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PRACTICAL SECTION FOR GROWERS

Commercial benefits of the project

This project has identified waste materials that can be used beneficially to substitute peat in growing media for a range of hardy ornamental nursery stock (HONS) species. Carpet shearing wastes incorporated at 25% v/v improved the growth of a range of herbaceous perennials and woody ornamentals grown in finished pots and 9 cm liners. Composted paper wastes incorporated at 50% v/v improved the growth and flowering of a range of herbaceous perennials. The results of this work have the potential to improve the performance of HONS growing media and to reduce environmental pressure on the industry due to usage of peat.

Background and objectives

Around 400,000 m^3 of growing media are used for HONS production in the UK annually and peat still accounts for about 80% of this volume. Environmental pressure against peat extraction means that there is a need for sustainable and viable alternatives. It is clear that any substitute material must enhance or replace the properties of peat, without introducing additional costs and undesirable characteristics or other environmental disadvantages. This almost inevitably means that the material must be a by-product from another process, and that subsequent processing is minimal or not required. Previous research has shown that wastes from the paper industry could be used successfully in nursery stock media. These wastes, which are in plentiful supply in the UK, have good water and air holding characteristics, and if composted with a nitrogen source, do not immobilise (lock-up) nitrogen. These materials were therefore the main focus of this research, although other organic and inorganic wastes were also investigated as peat substitute for HONS production.

Commercial Objectives

1. Identify at least three suitable (technically and economically) materials for commercial development for HONS growing media production (finished pots and liners of herbaceous perennials and woody ornamentals).
2. Identify materials with the potential to replace, in total, 40% of the peat used by the UK nursery stock industry.

Summary of results and conclusions

After a preliminary screening of waste materials based on physical and chemical characteristics, wastes from different sectors of the paper industry and carpet shearing waste were considered to have most potential as peat substitutes in HONS growing media. Three types of paper wastes were used: a ‘crumb’ waste from recycled paper production, a ‘pulp’ waste from virgin paper production, and a ‘compacter’ waste from recycled cardboard production. Raw or composted paper and cardboard wastes, which were slightly alkaline, were mixed at 50 v/v with peat without lime. The carpet shearing wastes were a by-product from wool-based carpet production and were incorporated at 25 or 50% v/v into proprietary peat-based growing media. Experiments were conducted in two growing seasons using a range of herbaceous perennials and woody ornamentals, both in 2L or 3L finished pots and in 9 cm liners. Preliminary experiments showed that the paper wastes immobilised nitrogen, resulting in deficiency symptoms. Subsequent experiments were therefore conducted with paper and cardboard wastes that had been composted with a nitrogen source (ammonium sulphate or urea).

For the following herbaceous perennial species, the best overall treatment in terms of plant growth and flowering was 50% composted paper crumb waste: *Aster* x *frikartii* ‘Mönch’, *Aster novi-belgii* ‘Purple Dome’, *Delphinium* ‘Guardian Blue’, *Penstemon* ‘Vesuvius’. For *Geranium* ‘Sabani Blue’ and *Lavandula angustifolia* ‘Hidcote’, 25 or 50% carpet waste treatments performed best, and for *Rudbeckia fulgida* ‘Goldsturm a 50% composted paper pulp waste performed best. However, even for these species, the 50% composted paper crumb waste treatment performed at least as well as the peat control treatment.

For 9 cm liners of the following species, the best treatments in terms of plant growth were 25 and 50% carpet waste, except for *Penstemon* ‘Vesuvius’ where the peat control was best: *Delphinium* ‘Guardian Blue’, *Geranium* ‘Sabani Blue’, *Lavandula angustifolia* ‘Hidcote’ and *Viburnum tinus* ‘French White’. Liners of *Lavandula stoechas* ‘Purple Wings’ and *Verbena* ‘Claret’ also grew significantly better in a medium amended with 25% carpet waste than in the peat controls.

The 50% composted paper waste treatment was equal in performance to the peat control for *Chamaecyparis lawsoniana* ‘Ellwoodii’ and *Rosa* ‘Paddy Stephens’. For *Viburnum tinus* ‘Pupureum’, media containing 50% composted cardboard waste or carpet waste were equal in performance to the peat control. For *Clematis montana* 'Tetrarose', a 50% carpet waste medium produced significantly better vegetative growth than the peat control but reduced flower number. A 25% rate of carpet waste was not used in the 2005 experiment, but the growth of *Clematis montana* 'Tetrarose' and *Viburnum tinus* 'French White' plants in this treatment was better than that of the peat control in the 2006 experiment. For all the woody ornamental and herbaceous species, the carpet waste amendment resulted in plants with darker leaves than the peat control. The source of eight different carpet wastes was not important in terms of plant response.

Composting of paper crumb waste with ammonium sulphate prevented the immobilisation of nitrogen that occurred when the uncomposted material was used in growing media. For herbaceous perennials, a lower rate of ammonium sulphate (3.4 kg/m^3) was better whereas for roses, a higher rate (6.5 kg/m^3) was better.

The relative performance of the treatments was generally unaffected by the irrigation system (sprinklers or drippers) and all the treatments received the same amounts of water. The use of the substitute materials investigated in this work should therefore not affect the amount of irrigation water used.

Action points for growers

- Carpet shearing waste should be tested at incorporation rates of 25% v/v or less in growing media for liners of herbaceous perennials and woody ornamentals (Warwick HRI can be contacted about the availability and use of this material).
- The use of carpet shearing waste in growing media should be tested in finished pots of genera and species shown to have particularly benefited from this material: *Geranium, Lavandula, Clematis montana, Viburnum tinus*.
- Other species which should be tested for the incorporation of carpet shearing waste in the growing medium are those which are likely to benefit from a slow release form of nitrogen and/or from a reduction in growing medium pH.
- Growers should be aware of the potential benefits in the growth and flowering of a range of herbaceous perennials from the incorporation of composted paper wastes in the growing medium.
- Further development in commercial-scale composting of paper wastes is required before growers can access this material. It is anticipated that further

work in this area will commence in 2007, particularly as the materials are a disposal problem for paper mills.

Anticipated practical and financial benefits

The use of wastes from paper and carpet production in growing media for HONS has the potential to:

- Improve the growth, quality and flowing of a range of herbaceous perennials and woody ornamentals in finished pots and liners.
- Reduce the need for controlled release fertilisers and lime in growing media.
- Reduce the incidence of soil-borne diseases caused by pathogens such as *Phytophthora* and *Pythium* species by the incorporation of composted paper wastes in growing media. This aspect was not investigated in this project, but is supported by a significant amount of research into disease suppression using composts.
- Improve the environmental image of the HONS industry by reducing peat consumption and reducing waste landfilling of other industries.

SCIENCE SECTION

Introduction

Background

Around 400,000 m^3 of growing media are used for hardy ornamental nursery stock (HONS) production in the UK annually (Waller & Holmes, 2006). Due to its excellent water and air holding properties, and low electrical conductivity (EC) and pH, peat still accounts for about 80% of this volume of growing media. However, environmental pressure against peat extraction means that there is a need for sustainable and viable alternatives. It is clear that any substitute material must add to or replace these properties, without introducing undesirable characteristics or other environmental disadvantages. For example, coir, perlite, vermiculite and rockwool require significant energy input in their transportation and/or production. The material must also be available in sufficient supply, ideally in locations close to end-use, and be competitive with peat on price. This almost inevitably means that the material must be a by-product from another process, and that subsequent processing is minimal or not required.

Diversion of wastes from landfill means that there are strong financial drivers for waste producers to find potential markets for their by-products. However, mineral and inorganic wastes are usually too heavy, and/or have insufficient water holding capacity for them to be suitable as peat substitutes. This leaves organic wastes as the only possible alternatives.

Composted bark and green wastes are used quite widely in the HONS industry and are added to peat-based mixes to increase porosity and to supply some plant nutrients. These materials can also suppress soil-borne pathogens such as *Pythium* and *Phytophthora* species (Noble & Coventry, 2005). Inclusion rates are usually limited to about 25% by volume, to avoid excessive bulk density, porosity, EC, pH and/or variability in the substrate. Composted bark is also more expensive than peat for an equivalent volume. The use of green waste composts for HONS production has been investigated in UK in work funded by WRAP (Adlam *et al.*, 2004). These materials were therefore excluded from the current project.

The majority of peat used in the HONS industry is in finished pots, with smaller quantities used in liners. Substrates used in propagation constitute only a small proportion of the total volume, and due to the specialised needs of this sector, the use of more expensive peat-substitute materials such as coir, perlite and vermiculite is already quite widespread. It was therefore decided to concentrate the experimental work on growing media for finished pots and liners.

Previous work

Due to improved aeration of growing media, the most widely investigated and used peat alternatives and substitutes in HONS production are bark-based and wood fibre products (Sawyer, 2005). Good to satisfactory results with both types of products relative to peat have been obtained (Laatikainen, 1973; Bohne, 2004) (Table A1, Appendix) although plants growing in them generally require more frequent waterings. They can also have a tendency to immobilise nitrogen; this can be reduced by first composting with a nitrogen source such as urea, and/or by adding more nitrogen to the growing media (Scott, 1984). Chong (2003) found that a bark mix containing 15% peat and 5% top soil performed better for a range of HONS species than a 100% bark medium. Scott (1984) found that the optimum rate of adding bark to peat was about 30% v/v for a range of HONS species and pine bark was found to produce better results than spruce bark.

There has been a significant amount of research into utilising waste materials in growing media for HONS production. Tables A1 and A2 in the Appendix list research results according to performance of the substitute materials relative to the control material (peat and/or bark, with or without other materials such as perlite). Much of this work, particularly in North America, has been conducted with bark or perlite as control media. Since these materials generally have lower water holding capacities and require more frequent watering than peat (Verdonk, 1983), the performance of bark substitute materials (Table A2) may appear more favourable than if the comparisons had been made with peat (Table A1). Chong *et al.* (1991, 1998) and Chong (2004) obtained at least as good growth of a range of HONS species in bark amended with 50% v/v raw paper mill wastes, or municipal waste, turkey litter or spent mushroom composts as in bark alone (Table A2). Chong (1992) also found that a growing medium containing up to 90% v/v apple pomace produced at least as good growth of four different HONS species as a peat/bark/sand control medium (Table A1). These results may be due to the frequency of watering used. Experience in Europe indicates that similar materials, if used at these inclusion rates in growing media, would cause problems due to high EC and pH values and/or immobilisation (lock-up) of N (Molitor & Brückner, 1997; Maher et al., 2000, 2001). However, inferior results with *Spiraea* x *bumalda*, *Viburnum farreri* and *Ligustrum vulgare* were obtained when 33% v/v or more of raw paper sludge or spent mushroom compost were added to bark media (Chong *et al.*, 1991; Bellamy *et al.*, 1995 and Chong & Hamersma, 1996; Chong & Purvis, 2004) (Table A2). A number of materials in Tables A1 and A2 such as coir (Scagel, 2003), coco fibres (Guerin *et al.*, 2000) and rice hulls (Bohne, 2004) would require significant transportation costs to the UK. Although good to satisfactory growth results with a number of HONS species were obtained with media prepared from or with clay (Bohne, 2004), crushed bricks (Fischer & Poppe, 1998) and river waste (Benedetto et al., 2004), the bulk density of these mineral materials would add significantly to handling and transport costs.

Amendment of peat-based media with up to 50% v/v composted green waste has been found to give good to satisfactory results for a number of HONS species (Kohstall & Alt, 1978; Burger *et al.*, 1997; Fischer & Popp, 1998; Guerin *et al.*, 2000; Chong, 2004; Adlam *et al.*, 2004). Results with these composts alone were usually poor (Burger *et al.*, 1997; Hicklenton *et al.*, 2001) as was cattle manure compost (Guerin *et al.*, (2000). However, Fitzpatrick *et al.* (1998) found that the growth of dwarf oleander was better in compost prepared from green waste and sewage sludge than in a peat/sawdust/sand medium (Table A1). Variability among sources is a significant disadvantage of green waste composts (Burger *et al.*, 1997; Litterick & Ward, 2005). Kohstall & Alt (1978) found that the high and variable salt content of refuse composts meant that only 20% v/v of the material could be used in peat-based media without causing a significant growth check.

Research, mainly in North America and Germany, showed that composted wastes from the paper industry could be used successfully in nursery stock media. These materials have good water and air holding characteristics, and if composted with a nitrogen source, do not immobilise nitrogen (Molitor & Brückner, 1997; Sesay *et al.*, 1997). About 700,000 tonnes of waste sludge are produced by the UK paper industry annually (Sesay *et al.*, 1997). Since the inputs (raw wood pulp or recycled paper) and processes for each type of paper production (newsprint, tissue paper, cardboard etc) are consistent, the by-products are also uniform in chemical and physical characteristics. Although raw paper sludges and biosolids have been used successfully as amendments in HONS growing media (Chong, 2003), the growth of a range of HONS species has generally been better using composted paper sludges as media amendments rather than the raw paper wastes (Tripepi *et al.*, 1996; Chong & Purvis, 2004).

Chong (1993) and Raymond *et al.* (1998) successfully grew a range of HONS species in media containing up to 50% v/v of raw or composted waxed corrugated cardboard (Tables A1 and A2). Zheljazkov (2005) showed that addition of 2% w/w (equivalent to about 20% v/v) wool waste to soil increased the growth of basil (*Ocimum basilicum*), thorn apple (*Datura innoxia*), peppermint (*Mentha* x *piperita*) and garden sage (*Salvia officinalis*).

Bragg (1990) and Pryce (1991) mention expanded polystyrene beads in growing media for container nursery stock. Scott (1991, 1992) used wood fibre, wood chips, and composted bark, straw with manure, and flax waste and bark for several HONS species. However, none of these materials produced results comparable with peat.

Due to the wide range of species used in the experiments in Tables A1 and A2, there are few trends regarding the tolerance of species to peat substitution. Guerin *et al.* (2000) and Adlam *et al.* (2004) found that peat substitution with 30-50% v/v green waste compost produced good or satisfactory results with *Viburnum tinus*. Fitzpatrick *et al.* (1998) and Chong (2004) showed that *Nerium oleander* and *Cotoneaster dammeri* were tolerant to high rates of green waste compost. Most of the work in Tables A1 and A2 was conducted with woody ornamental species, using pot sizes of 1 litre or greater; there is relatively little work on peat substitution on herbaceous perennial species, or in liner (9 cm pot) production.

Commercial Objectives

1. Identify at least three suitable (technically and economically) materials for commercial development for growing media production.
2. Identify materials with the potential to replace, in total, 40% of the peat used by the UK nursery stock industry.

Materials and Methods

Development of growing media

By-products were obtained from a range of industries (Table 1). A preliminary screening of materials was conducted, based on pH, EC, bulk density and available quantity. Materials with pH values >8, EC values > 1.5 mS/cm and/or bulk densities

>500 g/L were excluded from further tests. As mentioned in the introduction, green waste compost and composted wood fibres were excluded from further work. Granulated used rockwool was also excluded due to possible pathogen contamination and difficulty in granulating.

Table 1. Properties and quantities of waste materials

Material	Source	pH	EC	Bulk density		Quantity
				dry	wet	
			mS/cm	g/L	g/L	m^3/yr (K)
bark, composted fines	Melcourt Ltd	6.1	0.97	271	752	>100
cardboard compacter waste	Kappa SSK	7.3	0.62	123	542	5
carpet shearing waste	Axminster	5.0	0.55	99	489	10
coir	Marson Biocare	6.5	1.34	171	858	>100
coir matting dust	Rawtex Ltd	5.4	1.35	174	860	1
colliery washings	UK Coal	7.7	0.63	837	1257	>100
foundry slag waste	G. Clancey Ltd	7.2	0.61	1340	n.d.	30
green waste compost	J. Moody	7.9	0.94	416	929	300
paper mill pulp waste	Sappi	7.1	0.73	852	522	30
paper mill waste crumb	Bridgewater	7.9	0.56	338	1229	>100
polystyrene bead	Linpac	6.9	0.01	180	180	>100
pulverised cocoa shell	Cadbury	5.1	3.33	856	n.d.	4
quarry clay	R Bullivant	7.8	0.24	837	1381	40
spent mushroom compost	Warwick HRI	7.1	0.37	194	711	>100
sugar beet washings	British Sugar	9.1	1.55	501	720	>100
rockwool, used granulate	Cultilene	7.4	1.43	282	807	>20
textile recycle dust	E. Clay	5.1	1.34	48	651	3
wood waste	Bulrush Peat Co.	7.8	0.32	344	n.d.	>100

n.d. not determined

Based on the results of the preliminary screening, the following materials were included in further tests:

- Paper mill waste crumb, from recycled paper production (two sources, Aylesford Newsprint, Maidstone and Bridgewater Paper, Ellesmere Port)
- Cardboard compacter waste (Kappa SSK, Birmingham)
- Paper pulp waste, raw pulp waste from graphics paper production (Sappi, Blackburn)

- Carpet shearing waste (two sources Axminster Carpets and Victoria Carpets, Kidderminster), containing 80-90% wool and 10-20% synthetic fibres (nylon, polyester)
- Textile waste recycling dust (Edward Clay Ltd, West Yorkshire) containing mixed fibres (40% cotton, together with polyester, nylon, acrylic, wool).

Preliminary germination tests were conducted twice with (20) tomato seeds (cv. Moneymaker). The carpet shearing waste and textile recycling wastes were incorporated at 25% v/v into a standard peat-based medium (Levington M2, Scotts Professional, Ipswich). There was no difference in germination between the Levington M2 (75-100% germination) and 25% carpet waste (75-95%) but germination in the 25% textile waste was significantly lower (65-75%). The textile waste was therefore excluded from further tests.

Analysis of materials

The substitute materials and mixed growing media used in the experiments were analysed for physical and chemical properties on at least two replicate samples. Properties of the mixed growing media were determined after the addition of lime and fertilisers.

Physical properties

The water retention and bulk density after drainage from saturation of the wastes and peat-based media were determined according to methods in Anonymous (1990; 1999a,b, 2000a). Pore space and dry bulk density were determined according to methods in Anonymous (1999a,b; 2000a).

Chemical properties

Nutrient contents were determined according to methods in Anonymous (1986) (nitrate-N, ammonium-N, phosphorus, potassium, calcium, magnesium, iron, manganese, sodium and boron). EC and pH of samples were determined according to methods in Anonymous (2000b,c) at the start and end of each crop.

Composting of paper and cardboard wastes

The following materials were composted at 50 C in 6-t capacity bulk aerated tunnels:

- Paper mill waste A (Bridgewater Paper)

- Paper mill waste B (Aylesford Newsprint)
- Cardboard compacter waste (Kappa SSK)
- Paper pulp waste (Sappi).

The materials were wetted to achieve a moisture content of about 55% w/w. Ammonium sulphate was added to the cardboard waste and paper crumb A at a higher and a lower rate; for paper crumb B, ammonium sulphate was added at a single intermediate rate (Table 2). Urea was added at a lower rate to cardboard and paper pulp wastes (Table 2). The wastes were filled on to a slatted base, mounted above an air plenum through which a controlled flow of air and steam maintained aerobic conditions and the required temperature in the wastes. Vertical partitions enabled up to three different materials to be composted in each tunnel at the same time. Ammonia in the compost was measured with Draeger gas detection tubes (Type CH 20501). The materials were composted until ammonia had cleared (31-52 days). Maximum ammonia concentrations during composting were higher when urea was used; however, the time taken to clear ammonia from the compost was similar to when a similar amount of N was added as ammonium sulphate. Other details of composting are shown in Table 2. The composted wastes were stored for at least 1 month in 1.5 m^3 bulk bags before use.

Table 2 Details of composting paper and cardboard wastes

Raw material	Weight kg	Volume m^3	N source	Quantity kg/ m^3	Duration days	Ammonia max. ppm
Cardboard	401	1.08	amm. sulph.	4.3	31	3
Cardboard	401	1.08	amm. sulph.	8.6	52	30
Cardboard	1684	4.53	urea	1.8	43	500
Paper crumb A	571	0.78	amm. sulph.	3.4	31	6
Paper crumb A	550	0.81	amm. sulph.	6.5	52	30
Paper crumb B	440	0.65	amm. sulph.	5.2	52	30
Paper pulp	443	0.49	urea	0.9	43	400

A Aylesford Newsprint B Bridgewater Paper

Growing Trials

The trials were conducted on Mypex matting, either outside or indoors in a polythene tunnel. Plants were irrigated daily with overhead sprinklers (up to 80 mL per 3L pot) or with drippers (up to 270 mL per 3L pot).

Comparisons of peat-substitute mixes were made against different commercial standard peat-based mixes. These contained various amounts of controlled release fertiliser (Sincrocell or Osmocote), base fertiliser and magnesian limestone (Dolokal). Some mixes also contained 15-30% v/v bark, depending on the species (herbaceous, woody ornamental, lavender), cropping duration (6 or 18 months), and environment (outside or indoor) (Table 3). Controlled release fertiliser and base fertiliser were incorporated into the peat-substitute mixes so that the rates were the same as in the standard peat-based media. Dolokal was added at 3-5 kg/m^3 to achieve the target pH in Table 3. All the mixes contained a polyacrylamide wetting agent (Fiba-Zorb, Sinclair), applied as a 10% solution at 1 L/m^3.

Table 3. Commercial peat-based mixes used in the experiments. Sufficient magnesian limestone was added to achieve the target pH value

Mix	Target pH	Peat % v/v	Bark % v/v	CRF kg/m^3	Fertiliser kg/m^3
Herbaceous I	5.0	85	15	3[a]	0.5[b]
Herbaceous II	5.7	80	20	3[c]	0.5[d]
Outdoor	5.5	100	0	5[a]	0.5[b]
Indoor	5.5	85	15	4[a]	0
Lavender	6	85	15	2[a]	0.5[e]
Conifer	5	75	25	3[f]	1.2[g]
Propagation, woody	5.5	70	30	3[h]	0.6

[a] Sincrocell 12 [b] Sincrostart (12:14:24) [c] Osmocote Plus 12-14months (15:8:11)
[d] 14N:16P:18K [e] 0N:24P:27K [f] Osmocote 16-18 months (16:8:9)
[g] 750 g 12N:14P:24K, 250 g calcium nitrate, 200 g fritted trace elements
[h] Osmocote Plus 12-14 months (15:8:11)

At the end of the first growing season, if over-wintered, and at the end of each crop, the following were recorded, where appropriate, for each species:

- Survival
- Plant growth (top fresh and dry weight, shoot number and plant height)
- Leaf colour, assessed with RHS colour cards and scored on a 1-3 scale (see Appendix, Table A3 for card numbers relating to leaf colour of different species).
- Number of buds and/or flowers or flower shoots.

Preliminary experiment

The following test species were used:

- *Rudbeckia fulgida* var. *sullivantii* ‘Goldsturm’ (3L pots, outside)
- *Aster* x *frikartii* ‘Mönch’ (2L pots, outside)
- *Viburnum tinus* ‘French White’ (3L pots, polythene tunnel).

For the standard peat-based mixes, the Outdoor mix was used for the herbaceous species and the Indoor mix was used for the *Viburnum* (Table 3).

The following materials were incorporated at 50% v/v in peat-based media:

- Paper mill waste crumb, raw (Bridgewater Paper)
- Carpet shearing waste (Axminster Carpets).

The carpet waste was mixed with the Outdoor or Indoor peat-based mixes. The paper mill waste was mixed with peat (Shamrock medium grade), to avoid adding lime from the peat-based media. CRF (Sincrocell 12), fertiliser (Sincrostart), and wetting agent (Fiba-Zorb) were added so that the rates in the final mixes were the same as those in the standard peat-based mixes (Table 3).

Six to nine replicate plants (9 cm liners) of each species were potted-up in week 22 (2005) in each of the three media, with overhead sprinklers or with dripper irrigation.

Aster and *Rudbeckia* plants were assessed for leaf colour and flower number on 26 October 2005 and harvested on 26 July 2006. *Viburnum* plants were harvested on 15 May 2006.

2005 Experiments

The following materials were incorporated at 50% v/v in peat-based media:

- Paper mill waste crumb A (Bridgewater Paper, composted low N)
- Paper mill waste crumb A (Bridgewater Paper, composted high N)
- Paper mill waste crumb B (Aylesford, composted medium N)
- Cardboard compacter waste (Kappa SSK, composted low N)
- Cardboard compacter waste (Kappa SSK, composted high N)
- Carpet shearing waste A (Axminster Carpets)
- Carpet shearing waste B (Victoria Carpets)

Due to the initial nitrogen immobilisation in the preliminary experiment, further experiments were conducted whereby the paper mill and cardboard wastes were first composted with a nitrogen source. The paper mill waste crumb and cardboard compacter waste were composted with ammonium sulphate according to the details in Table 2.

The composted paper and cardboard wastes were mixed with peat (Shamrock medium grade), and the carpet wastes were mixed with standard peat or peat/bark mixes appropriate for each test species (Table 3). A 50% carpet waste (Axminster): 50% composted cardboard waste (high N) mix was also prepared. Dolokal was added to this mix at 1 kg/m^3. Plants of each species and growing medium treatment were grown with overhead sprinklers or dripper irrigation in a split-plot design. Irrigation treatments (main plots) were replicated twice, with three replicates of each growing medium treatment (6 replicates of controls) allocated to sub-plots. This gave 6 replicates of each species in each growing medium and irrigation treatment (12 replicates for controls).

Herbaceous perennial species

The following test species were used:

- *Aster* x *frikartii* 'Mönch' (2L pots, outside)
- *Delphinium* 'Guardian Blue' (2L pots, outside).
- *Geranium* 'Sabani Blue' (2L pots, outside)
- *Penstemon* 'Vesuvius'(2L pots, outside)
- *Rudbeckia lacianata* 'Goldquelle' (3L pots, outside).

Liners (9 cm) were potted-up in week 29 and week 34 (*Aster* and *Delphinium*) in the Herbaceous peat mix I (Table 3), and 50% and 100% peat substitute media.

Penstemon plants were harvested on 26 October 2005. The other plants were assessed for flower number, leaf colour and height on 25 October 2005. *Delphinium* plants were over-wintered in a polythene tunnel and harvested on 12 May 2006. *Aster*, *Geranium* and *Rudbeckia* plants were over-wintered outside. Geranium plants were harvested on 15 May 2006.

Woody ornamental species

The following test species were used:

- *Clematis montana* 'Tetrarose' (2L pots, polythene tunnel)
- *Viburnum tinus* 'Pupureum' (3L pots, polythene tunnel)
- *Chamaecyparis lawsoniana* 'Ellwoodii' (3L pots, outside)

- *Rosa* 'Paddy Stephens' (3L deep, outside).

Liners (9 cm) were potted-up in the Indoor mix in week 29 and in the Outdoor mix in week 33 (*Chamaecyparis*) (Table 3). Bare root rose plants were potted-up in the Outdoor mix in week 44. The *Clematis* plants were supported by two stakes and pruned to the top of the stakes on 6 October 2005 and the *Viburnum* plants were pruned to 200 mm height on 13 May 2006.

The height of *Chamaecyparis* and *Viburnum* plants was measured on 25 October 2006 and 1 March 2006. The *Clematis* plants were harvested on 12 May 2006.

<u>2006 Experiments</u>

The following materials were mixed 50% v/v with peat (Shamrock, medium grade):

- Paper mill waste crumb (Bridgewater Paper, composted low N ammonium sulphate)
- Paper pulp waste (Sappi., composted low N urea)
- Cardboard compacter waste (Kappa SSK, composted low N urea).

The paper pulp and cardboard wastes were composted with urea; the paper mill waste crumb was composted with ammonium sulphate due to the higher initial pH of this material (Table 2). No lime was added to any of the media containing the above composted wastes.

The following material was mixed 25% v/v (also 50% v/v for liners) with standard peat or peat/bark mixes appropriate for each test species (Table 3):

- Carpet shearing waste (Victoria Carpets).

Plants of each species and growing medium treatment were grown with overhead sprinklers or capillary matting for Lavender in a randomised design, with six replicates of each growing medium treatment (12 replicates of controls). Due to the lack of effect of irrigation system on the relative performance of different growing media in the 2005 experiments, and the more widespread use of sprinklers, dripper irrigation was not used in the 2006 experiments.

Herbaceous perennials

The following test species were used in finished pots:

- *Aster novi-belgii* 'Purple Dome' (2L pots, outside)
- *Delphinium* 'Guardian Blue' (2L pots, outside)

- *Lavandula angustifolia* ‘Hidcote’ (2L pots, glasshouse then outside)
- *Rudbeckia fulgida* var. *sullivantii* ‘Goldsturm’ (3L pots, outside)
- *Penstemon* ‘Vesuvius’ (2L pots, outside).

Liners (9 cm) were potted-up in week 10 (*Delphinium*), week 12 (*Penstemon*) and week 17 (*Aster* and *Rudbeckia*) in the Herbaceous peat mix I (Table 3), and 25% and 50% peat substitute media. Lavenders were potted in week 19 using the Lavender peat mix (Table 3) as the control and for mixing with carpet wastes.

The following tests species were used in 9 cm liners:

- *Delphinium* ‘Guardian Blue’
- *Geranium* ‘Sabani Blue’
- *Lavandula angustifolia* ‘Hidcote’
- *Penstemon* ‘Vesuvius’

Seedlings of *Delphinium* and plugs of *Penstemon* were potted-up in week 12 in the Herbaceous peat mix I (Table 3), and 25% and 50% peat substitute media. Lavender plugs were potted-up in week 19 using the Lavender peat mix (Table 3) as the control and for mixing with carpet wastes. The liner and lavender plants were grown for 4 weeks in a glasshouse with frost protection before being transferred outside.

Woody ornamentals

The following test species were used:

- *Chamaecyparis lawsoniana* ‘Ellwoodii’ (3L pots, outside)
- *Clematis montana* ‘Tetrarose’ (3L deep pots, polythene tunnel)
- *Spiraea* ‘Candle Light’ (2L pots, outside)
- *Viburnum tinus* ‘French White’ (3L pots, polythene tunnel).

Liners (9 cm) of *Chamaecyparis* and *Viburnum* were potted-up in week 13 in the Conifer peat-based mix and Indoor peat mix respectively (Table 3), and 25% and 50% peat substitute media. *Clematis* and *Spiraea* were potted in week 18 using the Indoor mix and the Outdoor peat mix respectively (Table 3) as the control and for mixing with carpet wastes. *Clematis* plants were supported by two stakes and pruned to the top of the stakes on 30 June 2006.

The following tests species was used in 9 cm liners:

- *Viburnum tinus* ‘French White’.

The plugs were potted-up in week 13 in both the Indoor peat and Woody propagation mixes (Table 3), and 25% and 50% peat substitute media. The plants were raised in a polythene tunnel.

