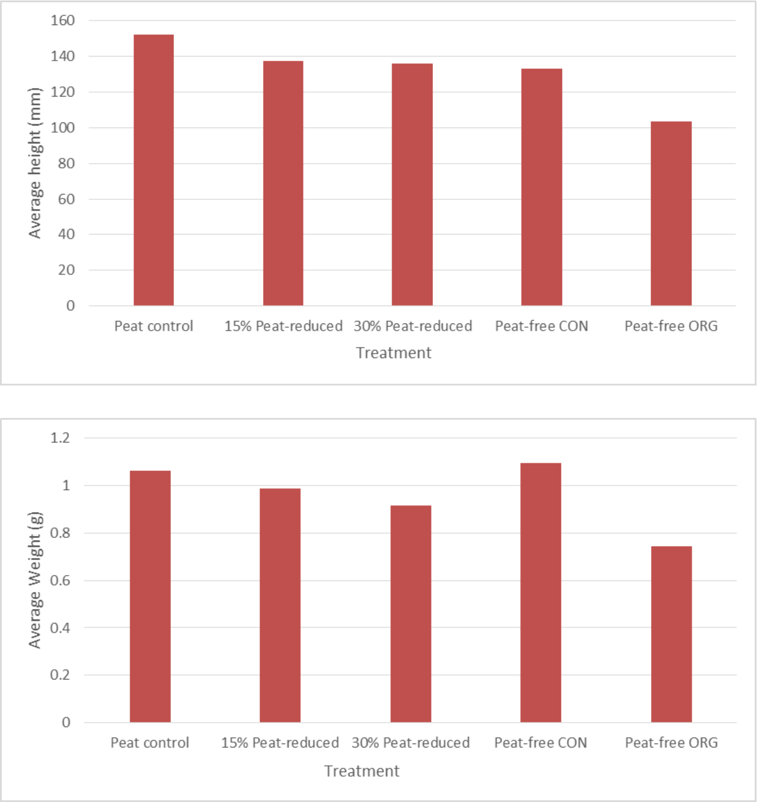

Figure 9. Module-grown broccoli for control, 15% peat-reduced, 30% peat-reduced, peat-free conventional (CON) and peat-free organic (ORG). The upper panel records heights, the lower panel fresh weights.

Harvest – Tenderstem broccoli

Table 5 shows individual mean plant weights and plants per plot for field grown tenderstem broccoli planted out from modules. The weight per plant is largest for the conventional peat-free material, perhaps reflecting the largest weight result at the pre-planting out stage. The organic peat-free substrate appears to give a weaker performance at the harvest-level.

Table 5. Module-grown broccoli, post-harvest assessment of field-grown plants for control, 15% peat-reduced, 30% peat-reduced, peat-free conventional and peat-free organic.

Treatment	Mean weight per plant (g)	Total plants per plot
Control	163.9	87
15% peat reduced	127.5	88
30% peat reduced	115.9	87
Conventional peat-free	173.8	85
Organic peat-free	143.9	82

Mechanical handling

This section summarises the mechanical handling aspects for all three propagation technologies using commercial blends both for filling / blocking for and planting out. Suitable mechanical handling behaviour is crucial for successful vegetable propagation, in addition to the substrate's ability to support germination and seedling growth.

Blocks

Usable blocks were created using the 15% peat reduced blend. However, the blocks were not as 'tidy' as those created using the nursery standard peat, as Figure 10 shows, and appear to be more friable. Even a modest level of non-peat material has a noticeable impact; the 30% peat-reduced blend was not used as a manufacturing defect resulted in too many large fragments of material, as recorded above.

Figure 10. Machine-made blocks using nursery standard blocking peat, left, and 15% peat-reduced commercial blend, right. The crop is celery; these blocks are ready for field planting. The peat-reduced blocks are clearly less tidy and appear more friable.

The 15% peat-reduced blocks with both lettuce and celery were successfully planted out. However, in the lettuce case a small fraction of the blocks disintegrated during automatic planting out, Figure 11. This graphically exposes the problem with alternative materials for blocking – if an alternative material causes any significant fraction of blocks to disintegrate then there are immediate crop production problems. The blocks plus root structure must retain their integrity during planting out.

Figure 11. Automatic field planting of 15% peat-reduced blocks. The disrupted region in the centre of the picture is due to disintegrating blocks. The crop is lettuce.

Ellepots

Ellepots were successfully created using the 50% peat reduced, 70% peat reduced and peat-free blends.

At planting out, to date only hand planting is available. No problems were detected at the manual field planting stage. The supportive paper sheath of the ellepot keeps the substrate in place and aids handling. Figure 12 shows lettuce plants ready for field planting having been raised in ellepots. The paper sheath has been removed to show the root system but also to reveal the quality of the substrate plug. The left-most plant corresponds to a peat-free blend that was discontinued due to poor growth, but even in this case the plug is of good quality.

Figure 12. Ellepot plugs, the sheath removed, for (left to right) peat-free, 50% peat-reduced, 70% peat-reduced and nursery 15% peat-reduced standard. The peat-free case was not planted on. The crop is lettuce.

Modules

Machine filled modules were successfully created using 15% peat-reduced, 30% peat-reduced, peat-free and peat-free organic blends. However, the two peat-reduced blends gave rise to 'untidy' trays due to the presence of wood fragments from wood-based components in the blends. This is undesirable, since if there are large fragments present the cells may not fill properly so need to be re-run, the fragments can clog the filling brushes, and seeds can bounce off the fragments. This was primarily a problem with the 30% blend, though as already noted this was a defective batch.

Modules were successfully planted out using a semi-automatic planter for 15% peat-reduced, 30% peat-reduced and peat-free blends. The crops successfully planted out were broccoli (inspiraction), kale (reflex), cauliflower (Cartagena, Isadora).

Prototype Materials

The physical parameters of the prototype materials were assessed with reference to the catalogue of materials from project CP138. This reference set is shown in Figure 13.

