FINAL REPORT

Comparison of 12-14 month CRFs under protection and outdoors at different potting dates.

HNS 43d
1998-99

Project title:	**Comparison of 12-14 month CRFs under protection and outdoors at different potting dates (HNS 43d).**
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Practical Section for Growers

Background and Objectives

The majority of UK production of hardy nursery stock (HNS) is based on the use of controlled release fertilisers (CRFs). A number of factors influence the nutrient release from CRFs and hence the performance of the plants grown; particularly, temperature and irrigation. The reasons for the responses are discussed later in the report. However, the consequence of these interactions is that different rates of fertiliser incorporation are needed to get the most cost-efficient plant production for different growing conditions.

The majority of HNS in the UK is still produced outside, with no environmental control and as such CRF rates need to take account of periods of heavy rain (which will leach nutrients out of the pots), as well as potentially cold temperatures in the spring (slowing nutrient release).

Protected cropping of HNS is steadily increasing with an estimated 400 ha of plants now grown under protection for some or all of the production cycle, including many of the high value species. There has also been an increase in autumn potted, protected cropping for a range of fast maturing flowering crops for marketing the following spring. Growing environment has a large influence on the release of nutrients from CRFs and the results of outdoor grown plants can differ from those grown in the warmer, more regularly irrigated environment, under protection.

In addition to the differences in release rates of CRFs with growing environment, account needs to be taken of the geographical location of the nursery. A cold, wet location with outdoor crops will have different optimal rate of CRF incorporation than a hotter, dryer location. A previous study (HNS 43a) investigated the nutrition of a range of species at a Northern and Southern site. This work showed that shorter longevity CRFs could be used in the North, due to the lower temperatures and shorter growing season, and produced similar results to the longer term formulations in the South. However the majority of northern UK producers appear to be using 12-14 month formulations, and it is these products that the study is concentrating on.

Since projects HNS 43 and HNS 43a were completed a range of new CRFs have been introduced onto the UK market. As products differ in their analysis and release characteristics, some species (or groups of species) may grow better with certain CRFs. The comparison of the growth and quality responses to *all* the CRFs now available, as reported here, is essential information for the UK grower in helping to choose the most suitable cost-effective product for their own production.

This project, as well as comparing the currently available CRF products, examined an alternative approach to containerised HNS nutrition; namely, the use of nutrient loaded zeolite (Ferticult).

Zeolite is a volcanic mineral that has a very high cation exchange capacity, and hence the capacity to absorb nutrients and then release them to the plants during the growing period. Preliminary observations on the potential of Ferticult as a CRF replacement are included in this report. Additionally, a small scale laboratory observation was undertaken to evaluate the potential of using the high affinity for cations of unloaded zeolite as a means of absorbing excess nutrients and reducing nutrient leaching.

The objectives of this project were to:

- Compare a range of 12-14 month CRF formulations currently available and those about to be introduced onto the market, at manufacturer's recommended rates
- Monitor crop response both outdoors and under protection from a spring potting
- Examine use of CRFs for shorter term autumn potted crops for following spring sales
- Investigate North/South variation in response to CRFs for an outdoor spring potted crop
- Monitor potential of nutrient charged Zeolite (Ferticult) to provide plant nutrient requirements over the season
- Investigate the use of unloaded zeolite as a means to reduce the leaching of nutrients from a container system.

Summary of Results

Overall, similar quality plants were produced across a wide range of products.

Spring potted species

1. In general, the same CRFs produced the greatest growth responses at HRI-Efford as Johnson's of Whixley, showing that the CRFs were behaving in a similar manner relative to each other albeit at lower release rates overall. This was most markedly shown with the trimming weight of *Weigela* which showed that although plant growth was reduced at the Northern site, the pattern of plant growth response among CRFs was the same.

2. Osmocote Plus, Osmocote Exact Hi-Start and Multicote 12 produced large plants with the majority of species, notably *Viburnum, Weigela, Cytisus* and *Pieris*. It was also clear that Ficote 180 TE, Vitacote and Polyon generally produced smaller plants although some species produced greater than average growth with these CRFs (Ficote 180 TE – *Photinia* and *Jasminum*; Vitacote – *Pieris* and *Cytisus*; Polyon – *Chamaecyparis* and *Photinia*).

3. It would appear that Ficote 180 TE and Polyon were both releasing less nutrients than the other CRFs in the trial. It is known that Ficote 180 TE initially releases slowly (HNS 43b) and it is recommended by the supplier (Scotts/Levington) that single superphosphate (750 g/m^3) is incorporated at potting. However in the cold growing year 1998/99 Ficote 180 TE did not release as much N, P or K, as the other CRFs, which can explain the smaller plants. The Polyon studied here was a CRF used in North America, with a coating that released nutrients at temperatures > 12°C. Following results in the UK the coating has been altered to maintain nutrient release at lower temperatures, and it is this improved product that is now on the UK market.