Carpet shearing waste uniformity experiments

Samples of carpet shearing and wool yarn wastes were obtained from different sources (Table 4). The wastes were mixed (25% v/v) with the Herbaceous mix II or Lavender peat mixes (Table 3). These peat mixes, together with Herbaceous mix I, were also used as controls. CRF, base fertiliser and wetting agent were added to the carpet or wool waste fractions as previously described. Eight replicate pots of each test species in each carpet/wool waste type and peat control treatment were prepared on 31 May 2006. The 9 cm liner pots were set out on Mypex matting with sprinkler irrigation in a randomised paired design i.e. two replicate pots of the same type were positioned next to each other to determine pot-pot variability.

Table 4. Sources of carpet shearing and wool yarn wastes used in the liner experiments

Company	Wool, %	Nylon, %
A Axminster Carpets, 1st cut	90	10
B Axminster Carpets, 2nd cut	90	10
C Brockway Carpets	80	20
D Newhey Carpets	80	20
E Pownall Carpets	80	20
F Victoria Carpets	80	20
G Wilton Carpets	80	20
H Wool Yarn Waste, F. Singleton Ltd	100	0

The following test species were used:

- *Agapanthus* ‘Purple Cloud’
- *Verbena* ‘Claret’
- *Lavandula* ‘Purple Wings’

Results

Analysis of materials and media

Physical properties

Before use, all of the raw wastes were drier than the peat-based media (Table 5). Wetting and composting, particularly of the cardboard waste, resulted in a significant uptake of moisture. Bulk densities and water and air holding characteristics of the wastes and mixed media are shown in Table 5. Initial bulk densities are at the moisture content delivered to the nursery or after composting. Herbaceous mix II had higher initial (moist) and dry bulk densities than the other peat-based mixes. Composting increased the moist and dry bulk densities of all the cardboard and paper wastes, except the dry bulk density of cardboard waste with urea. The composted paper wastes had higher bulk densities than the composted cardboard wastes; all had higher moist bulk densities than the peat-based media. The raw and composted cardboard wastes and carpet shearing wastes had similar or lower bulk densities than the peat-based media.

The saturated peat-based media did not have significantly different bulk densities. At saturation, raw and composted paper crumb waste B and the peat-based media had similar bulk densities. At saturation, raw and composted paper crumb waste A and paper pulp waste had significantly higher bulk densities, whereas the raw and composted cardboard waste and carpet shearing wastes had significantly lower bulk densities than the peat-based media.

The total pore space of Herbaceous mix II was lower, and that of the Outdoor mix slightly higher than those of the other peat-based media. The pore space of the raw and composted cardboard waste and the carpet shearing wastes was generally slightly higher, and that of the raw and composted paper wastes lower than those of peat-based media. All of the waste amendments had higher air and lower water volumes at saturation than the peat-based media. The cardboard and carpet shearing wastes had the highest air volumes at saturation. Differences in water volume at saturation between peat-based media and between waste amendments were small.

Table 5. Physical properties of peat-based media, raw and composted paper wastes, carpet shearing wastes

Material	DM	Bulk density, g/L			Water	Pore	Air vol.,
	% w/w	initial	dry	wet	vol., %	space, %	%
Peat mixes							
Herbaceous I	32.2	395	184	786	65.5	88.4	22.8
Herbaceous II	39.5	456	260	836	64.6	84.3	19.7
Outdoor	34.8	374	159	861	73.5	89.9	16.4
Indoor	34.4	393	192	775	64.0	88.0	24.0
Lavender	36.4	n.d.	190	838	70.9	88.2	17.3
Raw paper wastes							
Cardboard	72.0	498	123	597	39.9	92.3	52.4
Paper crumb A	66.0	534	410	876	49.0	80.6	31.5
Paper crumb B	65.7	441	337	771	49.7	83.3	33.6
Paper pulp	58.0	785	522	852	38.2	73.2	35.0
Paper wastes composted with ammonium sulphate							
Cardboard, low N	31.7	590	156	549	39.5	90.4	50.8
Cardboard, high N	36.2	547	154	553	41.3	90.6	49.2
Paper crumb A, high N	62.7	796	500	944	44.0	75.2	31.2
Paper crumb B, low N	43.0	759	448	768	41.2	77.5	36.3
Paper crumb B, high N	51.2	745	446	857	47.1	78.0	31.0
Paper wastes composted with urea							
Cardboard, low N	57.0	560	122	611	41.4	92.4	51.0
Paper pulp, low N	52.6	936	450	966	36.2	78.8	42.6
Carpet shearing wastes							
Axminster	88.5	169	114	567	38.9	92.6	53.7
Brockway	91.7	192	116	616	44.8	92.5	47.7
Victoria	90.8	99	90	488	38.2	94.1	55.9
LSD (P = 0.05)	6.08	71.1	14.2	76.0	19.74	0.98	19.36

A Bridgewater Paper B Aylesford Newsprint DM dry matter n.d. not determined

Chemical properties of materials

Nutrient content. Composting of the paper crumb and cardboard board wastes with urea or ammonium sulphate increased the total nitrogen (N) content of the materials (Table 6). The carpet wastes had much higher total N contents than the composted paper and cardboard wastes. The paper crumb wastes had the highest total levels of phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg). Composted paper crumb A had higher total levels of P, K and Mg than composted paper crumb B whereas the latter material had a higher Ca content. The cardboard and paper pulp wastes also had high levels of Ca and Mg. The Axminster carpet waste had higher total levels of N, P and K than the Victoria carpet waste whereas the latter material had higher levels of Ca and Mg (Table 6).

All the materials had low levels of water soluble nitrate N and P. The composted paper crumb also had a low water soluble ammonium N content (Table 7). The cardboard waste composted with the higher rate of ammonium sulphate and the paper pulp waste composted with urea had the highest levels of water soluble ammonium N. Composting of paper crumb or cardboard wastes with the higher rate of ammonium sulphate increased the amount of water soluble K. The composted paper crumb wastes had the highest levels of water soluble Ca and Mg. Axminster carpet waste had higher levels of soluble ammonium N, K, Ca and Mg than Victoria carpet waste.

Table 6. Total nutrient content of raw and composted paper wastes and carpet shearing wastes, dry matter basis

Material	N g/kg	Amm N mg/kg	P mg/kg	K mg/kg	Ca mg/kg	Mg mg/kg
Raw paper wastes						
Cardboard	1	n.d.	n.d.	n.d.	n.d.	n.d.
Paper crumb A	3.3	50	545	800	118000	1987
Paper crumb B	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Paper pulp	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Paper wastes composted with ammonium sulphate						
Cardboard, high N	3.5	n.d.	164	333	14300	653
Cardboard, low N	3.6	n.d.	165	322	13200	655
Paper crumb A, high N	4.8	n.d.	555	902	101000	3070
Paper crumb A, low N	5.7	n.d.	542	907	103000	2910
Paper crumb B, high N	3.9	n.d.	334	521	150000	2530
Paper wastes composted with urea						
Cardboard, low N	3.4	162	466	631	254000	2150
Paper pulp, low N	4.3	102	160	471	18600	982
Carpet shearing wastes						
Axminster	161	73	190	300	350	<100
Victoria	151	45	146	162	927	150

A Bridgewater Paper B Aylesford Newsprint n.d. not determined

Table 7. Content of water soluble macro-nutrients of raw and composted paper wastes and carpet shearing wastes

Material	Nitrate N mg/L	Amm N mg/L	P mg/L	K mg/L	Ca mg/L	Mg mg/L
Raw paper wastes						
Cardboard	<5	<1	n.d.	n.d.	n.d.	n.d.
Paper crumb A	0.15	0.25	n.d.	n.d.	n.d.	n.d.
Paper crumb B	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Paper pulp	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Paper wastes composted with ammonium sulphate						
Cardboard, high N	<6	42	<2	17	920	32
Cardboard, low N	<6	1	<2	10	474	23
Paper crumb A, high N	<6	<1	2	19	1327	74
Paper crumb A, low N	<6	2	<2	5	834	74
Paper crumb B, high N	<6	<1	<2	8	1556	49
Paper wastes composted with urea						
Cardboard, low N	<5	4	<2	5	59	5
Paper pulp, low N	<5	22	<2	21	214	8
Carpet shearing wastes						
Axminster	<5	13	2	34	35	5
Victoria	<5	6	2	10	<1	<1

A Bridgewater Paper B Aylesford Newsprint n.d. not determined

Composted paper crumb B (high N) and paper pulp had the highest levels of water soluble iron (Fe). Carpet waste A had the highest levels of water soluble manganese (Mn) and zinc (Zn) (Table 8). Composted paper crumb wastes had the highest sulphur (S) and sodium (Na) levels. Composted cardboard waste had the highest boron (B) level. Composted paper crumb A had the highest chloride (Cl^-) levels.

Ash content, pH and electrical conductivity of materials. Herbaceous mix II had a higher ash content (and therefore lower organic matter content) than the other peat-based media (Table 9). Raw and composted cardboard waste had similar ash contents to the peat-based media. The paper crumb and paper pulp wastes and composts had high ash contents. This is due to the clay content from recycled glossy magazines. Carpet shearing wastes had a very low proportion of ash.

Table 8. Content of water soluble micro-nutrients of composted paper wastes and carpet shearing wastes, mg/L

Material	Fe	Cu	Mn	Zn	S	B	Na	Cl$^-$
Paper wastes composted with ammonium sulphate								
Cardboard, high N	<0.5	<0.15	<0.1	0.36	842	0.74	79	48
Cardboard, low N	<0.5	<0.15	<0.1	0.25	398	0.56	75	47
Paper crumb A, high N	<0.5	<0.15	<0.1	0.19	1200	<0.1	230	149
Paper crumb A, low N	<0.5	<0.15	<0.1	0.23	796	0.11	287	230
Paper crumb B, high N	0.65	<0.15	<0.1	0.18	1350	0.12	235	54
Paper wastes composted with urea								
Cardboard, low N	<0.5	<0.5	<0.1	0.27	33	1.49	99	51
Paper pulp, low N	0.87	<0.5	<0.1	0.31	54	<0.1	53	59
Carpet shearing wastes								
Axminster	<0.5	<0.5	0.22	2.88	68	<0.10	40	10
Victoria	0.5	<0.5	<0.1	0.16	14	<0.10	24	25

A Bridgewater Paper B Aylesford Newsprint n.d. not determined

The peat-based mixes generally had pH values of 4.9 – 5.6; Herbaceous mix I and the Lavender mix were lower and higher in pH (Table 9). The raw and composted paper and cardboard wastes were slightly alkaline with cardboard waste composted with urea being the most alkaline. The carpet shearing wastes were slightly acidic with the Pownall and Victoria materials being the most and least acidic respectively (Table 10).

Of the peat-based mixes, the Indoor peat mix and the Woody propagation mix had the lowest ECs whereas the Conifer mix had the highest EC (Table 6). The raw paper, cardboard and carpet shearing wastes had similar ECs to the peat-based mixes. Composting of paper and cardboard wastes with ammonium sulphate resulted in a reduction in pH and increase in EC. Composting of these wastes with urea resulted in an increase in pH but did not significantly affect EC. Wool yarn waste and Wilton carpet waste had higher ECs than the other carpet wastes (Table 10). The carpet and wool wastes had dry matter contents of 88 – 94% w/w (Table 10).

Table 9. Ash content, pH and electrical conductivity (EC) of peat-based media, raw and composted paper wastes and carpet shearing wastes

Material	Ash, % of DM	pH	EC, mS/cm
Peat Mixes			
Herbaceous I	4.25	4.35	0.89
Herbaceous II	15.1	5.64	1.05
Outdoor	3.82	4.93	0.73
Indoor	8.01	5.48	0.40
Lavender	8.85	6.09	0.87
Conifer	n.d.	4.91	1.26
Propagation, Woody	n.d.	5.06	0.52
Raw paper wastes			
Cardboard	6.85	7.48	0.54
Paper crumb A	63.86	7.94	0.33
Paper crumb B	55.96	7.92	0.78
Paper pulp	49.15	7.13	0.73
Paper wastes composted with ammonium sulphate			
Cardboard, low N	10.59	7.35	0.84
Cardboard, high N	11.16	7.10	1.19
Paper crumb A, high N	55.45	7.70	1.17
Paper crumb B, low N	53.21	7.51	1.17
Paper crumb B, high N	57.26	7.61	0.99
Paper wastes composted with urea			
Cardboard, low N	8.13	8.28	0.37
Paper pulp, low N	65.03	7.68	0.29
Carpet shearing wastes			
Axminster	0.17	5.44	0.41
Brockway	0.31	4.60	0.40
Victoria	0.36	6.62	0.38
LSD (P = 0.05)	2.877	0.675	0.515

A Bridgewater Paper B Aylesford Newsprint DM dry matter n.d. not determined

Table 10. Initial dry matter content, pH and electrical conductivity of different sources of carpet shearing wastes

Source	Dry matter, % w/w	pH	EC, mS/cm
Axminster, 1st cut	88.1	5.59	438
Axminster, 2nd cut	88.8	5.34	370
Brockway	91.8	4.60	400
Newhey	92.7	4.48	491
Pownall	94.0	3.91	520
Victoria	90.7	6.63	415
Wilton	89.5	5.03	824
Wool Yarn Waste	89.6	5.85	952
LSD (P = 0.05)	4.1	0.47	93

Table 11. pH of peat control media, and media containing 50% v/v composted paper and cardboard wastes and carpet shearing wastes used for 2005 Experiments

Media	Outdoor mix	*Penstemon* mix	Indoor mix
Peat control	4.77	4.66	5.08
50% peat substitute media			
Paper crumb A high N	6.56	6.03	6.43
Paper crumb A low N	6.47	6.05	6.35
Paper crumb B high N	6.82	6.14	6.84
Cardboard high N	4.17	4.26	3.96
Cardboard low N	4.77	4.41	4.51
Carpet waste A	5.12	5.76	6.92
Carpet waste B	5.39	6.09	6.99
Carpet waste A + Cardboard high N	7.52	7.01	7.31

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Chemical properties of mixes used in individual experiments

2005 Experiments. The initial pH vales of growing media for outdoor and indoor species and *Penstemon* were similar for the same treatments (peat controls, 50% composted paper crumb mixes etc) (Table 11).The initial pH of the 50% composted cardboard waste (low N) treatments was similar to the pH of the peat controls for the respective applications (Table 11). The 50% composted cardboard waste (higher rate of ammonium sulphate) resulted in a lower growing medium pH than the peat control. The 50% paper crumb and carpet waste treatments all had higher initial pH values than the peat controls. The highest pH values were in the 50% carpet: 50% cardboard treatment (Table 11).

At the end of the cropping periods, the pH of media containing 50% composted paper crumb were higher than those of the peat controls, whereas those containing 50% carpet waste were lower (Table 12). The media containing 50% composted cardboard waste had similar pH values to the peat control. Across different herbaceous species in the experiment, the final pH vales of the media were similar (Table 12).

Except for the cardboard low N treatment, the initial ECs of the outdoor mixes were higher than those of the indoor and *Penstemon* mixes, reflecting the higher rates of fertiliser used in these mixes (Table 13). Media containing 50% composted cardboard (low N) had the lowest ECs. Increasing the rate of ammonium sulphate used in composting increased the EC of the composted cardboard waste but not paper crumb A. The ECs of media containing 50% carpet waste were higher than those of the other media. The ECs of media containing 50% of paper crumb wastes A and B were similar, as were media containing 50% of carpet wastes A and B (Table 13).

The final ECs of media at the end of the cropping periods used for *Aster* were similar (Table 14). For the other herbaceous species, media containing 50% carpet waste had the highest ECs at the end of the cropping periods. The ECs of media containing 50% composted paper crumb or cardboard waste were similar to those of the peat controls. Media used for *Penstemon* had higher final ECs than those used for the other herbaceous species due to the shorter cropping period.

Table 12. Final pH of peat control and 50% and 100% substitute media, herbaceous perennials, 2005 Experiment

Treatment	*Aster*	*Delphinium*	*Geranium*	*Penstemon*	*Rudbeckia*
Peat control	6.64	5.05	5.73	5.31	6.15
Paper A * high N 50%	7.71	7.76	7.60	7.76	7.87
Paper A * low N 50%	7.71	7.77	7.59	7.73	7.91
Paper B * high N 50%	7.87	7.77	7.68	7.77	8.05
Carpet A 50%	4.61	4.41	5.33	4.52	_
Carpet B 50%	4.40	4.11	5.57	4.94	_
Carpet A + Cardboard *	4.19	5.17	7.05	6.76	4.48
Cardboard * high N 50%	7.21	6.09	5.71	5.89	6.55
Cardboard * low N 50%	7.02	5.94	6.03	5.70	6.08

* composted with high or low rates of nitrogen

Table 13. Electrical conductivity (mS/cm) of peat control media, and media containing 50% v/v composted paper and cardboard wastes and carpet shearing wastes used for 2005 Experiments

Media	Outdoor mix	*Penstemon* mix	Indoor mix
Peat control	0.94	0.95	0.32
<u>50% peat substitute media</u>			
Paper crumb A high N	1.17	0.77	0.77
Paper crumb A low N	1.29	0.89	0.89
Paper crumb B high N	1.16	0.92	0.92
Cardboard high N	1.24	1.13	1.13
Cardboard low N	0.58	0.71	0.71
Carpet waste A	1.69	1.23	1.17
Carpet waste B	1.74	1.48	1.38
Carpet waste A + Cardboard high N	1.80	1.51	1.57

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Table 14. Final electrical conductivity of peat control and 50% and 100% substitute media, herbaceous perennials, 2005 Experiment

Treatment	*Aster*	*Delphinium*	*Geranium*	*Penstemon*	*Rudbeckia*
Peat control	350	408	430	709	235
Paper A * high N 50%	414	409	554	470	361
Paper A * low N 50%	425	412	586	641	382
Paper B * high N 50%	330	432	465	618	305
Carpet A 50%	474	551	1310	1839	_
Carpet B 50%	434	987	1054	2570	_
Carpet A + Cardboard *	390	696	2089	3630	714
Cardboard * high N 50%	292	456	423	406	322
Cardboard * low N 50%	339	356	399	434	237

* composted with high or low rates of nitrogen

Table 15. Initial pH of media used in the 2006 Experiments

	Peat control	Paper crumb 50%	Paper Pulp 50%	Cardboard 50%	Carpet waste 25%
Herbaceous	5.27	6.67	7.26	5.70	5.36
Outdoor	6.01	6.41	7.05	5.18	5.74
Indoor	5.83	6.53	7.05	5.71	5.82
Conifer	5.02	6.75	7.54	5.77	4.96
Lavender	5.61	6.72	6.68	5.44	5.75

Table 16. Final pH of peat control and 25% and 50% substitute media, herbaceous perennials, 2006 Experiment

Treatment	*Aster*	*Delphinium*	*Lavandula*	*Penstemon*	*Rudbeckia*
Peat control	5.33	5.87	6.43	5.24	5.86
Paper crumb 50% *	6.92	7.72	7.75	7.47	7.86
Paper pulp 50% *	7.28	7.80	7.80	7.93	7.91
Cardboard 50% *	6.71	6.96	7.31	7.13	7.09
Carpet 25%	5.85	3.82	5.47	3.87	4.48

* composted

2006 Experiments. Across different applications, peat control media for conifers had the lowest pH and those for outdoor woody species the highest pH (Table 15). For the 25 and 50% substitute treatments, the pH values across different applications were similar. The 50% composted paper crumb and paper pulp mixes had the highest pH values whereas the 50% composted cardboard and 25% carpet waste treatments had pH values similar to the peat controls (Table 15).

At the end of the cropping period for the herbaceous species, media containing 50% composted paper crumb had higher pH values than the peat controls, whereas media containing 50% carpet waste had lower pH vales (Table 16). Media containing 50% carpet waste had lower final pH values in the *Delphinium* and *Penstemon* pots than in the *Aster* and *Lavandula* pots (Table 16). For the peat controls and media containing composted paper or cardboard wastes, the final pH vales across different species were similar (Table 16).

The ECs of peat control media were highest for conifers and lowest for the indoor mix, reflecting the lower rate of fertiliser (Table 17). The ECs of the 50% composted paper crumb media had the highest initial ECs, except for conifer mixes where the peat control medium had the highest EC. Media containing 50% composted paper pulp or cardboard waste had the lowest initial ECs.

For *Aster*, the final pH values for the different treatments were similar (Table 18). For *Delphinium* and *Rudbeckia*, final ECs values in the peat controls were lower than in the other treatments. The 50% carpet waste resulted in the highest final EC in *Lavandula* whereas for *Penstemon*, the composted paper and cardboard wastes resulted in the highest final EC (Table 18).

In peat control media used for liners, the herbaceous and lavender mixes had slightly lower pH values and higher ECs than the outdoor mix (Tables 19 and 20). The herbaceous liner mixes had lower pH values than the outdoor and lavender mixes (Table 19). The outdoor liner mixes generally had lower ECs than the herbaceous or lavender liner mixes (Table 19). The 50% composted cardboard and 25 and 50% carpet waste treatments had similar pH values to the peat control, except for *Lavandula* where the composted cardboard waste had a higher pH value. The 50% carpet waste treatments had the highest ECs, except for the outdoor mix, where 50% paper crumb had the highest EC.

The final pH values of media used for liners were higher in media containing 50% composted paper crumb or cardboard waste than in the peat controls whereas the media containing 50% carpet waste had lower pH values (Table 21).

For *Delphinium*, *Geranium*, *Lavandula*, and *Viburnum*, the final ECs in the 25 and 50% peat substitute media were higher than in the peat controls (Table 22). For *Penstemon*, the final EC was higher in the 50% composted paper crumb treatment than in the other media.

Table 17. Initial electrical conductivity (mS/cm) of media used in the 2006 Experiments

	Peat control	Paper crumb 50%	Paper Pulp 50%	Cardboard 50%	Carpet waste 25%
Herbaceous	0.52	1.03	0.35	0.41	0.62
Outdoor	0.41	0.77	0.37	0.40	0.55
Indoor	0.14	0.79	0.36	0.21	0.33
Conifer	1.08	0.95	0.37	0.29	0.79
Lavender	0.77	0.92	0.30	0.20	0.88

Table 18. Final electrical conductivity of peat control and 25% and 50% substitute media, herbaceous perennials, 2006 Experiment

Treatment	*Aster*	*Delphinium*	*Lavandula*	*Penstemon*	*Rudbeckia*
Peat control	449	178	150	516	157
Paper crumb 50% *	583	293	238	1203	331
Paper pulp 50% *	522	317	227	929	434
Cardboard 50% *	484	342	153	851	349
Carpet 25%	451	251	698	301	427

* composted

Table 19. Initial pH of media used for liners in the 2006 Experiments

	Peat control	Paper crumb 50%	Cardboard 50%	Carpet waste 25%	Carpet waste 50%
Herbaceous	5.32	6.27	4.78	5.29	5.21
Outdoor	6.04	6.57	5.96	5.63	5.46
Lavender	5.61	6.72	6.68	5.75	5.68

Table 20. Initial electrical conductivity (mS/cm) of media used for liners in the 2006 Experiments

	Peat control	Paper crumb 50%	Cardboard 50%	Carpet waste 25%	Carpet waste 50%
Herbaceous	0.83	1.07	0.61	1.51	1.55
Outdoor	0.25	0.79	0.21	0.26	0.31
Lavender	0.77	0.92	0.20	0.88	1.32

Table 21. Final pH of peat control and 25% and 50% substitute media, 9 cm liners, 2006 Experiment

Treatment	*Delphinium*	*Geranium*	*Lavandula*	*Penstemon*	*Viburnum*
Peat control	4.74	6.43	6.63	4.79	6.68
Paper crumb 50% *	7.14	7.69	7.62	7.29	7.62
Cardboard 50% *	6.47	7.33	7.46	6.72	7.38
Carpet 25%	4.74	5.03	4.15	4.88	4.89
Carpet 50%	5.12	4.10	3.52	3.99	4.33

* composted

Table 22. Final electrical conductivity of peat control and 25% and 50% substitute media, 9 cm liners, 2006 Experiment

Treatment	*Delphinium*	*Geranium*	*Lavandula*	*Penstemon*	*Viburnum*
Peat control	276	163	156	475	122
Paper crumb 50% *	865	280	239	1125	272
Cardboard 50% *	373	245	191	321	190
Carpet 25%	523	238	518	596	200
Carpet 50%	623	348	287	467	274

* composted

Preliminary experiment

The relative differences between treatments with sprinkler and dripper irrigation were similar; mean results are therefore shown in Tables 23, 24 and 25. All three species grown in the 50% paper mill crumb waste showed initial signs of reduced growth. Leaf colour one to four months after potting was paler than in the control plants indicating immobilisation of nitrogen by the raw paper crumb. After over-wintering, the nitrogen deficiency symptoms in this mix declined.

- *Aster frikartii* ‘Mönch’

Top dry weight, shoot number, and flower number were all greater or better in the 50% carpet shearing waste and raw paper crumb mixes than in the peat control (Table 23, Picture 1). Leaf colour was darkest in the carpet shearing waste treatment. The final pH was lowest in the carpet shearing waste treatment; EC was lowest in the peat control mix (Table 23).

- *Rudbeckia fulgida* var. *sullivantii* ‘Goldsturm’

Top dry weight, shoot number, leaf colour and flower number were all greater or better in the 50% carpet shearing waste and raw paper crumb mixes than in the peat control (Table 24, Picture 2). Plants grown in the carpet shearing waste mix were shorter. The carpet shearing waste mix had the lowest final pH value and the raw paper crumb mix had the highest pH value. The final ECs of the carpet shearing waste and paper crumb mixes were slightly higher than that of the peat control (Table 24).

- *Viburnum tinus* ‘French White’

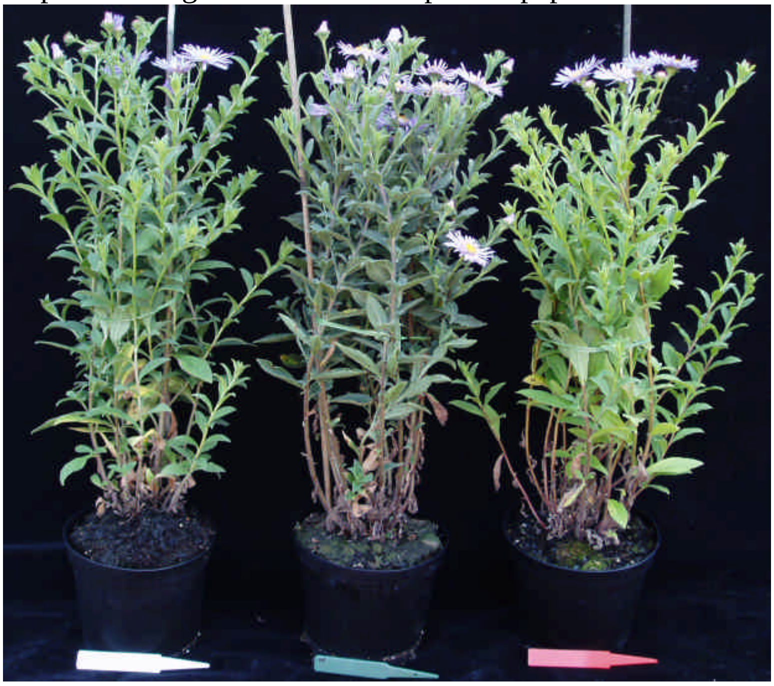
Substitution of 50% peat with carpet shearing waste resulted in increased plant top weight and height and darker leaf colour than plants grown in the standard peat/ bark Indoor mix (Table 25, Picture 3). The 50% raw paper crumb mix resulted in shorter plants with fewer flowers than the control but did not affect plant top dry weight or leaf colour at harvest. The 50% carpet waste mix had a lower pH and higher EC than the control at the end of the experiment. The 50% raw paper crumb treatment had the opposite effect (Table 25).

Table 23. Effect of 50% substitution of peat on *Aster frikartii* ‘Mönch’ in the preliminary experiment. Values are the means of at least 6 replicate plants irrigated with sprinklers and 6 replicate plants irrigated with drippers

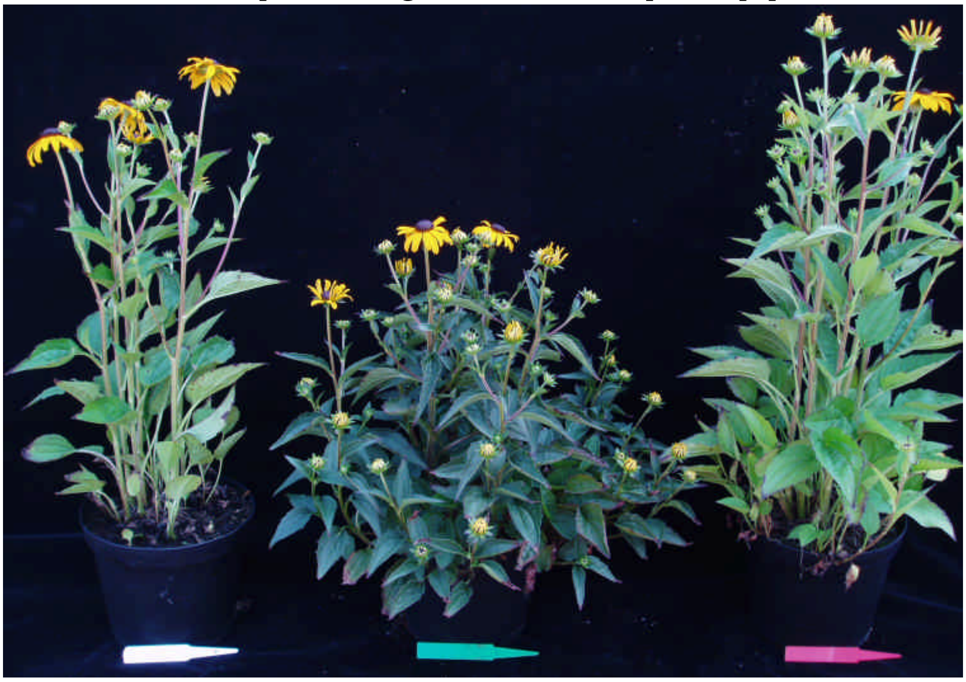
Treatment	Top dry weight, g	Height mm	Shoot number	Flower number	Leaf* colour	Final media	
						pH	EC, mS/cm
Peat (Outdoor mix)	13.1	568	9.0	9.5	2.1	7.57	171
50% Carpet waste	24.5	567	9.8	20.3	2.9	5.46	284
50% Paper crumb	25.5	603	9.7	19.7	2.0	7.74	282

* 1 = palest, 3 = darkest

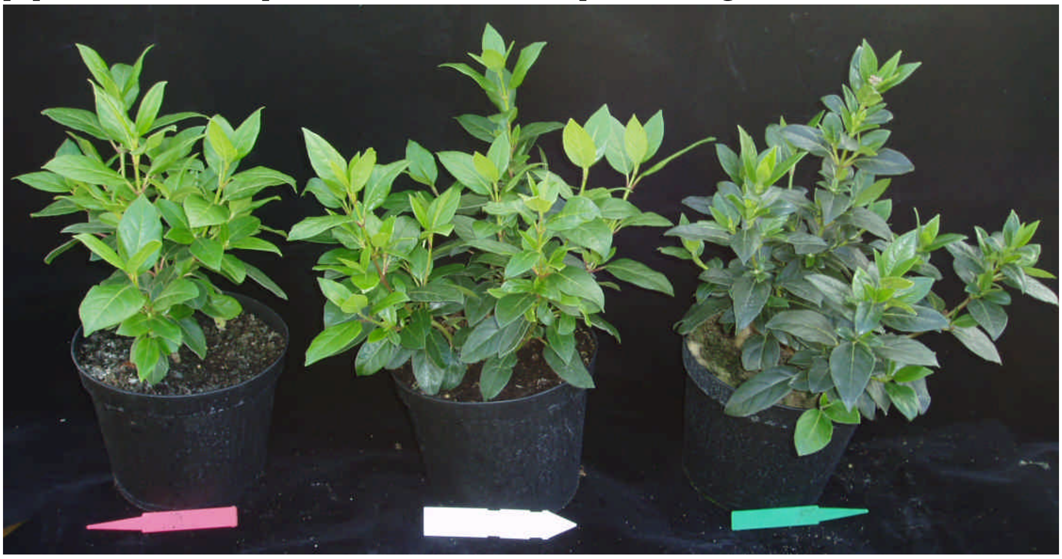
Picture 1. *Aster frikartii* 'Mönch' growing in (left to right) peat control and 50% carpet shearing waste and uncomposted paper crumb waste.