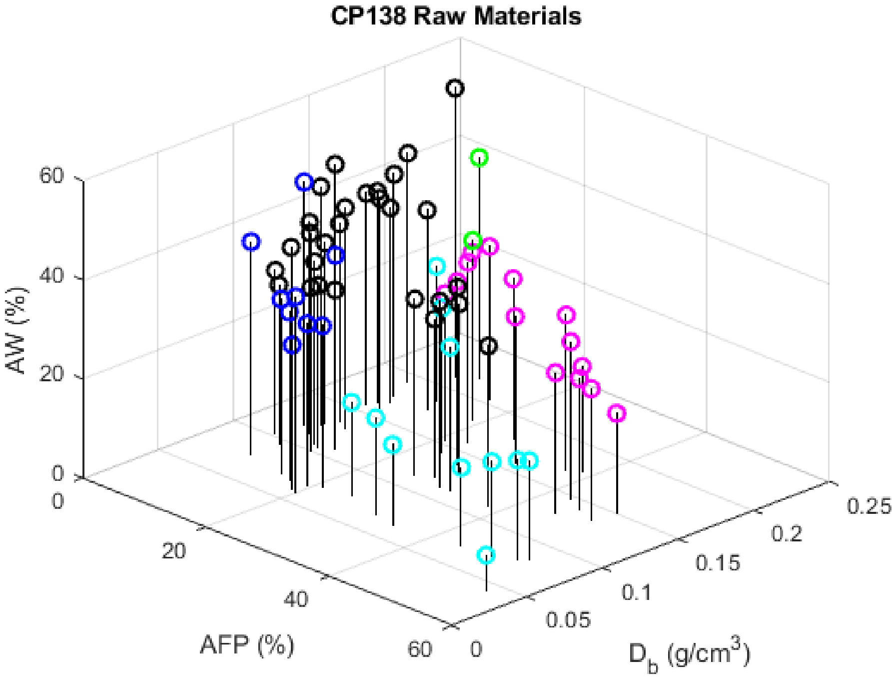

Figure 13 Physical parameter values for a collection of raw substrate materials. Black rings denote peat. There are two classes of peat. The larger cluster (smaller AFP) is fine peat, the smaller cluster (higher AFP) is coarse peat. The other materials are coir, green compost, wood fibre and bark.

It is difficult to interpret the data in three dimensions. It is therefore useful to plot the exact same data in two dimensions by ignoring the D_b axis, in other words by projecting along this axis. The result is depicted in Figure 14. This highlights the relationship between AFP and AW, and the wide range of AFP values of the barks and wood fibres. Note that the general ‘envelope’ enclosing the points in this two-dimensional plot tracks to the fact that all the materials here are plant-based.

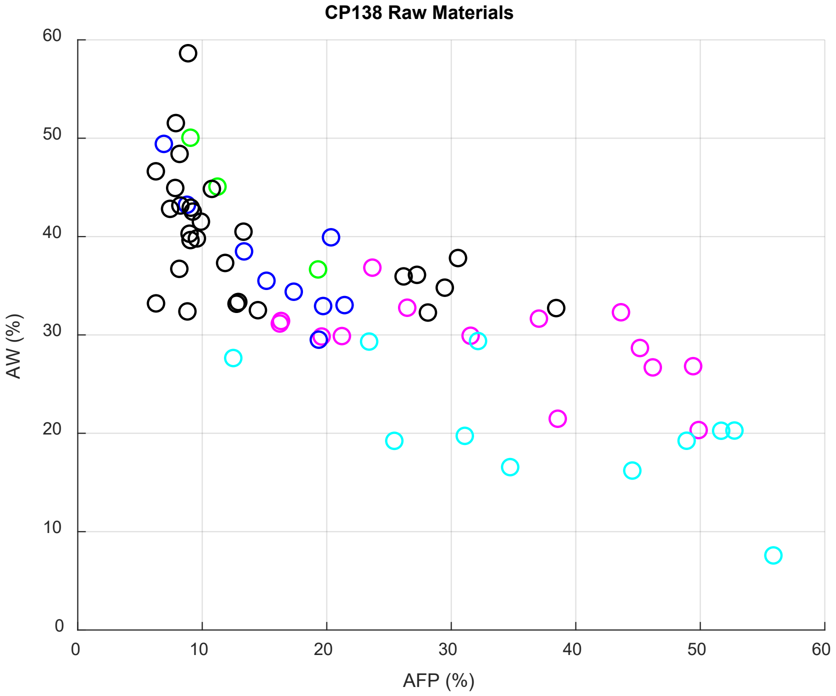

Figure 14. Physical parameters in 2D for the reference raw materials. This plot shows the same data as the previous figure but projected along the D_b axis such that D_b values vanish. Black rings denote peat. The other materials are coir, green compost, wood fibre and bark.

The physical parameters of the supplied prototype materials can be plotted on the same type of three-dimensional plot, Figure 15. Identifying labels have been omitted for reasons of commercial confidentiality. This figure shows only 19 points: there is one remaining point at a very high D_b which can only be captured if the D_b axis is extended, as in Figure 16. The penalty for displaying the high-D_b point is that the other points appear crammed together.

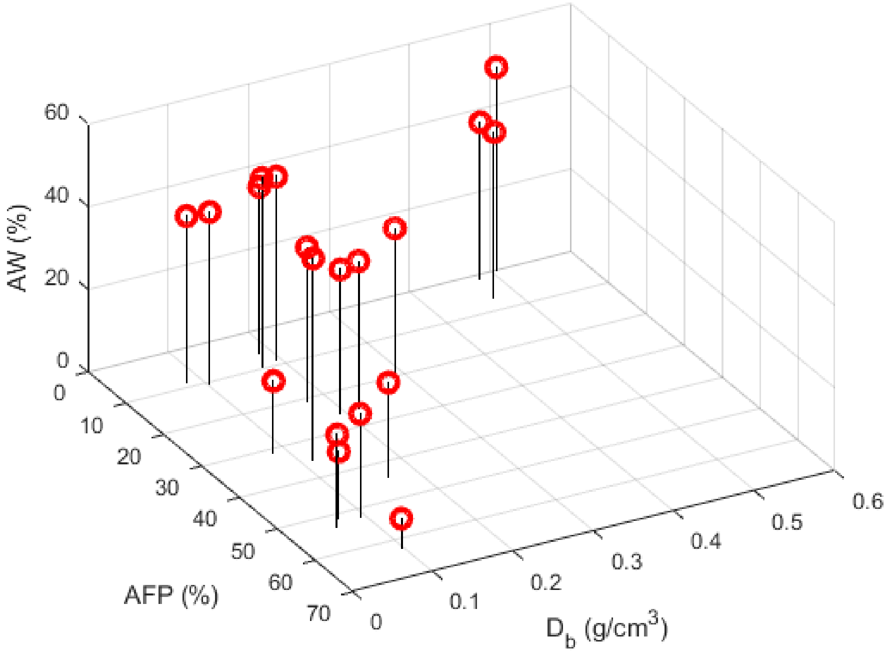

Figure 15. Physical parameters of the prototype materials in three-dimensions. The materials are anonymised for reasons of commercial sensitivity. Only 19 of the 20 are displayed because one point has a large D_b value.