4. Sincrocell 12 and Plantacote pluss gave acceptable results with all species. At the rates studied both CRFs generally produced slightly less growth than Osmocote Plus, Osmocote Exact Hi-Start and Multicote 12 throughout the growing season, and there was indications that the lighter foliage colour seen in *Choisya* grown with Plantacote pluss under protection may have had less nutrients remaining by the end of the trial, although this contrasted with the observed foliage colour of *Jasminum,* which remained dark with Plantacote pluss .

5. Early growth benefited at Johnson's of Whixley from the addition of Sincrostart to Sincrocell with *Viburnum* and *Weigela*. However, the late potting reduced the necessity for a soluble base fertiliser and high rainfall early on may have washed out some of the soluble fertiliser before it was utilised by the plants, limiting its effectiveness.

6. Multicote 8 produced quality plants with most species, although with *Ceanothus, Choisya, Jasminum,* and *Photinia* grown under protection there were indications that the longevity was inadequate, compared to Multicote 12, and that nutrient reserves were exhausting by the end of the trial.

7. In a number of species, CRF treatment influenced the amount of flowers (*Viburnum, Weigela* and *Lavandula*) and the timing of flowering (*Ceanothus* and *Cytisus*). Flowering was influenced by two groups of CRFs: those associated with larger plants (e.g. Osmocote Plus, Multicote 8 and 12) and those associated with smaller plants (e.g. Exact Lo-Start, Ficote 180 TE, Polyon). It can be assumed that the response was due to differences in mineral nutrient supply among CRF treatments. Further work is necessary to establish the cause/mechanism of this effect which could be of significant commercial benefit.

Autumn potted species

8. With the short term autumn potted crops, all CRFs produced satisfactory results, with only small differences between them. There were indications of improved flowering with Ficote 180 TE, Multicote 8, Vitacote and Sincrocell 12 (*Lavandula*). More work is required to see whether the discolouring of the foliage on the *Hebe* was due to slower release of nutrients and subsequent re-distribution within the plants or other factors such as susceptibility to disease.

Ferticult

9. Loaded zeolite (Ferticult) produced poorer quality plants than the industry standard CRF: Osmocote Plus. Before quality plants can be grown with Ferticult as a major nutrient source two issues need to be addressed: 1) the supply of phosphate is difficult to maintain over time; and 2) there is some indication that the balance of N:K is incorrect. However, Ferticult could yet be involved in plant nutrition as a nutrient buffer and source of cations, in association with other sources of nutrients (e.g. organic matter, rock phosphate). Further work is needed to improve the understanding of nutrient release kinetics from Ferticult before further progress can be made in this area.

Zeolite

10. Zeolite has the ability to markedly reduce the loss of cations such as ammonium and potassium, but loss of anions such as nitrate and phosphate (the two main pollutants of waterways) are uncontrolled. This limits the effectiveness of this approach as a means to reduce nutrient leaching *on its own*. However, the use of zeolites as a component of a larger leachate controlling strategy may have benefits for the horticulture industry as a whole.

Action Points

- Differences between CRFs, whilst statistically significant, were relatively small and not considered commercially significant enough to suggest that different CRFs should be used for individual species. General HNS producers can produce saleable plants with all the CRFs currently on the market at manufacturer's recommended rates. Consequently, grower choice can be dictated by other criteria including price.

- Subtle differences may be of use where large numbers of single species are being produced, and a 'horses for courses' approach to nutrition may be of benefit.

- Some observed differences (e.g. flowering) may be of particular interest to specialist growers. however more work is needed to investigate this response.

- There were indications that manufacturers' recommended rates could be higher than required by the plants. However, this aspect, in particular, needs further independent study, as if proven, this would have significant cost-saving potential.

Practical and Financial Benefits

With CRFs producing similar quality plants at manufacturers' recommended rates, cost savings can be made through product choice based on price alone.

Science Section

Introduction

The majority of UK production of hardy nursery stock (HNS) is based on the use of controlled release fertilisers (CRFs). A number of factors influence the nutrient release from CRFs and hence the performance of the plants grown; particularly, temperature and irrigation. The reasons for the responses are discussed later in the report. However, the consequence of these interactions is that different rates of fertiliser incorporation are needed to get the most cost-efficient plant production for different growing conditions.

The majority of HNS in the UK is still produced outside, with no environmental control and as such CRF rates need to take account of periods of heavy rain (which will leach nutrients out of the pots), as well as potentially cold temperatures in the spring (slowing nutrient release).

Protected cropping of HNS is steadily increasing with an estimated 400 ha of plants now grown under protection for some or all of the production cycle, including many of the high value species. There has also been an increase in autumn potted, protected cropping for a range of fast maturing flowering crops for marketing the following spring. Growing environment has a large influence on the release of nutrients from CRFs and the results of outdoor grown plants can differ from those grown in the warmer, more regularly irrigated environment, under protection.

In addition to the differences in release rates of CRFs with growing environment, account needs to be taken of the geographical location of the nursery. A cold, wet location with outdoor crops will have different optimal rate of CRF incorporation than a hotter, dryer location. A previous study (HNS 43a) investigated the nutrition of a range of species at a Northern and Southern site. This work showed that shorter longevity CRFs could be used in the North, due to the lower temperatures and shorter growing season, and produced similar results to the longer term formulations in the South. However the majority of northern UK producers appear to be using 12-14 month formulations, and it is these products that the study is concentrating on.