Picture 2. *Rudbeckia fulgida* var. *sullivantii* 'Goldsturm' growing in (left to right) peat control and 50% carpet shearing waste and uncomposted paper crumb waste.



Picture 3. *Viburnum tinus* 'French White' growing in (left to right) 50% uncomposted paper crumb waste, peat control and 50% carpet shearing waste.



Picture 4. Penstemon 'Vesuvius' grown in (clockwise from top left) peat control, and 50% mixes containing carpet shearing waste, composted cardboard waste and composted paper crumb waste.

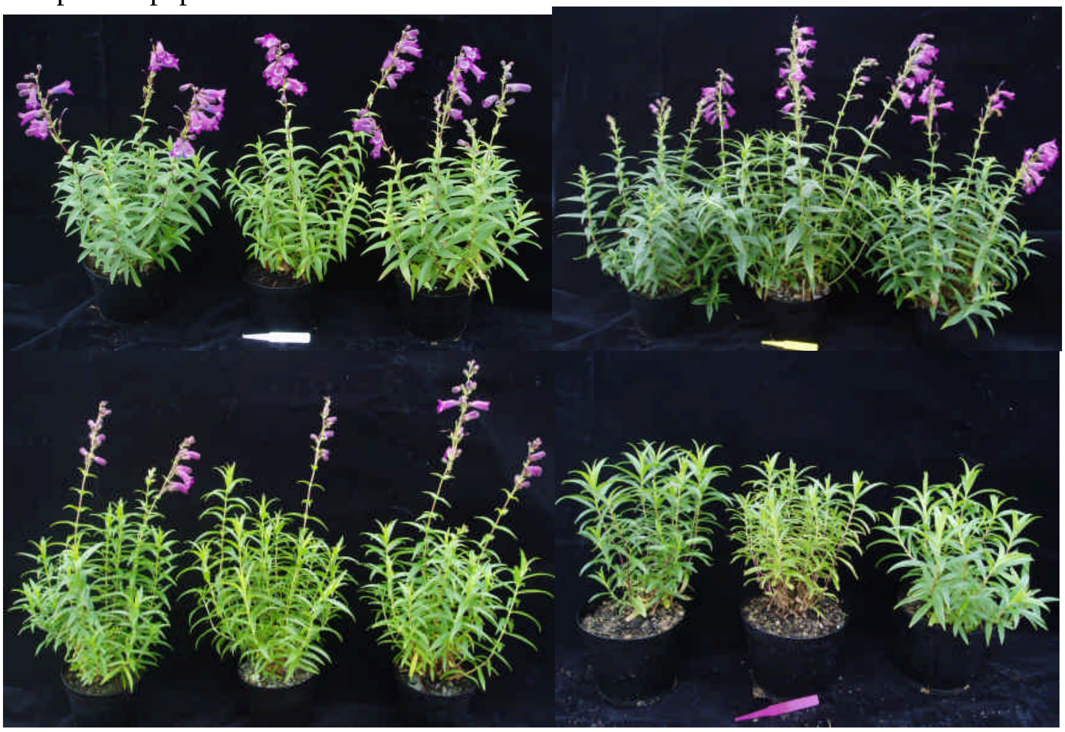


Table 24. Effect of 50% substitution of peat on *Rudbeckia sullivantiii* 'Goldsturm' in the preliminary experiment. Values are the means of at least 6 replicate plants irrigated with sprinklers and 6 replicate plants irrigated with drippers

Treatment	Top dry weight, g	Height mm	Shoot number	Flower number	Leaf* colour	Final media pH	EC, mS/cm
Peat (Outdoor mix)	27.0	46.3	17.5	18.0	2.0	6.5	305
50% Carpet waste	44.5	37.9	28.1	43.3	3.0	4.9	385
50% Paper crumb	47.8	46.8	23.1	31.1	1.8	7.6	416

* 1 = palest, 3 = darkest

Table 25. Effect of 50% substitution of peat on *Viburnum tinus* 'French White' in the preliminary experiment. Values are the means of at least 6 replicate plants irrigated with sprinklers and 6 replicate plants irrigated with drippers

Treatment	Top dry weight, g	Height mm	Flower number	Leaf colour	Final media pH	EC, mS/cm
Peat (Indoor mix)	36.2	304	14	1.9	5.63	0.65
50% Carpet waste	56.6	340	17	3.0	4.25	1.20
50% Paper crumb	34.7	235	3	1.8	7.77	0.42

* 1 = palest, 3 = darkest

<u>2005 Experiments</u>

For the majority test species and measurements, there was no significant effect of irrigation system (sprinklers or drippers). Only those instances where there was a significant effect of irrigation on the mean effect or on the relative performance of different growing media are therefore mentioned.

Herbaceous perennials

- *Rudbeckia lacianata* 'Goldquelle'

In the first year of growth, leaf colour score and flower number were significantly higher in the 50% carpet waste treatments than in the peat control (Fig. 1a). Plants grown in 50% composted paper waste (high N) or composted cardboard wastes produced few or no flowers. Plants did not over-winter in the 50% carpet waste treatments and plant survival was only comparable in the paper waste A (low N) and B treatments with that in the control (Fig. 1b). In the second year of growth, plants grown in carpet + cardboard waste had the greatest top dry weight, numbers of flowers and shoots, and the darkest leaf colour (Fig. 1c). These measurements were also greater in the composted cardboard treatments than in the peat control. Plants grown in 50% composted paper wastes were not significantly different from the peat control plants.

- *Penstemon* 'Vesuvius'

Top dry weight and flower stem number were significantly greater and leaf colour significantly darker in the 50% carpet waste A and B treatments than in the control (Figure 2, Picture 4). The composted cardboard waste treatments resulted in a lower top dry weight whereas the composted paper waste treatments were not significantly different to the peat control. All the composted paper and cardboard treatments reduced flower stem number but did not affect leaf colour.

- *Delphinium* 'Guardian Blue'

In the Year 1 and Year 2 (over-wintered plants) assessments, the composted paper wastes and carpet waste B treatments resulted in a greater plant height and top dry weight than the peat control (Figs. 3a and 3b, Picture 5). In Year 1, the other treatments were not significantly different from the control (Fig. 3a) but in Year 2, carpet waste A (with peat or cardboard waste) significantly reduced top dry weight (Fig. 3b). In Year 1, leaf colour and flower spike number were not affected by the treatments. In Year 2, the composted paper wastes and carpet shearing waste B resulted in a greater flower spike number than the control but the carpet + cardboard wastes treatment reduced flower spike number (Fig. 3b).

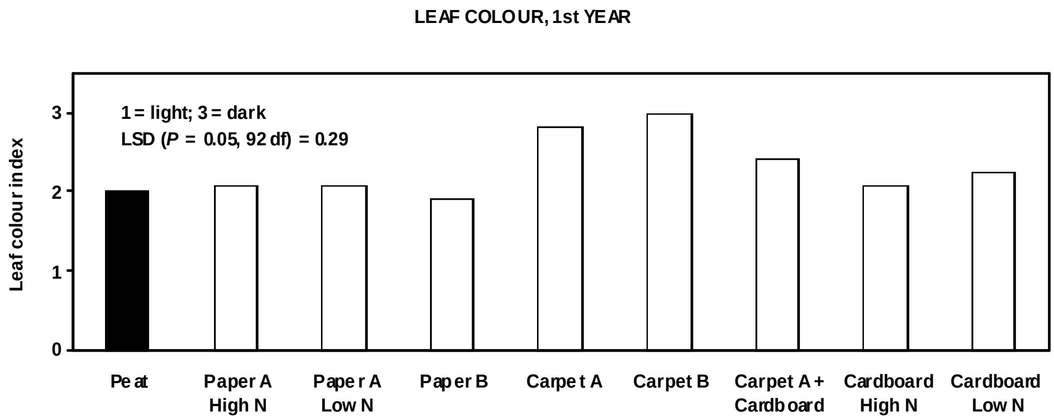
- *Geranium* 'Sabani Blue'

The carpet waste and carpet + cardboard waste treatments resulted in a greater top dry weight, darker leaf colour (Year 1 and 2 assessments) and greater flower number than the peat control (Fig. 4, Picture 6). The composted paper and cardboard treatments were not significantly different from the control in any of these measurements.

- *Aster* x *frikartii* 'Mönch'

In Year 1, plant height was not affected by the treatments (Fig. 5a). Leaf colour was slightly paler in the 50% paper waste (high N) than in the peat control. Very few flowers were produced in the peat control; the carpet waste and paper waste (high N) produced the most flowers. Over-wintering plant survival was lower in the carpet and carpet + cardboard treatments than in the other treatments (Fig. 5b). In Year 2, plants grown in composted paper waste (low N) had the greatest top dry weight and number

Figure 1a. *Rudbeckia* 'Goldquill' 2005 Experiment, Year 1 assessments



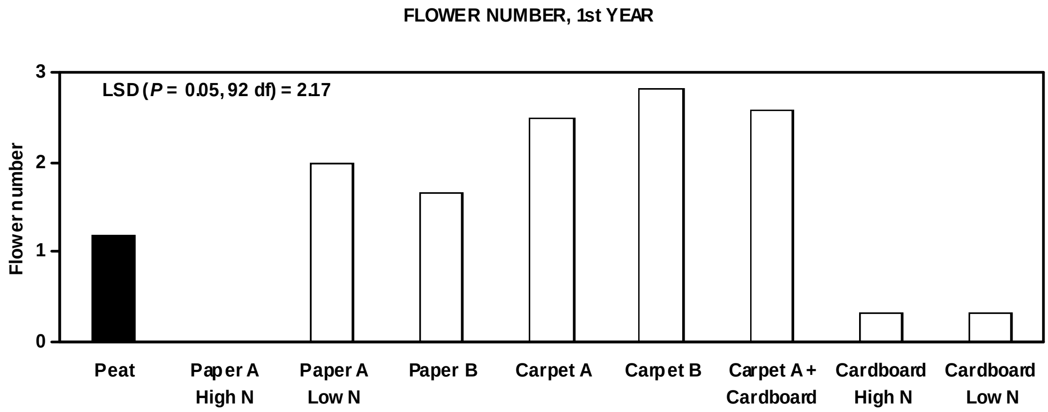


Figure 1b. *Rudbeckia* 'Goldquill' 2005 Experiment, Plant survival

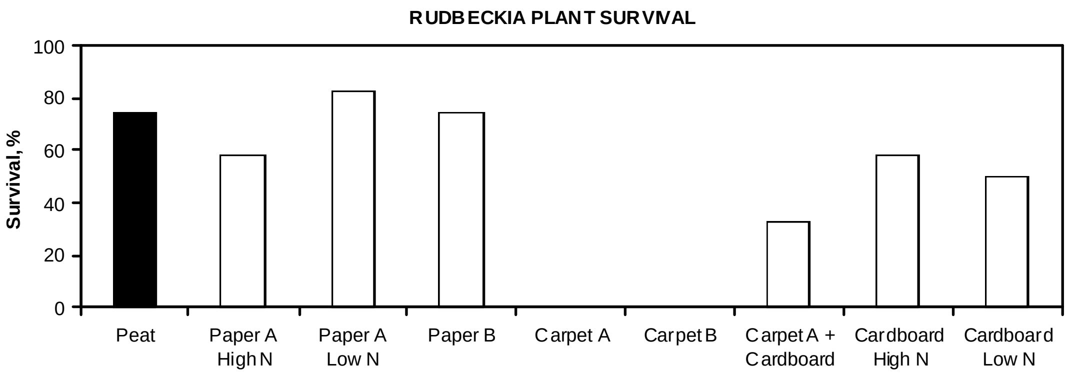
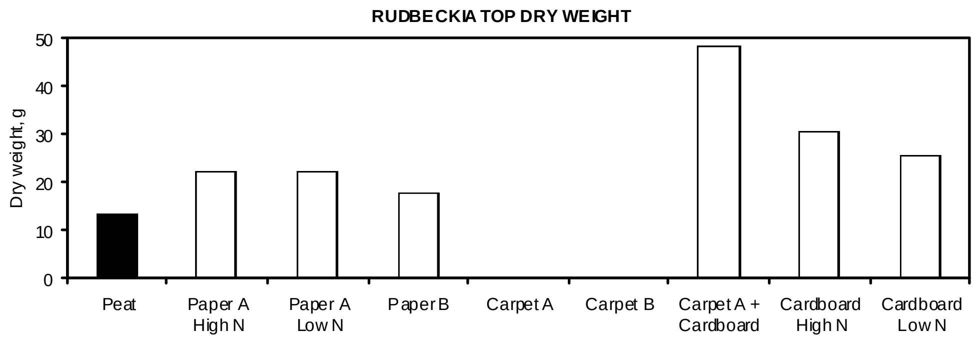
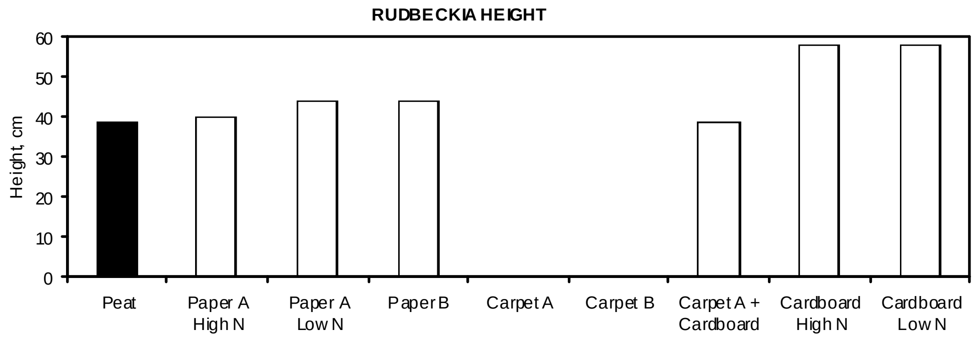
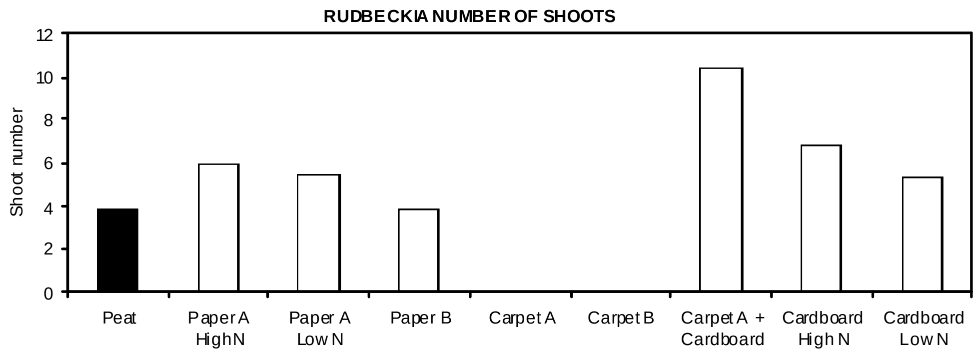
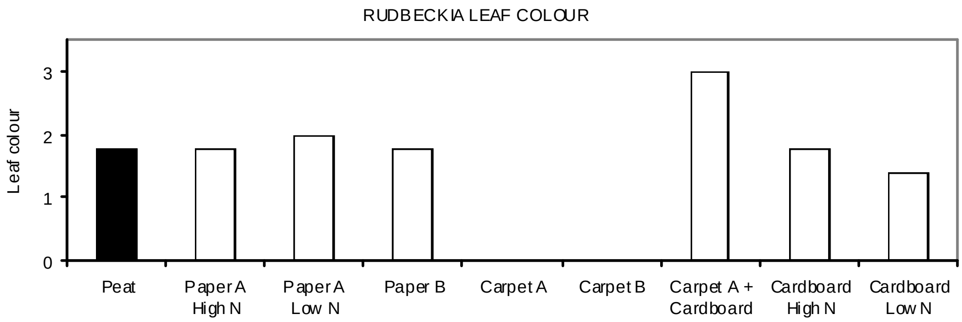


Figure 1c *Rudbeckia* 'Goldquill' 2005 Experiment, Year 2 assessments


RUDBECKIA TOP DRY WEIGHT
Dry weight, g
0
10
20
30
40
50
Peat
Paper A High N
Paper A Low N
Paper B
Carpet A
Carpet B
Carpet A + Cardboard
Cardboard High N
Cardboard Low N


RUDBECKIA HEIGHT
Height, cm
0
10
20
30
40
50
60
Peat
Paper A High N
Paper A Low N
Paper B
Carpet A
Carpet B
Carpet A + Cardboard
Cardboard High N
Cardboard Low N


RUDBECKIA NUMBER OF SHOOTS
Shoot number
0
2
4
6
8
10
12
Peat
Paper A High N
Paper A Low N
Paper B
Carpet A
Carpet B
Carpet A + Cardboard
Cardboard High N
Cardboard Low N


RUDBECKIA LEAF COLOUR
Leaf colour
0
1
2
3
Peat
Paper A High N
Paper A Low N
Paper B
Carpet A
Carpet B
Carpet A + Cardboard
Cardboard High N
Cardboard Low N

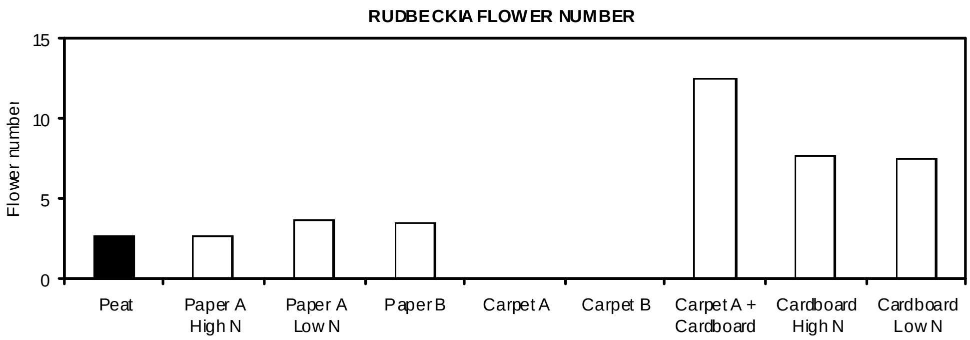
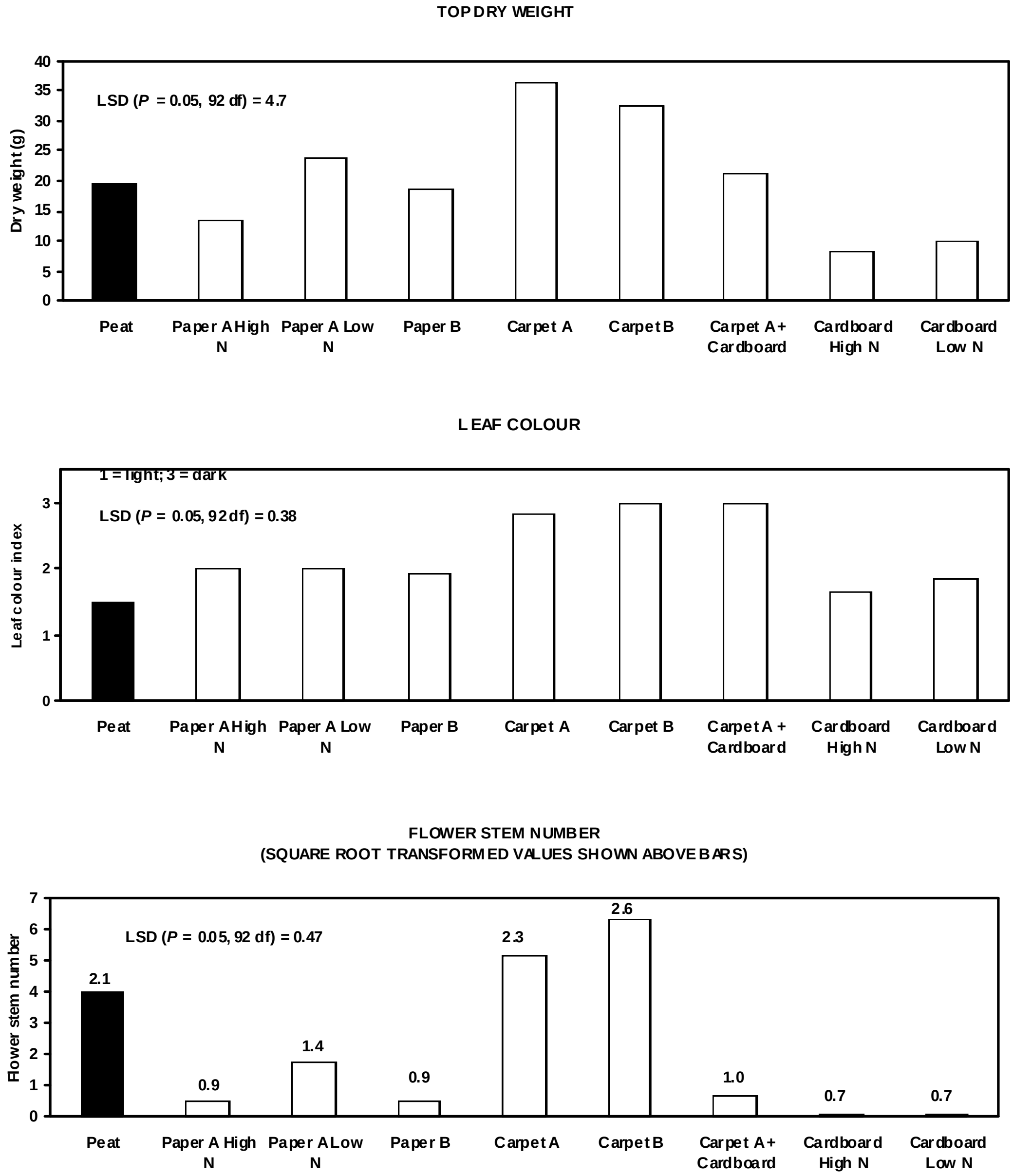
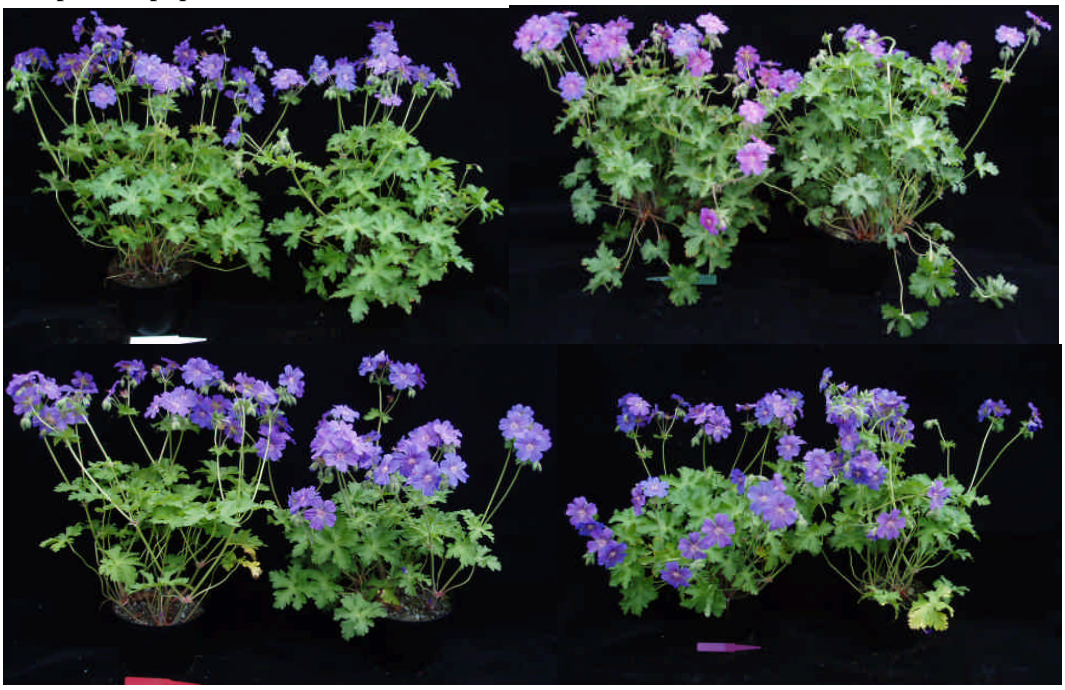

RUDBECKIA FLOWER NUMBER
Flower number
0
5
10
15
Peat
Paper A High N
Paper A Low N
Paper B
Carpet A
Carpet B
Carpet A + Cardboard
Cardboard High N
Cardboard Low N

Figure 2. *Penstemon* 'Vesuvius', 2005 Experiment

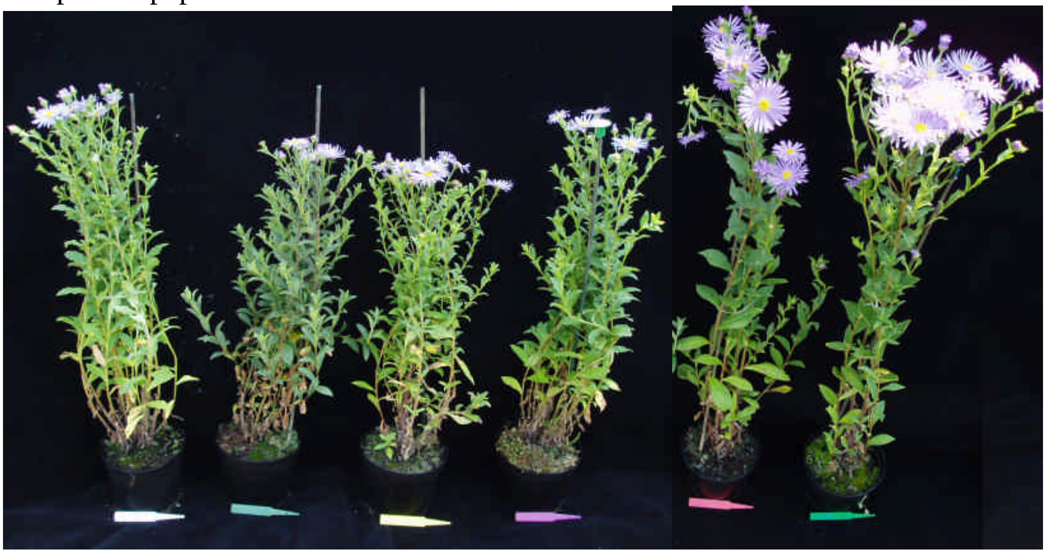


Picture 5. *Delphinium* ‘Guardian Blue’ grown in (clockwise from top left) peat control, and 50% mixes containing carpet shearing waste, composted cardboard waste and composted paper crumb waste.

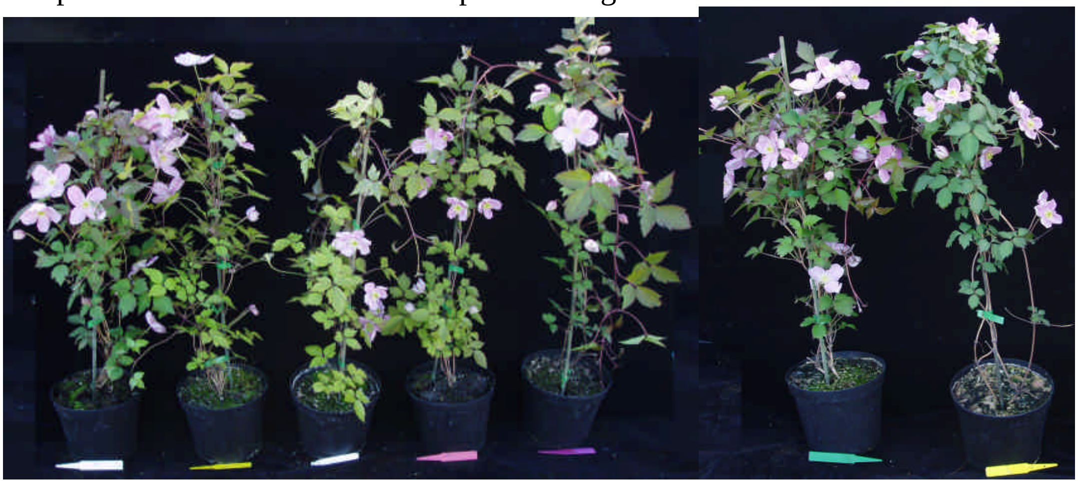
Picture 6. *Geranium* ‘Sabani Blue’ grown in (clockwise from top left) peat control, and 50% mixes containing carpet shearing waste, composted cardboard waste and composted paper crumb waste.



Picture 7. *Aster* x *frikartii* 'Mönch' grown in (from left) peat control, and 50% mixes containing carpet shearing wastes A and B, composted cardboard waste and composted paper crumb wastes A and B.