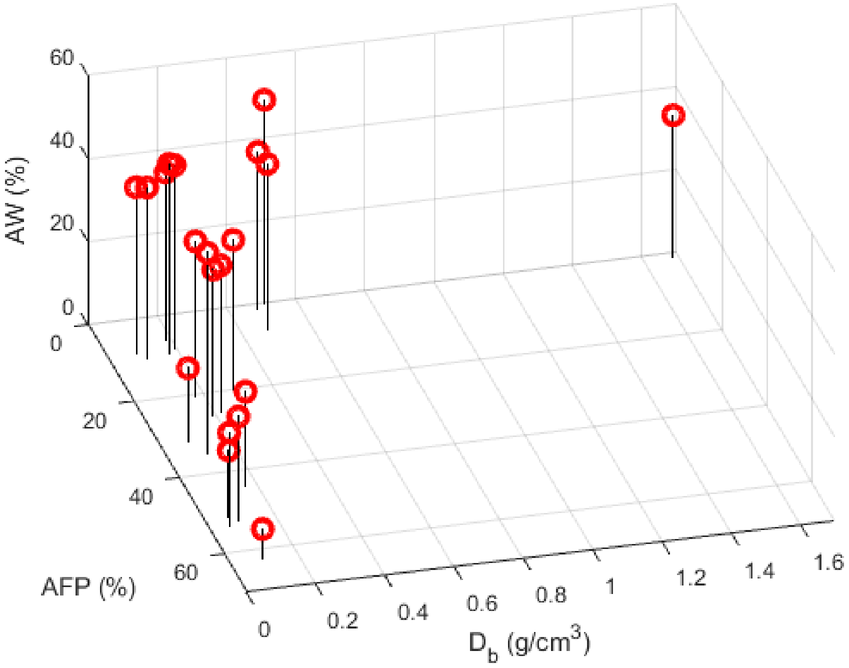

Figure 16. Physical parameters of the prototype materials in three-dimensions. This figure shows the same data as Figure 15 but with a modified D_b axis to capture the high-D_b value material.

Again, because the three-dimensional plots are relatively difficult to interpret we display the prototype materials data in two-dimensions, firstly with a simple anonymous label to allow discussion of individual points, and secondly in the context of the reference data set.

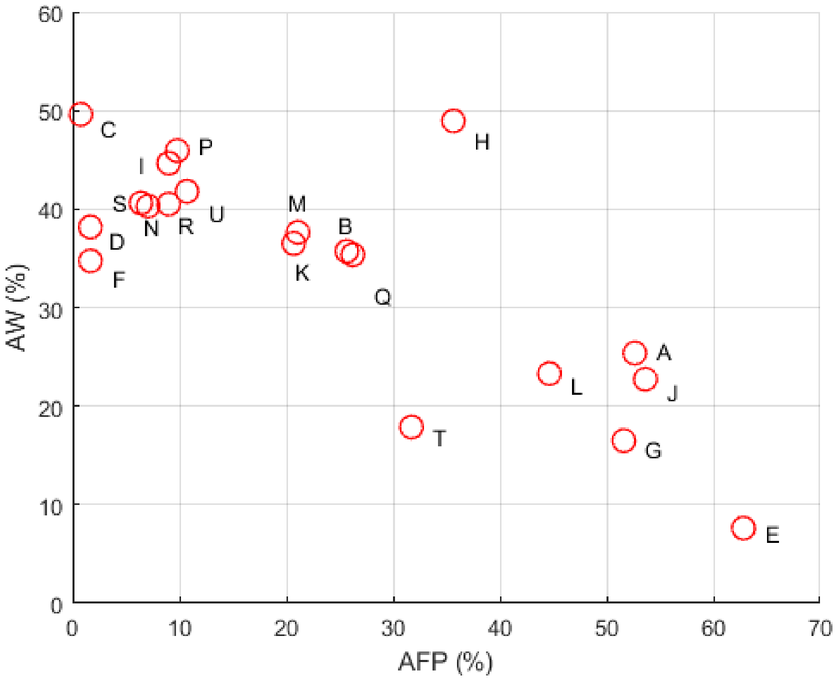

Figure 17. Physical parameters in 2D for the prototype materials. This figure shows the same data as Figure 15 but projected along the D_b axis such that D_b values vanish. The letters denote individual materials in an anonymous way.

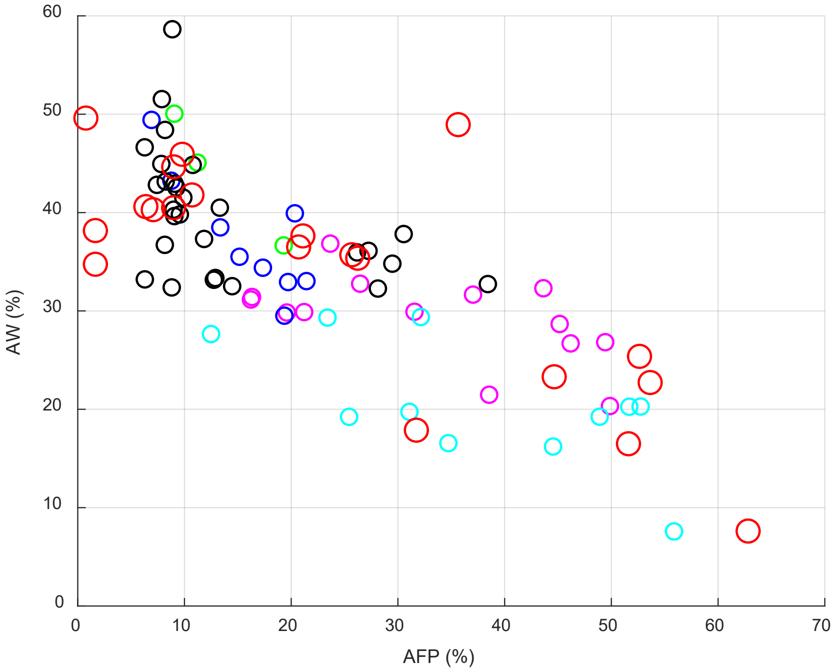

Figure 18. This figure is the union of figures 14 and 17. It shows prototype material values (red circles) in the context of the reference materials, all in two-dimensions. The reference materials are coir, green compost, wood fibre and bark.