Since projects HNS 43 and HNS 43a were completed a range of new CRFs have been introduced onto the UK market. As products differ in their analysis and release characteristics, some species (or groups of species) may grow better with certain CRFs. The comparison of the growth and quality responses to *all* the CRFs now available, as reported here, is essential information for the UK grower in helping to choose the most suitable cost-effective product for their own production.

The series of experiments and trials reported here were set up to study aspects of nutrition of containerised hardy nursery stock. The report is in two sections: CRF comparison trial; and a study of potential uses of zeolite. The CRF comparison trial compared 12 formulations of CRF, which differed in coating composition and thickness, and core granule analysis. The work was set up to study CRF use under different growing environments and time of year potted, with species appropriate to the situation. The CRFs were incorporated at manufacturer's recommended rates. Consequently, comparisons between treatments were a function of rate of fertiliser applied, the analysis of the core granule and the release characteristics of the granule coating.

A selection of the species grown outdoors on the southern site were also grown on a northern trial site. This allowed examination of the effect of environmental differences and duration of growing season on the relative plant growth responses to the CRF treatments.

Two experiments were undertaken with zeolite. First as the nutrient loaded form (ferticult) and second, as the unloaded form: the former material was studied as a replacement to CRFs and the latter as a means to reduce leaching of excess water soluble nutrients from growing media.

Part 1

CRF Comparison trials

Part 1. CRF comparison trials

A series of trials were undertaken at HRI-Efford and Johnson's of Whixley, with the following objectives.

- Compare range of 12-14 month CRF formulations currently available and those about to be introduced onto the market (*Trial A,B & C*)
- Monitor crop response both outdoors and under protection from a spring potting (*Trial A & B*)
- Examine use of CRFs for shorter term autumn potted crops for following spring sales (*Trial C*)
- Investigate North/South variation in response to CRFs for an outdoor spring potted crop (*Trial A*)

Fertilisers :

Product	Analysis	UK Supplier
Ficote 180 TE	14:8:8 TE	Levington Horticulture Ltd.
Multicote 8	18:6:12 (traces)	Hi-Chem (UK) Ltd.
Multicote 12	15:7:15 (traces)	Hi-Chem (UK) Ltd.
Osmocote Plus 12-14 Spring	15+9+11+2+traces	Scotts UK Ltd.
Osmocote Exact Hi-Start 12-14	15+10+10+traces	Scotts UK Ltd.
Osmocote Exact Standard 12-14	15+9+9+traces	Scotts UK Ltd.
Osmocote Exact Lo-Start 12-14	15+8+10+traces	Scotts UK Ltd.
Plantacote pluss 12M	14:8:14 (traces)	Kemira Horticulture
Polyon	17-5.5-11+T.E.	Vitax Ltd.[ϕ]
Sincrocell 12	14+8+13+TE	William Sinclair Horticulture
Vitacote	18-6-12+T.E.	Vitax Ltd.
*(Sincrostart)**	*12+14+24+TE*	*William Sinclair Horticulture*

* incorporated with Sincrocell for 3 species only, see Table 1&2.

[ϕ] suppliers from 1999 are Hortifeeds direct

Trial A Spring potted – Outdoor

This trial was undertaken at two sites: HRI-Efford and Johnson's of Whixley. The fertilisers compared were identical at the two sites, but the number of species was reduced at the Northern site.

Materials and Methods

HRI-Efford & Johnson's of Whixley

Fertiliser treatments and manufacturer's recommended rates are shown in Table 1.

Plants were grown outdoors on sandbeds covered with a double layer of Mypex, to prevent capillary action, with overhead irrigation.

Growing medium: 100% Irish premium peat
1.5 kg/m^3 Mg Lime (1.0 kg/m^3 –*Chamaecyparis l.*)
750 g/m^3 suSCon green

Start material: 9 cm liners bought in and potted-on into 3 litre containers

Species:

HRI-Efford	Johnson's of Whixley
Chamaecyparis lawsoniana 'Ellwoodii'	*Chamaecyparis lawsoniana* 'Ellwoodii'
Cotoneaster horizontalis	*Cotoneaster horizontalis*
Cytisus x *praecox*	
Photinia x fraseri 'Red Robin'	
Viburnum tinus 'Eve Price'	*Viburnum tinus* 'Eve Price'
Weigela 'Red Prince'	*Weigela* 'Red Prince'

Potting date: HRI-Efford week 21 (18/05/98)
Johnson's of Whixley week 22 (25/25/98)

Design:

Randomised block design with three plots per treatment and 10 plants per plot. Six plants were recorded with 4 plants acting as guard plants.

Table 1.

The late decision to include Sincrostart with the Sincrocell 12 treatments (as recommended by the supplier) meant that the Sincrocell 12 +/- Sincrostart treatments could only be included in three of the six species grown outdoors. Consequently, where the comparison is made of Sincrocell 12 versus Sincrocell 12 + Sincrostart there were 12 treatments. Where neither Sincrocell nor Sincrostart are included there were 10 treatments.