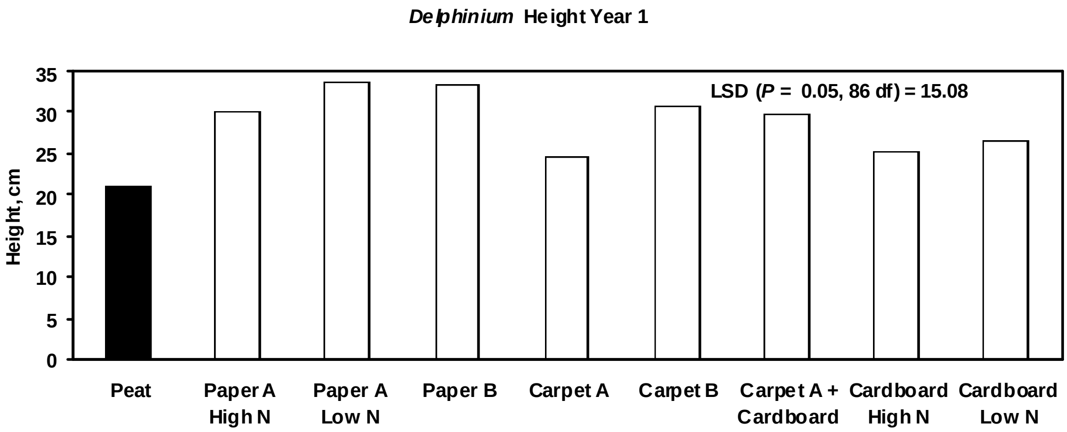


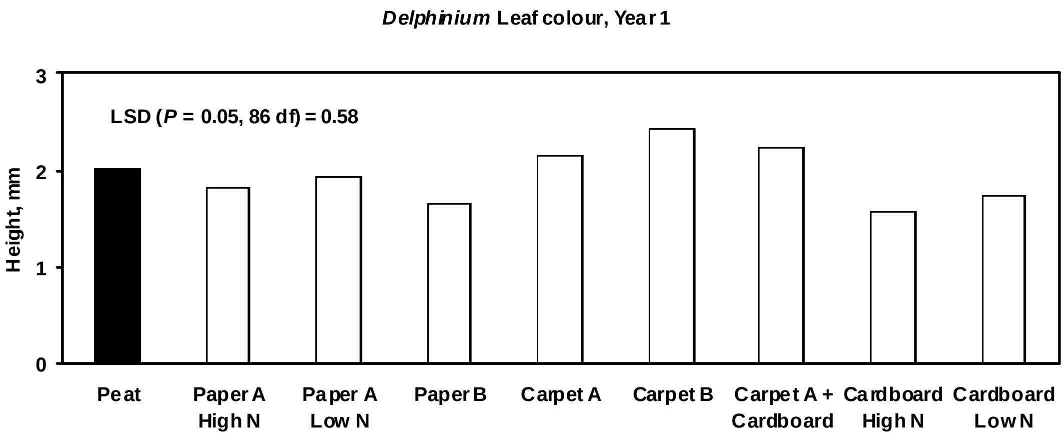
Picture 8. *Clematis montana* 'Tetrarose' grown in (from left) peat control, and 50% mixes containing composted paper crumb wastes B and A (high and low N), composted cardboard waste and carpet shearing wastes A and B.



Picture 9. *Viburnum tinus* 'Pupureum' grown in (from left) peat control, and 50% mixes containing composted paper crumb, carpet shearing waste and composted cardboard waste.

Figure 3a. *Delphinium* 'Guardian Blue', 2005 Experiment, Year 1 assessments





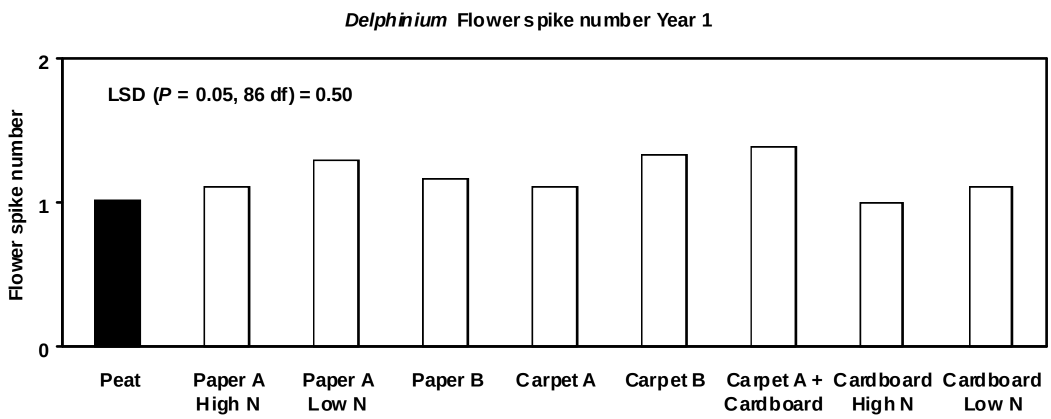
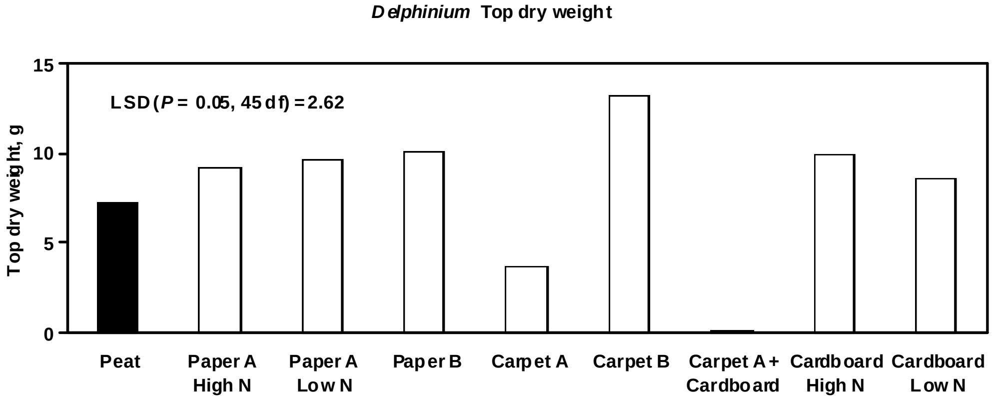
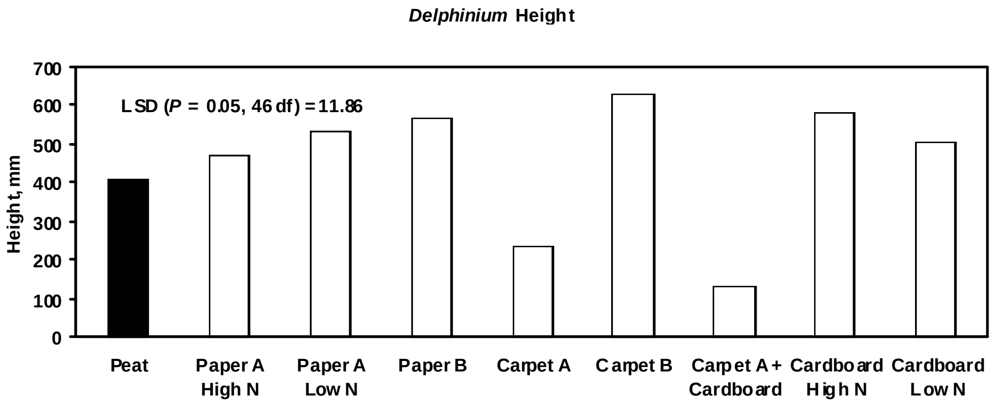
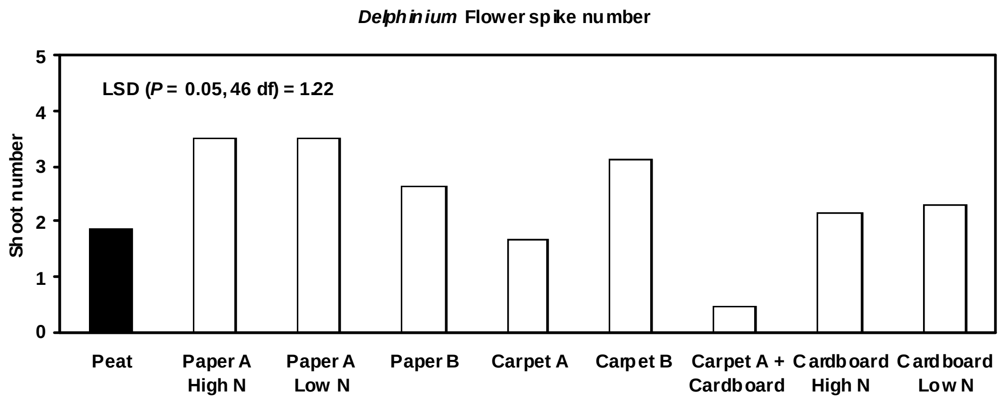


Figure 3b. *Delphinium* 'Guardian Blue', 2005 Experiment, Year 2 assessments







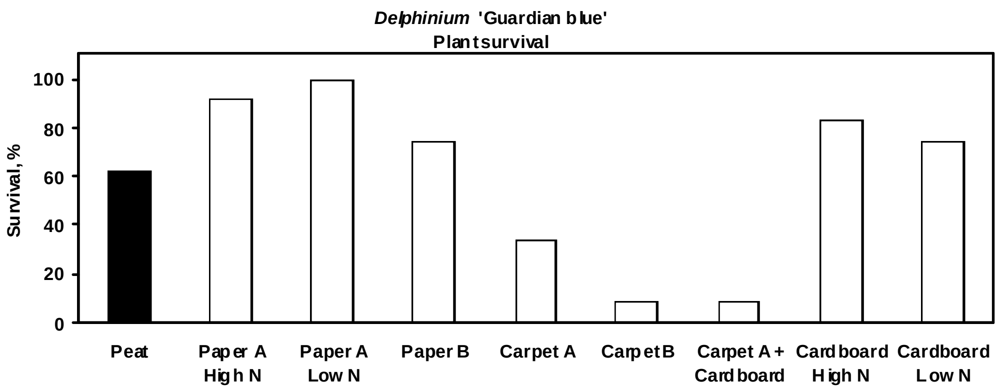
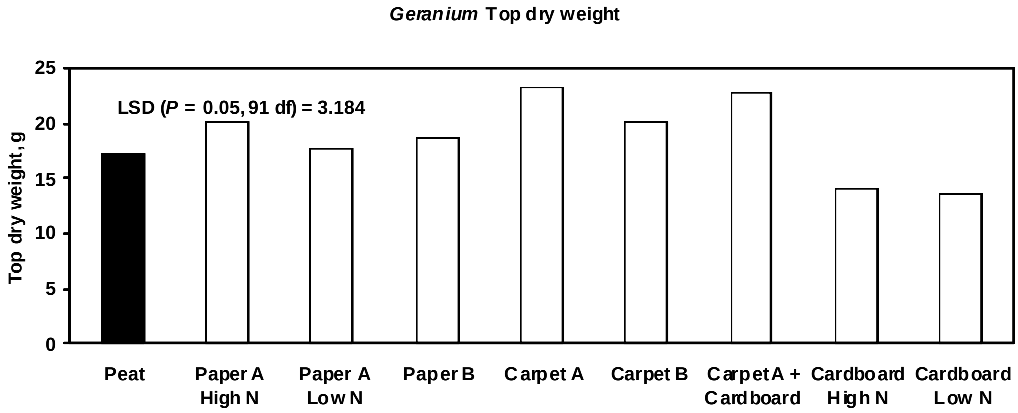
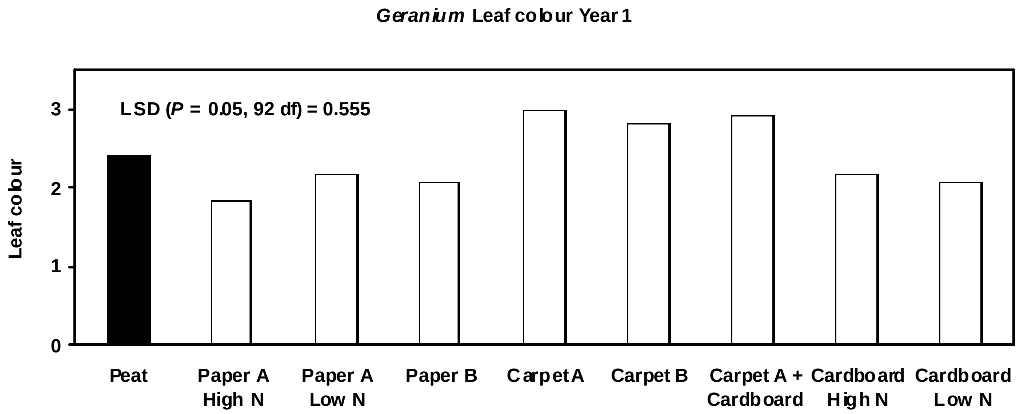
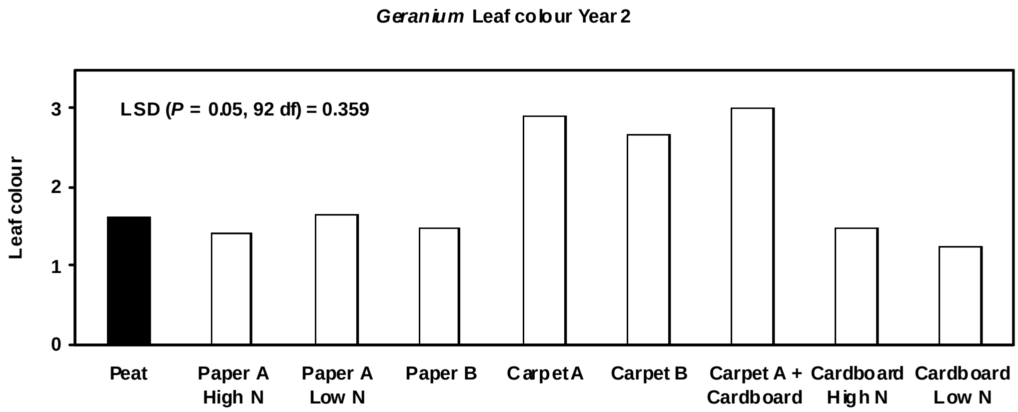


Figure 4 *Geranium* 'Sabani Blue' 2005 Experiment







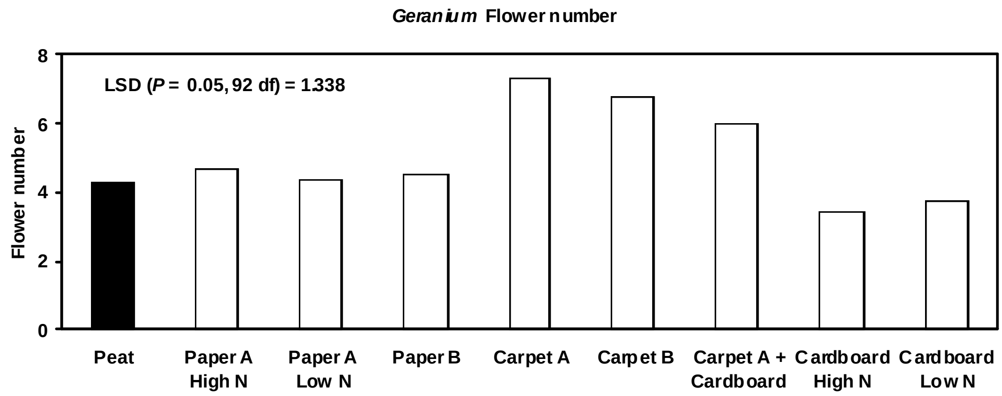
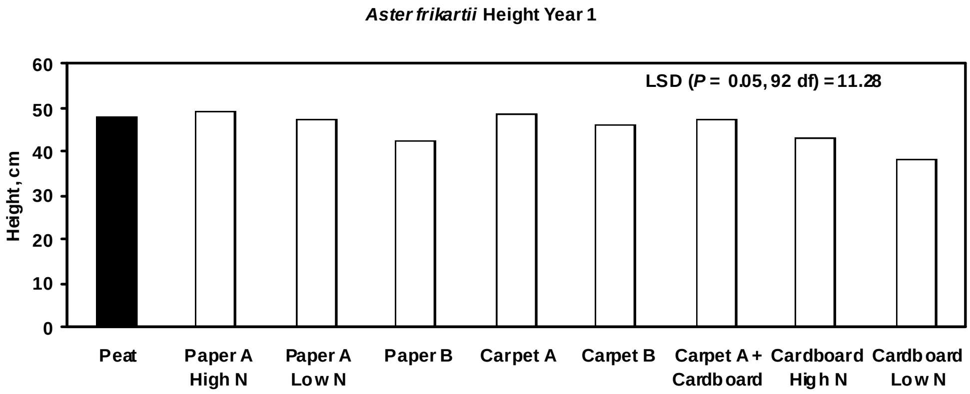
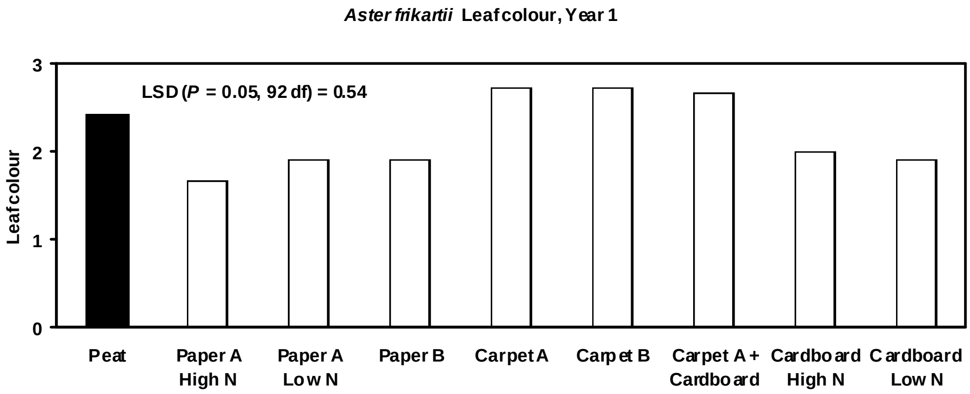


Figure 5a. *Aster* x *frikartii* ‘Mönch’ 2005 Experiment, Year 1 assessments





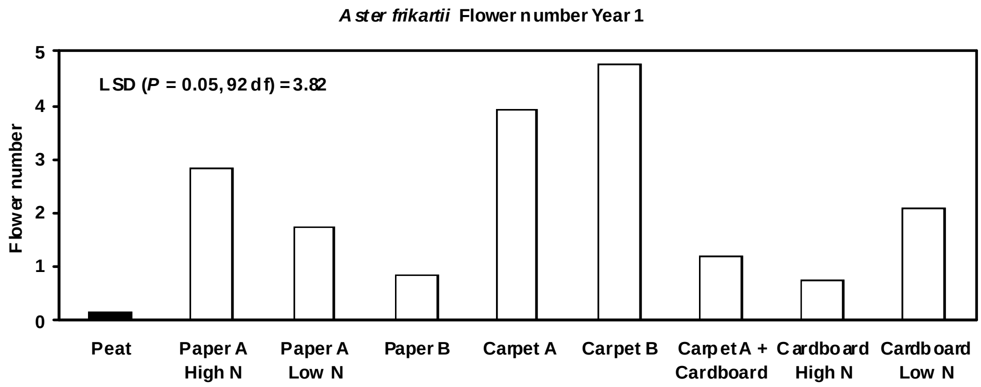


Figure 5b. *Aster* x *frikartii* ‘Mönch’ 2005 Experiment, Plant survival

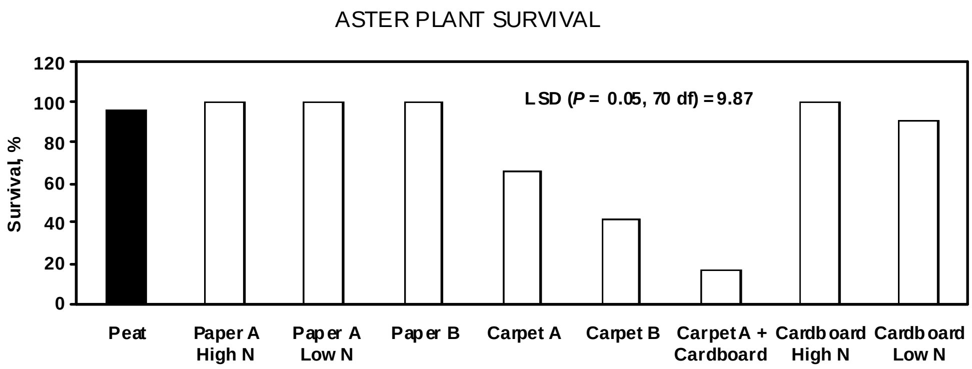


Figure 5c. *Aster* x *frikartii* ‘Mönch’ 2005 Experiment, Year 2 assessments

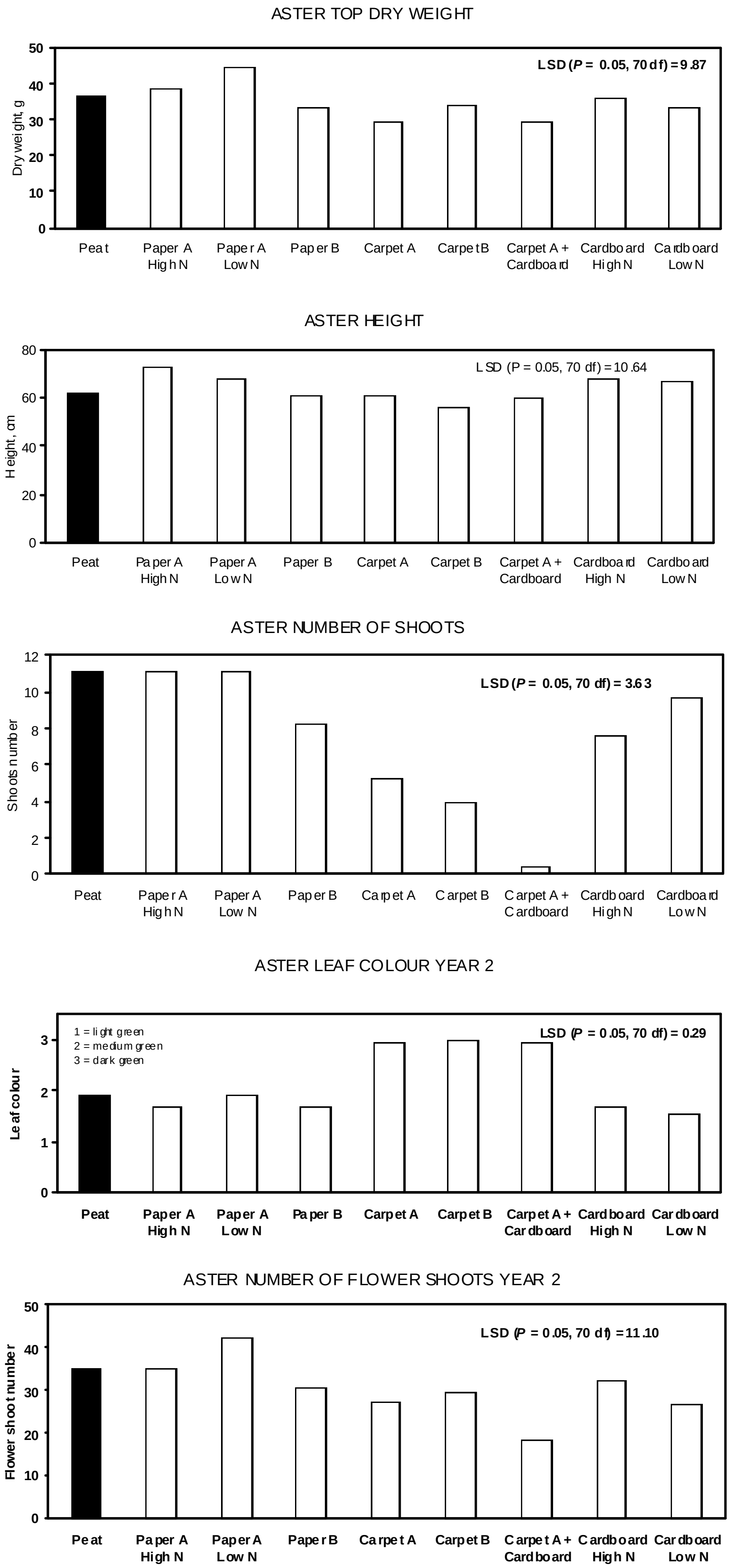
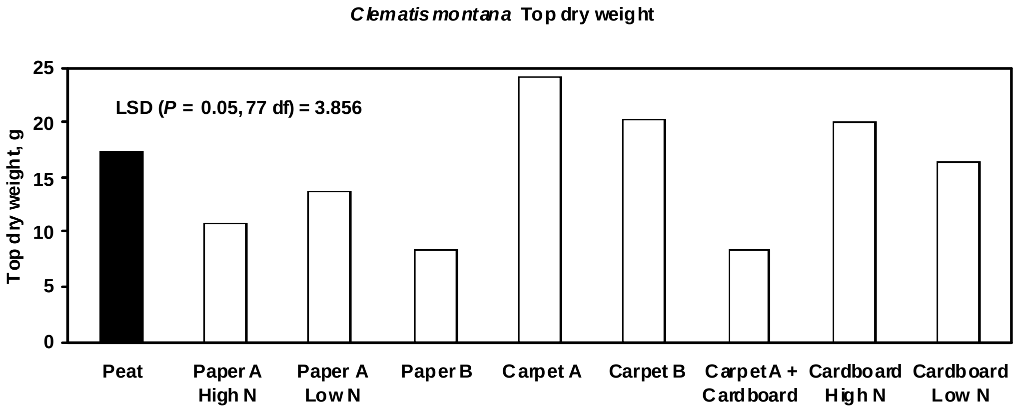
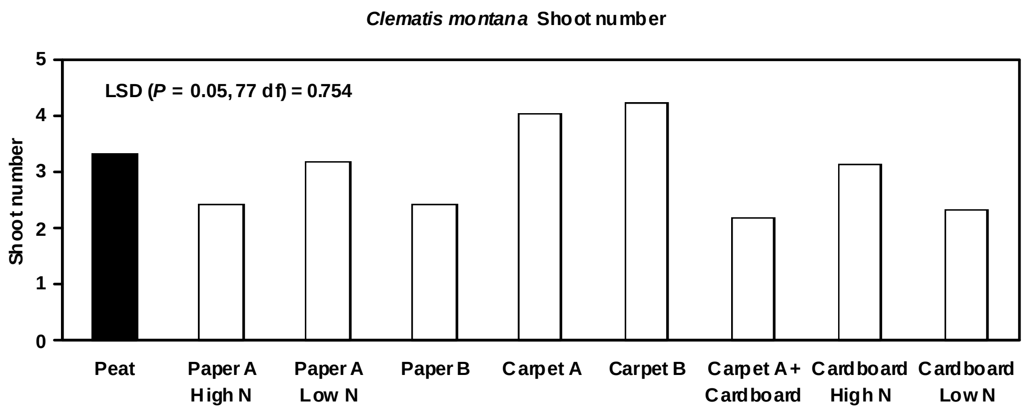


Figure 6a *Clematis montana* 'Tetrarose' 2005 Experiment





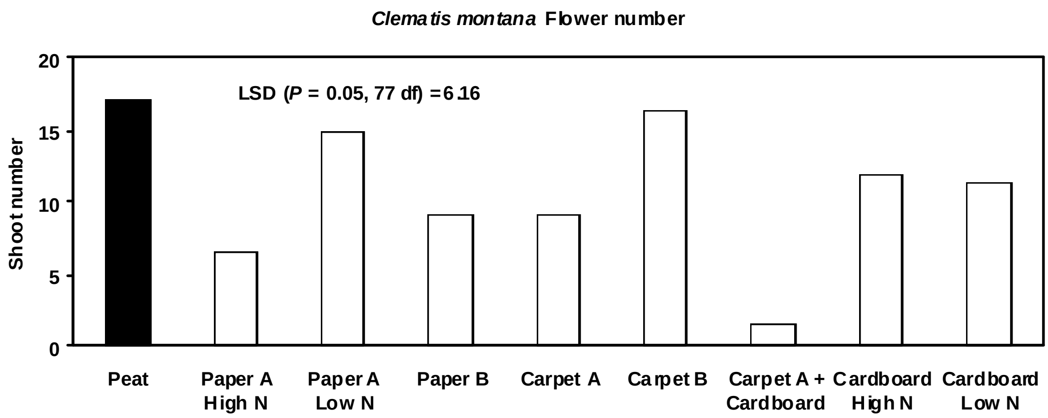
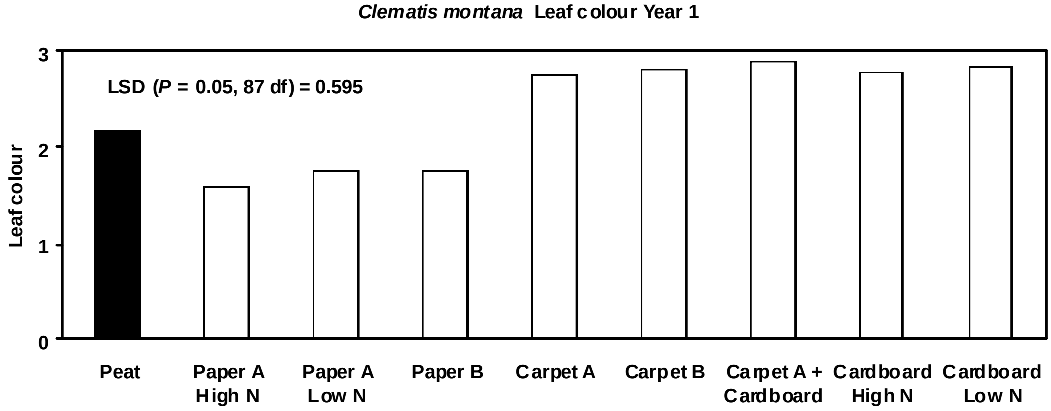


Figure 6b *Clematis montana* 'Tetrarose' 2005 Experiment, Leaf colour assessments