There are several noteworthy features of the prototype materials data. The group of points at high AFP and low AW (L, A, J, G, E) would typically correspond to poor substrate candidates, inhabiting a region of parameter space occupied by poorly performing barks and wood fibres. In addition, most of the AFP-AW values lie within a broad envelope. However, one material, H, lies outside that envelope. Three materials (C, D, F) have remarkably low AFP values, lower than any peat tested previously. It is possible that these four materials (H, C, D, F) are anomalous, and may not even been plant-based. For reasons of confidentiality the suppliers declined to comment on the nature of these (and some other) materials.

Selection of prototype materials to carry forward

The next stage was to select materials from this palette to carry forward for mechanical testing and grower assessment (Table 6). Materials might be used in a pure form, or as blends for two components. For two-component blends, due to time constraints and a large number of materials, only 50:50 blends were be assessed.

There are four criteria for selection: material availability, physical parameters, chemistry and additional physical characteristics (for example large wood fragments).

Table 6. Assessment of whether to carry prototype materials forward for further study in blends.

Material	Carry forward?	Comment
A	x	High AFP
B	✓	Must be sieved
C	x	Not available
D	✓	Must be sieved
E	x	High AFP
F	x	Poor consistency
G	x	Not available
H	x	Chemistry issues
I	x	Chemistry issues
J	x	High AFP
K	✓	Must be sieved
L	x	High AFP
M	x	Chemistry issues
N	x	Chemistry issues
P	x	Confidential
Q	✓	Must be sieved
R	✓	-
S	x	Confidential
T	✓	-
U	x	Confidential

Some of these materials required sieving. This improves their flow characteristics, removes unhelpful larger fragments, and in general improves their AFP. ‘Chemistry issues’ refers to problems such as high chloride, potassium or ammonia. Some materials turned out not to be available from the growing media suppliers to continue further with the project, with only enough available for basic testing. Materials with high AFP might have utility in some contexts but not at the 100% or 50% levels used in the project.

The fact that some of the materials required ‘post-processing’ before they could be used in the project is significant. Some were sieved in house by ADAS and some were specially milled to give finer-grade material. Both these processes change the physical parameters relative to those displayed in Figures 15 and 17 above which informed the selection of materials to carry forward. In addition, it is likely that additional milling will modify the chemical properties of a material. Data checking these physical and chemical effects were not acquired due to time constraints. The significance is that some of the materials carried forward are not the same as the materials originally selected. It also highlights the challenges facing growing media producers in supplying non-standard materials.

In total six materials were carried forward. Where these were used to create blends with peat, in all cases the same black Baltic peat was used for consistency. Fertiliser and wetter (as required) were calculated to be constant per litre for the final material. In addition, for some substrates a ‘plus binder’ option was created. The binder, which is included to enhance cohesion within the substrate material, was the same level per litre of final substrate in all applicable cases. The physical and chemical properties of the final substrates were not specifically assessed.

The amounts of material available were very limited, ranging from 4 to 30 litres in total. One litre of each was retained for mechanical compression testing. The rest were split (unevenly) between Crystal Heart (blocking, ellepots) or Sheepgate (modules). In all cases the amounts of material were insufficient for comprehensive testing on working site equipment for the creation of blocks, modules or ellepots. Instead, the propagation sites attempted to create modules, blocks or ellepots by hand in a manner representative of the real-world case. In addition, seeds were sown, and germination and early seedling growth assessed.

Table 7. Composition of substrate blends carried forward for mechanical handling and initial growing tests. Note ‘B’ indicates binder.

Substrate code	Composition	Binder	Peat reduced	Peat free
01	Peat + R		✓	
01B	Peat + R	✓	✓	
02	Peat + T		✓	
02B	Peat + T	✓	✓	
04	Peat + D		✓	
04B	Peat + D	✓	✓	
05	Peat + K		✓	
05B	Peat + K	✓	✓	
06	K			✓
07	Q			✓
07B	Q	✓		✓
08	Peat + Q		✓	
08B	Peat + Q	✓	✓	
09	Peat + B		✓	

Filling

Modules were filled manually in such a way as to emulate the mechanical filling process, including tamping down to match the pressure exerted by the rotating brush in the filling machine. Ellepots were filled using the ellepot filling machine. No blocks were created. The grower assessment was that none of the substrates supplied at this stage of the project would support block making.

Figure 19 shows some of the set of filled trays. At the top is a machine-filled tray containing nursery peat standard substrate. The middle panel shows a blend that contains fibres and fragments. These can cause problems, as described above, so the material would benefit from additional screening to remove fragments. Materials 07, 07B, 08 and 08B also contained fragments and would be better screened. Blends 04 and 04B were so fine that they ran out of the drainage holes at the bottom of the cells. The amount of substrate required to fill a cell ranged from 14 to 20 ml. This has economic implications.

Figure 19. The upper panel shows a module tray filled by machine with the nursery peat standard substrate. The middle panel shows a tray filled with trial blend 02B. There are fibres present in this blend. The bottom panel shows substrate 06, in such short supply that there is not enough to even fill a whole tray.

Machine filling of ellepots flagged similar issues: blends 04 and 04B were so fine as to potentially run out of the pots. Materials 07 and 07B were not well suited to ellepots as they contained coarse fibres that sometimes caused issues with the cutting blade that creates individual ellepots from the continuous filled tube. The fibres present in 02 and 02B were fine enough so as not to inhibit flow into the ellepots, but were able to provide a useful binding function.