Assessments

Plants were assessed in October 1998 and after the first flush of growth, in May 1999. The variables recorded differed with species, as appropriate, and are outlined in the results section.

Measurements of height and width were taken directly. Scoring of colour, vigour and form was subjective; made by visual comparison against selected standards each time. Both Efford and the Northern site were recorded against the same score plants – having been transported to Johnson's of Whixley. The Northern site was scored and sampled in the same manner as Efford, and at similar stages of growth. Photographs and measurements of these standards were taken.

Standard plants were selected for each assessed variable as follows: 6 plants displaying the full range of the variable were chosen from within the experimental plots and replaced into the body of plants after all plants had been scored against the standards. These plants were termed standard 0 to standard 5, with the variable the least for 0 and the greatest for 5; e.g. for colour, 0 was the plant with the lightest coloured foliage and standard 5 was the plant with the darkest foliage. The standards were grown under the same conditions as all the recorded plants. The standards were measured and photographed before being replaced. The standards were selected anew each time plants were scored.

Above ground biomass was recorded for half of all recorded plants by destructive sampling after the spring flush of growth.

Residual analysis **(Outdoor Spring potted trial only)**

At potting, and end of trial, 50 granules of each CRF treatment were collected, dried, ground up and analysed for available major and micro-nutrients (HRI-Wellesbourne). Samples at potting were taken directly from the bag, whereas the final sample was bulked across replicates of the spring potted *Chamaecyparis lawsoniana* 'Ellwoodii' only, as nutrient release is independent of plant species, and as such comparison between species was unnecessary.

Photographs

Photographs were taken as appropriate throughout trial.

Statistics:

Statistical analysis of all variables was carried out by the Biometric department at HRI-East Malling. Statistical analysis can be applied to data derived from a scoring system. There are many examples of this in the literature, especially within microbiology. Recording 5-6 plants per plot leads to a normally distributed population around the mean score value. Consequently, this score was used in ANOVA to derive significance of treatment responses.

Results

HRI-Efford

Weather data

The growing season was unusually wet especially at the beginning of summer and early Autumn (see Table 2). Rainfall was frequent but periods of low rainfall (<10mm / week) were observed in August and September.

The highest temperatures were recorded week 32 and 33 in 1998 and week 22 in 1999. Over winter there were two cold periods in week 49 and 7. An unusually cold week in April (wk 14) affected new growth on some of the outdoor plants at Efford (Figure 1).

Table 2. Monthly average rainfall, maximum and minimum temperatures at HRI-Efford as a percentage of the 49 year monthly average.

1998	May	June	July	Aug	Sept	Oct	Nov	Dec
Rainfall (mm)	44	158	105	36	30	171	52	108
Max °C	119	95	93	101	103	-	100	109
Min °C	128	114	101	91	109	100	92	115

1999	Jan	Feb	March	April	May
Rainfall (mm)	128	63	55	166	43
Max °C	-	-	88	110	112
Min °C	178	155	100	136	130

CRF residual analysis

The most striking observation was that the analysis of each CRF changed over the growing season, with N and K being released earlier than P. Phosphorous appeared to accumulate in some granules over time (Ficote 180 TE and Multicote 8). However this was an artefact due to low initial solubility of P in the granule i.e. in the analysis procedure only a proportion of the total P is measured. Differences in the rate of release were apparent from the changes in nutrient concentrations (See Appendix B, Table 1.)

Figure 1.

All the data is summarised in Appendix A, with appropriate data extracted in this section to illustrate specific points.

***Chamaecyparis lawsoniana* 'Ellwoodii'**

The height of each plant was measured after potting on and at autumn 98 and spring 99. Foliage scorch was scored in autumn 98 and spring 99.

The original liners were rather variable in height (average height 38.5 cm +/- 6.3 cm). However, the initial height did not effect subsequent changes in height i.e. was not correlated to the incremental increase in height at autumn 98 or spring 99, supporting the use of these results as valid treatment comparisons (see Table 3).

Table 3. Correlation matrix of growth measurements showing direction and significance of correlations.

	A	B	C	D	E
A Initial size (cm)	1				
B Growth May-Oct (cm)	ns	1			
C Growth May-Oct (%)	-0.75	0.85	1		
D Growth Oct-June (cm)	ns	ns	ns	1	
E Growth Oct-June (%)	ns	ns	ns	0.98	1

By spring 98, three treatments had produced significantly larger increments in height; namely, Osmocote Exact Lo-Start, Polyon and Multicote 12. The smallest increase in height was recorded for Ficote 180 TE. The height increment between autumn 98 and spring 99 was much smaller across all treatments. Osmocote Plus, Multicote 8 and Plantacote pluss producing the greatest increases in height, whereas Osmocote Exact Lo-Start, Ficote 180 TE and Multicote 12 produced the least increases in height. When the two periods of growth were considered together Multicote 12 and Polyon had supported the greatest increases in height and Ficote 180 TE the smallest (Figure 2.).