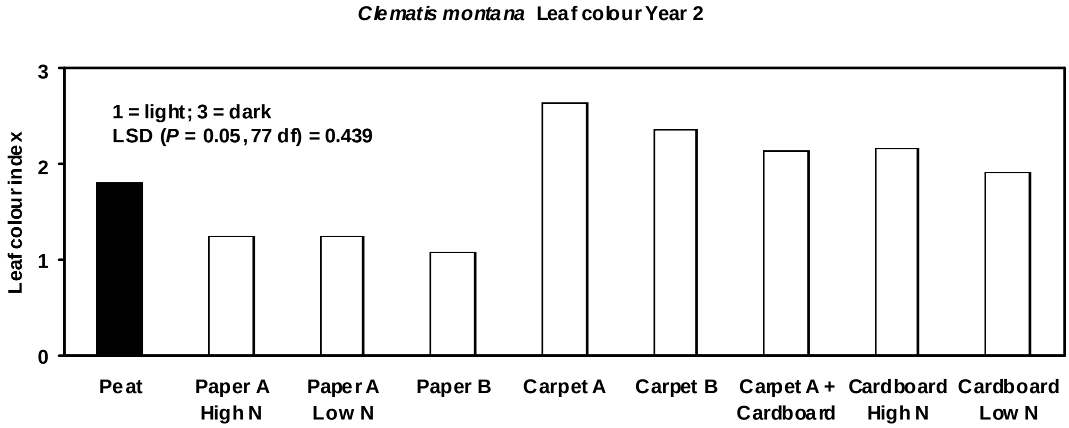
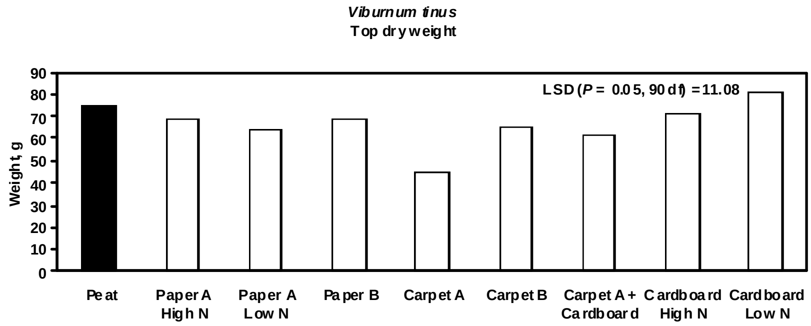
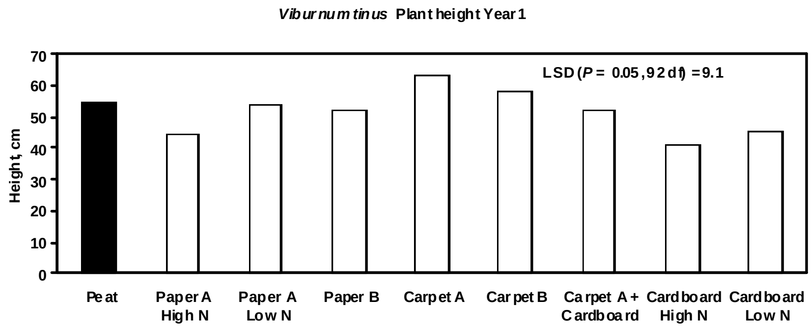
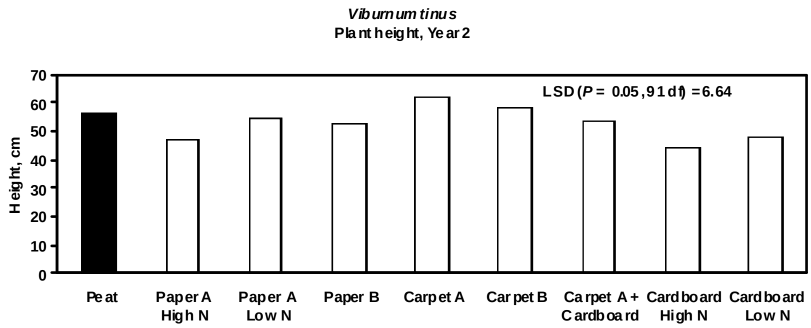
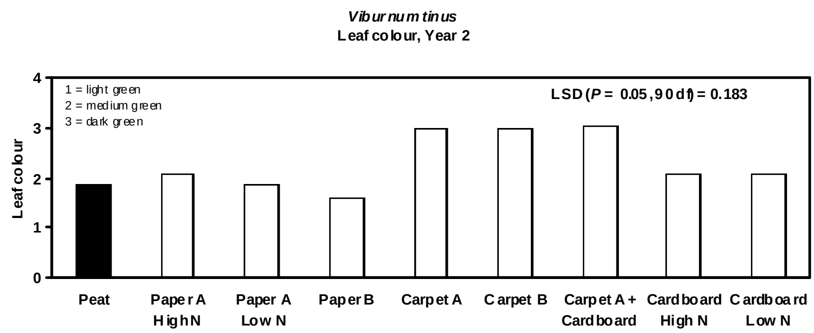


Figure 7. *Viburnum tinus* ‘Pupureum’ 2005 Experiment









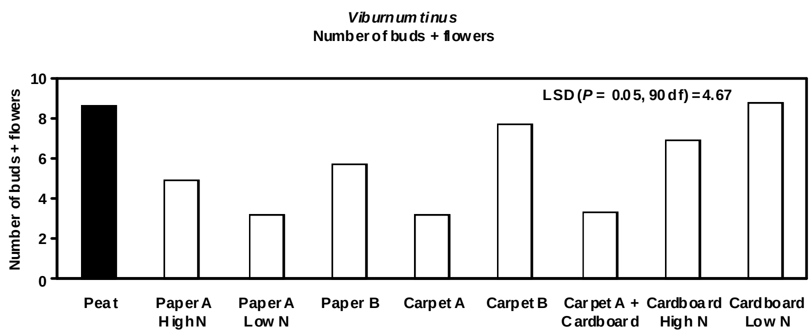
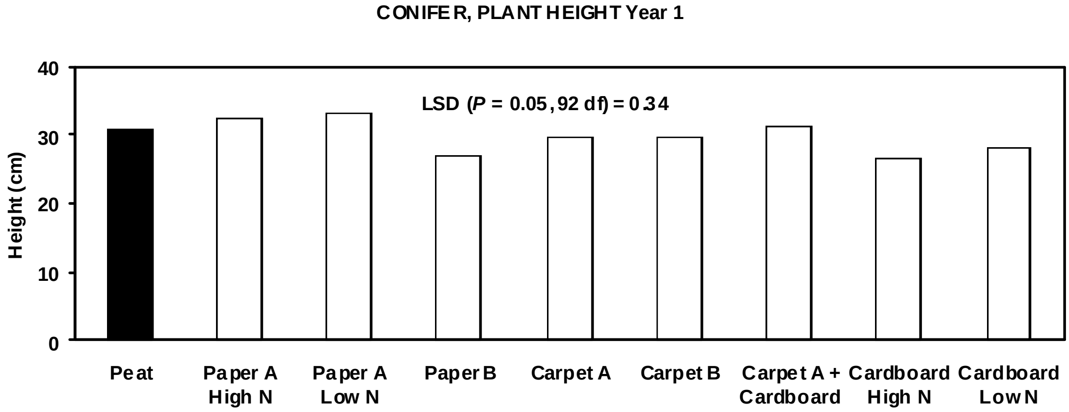


Figure 8a. *Chamaecyparis lawsoniana* 'Ellwoodii', 2005 Experiment, Year 1 assessments



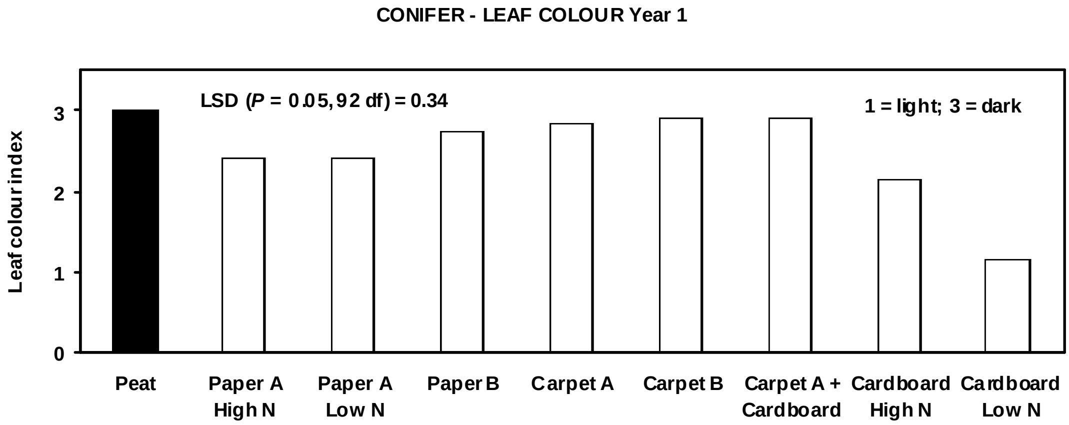


Figure 8b. *Chamaecyparis lawsoniana* 'Ellwoodii', 2005 Experiment, Plant survival

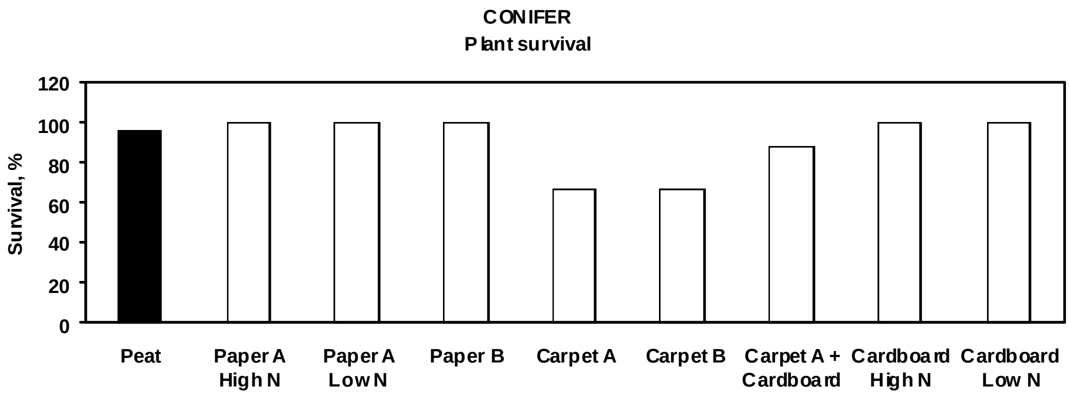
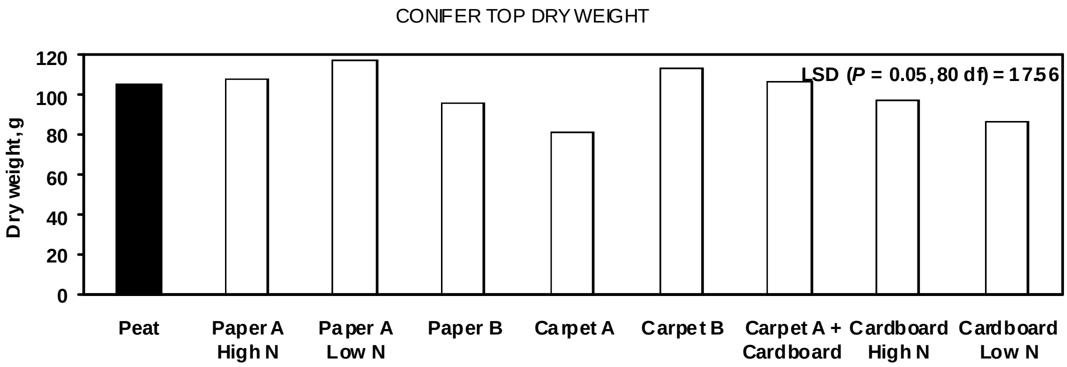
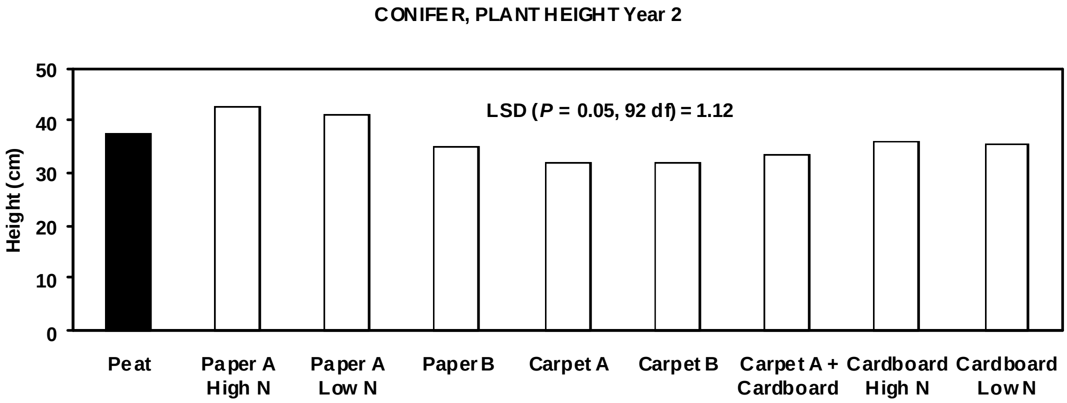


Figure 8c. *Chamaecyparis lawsoniana* 'Ellwoodii', 2005 Experiment, Year 2 assessments





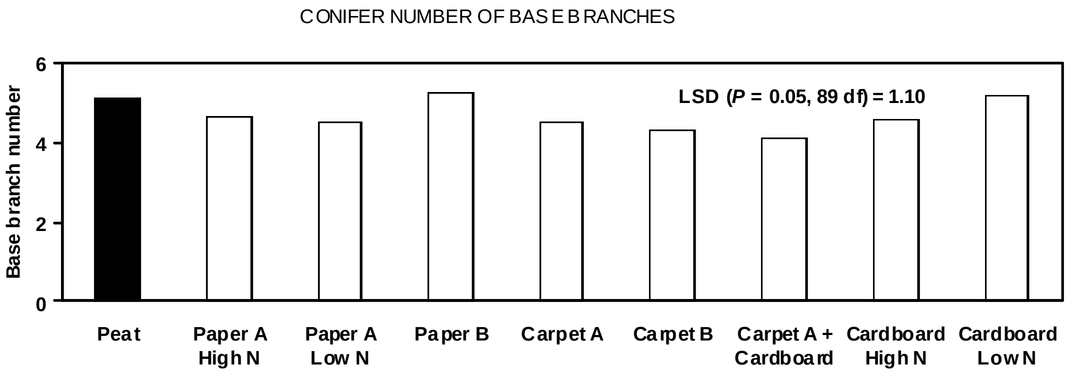
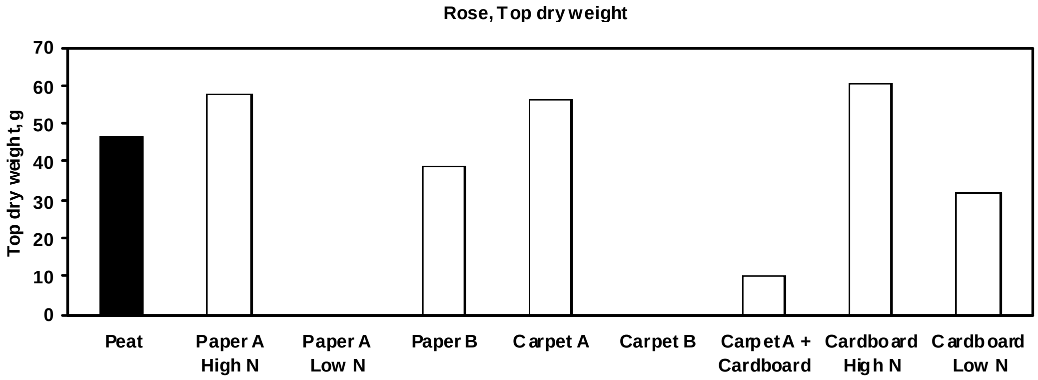
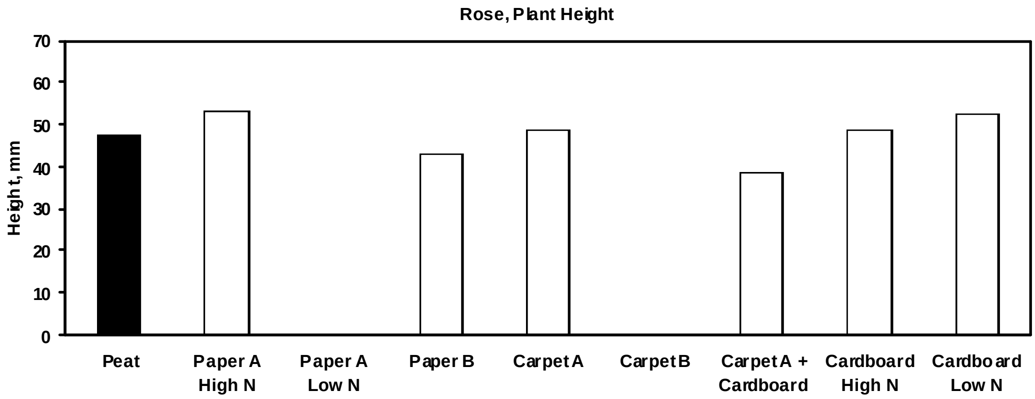
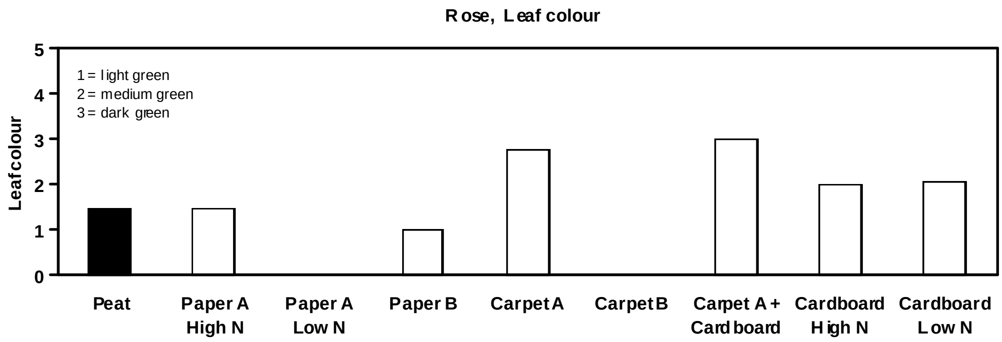
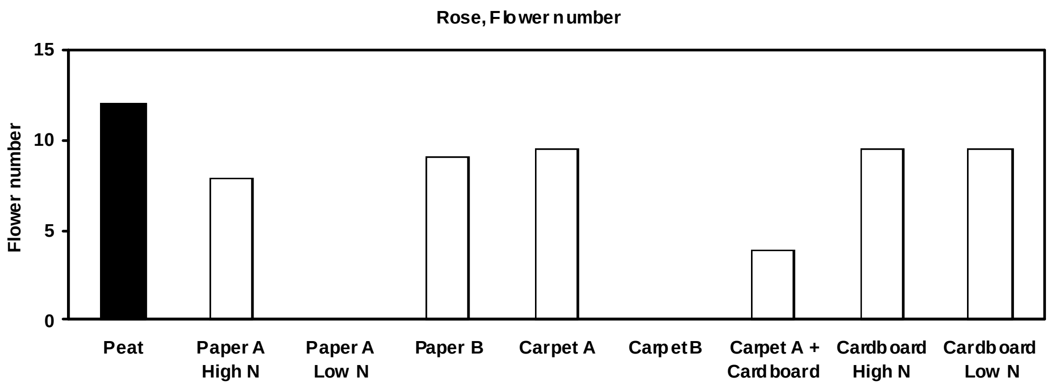


Figure 9. *Rosa* 'Paddy Stephens', 2005 Experiment









Picture 10. *Chamaecyparis lawsoniana* 'Ellwoodii' grown in (from left) peat control, and 50% mixes containing composted paper crumb, carpet shearing waste (with peat and with composted cardboard waste) and composted cardboard waste.

Picture 11. *Rosa* 'Paddy Stephens' grown in (clockwise from top left) peat control, and 50% mixes containing carpet shearing waste, composted cardboard waste and composted paper crumb.

al

of flowering shoots (Fig. 5c, Picture 7). Plants grown with 50% carpet waste had the darkest leaves but produced fewer shoots than the other treatments.

Woody ornamental species

- *Clematis montana* ‘Tetrarose’

Top dry weight, shoot number and leaf colour were significantly better in the 50% carpet waste treatments than in the peat control (Fig. 6a and 6b, Picture 8). However, flower number was reduced by the carpet A treatment, and by the 50% composted paper wastes (high N) and carpet + cardboard waste treatments. Leaf colour was paler in the composted paper waste treatments than in the control (Fig. 6b, Picture 8).

Plants grown with drippers produced more flowers than plants grown with sprinklers.

- *Viburnum tinus* ‘Pupureum’

Carpet waste A added at 50% reduced top dry weight; there were no other significant effects of the treatments on top dry weight or plant height (Fig. 7, Picture 9). Carpet waste treatments made leaves darker. Composted paper wastes and carpet waste A (with peat or cardboard waste) reduced flower number.

Dripper irrigation resulted in a greater top dry weight and taller plants than sprinklers.

- *Chamaecyparis lawsoniana* ‘Ellwoodii’

In Year 1 assessments, the 50% composted paper waste B and cardboard wastes slightly reduced plant height compared with the peat control (Fig. 8a). Leaf colour was paler in the 50% composted paper and cardboard waste treatments than in the peat control. Over-wintering survival was lower in the 50% carpet waste treatments than in the other treatments (Fig. 8b). In the final Year 2 assessment, plant top dry weight was lower in the 50% carpet waste A and cardboard (high N) treatments than in the control (Fig. 8c, Picture 10). Plant height was reduced by 50% carpet waste. There were no differences in the size of plants grown in the 50% composted paper wastes and in the peat control.

Plants grown with dripper irrigation were taller than those grown with sprinklers. There was no effect of irrigation on top dry weight except with 50% carpet waste where dripper irrigation resulted in a greater value than sprinklers.

- *Rosa* 'Paddy Stephens'

Plants grown in 50% composted paper crumb A (high N), cardboard waste (high N) or carpet waste A had a similar height but slightly greater top dry weight than plants grown in the peat control (Fig. 9, Picture 11). Composted paper crumb B (high N) and cardboard (low N) wastes resulted in a significantly lower top dry weight than the control. Plants grown in 50% paper crumb A (low N) or carpet waste B, or carpet + composted cardboard wastes did not survive or were very small. Leaf colour was darker in the media containing carpet waste A or composted cardboard wastes than in the peat control (Fig. 9, Picture 11). Flower number was slightly lower in the 50% composted paper crumb (high N) and cardboard (high and low N) wastes and carpet waste A treatments than in the peat control. The carpet A + composted cardboard waste treatment produced significantly fewer flowers than the control.

<u>2006 Experiments</u>

Herbaceous perennials

- *Aster novi-belgii* 'Purple Dome'

The 50% composted paper crumb or pulp waste treatments resulted in significantly greater top dry weight than the peat control (Fig. 10a, Picture 12). Plant height was not significantly affected by the treatments. The 50% composted paper crumb or cardboard treatments increased the number of flowering shoots compared with the control but the latter treatment reduced the total number of shoots (Figs. 10a and 10b, Picture 12). All the peat substitute treatments resulted in darker leaves than the peat control, with the 25% carpet waste producing the darkest leaves.

- *Delphinium* 'Guardian Blue'

The 50% composted paper crumb and cardboard treatments produced the highest and lowest top dry weights respectively (Fig. 11, Picture 13). The latter treatment also produced the smallest plant height and number of stems. All the peat substitute treatments resulted in darker leaves than the peat control, with the 25% carpet waste producing the darkest leaves.

- *Lavandula angustifolia* 'Hidcote'

The 25% carpet waste treatment resulted in the greatest top dry weight, tallest plants and greatest number of flowers (Fig. 12, Picture 14). The other 50% composted paper and cardboard treatments were not significantly different from the peat control.

- *Rudbeckia fulgida* var. *sullivantii* 'Goldsturm'

The 50% composted paper pulp waste treatment resulted in the greatest top dry weight, and equal with 50% composted paper crumb waste, the most base shoots, and most buds and flowers (Figs. 13a and b, Picture 15). The treatments did not significantly affect plant height, and with the exception of 25% carpet waste, leaf colour.

- *Penstemon* 'Vesuvius' (2L pots, outside)

The 50% composted paper crumb and pulp waste treatments resulted in the greatest top dry weight and tallest plants (Fig. 14a, Picture 16). The 50% composted paper crumb waste produced the greatest number of flowering shoots and, equal with 25% carpet waste, produced the greatest number of total shoots (Figs. 14a and b, Picture 16). Plants grown in the 25% carpet waste had the darkest leaves.

Herbaceous perennials, 9 cm liners

- *Delphinium* 'Guardian Blue'

The 50% composted paper crumb and 25% and 50% carpet waste treatments resulted in greater top dry weight than the peat control (Fig. 15, Picture 17). The 50% composted cardboard waste significantly reduced plant growth. The 50% composted paper crumb treatment produced the tallest plants and the carpet waste treatment produced plants with the darkest leaves.

- *Geranium* 'Sabani Blue'

The 50% composted paper crumb waste and 50% carpet waste treatments produced the greatest top dry weight (Fig. 16, Picture 18). The carpet waste treatments produced the darkest leaves.

- *Lavandula angustifolia* 'Hidcote'

The 25% carpet waste and 50% composted cardboard waste treatments resulted in the greatest and least top dry weight respectively (Fig. 17, Picture 19). None of the plants grown in the 50% carpet waste treatment survived.

- *Penstemon* 'Vesuvius'

All of the peat substitute treatments resulted in slightly smaller plants in terms of top dry weight, height and number of shoots than the peat control (Fig. 18). Leaf colour was slightly darker in the carpet waste treatments and slightly paler in the 50% composted paper crumb or cardboard treatments than in the peat control.

Figure 10a. *Aster novi-belgii* 'Purple Dome', 2006 Experiment

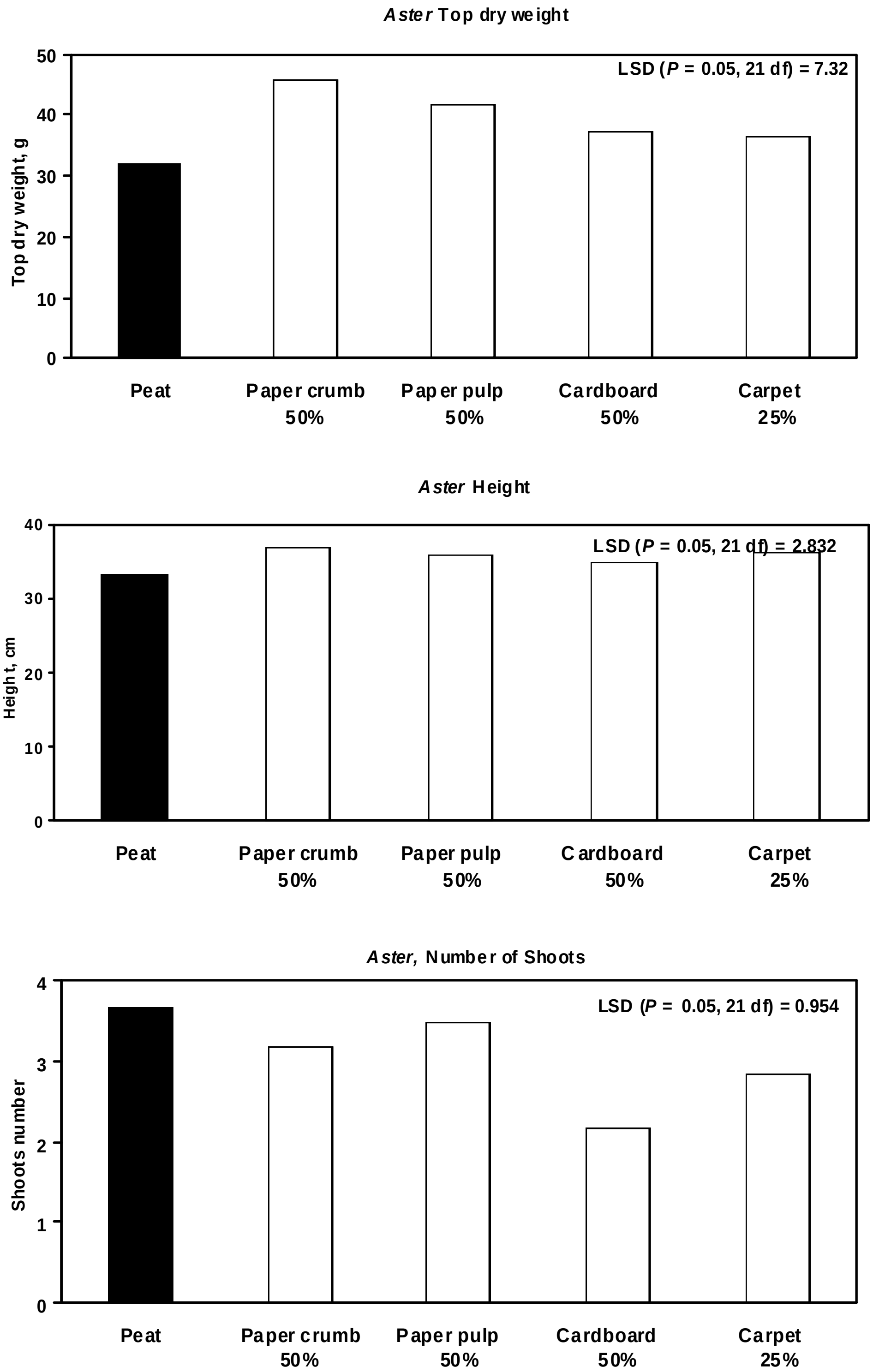
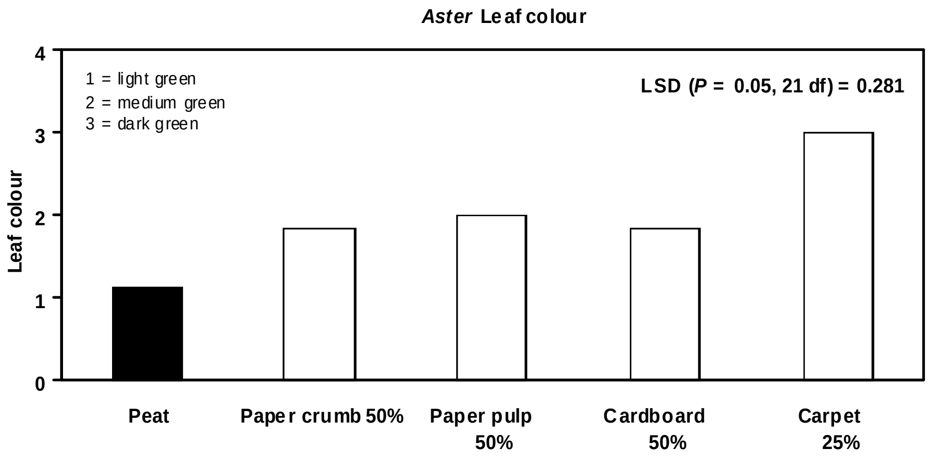