Table 8. Ranking for filling of module trays and ellepots on a scale of 1 to 5 (5 best). ‘Modules machine’ is the grower assessment of the likely success of machine filling in the absence of sufficient materials to perform real machine filling. The green background indicates peat-free substrates.

Substrate code	Machine ellepots	Modules manual	Modules machine*
standard	3	4	5
01	4	4	5
01B	3	4	5
02	4	3	3
02B	4	2	3
04	2	1	2
04B	3	1	2
05	-	4	5
05B	-	4	5
06	-	4	5
07	2	3	3
07B	2	3	3
08	3	3	3
08B	3	3	3
09	-	4	5

Growing

Small-scale growing trials were undertaken in ellepots (lettuce, little gem Elizium), assessed at 12 days, and in modules (tenderstem broccoli, Inspiration), final assessment at 29 days. Both systems produced useful outcomes but with one exception: seedlings grown in blends 04 and 04B were unusable. The reason for the failure of this blend for growing is unclear. It might be relevant that this blend will have an extremely low AFP which might give rise to water logging. There were no obvious problems revealed by the conventional chemistry tests though some kind of toxicity cannot be ruled out. Also, the material was not tested for biological stability. Perhaps ironically this material was subjectively perceived as quite promising for block formation.

Figure 20 shows three examples of the tenderstem broccoli grown in modules, ready for dispatch for planting. In each panel the right-hand tray is the machine-filled tray with nursery peat. Blends 04 and 04B are not viable for dispatch due to poor growth; for 05, 05B, 06 and 06B there was not enough substrate to fill a complete tray. For all other materials the trial modules were deemed suitable for planting out, as judged by the likelihood that plants could be successfully extracted from the tray.

Figure 21 shows three examples of little gem lettuce grown in ellepots. The upper-most panel is the 100% peat nursery standard, the middle panel is material 07, the lower panel blend 01B, the most vigorous of the group at time of assessment. Empty ellepots correspond to failed germination, notably in the middle panel. All substrates except 04 and 04B gave rise to ellepots suitable for planting on – each ellepot has a substrate-supporting sleeve that aids planting out.

Figure 20. Three examples of module trays ready for dispatch. In each panel, the right-hand tray is the machine-filled nursery peat standard. The top and bottom panels show 02B and

09 (50% peat + 50% other, the 02B contains binder). The middle panel, 07, is peat-free. The crop is tenderstem broccoli Inspiration.

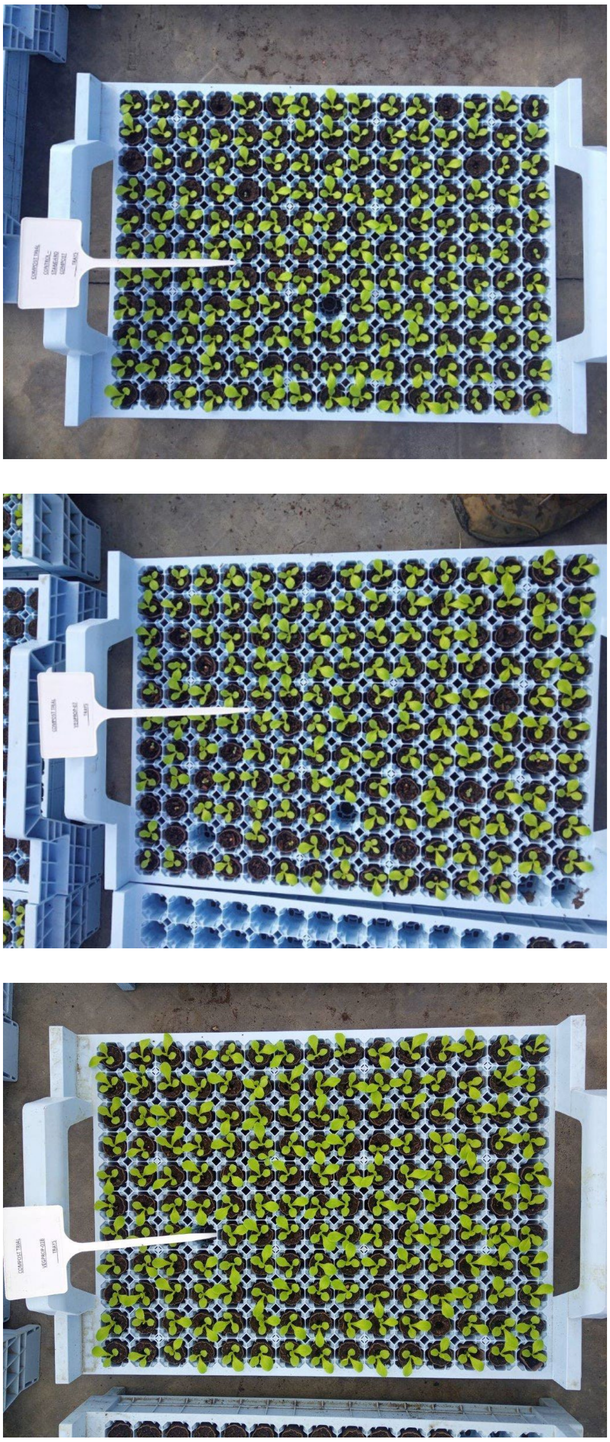

Figure 21. Three examples of ellepots loaded into their trays post-germination. The top panel is the peat-based nursery standard (100% peat). The middle panel is material 07 and shows growth that’s a little more vigorous than the standard but with several blanks corresponding to poor germination. The lower panel is blend 01B, and is the most vigorous of the group. The crop is lettuce, little gem Elizium.

The results of the growing trials are summarised in Table 9. Care must be exercised when making comparisons across the two container systems since the crop types are also different. Only top growth was assessed.

Table 9. Summary of germination and seedling development for tenderstem broccoli in modules and little gem lettuce in ellepots. The 'seedlings' scale runs 1 to 5 (5 best). The germination scale is **P**oor, **F**air or **G**ood. The green background indicates peat-free substrates.