Tip scorch was observed from July-August 98 onwards with a number of treatments displaying marked symptoms (Osmocote Exact Standard, Ficote 180 TE and Sincrocell 12). In general the symptoms decreased following the spring flush of growth, but scorching was still visible on those plants grown with Osmocote Exact Standard, Ficote 180 TE and Sincrocell 12. Some scorching was also becoming visible on the Osmocote Exact Hi-Start plants (Appendix A, Plate 1). Plants grown with Multicote 12 appeared to be the least affected. Dry weights were not estimated for this species.

Figure 2

Cotoneaster horizontalis

Size was scored autumn 98 and spring 99.

All CRFs produced plants of similar appearance and quality by autumn 98 and spring 99. However significant differences were apparent for biomass with two treatments: Osmocote Exact Hi-Start and Multicote 12 having the two highest values.

Cytisus x praecox

Plants were scored for size and foliage colour autumn 98, and size and flower were scored spring 99.

Early nutrients appeared to benefit growth with Osmocote Exact Hi-Start > Standard > Lo-Start (Figure 3). Plants grown with Ficote 180 TE and Polyon were smaller than average, and those grown with Ficote 180 TE, Polyon and Osmocote Exact Lo-start had significantly darker foliage at recording. Notably, there was a significant negative correlation between size score and foliage colour ($r = -0.70$, $p = 0.05$), where the smaller plants had darker foliage colour.

The relative performance of the CRF treatments was the same following the spring flush of growth. All treatments flowered well but plants grown with Osmocote Exact Lo-Start, Ficote 180 TE and Polyon flowered earlier. This response was correlated with reduced plant size suggesting lower initial nutrition may be involved.

Significant differences in biomass were observed between treatments. The largest biomass was produced by plants grown with Multicote 12, Vitacote, Osmocote Plus and Osmocote Exact Hi-Start. Ficote 180 TE and Polyon treatments gave plants with the smallest biomass.

***Photinia x fraseri* 'Red Robin'**

Plants were scored for size and quality and foliage colour (an indicator of new growth at time of recording) autumn 98; trimmings were weighed and size and foliage colour of the new growth were scored spring 99. The spring results were assessed on a new flush of growth following pruning back of plants.

The plants grew on strongly after potting, and by August the largest plants were those grown with Osmocote Plus, Osmocote Exact Lo-Start, Ficote 180 TE, Polyon, and Multicote 8. Multicote 12 produced the smallest plants (Figure 4). The growth was then trimmed back and the trimmings were weighed. Interestingly, although size score correlated with trimming biomass for most treatments, the biomass was lower than was predicted from the size score with Ficote 180 TE, Polyon and Multicote 12 (Figure 4). The opposite was observed with Osmocote Plus and Vitacote. It was observed that plants grown with Ficote 180 TE and Polyon had significantly more new growth at the time of recording, in autumn 98.

By spring 99 the general size score responses were similar to autumn 98. Two treatments stood out as being relatively smaller, namely Osmocote Exact Lo-Start and Multicote 8. The above ground biomass by spring showed little significant differences with only Osmocote Plus being significantly heavier than any other treatment. The least biomass was measured from Polyon, Multicote 8 and 12.

As with the spring records Ficote 180 TE and Polyon were actively supporting new growth relative to most treatments. However in contrast to the autumn, plants grown with Osmocote Plus, Osmocote Exact Standard and Lo-Start also had a large amount of new growth.

Viburnum tinus **'Eve Price'**

Plants were scored for size and flowering autumn 98, and size was scored spring 99.

By the autumn recording date visual differences in growth were clearly apparent between treatments. The largest plants were produced with Osmocote Plus, Osmocote Exact Hi-start, Standard and Multicote 12. Significantly small plants were grown with Ficote 180 TE, Vitacote and Polyon.

The most striking result with this species was the significant difference observed in the degree of flowering with Osmocote Plus, Osmocote Exact Standard and Multicote 8 and 12 bearing the most flowers (Appendix A, Plate 2).

The relative plant size scores in spring were similar to those recorded in autumn, with the exception of two treatments: Ficote 180 TE and Multicote 12. The relative size of the plants grown with Ficote 180 TE had increased by spring, whereas those grown with Multicote 12 had decreased.

The biomass of the plants showed a similar response to the size score for all treatments except Osmocote Exact Hi-Start (Figure 5). Both Osmocote Exact Hi-Start and Osmocote Plus had similar size scores, but Osmocote Exact Hi-Start had significantly lower biomass.

fig 3 and 4

fig 5

Weigela 'Red Prince'

Plants were scored for size autumn 98, and following pruning, the trimmings were weighed in Winter 98.

Unfortunately following pruning the new growth suffered following some hard frosts, and too many plants died to get viable data at the time of recording in spring 99.

At the time of recording in autumn 98 plants grown with Multicote 12, Plantacote pluss, Vitacote, Osmocote Plus and Osmocote Exact Hi-Start were all relatively larger. The smallest plants were observed in the Ficote 180 TE, Polyon and Multicote 8. There was a marked decrease in size score with the Osmocote Exact range: Hi-Start > Standard > Lo-Start.