Figure 10b. *Aster novi-belgii* ‘Purple Dome’, 2006 Experiment



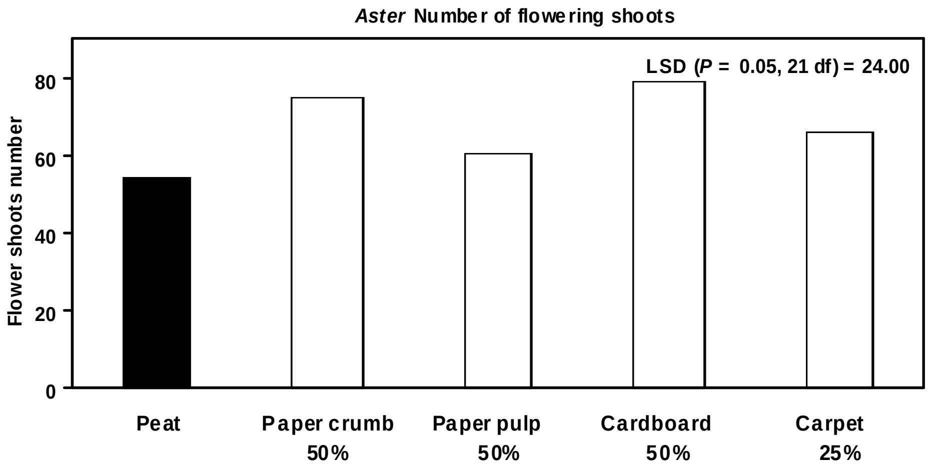
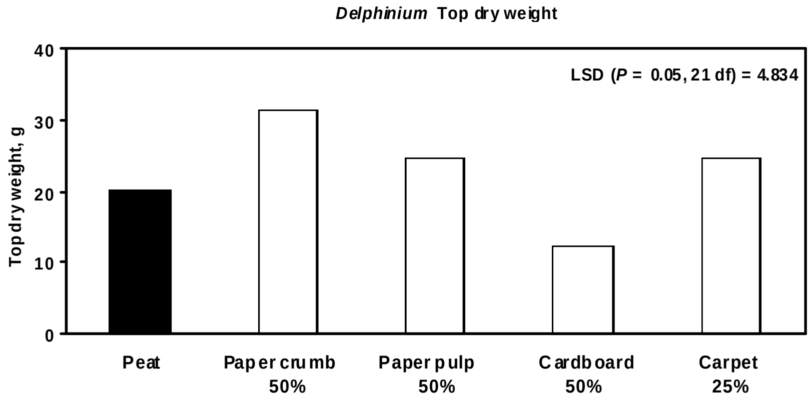
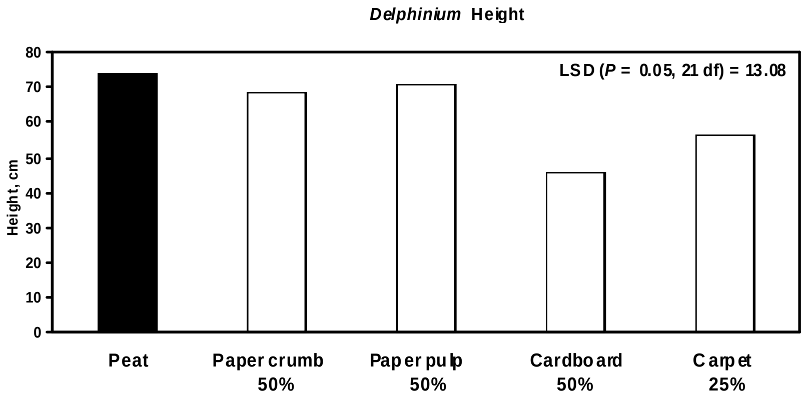
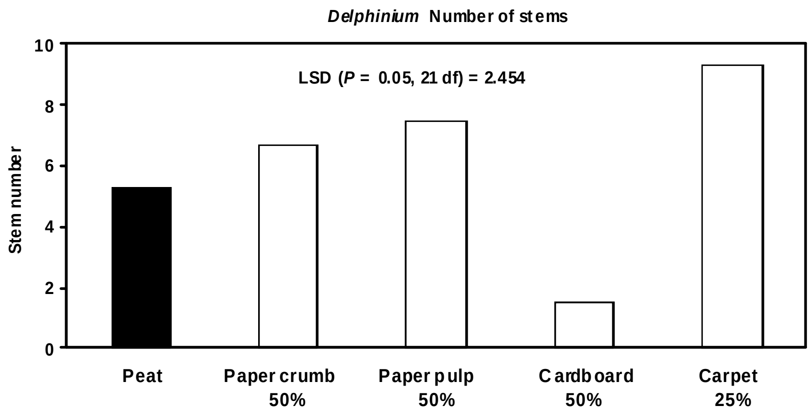


Figure 11. *Delphinium* 'Guardian Blue', 2006 Experiment







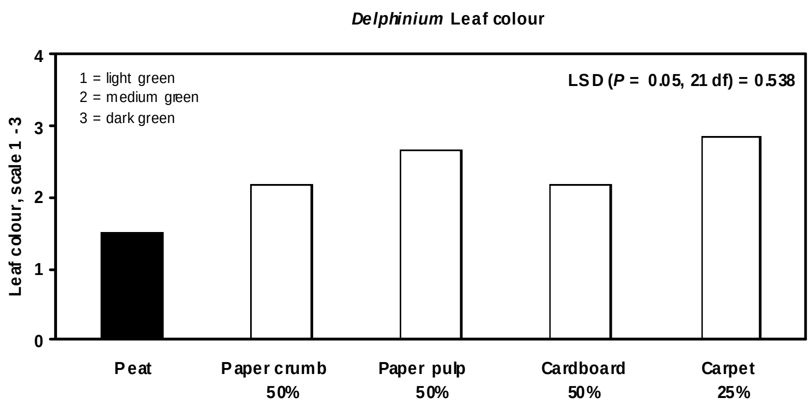
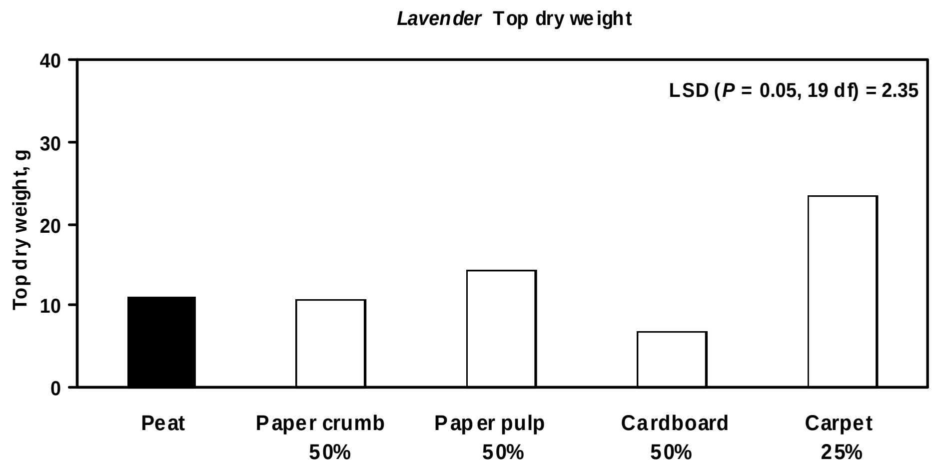
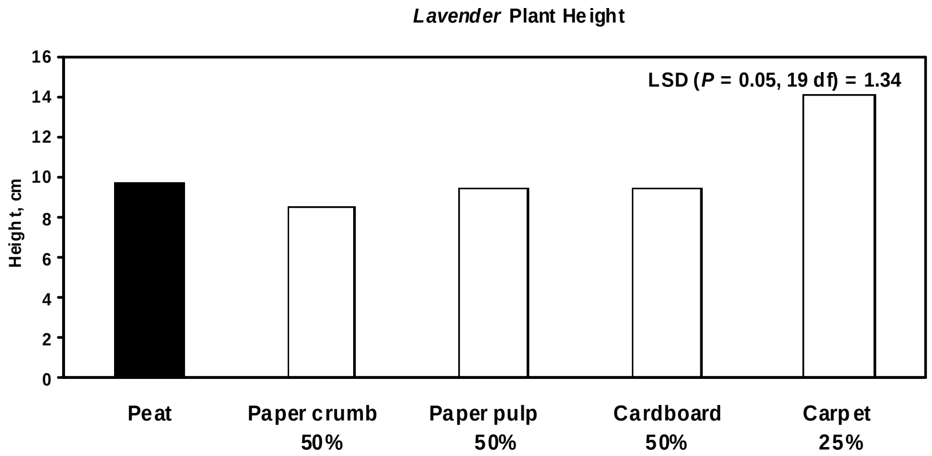


Figure 12. *Lavandula angustifolia* 'Hidcote', 2006 Experiment





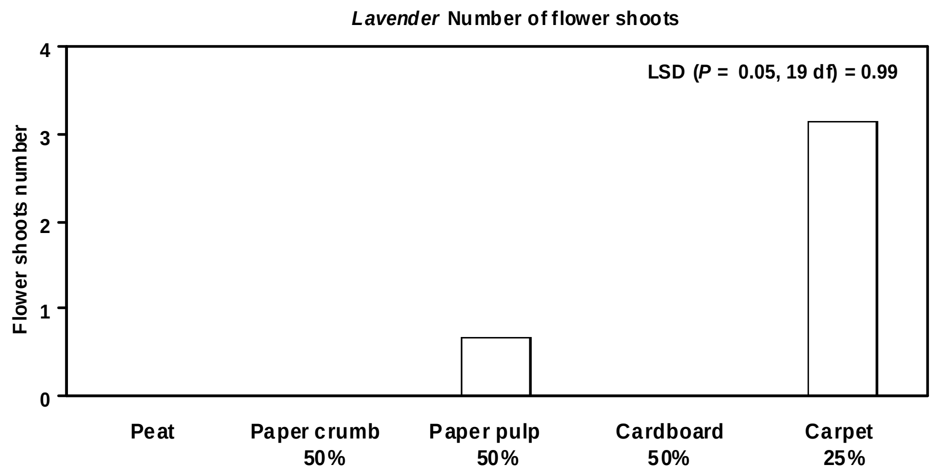
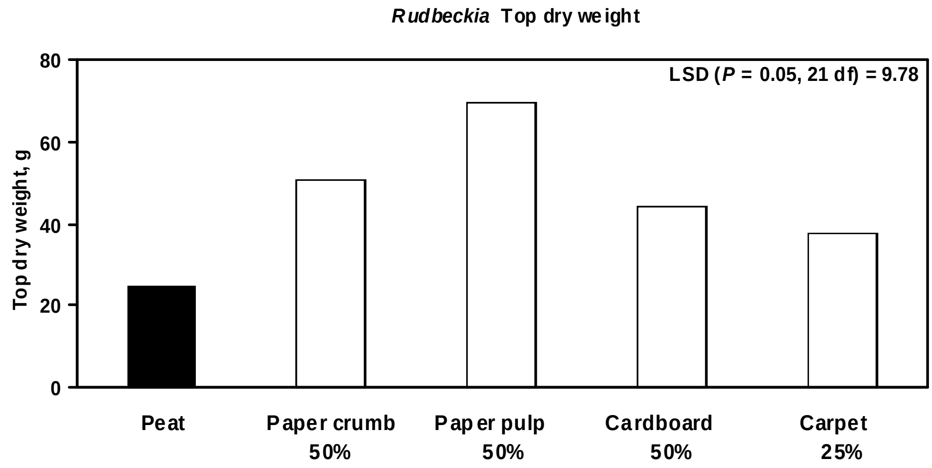
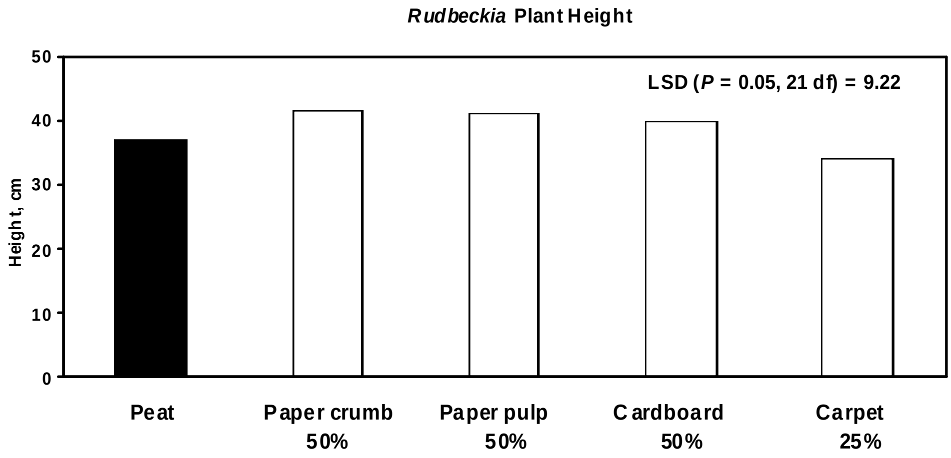


Figure 13a. *Rudbeckia fulgida* var. *sullivantii* 'Goldsturm', 2006 Experiment





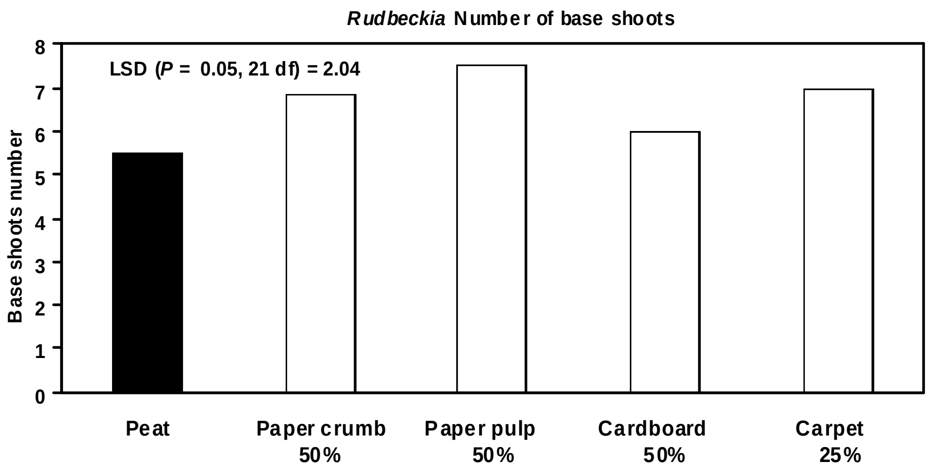
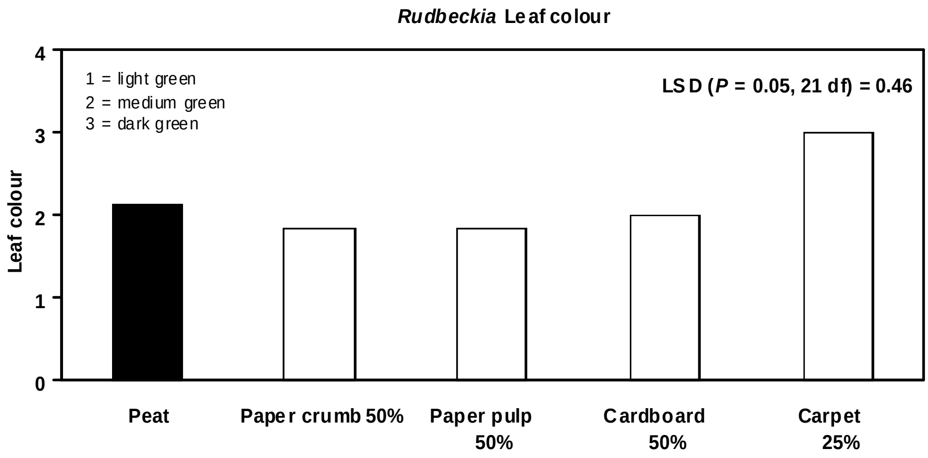


Figure 13b. *Rudbeckia fulgida* var. *sullivantii* 'Goldsturm', 2006 Experiment



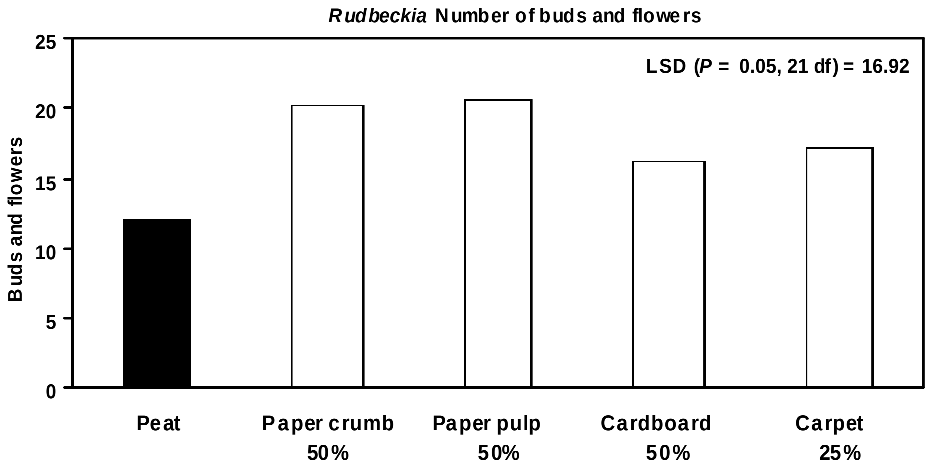
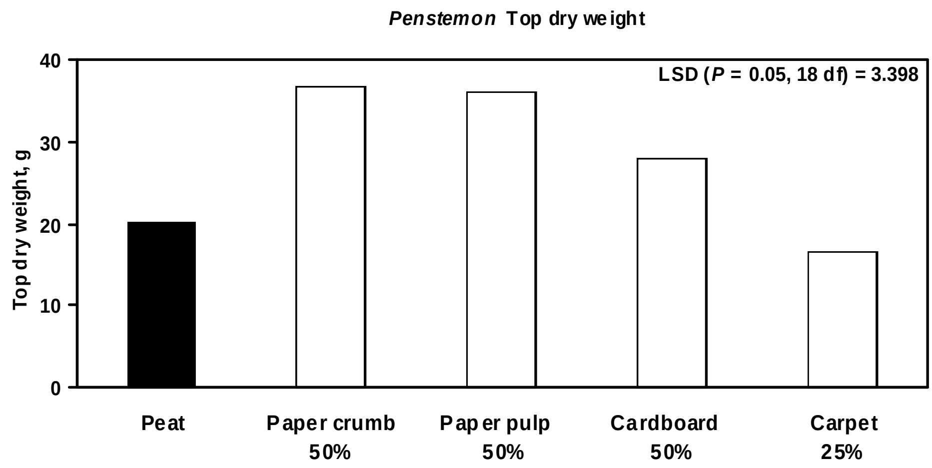
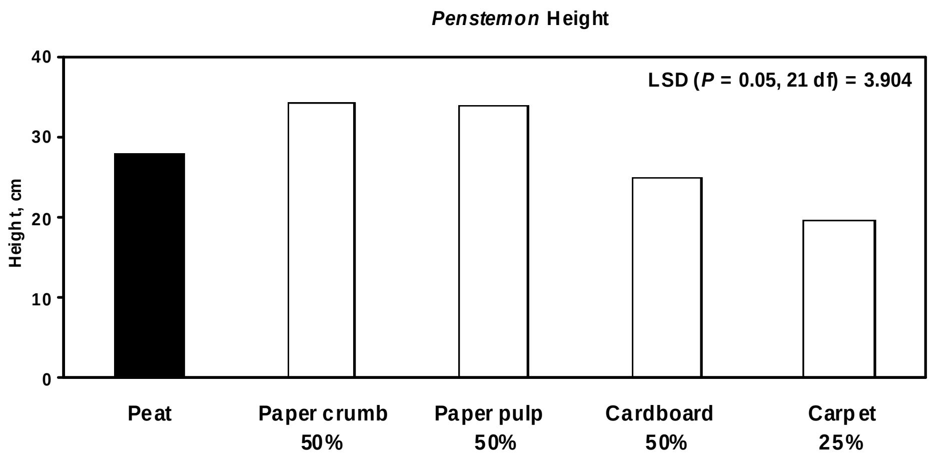


Figure 14a. *Penstemon* 'Vesuvius', 2006 Experiment





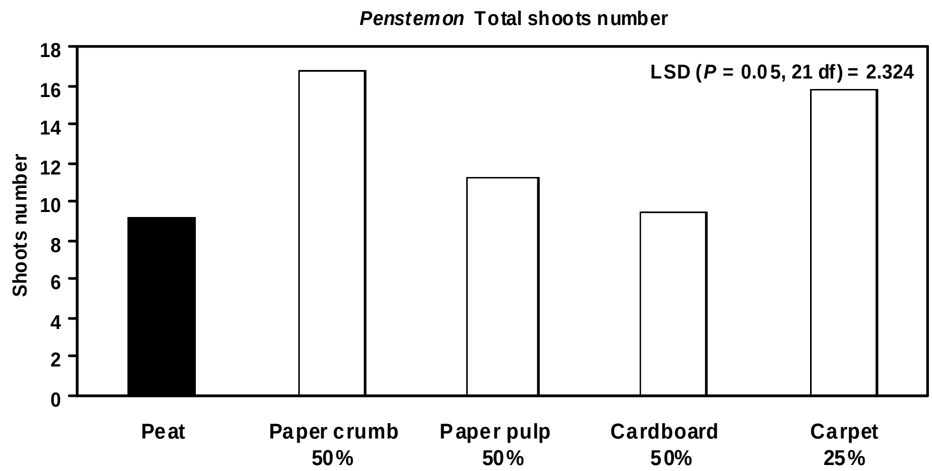
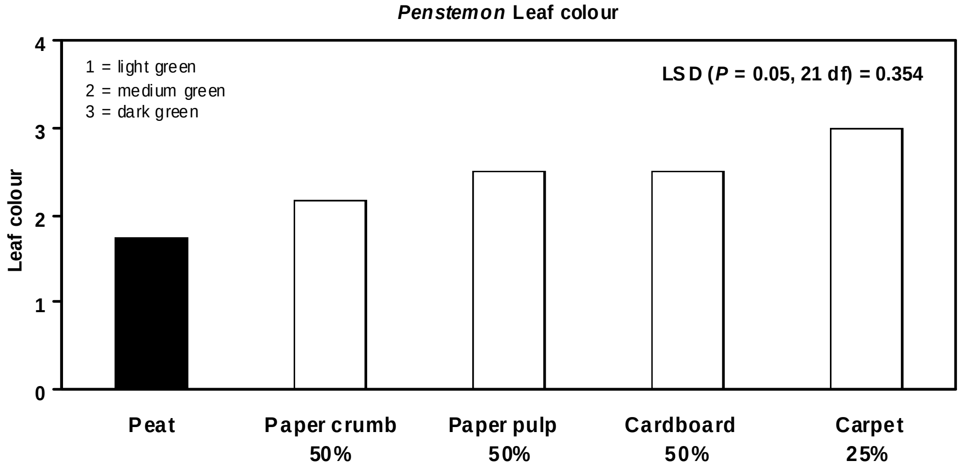
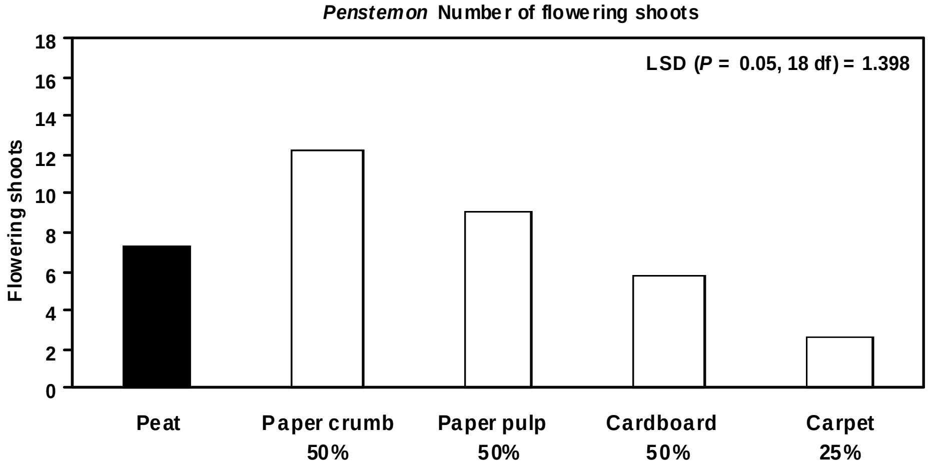


Figure 14b. *Penstemon* 'Vesuvius', 2006 Experiment

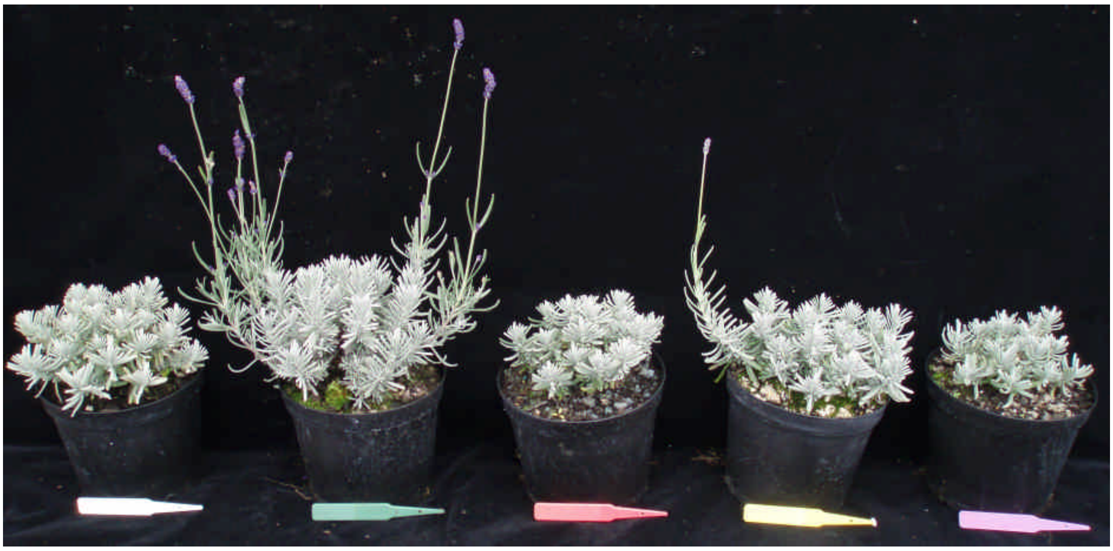




Picture 12. *Aster novi-belgii* ‘Purple Dome’ grown in (top row left to right) peat control, 50% composted paper crumb and paper pulp wastes (bottom row) 50% composted cardboard waste and carpet shearing waste.

Picture 13. *Delphinium* ‘Guardian Blue’ grown in (left to right) peat control, 50% carpet shearing waste, and 50% composted paper crumb, paper pulp and cardboard wastes

Picture 14. *Lavandula angustifolia* 'Hidcote' grown in (left to right) peat control, 50% carpet shearing waste, and 50% composted paper crumb, paper pulp and cardboard wastes.

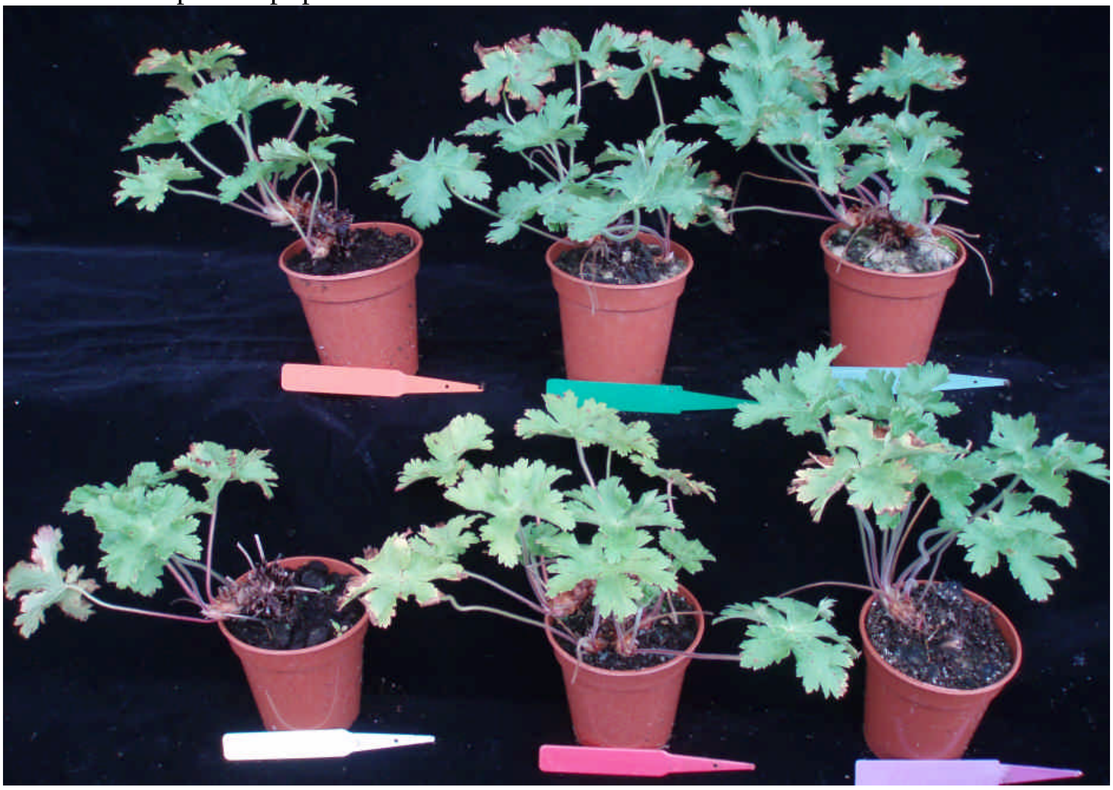


Picture 15. *Rudbeckia fulgida* var. *sullivantii* 'Goldsturm' grown in (left to right) peat control, 50% carpet shearing waste and 50% composted paper pulp and paper crumb wastes.

Picture 16. *Penstemon* 'Vesuvius' grown in (left to right) peat control, 50% composted paper crumb, paper pulp and cardboard wastes.

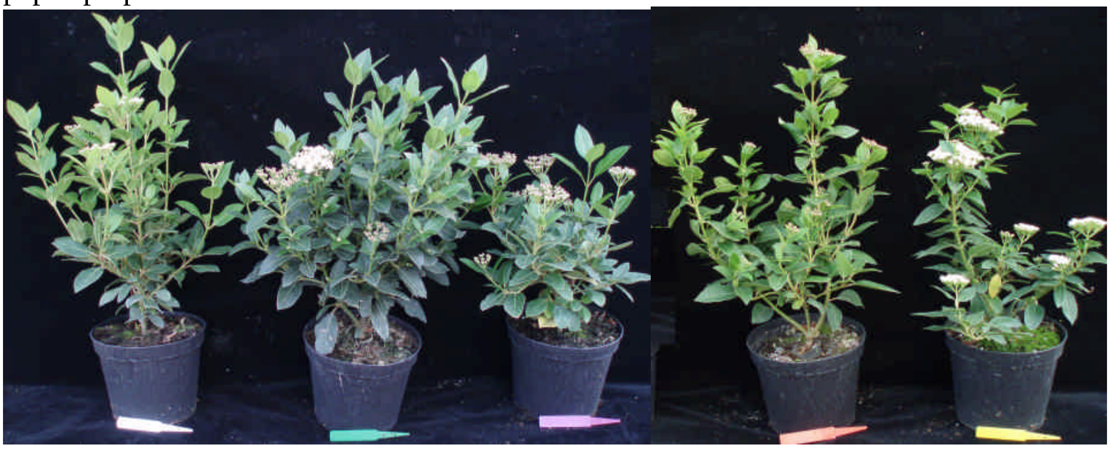
Picture 17. Liners of *Delphinium* 'Guardian Blue' grown in (left to right) peat control, 25 and 50% carpet shearing waste, and 50% composted paper crumb and cardboard wastes.