Substrate code	Germination ellepots	Germination modules	Seedlings ellepots	Seedlings modules
standard	F	G	3	5
01	F	G	4	5
01B	F	G	5	5
02	F	G	4	3
02B	G	G	4	3
04	F	P	1	1
04B	G	F	1	1
05	-	G	-	3
05B	-	F	-	3
06	-	F	-	4
07	P	G	4	5
07B	G	G	4	5
08	F	G	3	5
08B	F	G	4	5
09	-	G	-	3

Mechanical Testing

Mechanical testing of blocks of substrate was undertaken only for prototype materials. Measurements were recorded on three different blocks and where appropriate the results averaged. Figure 22 shows a typical load-displacement plot.

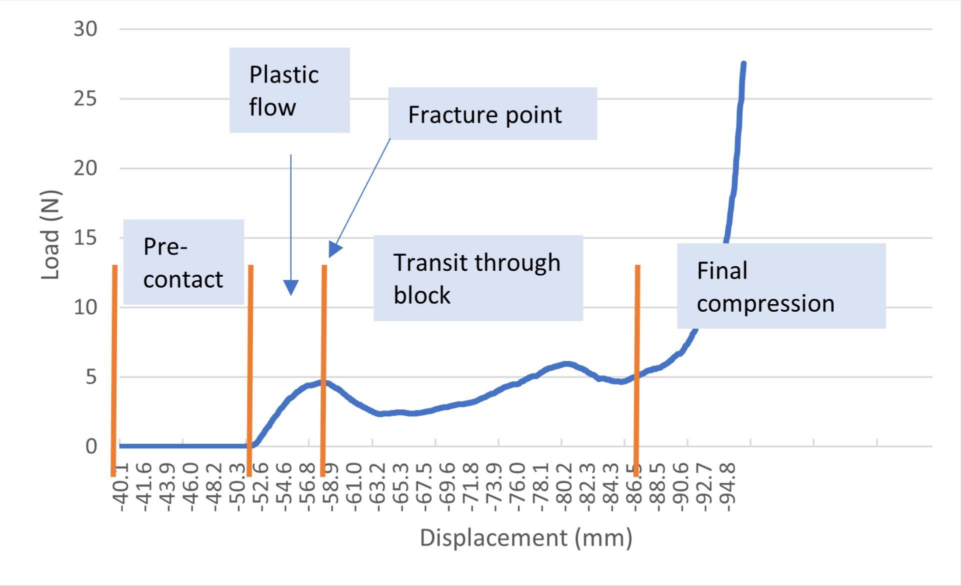

Figure 22. Plot of load versus displacement for black Baltic peat control with 400ml of water added per 2 litres of substrate. Displacement is shown as negative as the motion is downwards (compression).

Starting at the lower left corner, in this region the compression element has yet to make contact with the substrate block, and the load is therefore zero. In this example, at a displacement of approximately 51mm from the starting position the compression element reaches the block. It is already known that moist substrates exhibit very little elastic behaviour: a depression made in a block of substrate by a dibber remains a depression and does not spring back. After the compression element first makes contact with the block there is a region of plastic flow, where the block is irreversibly deformed and load is approximately proportional to displacement. At a load which, in this example, is close to 5N at a displacement of 58 mm there is a local maximum. As the compression element continues the block starts to fracture, and as a result the load required to progress diminishes. There follows a region where the load-displacement pattern varies considerably from sample to sample. Finally, a steep rise represents the final few millimetres of travel where material is being directly compressed beneath the compression element and the load required to achieve this is high. We have used the load value of the left-most local maximum, the fracture point, in this case 5N (at displacement 58 mm), as the effective 'strength' of the substrate block.

The strength of the block, in other words the load required to fracture it, does not have any absolute meaning since it depends on the details of the mechanical testing setup. However, the *relative* values obtained for different substrates hopefully indicate those that are the most resistant to failure in mechanical handling.

It is to be expected that the water content of the substrate impacts on mechanical strength. To explore this, we combined differing amounts of water and measured the block strength according to the strategy above, Figure 23

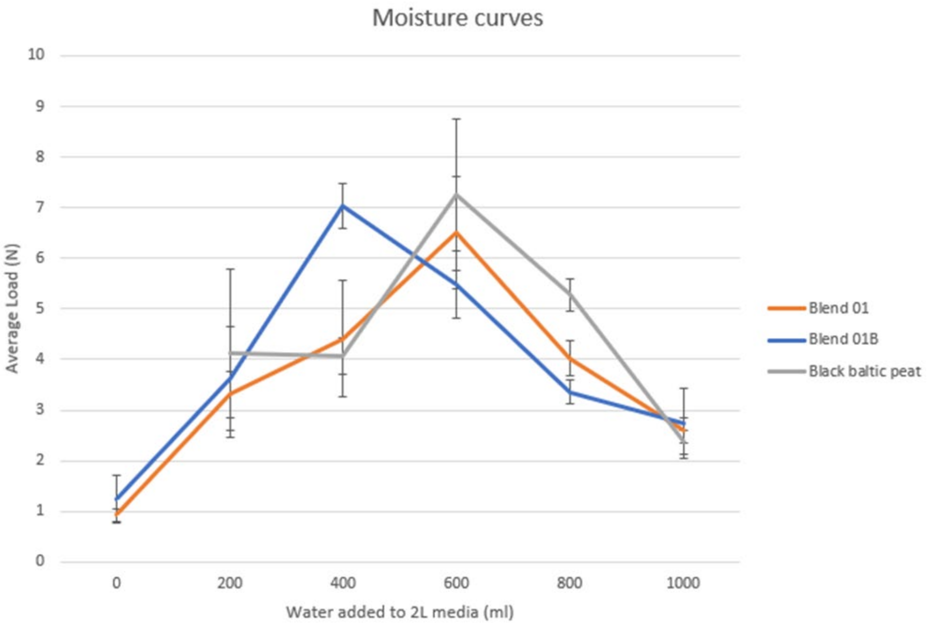

Figure 23. The dependence of block fracture load on the water content of the substrate for blends 01, 01B and black Baltic peat. Blend 01B is the same as 01 but has added binder. The plotted points are the average of three values. The error bars show one standard deviation.

As expected, Figure 23 shows that the water content is important, with the strongest blocks having intermediate water content. In the case of blend 01, addition of binder (01B) means that less water is required to reach the maximum block strength. The plot also suggests that, according to this method, a block of blend 01 is of similar strength to a block of black Baltic peat.