The biomass of trimmings followed the same pattern as size score with the weight of trimmings from the plants grown with Multicote 12 and Plantacote pluss being twice that of Ficote 180 TE, Polyon and Multicote 8 (Figure 6).

Summary

- The majority of CRFs gave similar results at the recommended rates in this season.
- However, with the cooler wet growing season experienced this year, the 180 day Ficote 180 TE formulation released too slowly, and similar results were obtained from Polyon. These results need confirming over other seasons.
- Significant differences were observed in the flowering of *Viburnum tinus*'Eve Price'

Fig 6.

Johnson's of Whixley

Weather data

Compared to HRI-Efford, temperatures at Johnson's of Whixley were generally lower. Over the duration of the experiment, the average daily temperature at Johnson's of Whixley was 1.2 °C lower than HRI-Efford; and the average daily temperature was higher at Johnson's of Whixley in only five of the 45 weeks that the experiment was concurrent on the two sites (Figure 1, page 15). Although the rainfall pattern differed at Johnson's of Whixley compared to HRI-Efford, over the growing season only 5 mm more rain fell at Johnson's than at Efford.

Residual analysis

For each CRF the amount of nutrients (N, P and K) remaining in the granules at the end of the trial was significantly more at Johnson's of Whixley than HRI-Efford (Table 4). Differences were apparent among CRFs in the release rates of different salts and are presented in Appendix B, Table 2.

Table 4. Major elements in CRF granules at end of experiment as a proportion of initial analysis (average of all treatments)

	HRI-Efford	**Johnson's of Whixley**
	(%)	(%)
N	22.9	44.4
P_2O_5	58.9	73.6
K_2O	41.8	66.4

Chamaecyparis lawsoniana **'Ellwoodii'**

The height of each plant was measured three times: after potting on, autumn 98 and spring 99. Foliage scorch was scored in autumn 98 and spring 99.

As described previously (page 16), the original liners were rather variable in height (average height 38.5 cm +/- 6.3 cm). However, the initial height was not correlated to the incremental increase in height by autumn 98 or spring 99, i.e. had no measurable influence on the ensuing growth, supporting the use of these results as valid treatment comparisons.

The average total increase in height was 18.9 cm, which was less than that seen at HRI-Efford. However, there were no significant differences among CRF treatments for increments of height by autumn, spring or total height increase (Figure 2, page 17).

Tip scorch was observed from July-August 98 onwards with a number of treatments displaying marked symptoms (Osmocote Exact Lo-Start, Ficote 180 TE, Sincrocell 12 & Sincrostart and Plantacote pluss). In general the symptoms decreased following the spring flush of growth, but scorching was still visible. Plants grown with Polyon appeared to be the most healthy.

Dry weights were not estimated for this species

Cotoneaster horizontalis

Size was scored autumn 98 and spring 99.

As at Efford, all CRFs produced similar results in growth and form for this species. However, Multicote 12 produced significantly more biomass than any other treatment at Johnson's of Whixley.

Compared to HRI-Efford greater biomass was produced by all but one CRF treatment (Osmocote Exact Hi-Start).

***Viburnum tinus* 'Eve Price'**

Plants were scored for size and flowering autumn 98, and size was scored spring 99.

The plants grown at the Northern site were significantly smaller than those grown at Efford. The differences between fertiliser treatments were also smaller. By autumn 98, those plants grown with Osmocote Plus, Osmocote Exact Hi-Start and Sincrocell 12 & Sincrostart were the largest, whereas plants grown with Polyon and Multicote 8 were the smallest.

In general, following the spring flush of growth, plants displayed a similar pattern of response to CRF treatment. The only exceptions being those grown with Ficote 180 TE and Polyon, which were noticeably smaller than the rest. The total biomass was also very similar among treatments, with only Ficote 180 TE, Polyon and Multicote 8 producing plants with significantly less biomass (Figure 5, page 21).

In contrast to Efford, flowering was sparse and not markedly different with any treatment.

Weigela 'Red Prince'

Plants were scored for size autumn 98, and for size and flowering spring 99. The trimmings were weighed Winter 98.

By autumn 98 differences were apparent in the growth of different treatments. The largest plants were grown with Osmocote Plus, Osmocote Exact Hi-start, Sincrocell 12, Sincrocell 12 & Sincrostart, Plantacote pluss and Multicote 12. The smallest plants were grown with Ficote 180 TE and Polyon. The dry weight of the trimmings showed a similar pattern to the size score. The trimming dry weight, although less than those measured for the same treatments at HRI-Efford, showed the same relative responses. (Figure 6, page 23).

Following pruning the new growth was scored and showed little difference among treatments, with the only notably larger size score being achieved by Osmocote Exact Lo-Start.

The most flowers were produced on the plants fertilised with Ficote 180 TE, Vitacote and Multicote 8.