Picture 18. Liners of *Geranium* ‘Sabani Blue’ growing (top row left to right) peat control B, 25 and 50% carpet shearing waste (Bottom row left to right) peat control A, and 50% composted paper crumb and cardboard wastes.



Picture 19. Liners of *Lavandula angustifolia* ‘Hidcote’ growing in (left to right) peat control, 25% carpet shearing waste, and 50% composted paper crumb, paper pulp and cardboard wastes.

Picture 20. *Viburnum tinus* 'French white' growing in (top row left to right) peat control, 25% carpet shearing waste, and 50% composted cardboard, paper crumb and paper pulp wastes.



Picture 21. Liners of *Viburnum tinus* 'French white' growing in (top row left to right) peat control A, 25% and 50% carpet shearing waste, and (bottom row left to right) peat control B and 50% composted paper crumb and cardboard wastes.

Figure 15. *Delphinium* 'Guardian Blue' liners, 2006 Experiment

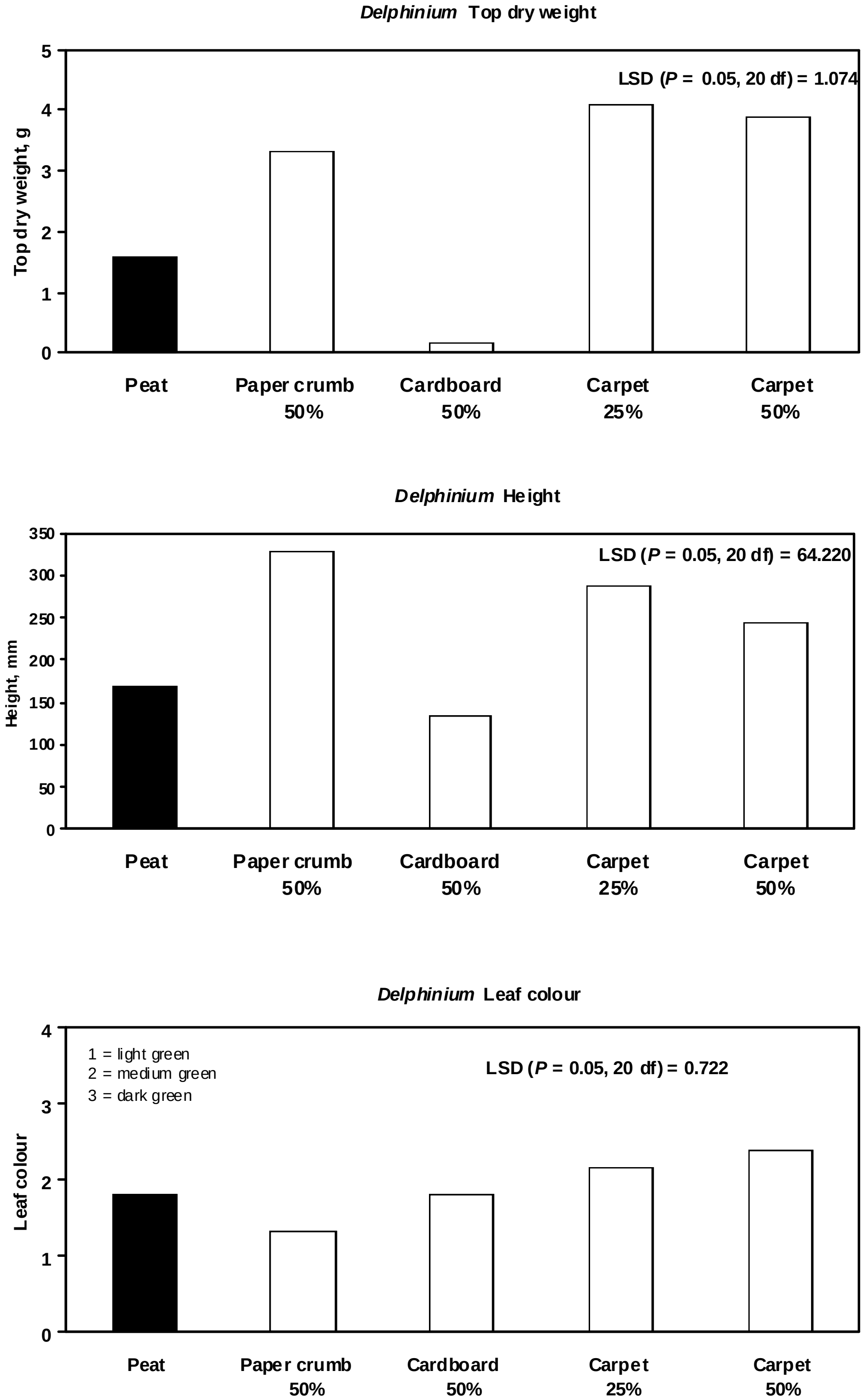
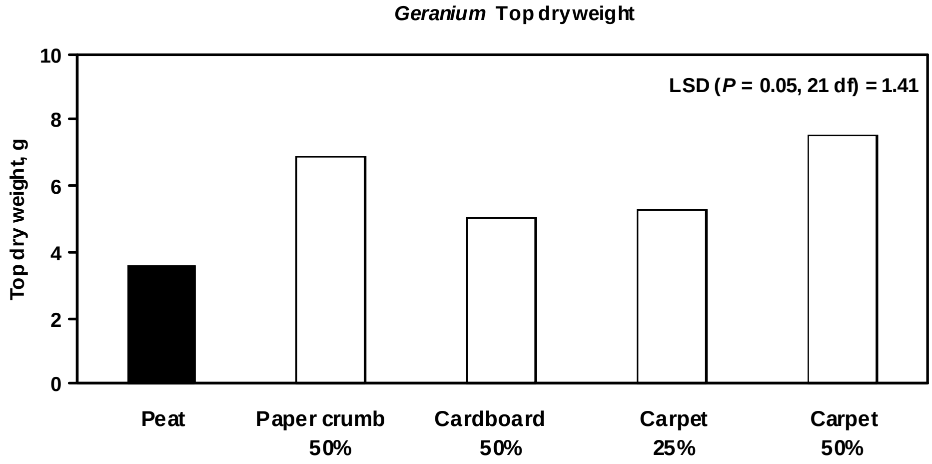


Figure 16. *Geranium* 'Sabani Blue' liners, 2006 Experiment



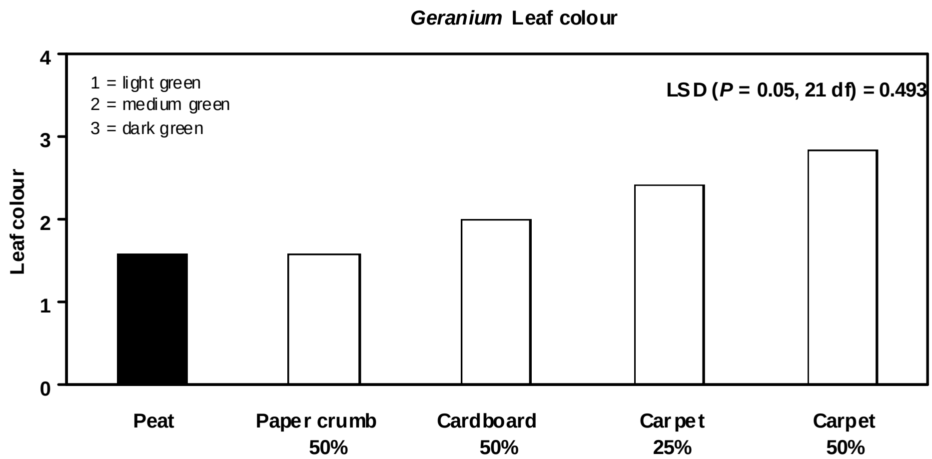


Figure 17. *Lavandula angustifolia* 'Hidcote' liners, 2006 Experiment

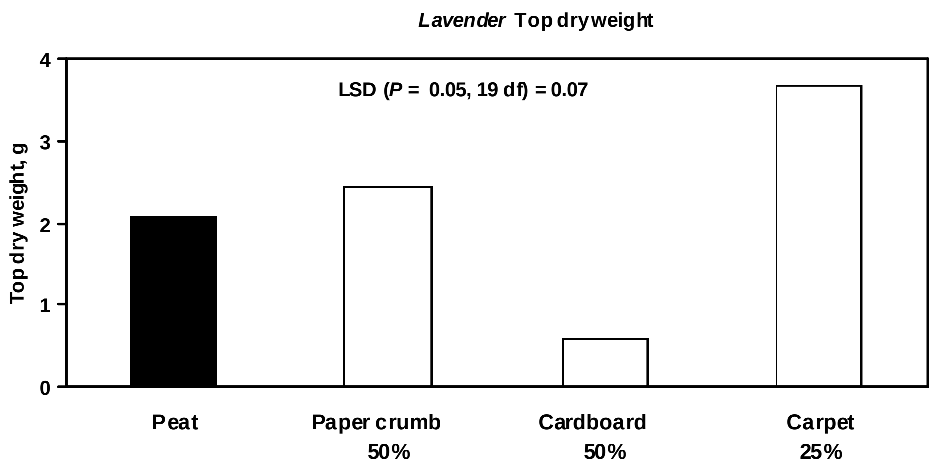
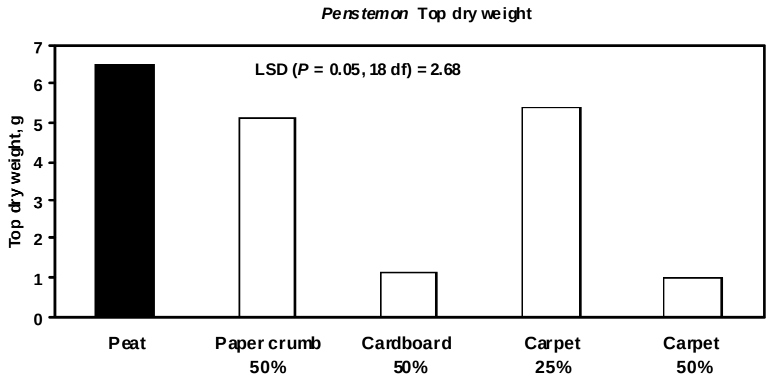
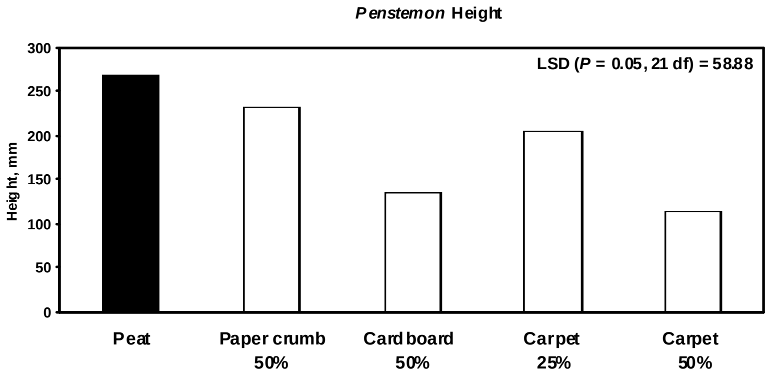
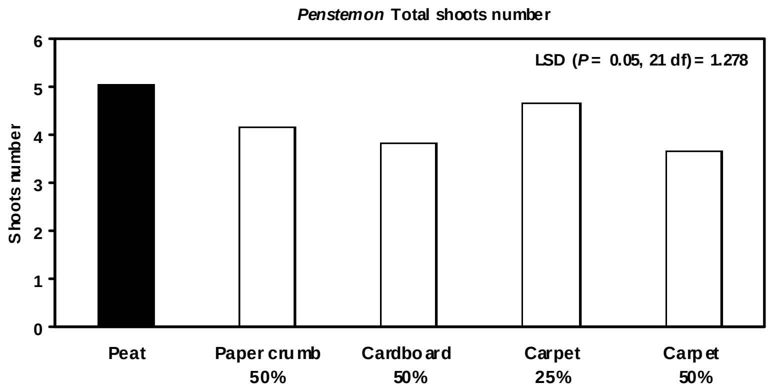


Figure 18. *Penstemon* 'Vesuvius' liners, 2006 Experiment







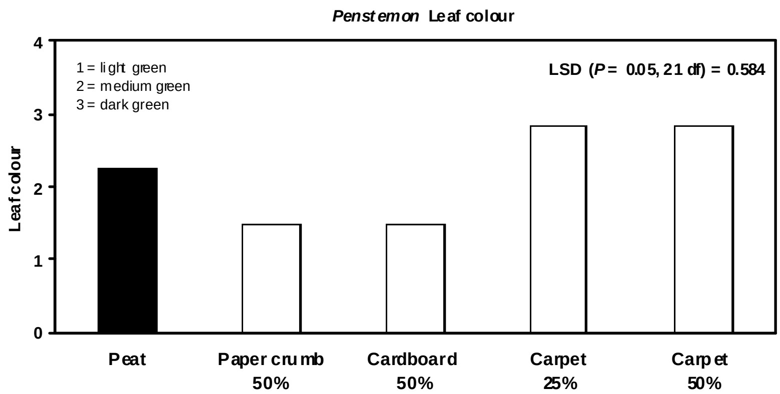


Figure 19. *Viburnum tinus* 'French white', 2006 Experiment, 1st Year assessments

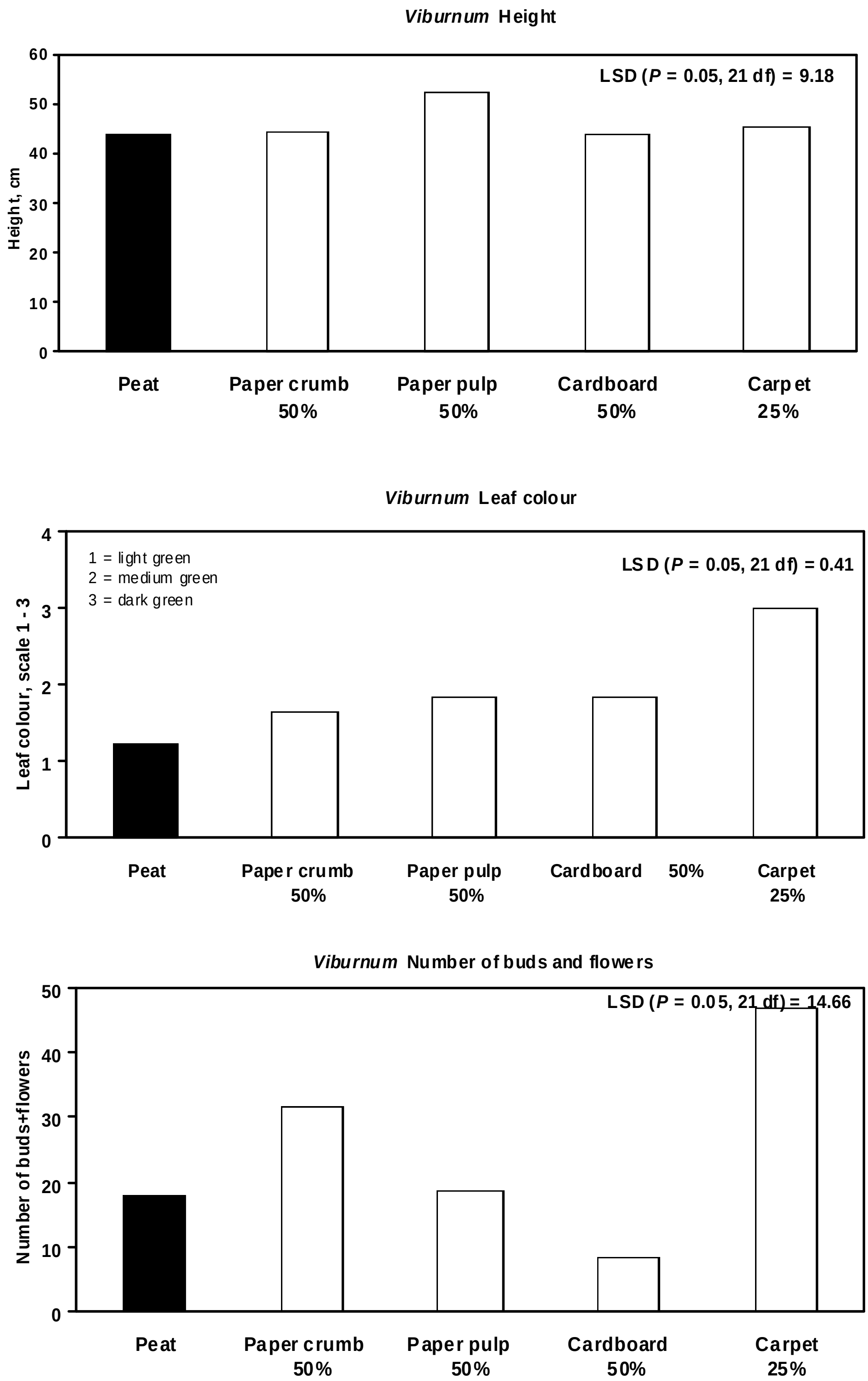
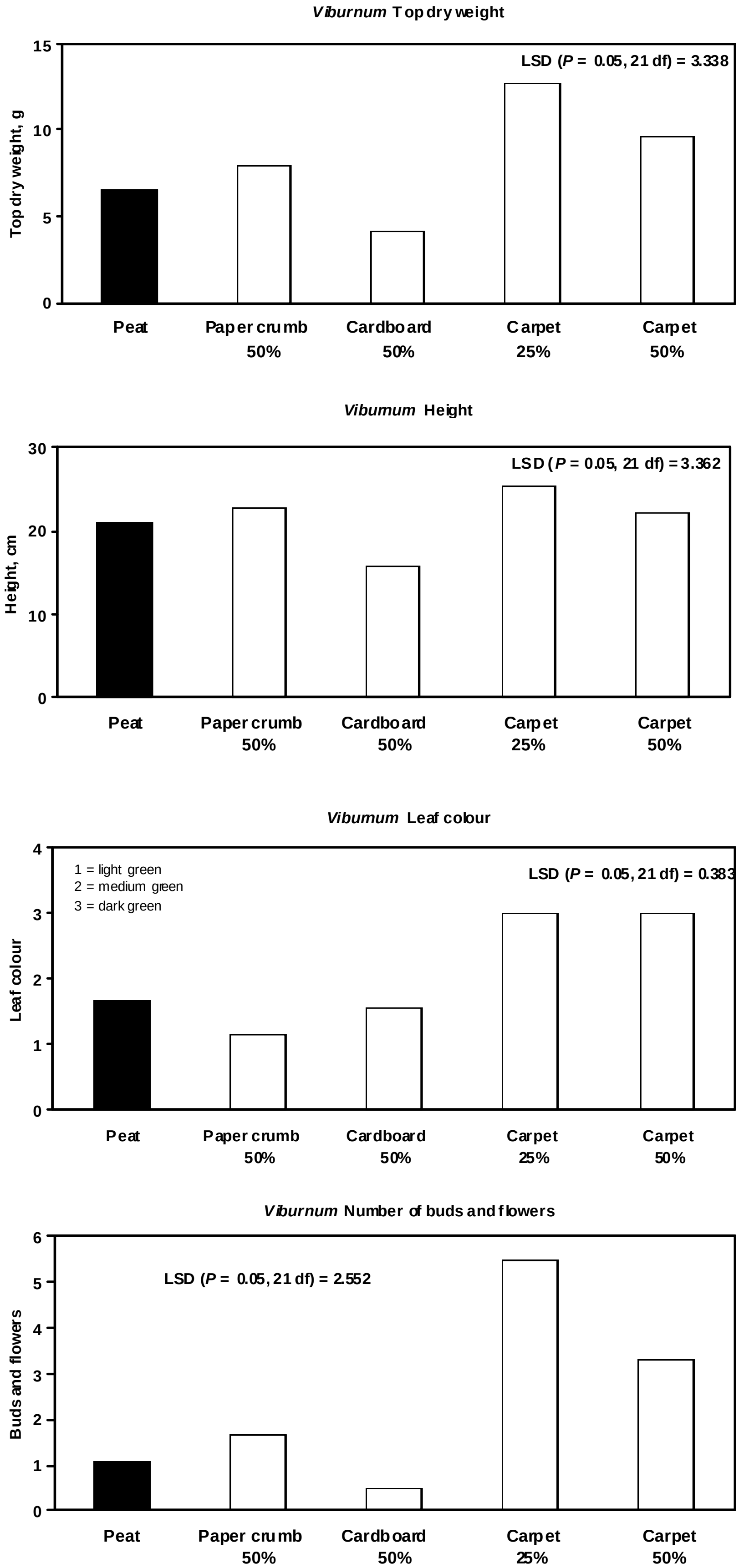


Figure 20. *Viburnum tinus* 'French white' liners, 2006 Experiment



Woody ornamentals

The following test species are being over-wintered and will be recorded in spring 2007:

- *Chamaecyparis lawsoniana* 'Ellwoodii' (3L pots)
- *Clematis montana* 'Tetrarose' (3L deep pots)
- *Spiraea* 'Candle light' (2L pots)
- *Viburnum tinus* 'French white' (3L pots)

Preliminary assessments were made on 10 October 2006 on the *Viburnum* plants. Plant height was not significantly affected by the treatments (Fig. 19, Picture 20). Leaf colour score and number of buds and flowers were greatest in the 25% carpet waste treatment. The 50% cardboard waste treatment produced the fewest buds and flowers.

Woody ornamentals, 9 cm liners

- *Viburnum tinus* 'French white'

The 25 and 50% carpet waste treatments resulted in the greatest top dry weight and numbers of buds and flowers, and the darkest leaves (Fig. 20, Picture 21). The 50% composted cardboard waste reduced plant size.

<u>Carpet shearing waste uniformity experiments</u>

- *Agapanthus* 'Purple Cloud'

Plants are being over-wintered and will be recorded in the spring of 2007. A picture taken on 15 September 2006 shows that the carpet and wool waste treatments had resulted in more growth than the peat controls (Picture 22).

- *Verbena* 'Claret'

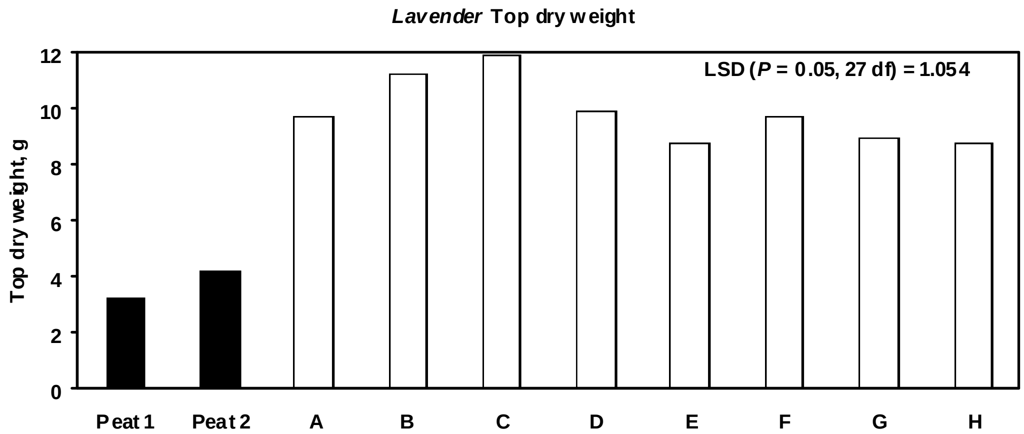
All of the carpet waste treatments resulted in a greater top dry weight and better leaf colour than the two peat control treatments; there was no significant difference between carpet waste treatments in top dry weight or leaf colour (Fig. 21, Picture 23). Carpet waste E produced the most flower heads; peat control 1 did not flower. There were no significant differences in flower head number between the other treatments.

- *Lavandula* 'Purple Wings'

All of the carpet waste treatments produced a greater top dry weight than the two peat controls (Fig. 22, Picture 24). Carpet waste C produced a greater top dry weight than carpets wastes A, D, E, F, G and H. Carpet waste C and Peat Control 1 produced the most and least flower stems respectively. There was no significant difference in flower stem number between the other treatments.

For *Lavandula and Verbena,* media containing carpet wastes A, B, C, F and G had lower pH values at the end of the cropping period than the peat controls and media containing carpet wastes D,E and H. For Lavandula, the lower pH of the media containing carpet C (Brockway Carpets) may have been responsible for its slightly improved performance compared with the other carpet wastes. The final EC of all the media containing 25% carpet waste were higher than those of the peat controls (Table 26). Carpet waste C resulted in the highest EC at the end of the cropping period.

Figure 22. *Lavandula* 'Purple Wings' liners, 2006 Experiment. Comparison of Peat media 1 and 2 with media containing 25% v/v of carpet wastes A to H.



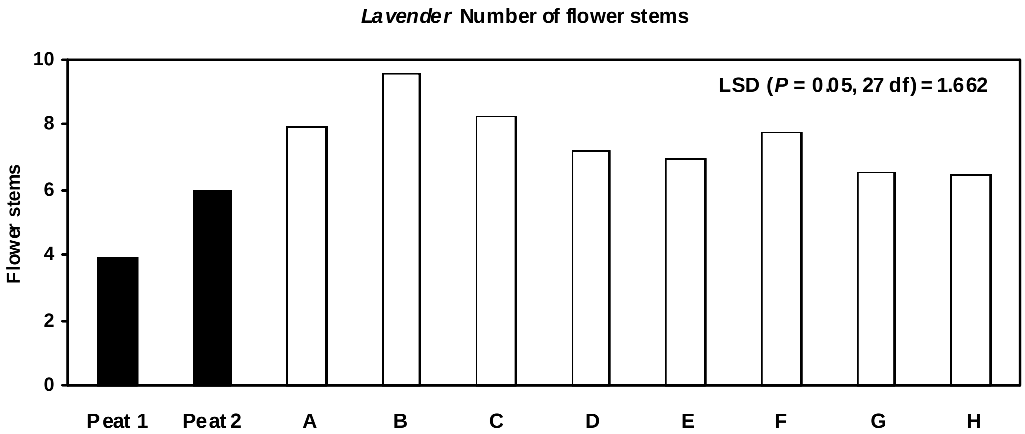
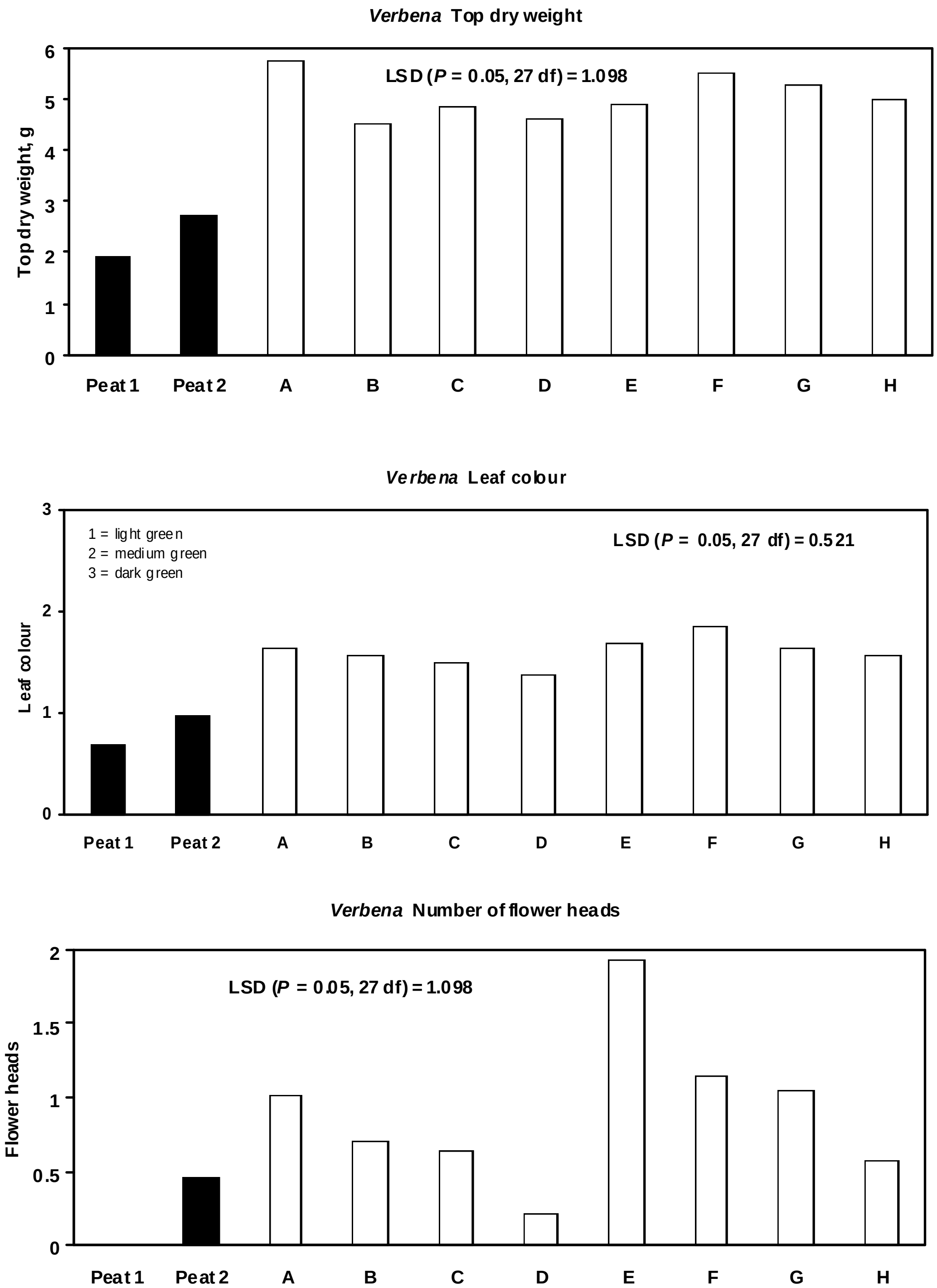


Figure 21. *Verbena* ‘Claret’ liners, 2006 Experiment. Comparison of Peat media 1 and 2 with media containing 25% v/v of carpet wastes A to H.



Picture 22. Liners of *Agapanthus* ‘Purple Cloud’ growing in two peat controls (left of each row) and 8 peat growing media containing 25% of different carpet shearing wastes.