We have also compared the strength of blocks of different substrates, as measured using this method. Figure 24 shows block strength for the prototype materials except for blends 04 and 04B, which had biologically deteriorated to the extent they could no longer be handled. Materials 06B and 09B are absent because there was insufficient material available. The water content of each substrate was judged to be consistent with maximum block strength. This plot suggests that, according to our mechanical testing method, all materials can yield blocks of strength comparable to that of black Baltic peat, and some (02B, 08B) may even exceed it. It is difficult to discern a clear pattern across the dataset arising from the inclusion of binder. The data do suggest that 08B is stronger than 08. It is of course plausible that the relative contribution of a binder is substrate-dependent.

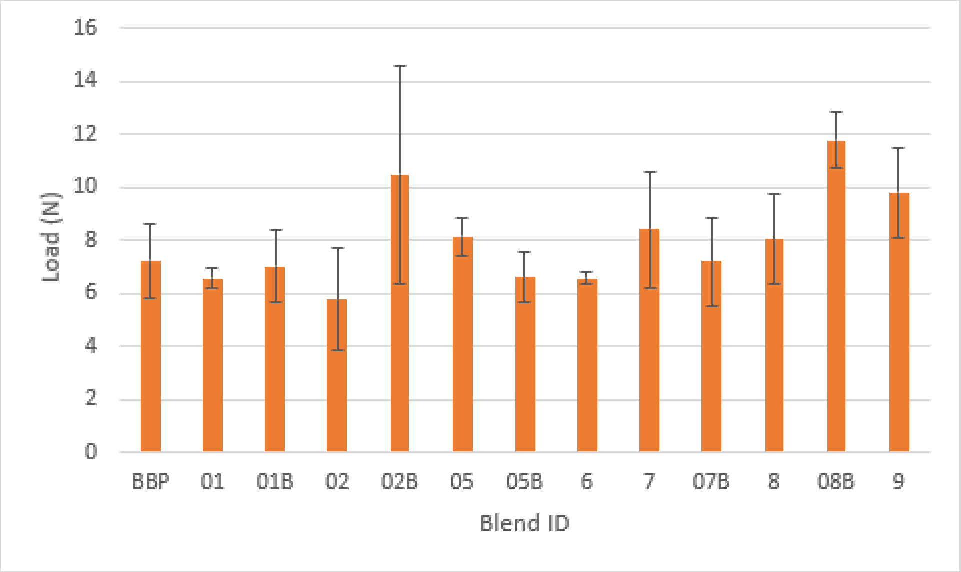

Figure 24. Substrate block strength for prototype substrates. ‘BBP’ is black Baltic peat for comparison. The error bars are one standard deviation.

Discussion

Substrates for vegetable propagation need to support germination, seedling growth and the creation of small growing units (blocks, ellepots, modules). In addition, those small growing units must be able to sustain mechanical handling. This project set out to explore substrates, both peat-reduced and peat-free, that meet these requirements.

For modules and ellepots there already exist peat-reduced (50% and 70%) and peat-free substrates that, according to this project, are viable solutions: modules and ellepots can be created, seeds germinate and develop, and planting out is successful. However there are some caveats here and in what follows. Firstly, this work was very much in the spirit of a ‘first-look’ which means that trials were not robustly randomized and subject to full statistical analysis. Secondly, only a limited number of crops were investigated and only for a single season.

Continuing with modules and ellepots, two different peat-free blends were contributed by industry partners, and one of these apparently performed poorly. For this material the chemistry assessment gave no clear reason for this. Physical parameter assessment was not available and it is unclear why this material underperformed, though it is impossible to eliminate potential husbandry issues. With those caveats, it nonetheless appears safe to assert that not all peat-alternative substrates perform equally well. In addition, an organic peat-free substrate was trialled for modules. Its growing performance was disappointing and it was not taken forward to planting out.

For blocking, the demands on the substrate are particularly challenging because the blocks have to support their structure unaided by any container. Only a single 15% peat-reduced substrate was explored. This was successful, but the inferior blocks relative to the peat nursery standard hint at the difficulties moving forward to substrates having lower or even zero peat content.

In the second phase of the project, prototype materials were contributed by the growing media manufacturers. Many of these materials were not available commercially. The nature of some materials was totally hidden from the project. The physical and chemical properties of these materials were analysed and, along with considerations such as material availability and further physical characteristics such as flow, used as a basis for selections to carry forward.

With regard to physical parameters, AFP, D_b and AW, comparison with a reference library of raw material values saw five materials dropped. Other materials were dropped on the basis that, even at a 50% blend with peat, some chemical properties might remain problematic. Other materials were simply unavailable. In conclusion, the project generated a list of eight substrates (comprising six prototype materials) to carry forward. Two of these were peat-free. The remaining six were peat-reduced at the level of 50% peat and 50% non-peat. In all cases there were severe limitations on the availability of materials that impacted directly on project outputs – some materials were available in only a few litres in an industry where cubic metres are necessary to fully test the entire production process.

The non-peat materials used were wood fibre, coir, composted bark (0-2mm) and two unidentified materials. Both the peat-free options were 100% composted bark (0-2mm).

Particularly relevant for blocking, it is possible that the inclusion of binder additives may help to provide additional substrate cohesion. For this reason, where sufficient material was available a ‘with binder’ version was also created. Counting the no-binder and with-binder versions as distinct, in total fourteen materials were carried forward for limited assessment.

For both ellepots and modules the blends 04 and 04B performed poorly at the seedling growing stage. This could potentially be due to waterlogging, toxicity or biological activity but the reasons are not clear. Whatever the reason, in its current form (50% peat and 50% material D) this blend was not successful in terms of seedling growth.