Summary

- Plant size and treatment differences were smaller than observed at Efford, but the underlying trends were the same.
- In general, similar growth was obtained with all CRF products, at manufacturers recommended rates.
- However, Ficote 180 TE and Polyon appeared to be releasing more slowly, leading to reduced growth.

Trial B Spring potted – Protected

This trial was undertaken at HRI-Efford only

Materials and Methods

Fertiliser treatments and manufacturer's recommended rates are shown in Table 5.

Plants were grown in poly-tunnels with net sides, on sandbeds covered with a double layer of Mypex, to prevent capillary action, with overhead irrigation (spot watering over winter).

Growing medium: 100% Irish premium peat
1.5 kg/m^3 Mg Lime (1.0 kg/m^3 –*Pieris*)
750 g/m^3 suSCon green

Start material: 9 cm liners bought in and potted-on into 3 litre containers

Species:

Ceanothus impressus 'Puget Blue'
Choisya ternata
Euonymous fortunei 'Emerald 'n' Gold'
Hedera colchica 'Sulphur Heart'
Jasminum nudiflorum
Pieris 'Forest Flame'

Potting date: HRI-Efford week 21 (18/5/98)

Design:

Randomised block design with three plots per treatment and 10 plants per plot. Six plants were recorded with 4 plants acting as guard plants.

The late decision to include Sincrostart with the Sincrocell 12 treatments (as recommended by the supplier) meant that the Sincrocell 12 +/- Sincrostart treatments could only be included in three of the six species grown under protection. Consequently, where the comparison is made of Sincrocell 12 versus Sincrocell 12 + Sincrostart there were 12 treatments. Where neither Sincrocell nor Sincrostart are included there were 10 treatments.

Assessments and Statistics were as described on page 12.

table 5.

Results

Temperature data

The temperature under the polythene structures followed a similar pattern to that outside, but at a higher temperature. On average, over the growing season, the temperature was 1.0 °C higher under protection than outside (see Figure 7)

Ceanothus impressus 'Puget Blue'

Plants were scored for size autumn 98; size, foliage colour and flowering was scored spring 99.

Osmocote Exact Hi-Start and Multicote 12 produced the largest plants by autumn 98. Ficote 180 TE and Sincrocell 12 produced the smallest plants. There was a clear response with the Exact products with Hi-Start > Standard > Lo-Start.

Following winter, Osmocote Hi-Start and Multicote 12 maintained the greatest growth and, in addition, Osmocote Exact Standard had caught up with them. Ficote 180 TE and Sincrocell 12 were still the smallest plants (Figure 8a).

Foliage colour showed some clear differences among treatments with plants grown with Ficote 180 TE having the darkest foliage, whereas Sincrocell 12 & Sincrostart and Multicote 8 had the lightest foliage colour (Figure 8b).

The extent of flowering at the time of recording also displayed differences, with Ficote 180 TE, Polyon, Plantacote pluss and Multicote 12 all having more flowers; Multicote 8 had the least (Figure 8c).

The biomass of above ground material followed the same relative pattern as the size score with one exception: Plantacote pluss had a greater biomass than would be expected from its size score in spring 99.

figure 7

figure 8

***Euonymous fortunei* 'Emerald 'n' Gold'**

Plants were scored for size autumn 98 and spring 99.

No differences were apparent among treatments by autumn 98 and after winter all treatments produced new growth of a similar quality. However, Osmocote Exact Hi-Start was noted as producing new growth earlier than most other treatments.

The biomass of above ground plant parts was similar for all treatments except Plantacote pluss which had a significantly lower biomass.

***Hedera colchica* 'Sulphur Heart'**

Height of growth was assessed in autumn 98 and spring 99

Following potting on differences were observed in the extent of growth up the cane. Polyon had the least growth (79.6 cm) whereas Sincrocell 12 & Sincrostart had the most (98.9 cm). By the following spring all the treatments had achieved a similar height, with the exception of Polyon, which was still significantly smaller, suggesting that the former had stronger stems.

By the end of the trial significant differences were present for biomass, with Osmocote Exact Standard and Lo-Start producing the greatest amount of biomass, and Ficote 180 TE, Polyon and Multicote 8 the least.

***Pieris* 'Forest Flame'**

Plants were scored for size and flower in autumn 98; and size, new growth and flower in spring 99.

This species tends to have an untidy growth habit and the plants were quite variable within treatments. In general, plants grown with Ficote 180 TE, Polyon and Plantacote pluss were smallest and those grown with Vitacote were largest. Most flowers were observed on Osmocote Exact Standard whereas the least were on Multicote 12.

By spring 99 the largest plants were those grown with Vitacote and Multicote 12. Those in Osmocote Exact Lo-Start, Ficote 180 TE, Polyon and Plantacote pluss were generally smaller than average. New growth also differed between treatments with Osmocote Exact Hi-Start, Ficote 180 TE and Multicote 12 having greater than average early growth. Plants grown with

Osmocote Plus, Osmocote Exact Lo-Start, Ficote 180 TE, Plantacote pluss and Multicote 8 all produced an above average quantity of flowers.