Picture 23. Liners of *Verbena* ‘Claret’ growing in two peat controls (left of each row) and 8 peat growing media containing 25% of different carpet shearing wastes.

Picture 24. Liners of *Lavandula* 'Purple Wings' growing in two peat controls (left of each row) and 8 peat growing media containing 25% of different carpet shearing wastes.

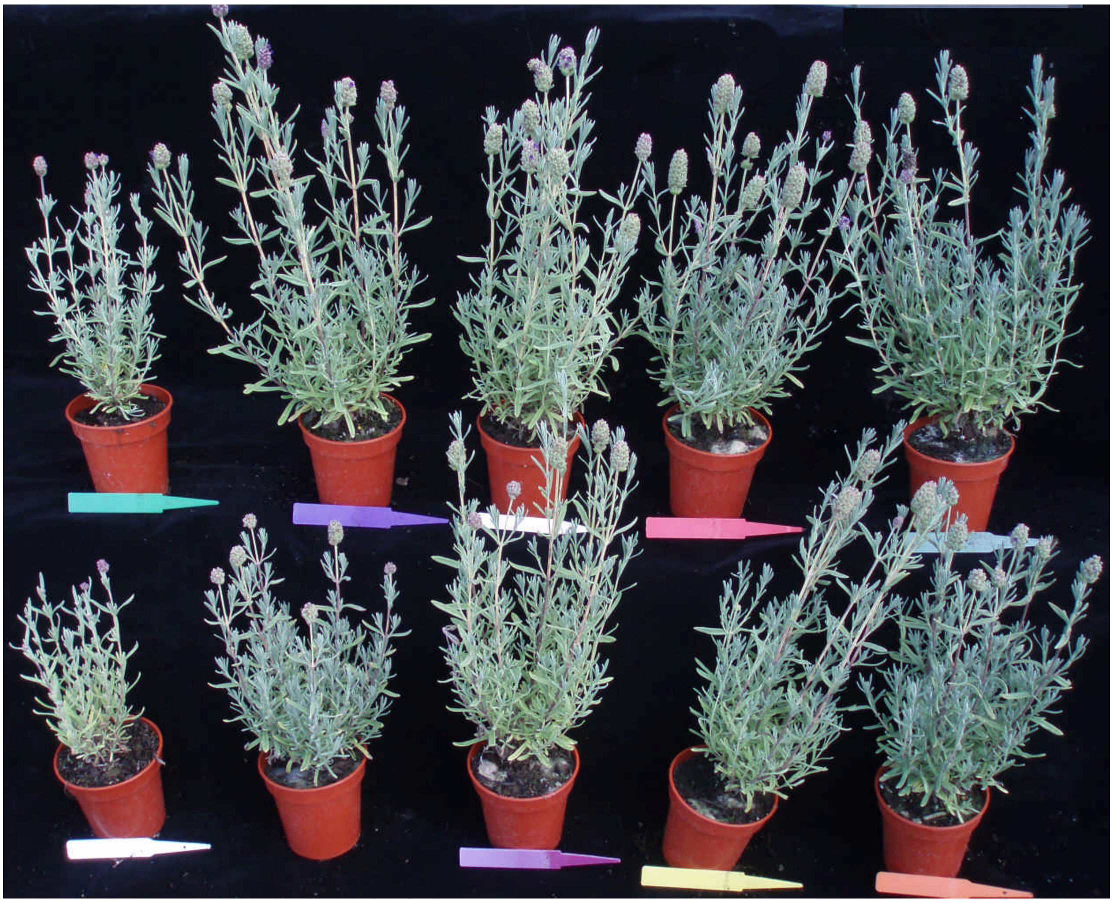


Table 26. Final pH of peat control media and 25% carpet waste substitute media, 9 cm liners, 2006 Experiment

Treatment	*Lavandula* 'Purple Wings'		*Verbena* 'Claret'	
	pH	EC, mS/cm	pH	EC, mS/cm
Peat control 1	6.61	234	6.82	87
Peat control 2	6.40	139	6.95	148
Carpet waste A	5.37	630	6.04	298
Carpet waste B	5.17	599	5.51	262
Carpet waste C	4.80	820	4.78	448
Carpet waste D	7.24	316	6.54	268
Carpet waste E	6.64	438	6.73	238
Carpet waste F	5.73	481	5.86	281
Carpet waste G	5.76	484	5.48	440
Carpet waste H	6.79	357	6.73	367

Discussion

For most of the herbaceous perennial species, the best overall treatment in terms of plant growth and flowering was 50% composted paper crumb waste (low N) (Table 27). The exceptions were for *Geranium* 'Sabani Blue' and *Lavandula angustifolia* 'Hidcote' where 25 or 50% Carpet waste performed best and *Rudbeckia fulgida* 'Goldsturm where 50% composted paper pulp waste performed best. However, even for these species, the 50% composted paper crumb waste (low N) treatment performed at least as well as the peat control treatment.

For 9 cm liners, the best treatments were 25 and 50% Carpet waste, except for *Penstemon* 'Vesuvius' where the peat control was best (Table 28). Eight different sources incorporated at 25% resulted in improved growth of *Lavandula* and *Verbena* liners compared with peat controls. Carpet waste source is therefore not important.

For woody ornamental species, none of the peat substitute treatments used in the 2005 experiment performed better than the peat control. However, the 50% composted paper waste (high N) treatment was equal in performance to the peat control for *Chamaecyparis lawsoniana* 'Ellwoodii' and *Rosa* 'Paddy Stephens' (Table 29). For *Viburnum tinus* 'Pupureum' the 50% composted cardboard waste (high N) and 50% Carpet waste treatments were equal in performance to the peat control. For *Clematis montana* 'Tetrarose', the 50% Carpet waste produced significantly better vegetative growth than the peat control but reduced flower number. A 25% rate of carpet waste was not used in the 2005 experiment, but the growth of *Clematis montana* and *Viburnum tinus* 'French White' plants in this treatment is already better than that of the peat control in the 2006 experiment. For all the woody ornamental and herbaceous species, the carpet waste amendment resulted in plants with darker leaves than the peat control. The improved growth and leaf colour of plants resulting from amendment of the growing media with carpet waste was probably due to slow release of nitrogen; there was little water soluble nitrogen in the initial material. The carpet waste also maintains a low pH in the growing medium which may assist in nutrient uptake. This lowering of pH could make amendment of growing media with carpet waste particularly suitable for acid-loving plants such as heathers, rhododendrons and camellias. The high EC of growing media containing 50% carpet waste at the end of crops was due to the significant release of plant nutrients resulting from the degradation of the wool. This explains why the 50% rate of carpet waste was too high for some species (e.g. *Lavandula* and *Viburnum*) although it did not adversely affect *Geranium* or *Delphinium* grown in liners.

The results agree with work presented in the introduction which indicated that paper wastes perform better as peat substitutes after they are composted with a nitrogen source. For herbaceous perennial species, the lower rate of ammonium sulphate (3.4 kg/m^3) produced better results than the higher rate (6.5 kg/m^3), whereas for roses the high rate was better. Composting with ammonium sulphate resulted in a greater reductions in pH and increases in EC compared with composting with urea. The results for cardboard wastes composted with ammonium sulphate in 2005 were generally better than the results for cardboard waste composted with urea in 2006.

The suitability of composted paper crumb waste for herbaceous flowering perennials is probably due to the availability of potassium and phosphorus from this material. The significant clay content of this material may also improve the cation exchange capacity of soilless growing media. The higher pH resulting from the use of composted paper crumb waste, compared with peat-based mixes, did not appear to be a disadvantage. Composted cardboard waste, which had a lower pH more typical of the peat mixes, did not perform as well as composted paper crumb waste for most species. Composted paper crumb performed better than composted paper pulp, except for *Rudbeckia* and *Lavandula*. The greater availability and lower bulk density of the crumb waste also make this material more attractive. The use of composted materials has been shown to suppress a number of diseases caused by soil-borne pathogens such as *Phytophthora* and *Pythium* species (Noble & Coventry, 2005). This particular aspect was not examined in this project but should be investigated in the future.

All the plants in the trials received the same amounts of water, and there generally no effects of irrigation system (sprinklers or drippers) on the relative performance of different materials. This means that the introduction of the substitute materials used in these trials should not affect the amount of irrigation water required.

Table 27. Best overall treatments for herbaceous perennial species in 2005 and 2006 experiments

Species and cultivar	**2005 Experiment**	**2006 Experiment**
Aster x *frikartii* 'Mönch'	50% Paper A (low N)	_
Aster novi-belgii 'Purple Dome'	_	50% Paper A (low N)
Delphinium 'Guardian Blue'	50% Paper A (low N) 50% Carpet waste	50% Paper A (low N)
Geranium 'Sabani Blue'	50% Carpet waste	_
Lavandula angustifolia 'Hidcote'	_	25% Carpet waste
Penstemon 'Vesuvius'	50% Carpet waste	50% Paper A (low N)
Rudbeckia lacianata 'Goldquelle'	Peat 50% Paper A (low N)	_
Rudbeckia fulgida 'Goldsturm'	_	50% Paper pulp

Table 28. Best overall treatments for 9 cm liners in 2006 experiment

Species and cultivar	**Best treatment**	**2nd best treatment**
Delphinium 'Guardian Blue'	50% Carpet waste	25% Carpet waste
Geranium 'Sabani Blue'	50% Carpet waste	50% Paper A (low N)
Lavandula angustifolia 'Hidcote'	25% Carpet waste	50% Paper pulp
Penstemon 'Vesuvius'	Peat	25% Carpet waste 50% Paper A (low N)
Viburnum tinus 'French White'	25% Carpet waste	50% Carpet waste

Table 29. Best overall treatments for woody ornamental species in 2005 experiment

Species and cultivar	**Best treatment**	**2nd best treatment**
Chamaecyparis lawsoniana	Peat, 50% Paper (high and low N) equal best	
Clematis montana 'Tetrarose'	Peat	50% Carpet waste
Rosa 'Paddy Stephens'	Peat, 50% Paper (high N) equal best	
Viburnum tinus 'Pupureum'	Peat, 50% Cardboard, 50% Carpet waste equal best	

Conclusions

1. Raw and composted paper and cardboard wastes were slightly alkaline; no lime was therefore added in mixtures with peat. Carpet shearing wastes were slightly acidic and could be added to fertilised peat-based media without adding more lime to the mix.
2. For the following herbaceous perennial species, the best overall treatment in terms of plant growth and flowering was 50% composted paper crumb waste (low N): *Aster* x *frikartii* 'Mönch', *Aster novi-belgii* 'Purple Dome', *Delphinium* 'Guardian Blue', *Penstemon* 'Vesuvius'.
3. For *Geranium* 'Sabani Blue' and *Lavandula angustifolia* 'Hidcote' the 25 or 50% Carpet waste treatments performed best and for *Rudbeckia fulgida* 'Goldsturm' the 50% composted paper pulp waste performed best. However, even for these species, the 50% composted paper crumb waste (low N) treatment performed at least as well as the peat control treatment.
4. For 9 cm liners of the following species, the best treatments in terms of plant growth were 25 and 50% Carpet waste, except for *Penstemon* 'Vesuvius' where the peat control was best: *Delphinium* 'Guardian Blue', *Geranium* 'Sabani Blue', *Lavandula angustifolia* 'Hidcote' and *Viburnum tinus* 'French White'.
5. The 50% composted paper waste (high N) treatment was equal in performance to the peat control for *Chamaecyparis lawsoniana* 'Ellwoodii' and *Rosa* 'Paddy Stephens'.
6. For *Viburnum tinus* 'Pupureum' the 50% composted cardboard waste (high N) and 50% Carpet waste treatments were equal in performance to the peat control.
7. For *Clematis montana* 'Tetrarose', the 50% Carpet waste produced significantly better vegetative growth than the peat control but reduced flower number. A 25% rate of carpet waste was not used in the 2005 experiment, but the growth of *Clematis montana* and *Viburnum tinus* 'French White' plants in this treatment is already better than that of the peat control in the 2006 experiment.
8. For all the woody ornamental and herbaceous species, the carpet waste amendment resulted in plants with darker leaves than the peat control.
9. The source of the carpet waste was not important in terms of plant response.

10. The improved growth and leaf colour of plants resulting from amendment of the growing media with carpet waste was probably due to slow release of nitrogen; there was little water soluble nitrogen in the initial material.
11. The composted paper wastes were good sources of water soluble potassium and phosphorus, which explains there suitability for flowering herbaceous perennials. The carpet waste had a higher total nitrogen content, as well as significant potassium and phosphorus contents. These nutrients were slowly released during the growing period.
12. The composted paper wastes resulted in higher media pH values than peat controls whereas carpet wastes resulted in a reduction in medium pH during the growing season.
13. The relative performance of the treatments was generally not influenced by the irrigation system (sprinklers or drippers) and all the treatments received the same amounts of water. The use of the substitute materials investigated in this work should therefore not affect the amount of irrigation water used.
14. All of the waste amendments had higher air and lower water volumes at saturation than the peat-based media. The cardboard and carpet shearing wastes had the highest air volumes at saturation. Differences in water volume at saturation between different peat-based media and between different waste amendments were small.
15. Composting of paper wastes with ammonium sulphate or urea prevented the immobilisation of nitrogen that occurred when the uncomposted material was used in growing media. For herbaceous perennials, a lower rate of ammonium sulphate (3.4 kg/m^3) was better whereas for roses, a higher rate (6.5 kg/m^3) was better.
16. Composting with ammonium sulphate resulted in greater reductions in pH and increases in EC compared with composting with urea. The results for cardboard wastes composted with ammonium sulphate in 2005 were generally better than the results for cardboard waste composted with urea in 2006.

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APPENDIX

Table A1. Materials examined as a substitute for peat-based in nursery stock container media

Material RESULT	Plant species	Rate (% v/v)	Control media Peat, plus	Reference
COMPARABLE/ENHANCED				
Bark, pine (composted)	*Chamaecyparis lawsoniana*	30	-	Scott, 1984
Bark, pine (composted)	*Viburnum* x *burkwoodii*	30	-	Scott, 1984
Coco fibres	*Viburnum tinus* 'Eve Price'	50	Bark	Guerin *et al*., 2000
Green waste compost	*Nerium oleander*	100	Sawdust + Sand	Fitzpatrick *et al*., 1998
Green waste compost	*Viburnum tinus* 'Eve Price'	50	Bark	Guerin *et al*., 2000
Paper sludge (composted)	*Acer tataricum* ssp. *Ginnala*	25, 50	-	Tripepi *et al*., 1996
Paper sludge (composted)	*Prunus* x *cistena* 'Hansen'	25, 50	-	Tripepi *et al*., 1996
Paper sludge (composted)	*Syringa vulgaris*	25, 50	-	Tripepi *et al*., 1996
River waste	*Erigeron speciosus*	50, 100	Perlite + Vermiculite	Benedetto *et al*., 2004
River waste	*Sidalcea malviflora*	50, 100	Perlite + Vermiculite	Benedetto *et al*., 2004
River waste	*Veronica spicata*	50, 100	Perlite + Vermiculite	Benedetto *et al*., 2004
Wood fibre	*Lonicera nitida* 'Maigrun'	25 - 100	-	Bohne, 2004
Wood fibre	*Prunus laurocerasus* 'Otto Luyken'	25 - 100	-	Bohne, 2004
Wood fibre	*Thuja occidentalis* 'Aureospicata'	25 - 100	-	Bohne, 2004
Wood fibre	*Thuja occidentalis* 'Smaragd'	25 - 100	-	Bohne, 2004
COMPARABLE				
Apple pomace	*Cornus alba* 'Argenteo-marginata'	25 - 90	Bark + Sand	Chong, 1992
Apple pomace	*Euonymus fortunei* 'Emerald Gaiety'	25 - 90	Bark + Sand	Chong, 1992
Apple pomace	*Juniperus horizontalis*	25 - 90	Bark + Sand	Chong, 1992
Apple pomace	*Thuja occidentalis* 'Smaragd'	25 - 90	Bark + Sand	Chong, 1992
Bark (Milled)	*Pinus sylvestris*	100	-	Laatikainen, 1973
Bark compost + GWC	*Potentilla fruticosa*	75	Bark	Fischer & Popp, 1998
Bark compost + wood fibre	*Forsythia x intermedia* 'Spectabilis'	100	-	Bohne, 2004
Bark, pine	*Viburnum* x *burkwoodii*	30	-	Scott, 1984
Bark, spruce (composted)	*Viburnum* x *burkwoodii*	30	-	Scott, 1984
Coco fibres	*Euonymus japonicus*	50	Bark	Guerin *et al*., 2000
Coco fibres	*Euonymus japonicus*	50	Bark	Guerin *et al*., 2000
Coco fibres	*Viburnum tinus* 'Eve Price'	50	Bark	Guerin *et al*., 2000
Crushed brick + GWC	*Potentilla fruticosa*	75	Green waste compost	Fischer & Popp, 1998
Forest compost	*Nerium oleander* 'Emile Shaut'	50	Bark	Guerin *et al*., 2000
Forest compost	*Nerium oleander* 'Emile Shaut'	40	Bark	Guerin *et al*., 2000
Forest fibre + GWC	*Chamaecyparis lawsoniana* 'Pottenii'	100	Bark	Adlam *et al*., 2004
Forest fibre + GWC	*Lavandula angustifolia* 'Hidcote'	100	Bark	Adlam *et al*., 2004
Green waste compost	*Choisya ternata* 'Aztec Pearl'	30	Bark	Adlam *et al*., 2004
Green waste compost	*Cotoneaster dammeri* 'Coral Beauty'	25 - 75	-	Chong, 2004
Green waste compost	*Deutzia scabra*	40	-	Fischer & Popp, 1998
Green waste compost	*Euonymus japonicus*	50	Bark	Guerin *et al*., 2000
Green waste compost	*Hosta* 'Great Expectations'	30	Bark	Adlam *et al*., 2004
Green waste compost	*Hydrangea macrophyllum* 'Hamburg'	30	Bark	Adlam *et al*., 2004
Green waste compost	*Juniperus sabina* 'Moon Glow'	25 - 50	Sand + Sawdust	Burger *et al*., 1997
Green waste compost	*Photinia x fraseri*	25 - 50	Sand + Sawdust	Burger *et al*., 1997
Green waste compost	*Pittosporum tobira*	25 - 50	Sand + Sawdust	Burger *et al*., 1997
Green waste compost	*Viburnum tinus*	30	Bark	Adlam *et al*., 2004
Refuse compost	*Juniperus chinensis*	20	-	Kohstall & Alt, 1978
Rice hulls/coco fibres/clay	*Forsythia x intermedia* 'Spectabilis'	26	-	Bohne, 2004

Table A1 (cont.). Materials examined as a substitute for peat-based in nursery stock container media

Material **RESULT**	**Plant species**	**Rate** **(% v/v)**	**Control media** **Peat, plus**	**Reference**
COMPARABLE/ENHANCED				
River waste	*Achillea millefolium*	50, 100	Perlite + Vermiculite	Benedetto *et al*., 2004
River waste	*Alchemilla mollis*	50, 100	Perlite + Vermiculite	Benedetto *et al*., 2004
River waste	*Iberis sempervirens*	50, 100	Perlite + Vermiculite	Benedetto *et al*., 2004
River waste	*Oenothera missouriensis*	50, 100	Perlite + Vermiculite	Benedetto *et al*., 2004
River waste	*Salvia superba*	50, 100	Perlite + Vermiculite	Benedetto *et al*., 2004
River waste	*Veronica teucrium*	50, 100	Perlite + Vermiculite	Benedetto *et al*., 2004
NEGATIVE/COMPARABLE				
Bark	*Cotoneaster dammeri* 'Coral Beauty'	25 - 100	-	Hicklenton *et al*., 2001
Forest fibre + GWC	*Hosta* "Great Expectations"	100	Bark	Adlam *et al*., 2004
Forest fibre + GWC	*Viburnum tinus*	100	Bark	Adlam *et al*., 2004
River waste	*Physostegia virginiana*	50, 100	Perlite + Vermiculite	Benedetto *et al*., 2004
River waste	*Polygonum capitatum*	50, 100	Perlite + Vermiculite	Benedetto *et al*., 2004
NEGATIVE				
Cattle manure compost	*Nerium oleander* 'Emile Shaut'	50	Bark	Guerin *et al*., 2000
Cattle manure compost	*Viburnum tinus* 'Eve Price'	50	Bark	Guerin *et al*., 2000
Forest compost	*Viburnum tinus* 'Eve Price'	50	Bark	Guerin *et al*., 2000
Forest compost	*Viburnum tinus* 'Eve Price'	40	Bark	Guerin *et al*., 2000
Forest fibre + GWC	*Choisya ternata* 'Aztec Pearl'	100	Bark	Adlam *et al*., 2004
Forest fibre + GWC	*Hydrangea macrophylla* 'Hamburg'	100	Bark	Adlam *et al*., 2004
Green waste compost	*Chamaecyparis lawsoniana* 'Pottenii'	30	Bark	Adlam *et al*., 2004
Green waste compost	*Juniperus sabina* 'Moon Glow'	100	Sand + Sawdust	Burger *et al*., 1997
Green waste compost	*Lavandula angustifolia* 'Hidcote'	30	Bark	Adlam *et al*., 2004
Green waste compost	*Photinia* x *fraseri*	100	Sand + Sawdust	Burger *et al*., 1997
Green waste compost	*Pittosporum tobira*	100	Sand + Sawdust	Burger *et al*., 1997
Municipal solid waste	*Cotoneaster dammeri* 'Coral Beauty'	100	-	Hicklenton *et al*., 2001
River waste	*Doronicum orientale*	50, 100	Perlite + Vermiculite	Benedetto *et al*., 2004
River waste	*Saxifraga arendsii*	50, 100	Perlite + Vermiculite	Benedetto *et al*., 2004
River waste	*Solidago canadensis*	50, 100	Perlite + Vermiculite	Benedetto *et al*., 2004
River waste	*Veronica repens*	50, 100	Perlite + Vermiculite	Benedetto *et al*., 2004

Table A2. Materials examined as a substitute for bark or perlite in nursery stock container media

Material	Plant species	Rate (% v/v)	Control media	Reference
COMPARABLE/ENHANCED				
Green waste compost	*Cornus alba* 'Argenteo-marginata'	20 - 60	Bark	Chong & Purvis, 2004
Green waste compost	*Forsythia* x *intermedia* 'Lynwood Gold'	20 - 60	Bark	Chong & Purvis, 2004
Green waste compost	*Weigela florida* 'Red Prince'	20 - 60	Bark	Chong & Purvis, 2004
Paper mill biosolids	*Cornus alba* 'Sibirica'	20 - 60	Bark	Chong, 2003
Paper mill biosolids	*Forsythia* x *intermedia* 'Lynwood'	20 - 60	Bark	Chong, 2003
Paper mill biosolids	*Lonicera* x *xylosteoides*	15 - 60	Perlite	Chong *et al*., 1998
Paper mill biosolids	*Philadelphus* x *virginalis*	15 - 60	Perlite	Chong *et al*., 1998
Paper mill biosolids	*Physocarpus opulifolius*	20 - 60	Bark	Chong, 2003
Paper mill biosolids	*Prunus triloba* 'Multiplex'	15 - 60	Perlite	Chong *et al*., 1998
Paper mill biosolids	*Prunus* x *cistena*	15 - 60	Perlite	Chong *et al*., 1998
Paper mill biosolids	*Symphoricarpos* x *chenaultii* 'Hancock'	15 - 60	Perlite	Chong *et al*., 1998
Paper mill biosolids	*Viburnum dentatum*	15 - 60	Perlite	Chong *et al*., 1998
Paper mill biosolids	*Weigela florida* 'Variegata Nana'	20 - 60	Bark	Chong, 2003
Paper mill sludge (compost)	*Cornus alba* 'Argenteo-marginata'	20 - 60	Bark	Chong & Purvis, 2004
Paper mill sludge (compost)	*Forsythia* x *intermedia* 'Lynwood Gold'	20 - 60	Bark	Chong & Purvis, 2004
Paper mill sludge (compost)	*Weigela florida* 'Red Prince'	20 - 60	Bark	Chong & Purvis, 2004
Paper mill sludge (raw)	*Cornus amomum*	10 - 60	Perlite	Chong *et al*., 1998
Paper mill sludge (raw)	*Cornus sericea* 'Flaviramea'	15, 30	Bark	Chong & Cline 1993
Paper mill sludge (raw)	*Cotoneaster dammeri* 'Coral Beauty'	15, 30	Bark	Chong & Cline 1993
Paper mill sludge (raw)	*Forsythia* x *intermedia* 'Lynwood'	15, 30	Bark	Chong & Cline 1993
Paper mill sludge (raw)	*Hydrangea paniculata* 'Grandiflora'	10 - 60	Perlite	Chong *et al*., 1998
Paper mill sludge (raw)	*Spiraea* x *bumalda* 'Goldmound'	10 - 60	Perlite	Chong *et al*., 1998
Paper mill sludge (raw)	*Symphoricarpos orbiculatus*	10 - 60	Perlite	Chong *et al*., 1998
Paper mill sludge (raw)	*Weigela florida* 'Variegata'	15, 30	Bark	Chong & Cline 1993
Paper mill sludge (raw)	*Weigela florida* 'Variegata'	10 - 60	Perlite	Chong *et al*., 1998
Spent mushroom compost	*Cornus alba*	25, 50	Bark	Chong *et al*., 1994
Spent mushroom compost	*Cornus alba* 'Argenteo-marginata'	33 - 100	Bark	Chong *et al*., 1991
Spent mushroom compost	*Deutzia gracilis*	33 - 100	Bark	Chong *et al*., 1991
Spent mushroom compost	*Forsythia* x *intermedia* 'Lynwood'	25, 50	Bark	Chong *et al*., 1994
Spent mushroom compost	*Forsythia* x *intermedia* 'Lynwood Gold'	33 - 100	Bark	Chong *et al*., 1991
Spent mushroom compost	*Physocarpus opulifolius*	33 - 100	Bark	Chong *et al*., 1991
Spent mushroom compost	*Potentilla fruticosa* 'Red Ace'	33 - 100	Bark	Chong *et al*., 1991
Spent mushroom compost	*Rosa* 'John Franklin'	33 - 100	Bark	Chong *et al*., 1991
Spent mushroom compost	*Weigela florida* 'Variegata'	25, 50	Bark	Chong *et al*., 1994
Spent mushroom compost	*Weigela florida* 'Variegata Nana'	33 - 100	Bark	Chong *et al*., 1991
COMPARABLE				
Coir	*Arctostaphylos uva-ursi*	10, 20	Bark	Scagel, 2003
Coir	*Gaultheria shallon*	10, 20	Bark	Scagel, 2003
Coir	*Kalmia latifolia*	10, 20	Bark	Scagel, 2003
Coir	*Pieris japonica* 'Snowdrift'	10, 20	Bark	Scagel, 2003
Coir	*Rhododendron* spp.	10, 20	Bark	Scagel, 2003
Coir	*Vaccinium vitis-idaea* 'Erntedank'	10, 20	Bark	Scagel, 2003
Green waste compost	*Cornus alba 'Sibirica'*	25 - 50	Bark	Chong, 2004
Green waste compost	*Forsythia* x *intermedia* 'Lynwood Gold'	25 - 50	Bark	Chong, 2004
Green waste compost	*Weigela florida 'Variegata Nana'*	25 - 50	Bark	Chong, 2004
Paper mill sludge (raw)	*Cornus alba* 'Argenteo-marginata'	20 - 60	Bark	Chong & Purvis, 2004
Paper mill sludge (raw)	*Forsythia* x *intermedia* 'Lynwood Gold'	20 - 60	Bark	Chong & Purvis, 2004
Paper mill sludge (raw)	*Weigela florida* 'Red Prince'	20 - 60	Bark	Chong & Purvis, 2004

Table A2 cont. Materials examined as a substitute for bark or perlite in nursery stock container media

Material	Plant species	Rate (% v/v)	Control media	Reference
COMPARABLE/ENHANCED				
Spent mushroom compost	*Cornus alba 'Sibirica'*	25 - 50	Bark	Chong *et al*., 1991
Spent mushroom compost	*Cotoneaster dammeri* 'Coral Beauty'	25, 50	Bark	Chong *et al*., 1991
Spent mushroom compost	*Forsythia* x *intermedia* 'Lynwood Gold'	25 - 50	Bark	Chong *et al*., 1991
Spent mushroom compost	*Weigela florida 'Variegata Nana'*	25 - 50	Bark	Chong *et al*., 1991
Turkey litter compost	*Cornus alba 'Sibirica'*	25 - 50	Bark	Chong, 2004
Turkey litter compost	*Forsythia* x *intermedia* 'Lynwood Gold'	25 - 50	Bark	Chong, 2004
Turkey litter compost	*Weigela florida 'Variegata Nana'*	25 - 50	Bark	Chong, 2004
Waxed cardboard compost	*Cornus alba*	25, 50	Sawdust	Chong, 1993
Waxed cardboard compost	*Cornus alba* 'Elegantissima'	25, 50	Bark + Peat	Raymond *et al*., 1998
Waxed cardboard compost	*Cornus sericea*	25, 50	Bark + Peat	Raymond *et al*., 1998
Waxed cardboard compost	*Deutzia gracilis*	25, 50	Bark + Peat	Raymond *et al*., 1998
Waxed cardboard compost	*Physocarpus opulifolius*	25, 50	Bark + Peat	Raymond *et al*., 1998
NEGATIVE/COMPARABLE				
Paper sludge	*Spiraea x bumalda* 'Antony Waterer'	33	Bark	Bellamy *et al*., 1995
NEGATIVE				
Paper mill sludge (raw)	*Viburnum farreri*	10 - 60	Perlite	Chong & Hamersma, 1996
Spent mushroom compost	*Ligustrum vulgare*	33 - 100	Bark	Chong *et al*., 1991

Table A3. Leaf colour scores for different species relating to Royal Horticultural Society Colour Card numbers

Species	**Score 1**	**Score 2**	**Score**
Aster x *frikartii* 'Mönch'	146C	146A	147A
Aster novi-belgii 'Purple Dome'	143C	138A	137B
Clematis montana 'Tetrarose'	144B,144C,151A		
Delphinium 'Guardian Blue'	144A, 144B	146B	137B, 137C ,146A
Geranium 'Sabani Blue'	144B	144A	146A
Penstemon 'Vesuvius'	146B	146A	137A
Rosa 'Paddy Stephens'	146B	146A	147A
Rudbeckia lacianata 'Goldquelle'	144B	144A	137B
Rudbeckia fulgida 'Goldsturm'	138A	137A	139A
Verbena 'Claret'	166A	148A	138A
Viburnum tinus 'French White'	144A	137C	147A
Viburnum tinus 'Pupureum'	146C	146A, 146B	137A, 137B 139A, 147A