For modules, the overall superior substrates in terms of both filling and seedling growth were 01/01B and 06. Note that substrate 06 is peat-free and comprises composted bark (0-2 mm). Importantly, bar 04/04B all blends gave modules that could be extracted from the module tray. In terms of filling, materials including 02/02B, 07/07B and 08/08B were all compromised to some extent by the presence of woody fragments. These fragments should not be there, and suggest that one improvement for module filling lies with improved quality control of substrates to ensure disruptive fragments are absent. Materials 07/07B and 08/08B gave good seedling growth. Recall that materials 07/07B are peat-free and comprise composted bark (0-2 mm). Blends 02/02B, 05/05B and 09 gave weaker growth. In summary, this work suggests that for module propagation there are several viable candidates amongst the prototype substrates trialled, and that the choice is governed to some extent by the compromise between mechanical handling and seedling growth. Both peat-reduced and peat-free candidates exist.

For ellepots, the overall superior substrates in terms of both filling and seedling growth were 01/01B and 02/02B, all peat-reduced blends. Note that some materials (05/05B, 06 and 09) were not available for ellepot trials due to shortage of material; 04/04B suffered poor top growth as highlighted previously. Planting out of ellepots was not explicitly trialled but no problems were anticipated at the planting out stage. The materials helped highlight issues specific to ellepots. Very fine materials (such as 04/04B when dry) are prone to running out of the open bottom of the cylinder. Material containing fragments, such as 07/07B, can cause jamming of the blade that cuts the continuous ellepot tube into short cylinders. Coarser materials typically result in poor levels of germination. Overall, the conclusion for ellepots matches that for modules – that there exist viable peat-reduced and peat-free candidates, though with improved quality control.

There are other interesting aspects of the data. Firstly, the amount of material used to fill an individual module ranges between 14 and 20 ml. For ellepots it is 48 to 65 ml. In both, the minimum is for the 07/07B material, implying the effect is real. If this aspect survives closer scrutiny it may be economically significant, since it implies as much as 30% more product per unit of supplied substrate.

Secondly, though there was no clear pattern of the impact of binders on the creation of modules and ellepots, there is a hint of some impact on growth. For ellepots, for 01/01B and 08/08B the binder version gave superior top growth, and 07B gave better germination rates than 07. The evidence is not robust but the impact of binder on top growth is likely worth further investigation.

In the case of blocking, according to subjective assessment none of the substrates carried forward in this project were likely to produce adequate blocks.

A third phase of this project was a laboratory-based mechanical assessment of substrates, performed independently of the module and ellepot filling and growing trials. Cubes of substrate were manufactured manually using a hand-press, and their compressive strength assessed. This confirmed that substrate blocks show only nominal elastic behaviour, that the material undergoes a plastic flow up to a fracture point, and that beyond this fracture point the block disintegrates. The applied load at the fracture point was taken to be the 'block strength'.

The data confirmed that water content is an important determinant of substrate block strength, rising initially from low values at low water content, reaching a maximum and then dropping again as the water content further increases. The water content at maximum strength is likely material-dependent, which is relevant to growers when creating cells and especially when manufacturing blocks.

We have compared the strength of blocks made with materials with and without binder for several cases. Generally, our testing method revealed no across the board correlation between block strength and the presence of binder. The one clear exception was 08 versus 08B, where the with-binder blend appears stronger. It is possible and plausible that the impact of binder is substrate-dependent, and that in some cases it makes no difference to block strength and in others it does.

It is likely the experimental method is not sufficiently refined to fully map the impact of binders. Factors here range from the variance in block strength due to the manual creation method, through to the speed of travel of the compression element. The assessment of the block strength recorded for each material is also a source of variance since this depends on the substrate water content so is not known accurately.

Finally, the mechanical testing program allows comparisons between blocks make of different materials and a block made of black Baltic peat, a material which can itself be used as a blocking substrate. Even if the absolute load values at block fracture do not have a directly accessible meaning, the hypothesis is that a comparison between a material of interest and black Baltic will be relevant. On this basis, all of the blocks tested are broadly comparable in strength with the black Baltic peat. Some – 08, 08B and 09 – appear stronger and might be considered candidates for blocking substrates. However, this does not agree with the subjective assessment of the suitability of these substrates for blocking. Proper testing of candidate materials – with sufficient quantities (in the cubic metre range) to run through real blocking equipment – would resolve the issue. It is also possible that the mechanical testing regime is not measuring the block mechanical properties in a way that is wholly relevant to blocking. It is clear this is an area requiring more investigation.

Conclusions

- The objective of this project was to explore peat-reduced and peat-free candidate substrates for vegetable propagation using blocking, modules and ellepots. We have confirmed that finding candidate substrates for blocking is the most difficult.
- Commercially available candidates, both peat-reduced and peat-free, are available for modules and ellepots.
- A 15% peat-reduced commercially available candidate for blocking exists
- Prototype materials were supplied by growing media manufacturers. These formed the basis of test substrates, though in some cases additional processing was required. Amongst these test substrates, viable peat-reduced and peat-free candidates were identified for modules and ellepots, but not for blocking.
- Among the new materials trialled, fine (0-2 mm) composted bark, a material not routinely available, was found to be of particular merit.
- Growing media producers struggle to supply substrates of adequate quality, or novel substrates in significant amounts. The supply of substrates is a pinch point on the path to peat-reduced and peat-free vegetable propagation.
- Mechanical testing of hand-formed substrate blocks showed that water content strongly influences their strength, and that some materials apparently gave rise to blocks sufficiently strong for mechanical blocking. This conflicts with subjective assessment of the materials as blocking candidates.
- Binders may have a role in substrate block strength, in the water content required to achieve that block strength, and in the growing success of the crop, but our data is not comprehensive enough for a definitive overview.

Knowledge and Technology Transfer

Chloe Whiteside attended a British Leafy Salad Association demonstration day at G’s, Cambridgeshire, 16 September 2021 where she spoke with visitors about the project. Celery blocks plus celery and lettuce ellepots were growing in the demonstration field for visitors to view. Chloe also presented a poster ‘Vegetable Propagation: Peat reduction and replacement demonstration trials’ Approximately 150 people attended.

Chloe Whiteside showcased the project at an Elsoms Open Day in Spalding on 13 October 2021. A range of crops in modules with different substrates were available to view. Chloe also presented a poster ‘Vegetable Propagation: Peat reduction and replacement demonstration trials’.

Andrew Watson will give an overview of the project in a talk entitled ‘Propagation with peat-free substrates’ at the Brassica and Leafy Salad Conference, Peterborough, 25 October 2022. Approximately 350 attendees are expected.

References

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