Plant biomass at the end of the experiment was greatest for Osmocote Plus, Vitacote and Multicote 12. The lowest biomass was those plants grown with Osmocote Exact Lo-Start, Polyon and Plantacote pluss. Of note was the response among the Exact products with Hi-Start > Standard > Lo-Start.

Choisya ternata

Plants were scored for size in autumn 98; and size, colour and flower in spring 99

By autumn 98 the plants were of a similar size except for those grown with Ficote 180 TE and Polyon, which were smaller.

A similar pattern of growth was observed in spring 99 with Ficote 180 TE and Polyon producing plants that were smaller than average. The darkest foliage was observed with Ficote 180 TE, Osmocote Exact Hi-Start and Multicote 12 (Figure 9a), and pale foliage was observed with those plants grown in Vitacote, Plantacote pluss and Multicote 8 (Figure 9b). Differences were observed in the extent of flowering at time of recording with Multicote 12 producing the least flowers (Figure 9c).

Significant differences occurred in the plant biomass with Osmocote Exact Hi-Start producing the greatest biomass. The lowest biomass was observed with Osmocote Exact Lo-Start, Ficote 180 TE , Polyon and Plantacote pluss. The Exact range again showed a clear response with Hi-Start > Standard > Lo-Start.

Jasminum nudiflorum

The height of growth was measured in autumn 98; and height of growth and colour were scored in spring 99

The greatest growth by autumn was obtained with Ficote 180 TE, and the least growth with Polyon. This same pattern was observed in the spring measurements where the largest plants were produced using Ficote 180 TE. Osmocote Plus, Osmocote Exact Standard and Osmocote Exact Lo-Start also produced large plants (Figure 10a). Foliage colour showed clear differences: Osmocote Plus, Exact products, Ficote 180 TE and Plantacote pluss all had darker foliage than the other treatments (Fig 10b).

The biomass data showed three groups of treatments: greatest (Osmocote Plus and Ficote 180 TE), intermediate (Osmocote Exact Hi-Start, Standard and Lo-Start) and least (Vitacote, Polyon, Plantacote pluss, Multicote 8 and 12)

Summary

- Ficote 180 TE produced better results under protection for this spring potting, compared with the outdoor results, an effect that can be attributed to the higher temperature.

- CRFs which appeared to release more slowly, initially, produced more flowers although on smaller plants

Figure 9

figure 10

Trial C Autumn potted - Protected

This trial was undertaken at HRI-Efford only

Materials and Methods

Fertiliser treatments and manufacturer's recommended rates are shown in Table 6.

Plants were grown in glasshouses, with frost protection heating. Plants were placed on capillary matting covered perforated polythene film (aquafoil). Irrigation was by hand.

Growing medium: 100% Irish premium peat
1.5 kg/m^3 Mg Lime (1.8 kg/m^3 –*Lavandula*)
0.5 kg/m^3 single superphosphate was incorporated with the Ficote 180 TE treatments
750 g/m^3 suSCon green

Start material: 9 cm liners bought in and potted-on into 3 litre containers

Species:

Cistus creticus
Hebe pinguifolia 'Pagei'
Lavandula angustifolia 'Hidcote'
Lavatera thuringiaca 'Rosea'
Solanum jasmanoides 'Album'

Potting date: HRI-Efford week 35 (24/8/98)

Design:

Randomised block design with three plots per treatment and 10 plants per plot. Six plants were recorded with 4 plants acting as guard plants.

Assessments and staistics were as described on page 12.

Table 6

Results

Temperature data

The temperature in the glasshouse followed a similar pattern to that outside, though higher. On average, over the growing season, the temperature was 3.5 °C higher than outside and 2.5 °C higher than that under the polythene structures (see Figure 7, page 30).

Cistus creticus

The plants were scored for size and colour at the end of the trial.

All fertilisers produced plants of similar size and quality. Flowering was uniform between and within treatments.

There were no significant differences in biomass

Hebe pinguifolia 'Pagei'

At the end of the trial plants were scored for size and quality

As with *Cistus* all fertilisers produced plants of similar size, however differences were obvious in the extent of discolouring of the lower leaves. This was especially marked in those plants grown with Ficote 180 TE, Plantacote pluss and Multicote 12. The least discolouring was observed on plants grown with Osmocote Exact Standard, Vitacote and Multicote 8.

There were no significant differences in biomass

Lavandula angustifolia 'Hidcote'

Plants were scored for size, quality, the extent of flowering at the end of the trial. Additionally, the number of dead plants was counted

Plants were of a similar size among treatments except for those grown with Vitacote, which produced the largest plants, and Plantacote pluss which produced the smallest (Figure 11a). Most flowering spikes were produced by those plants grown with Ficote 180 TE, Vitacote, Sincrocell and Multicote 8 (Figure 11b).

Lavender is a notoriously difficult crop to grow well and can suffer varying degrees of plant losses. This can be influenced by nutrition. The most deaths were observed in those plants grown with Osmocote Plus, Osmocote Exact Standard and Multicote 12 (Figure 11c).

No significant differences in biomass were observed between treatments.

***Lavatera thuringiaca* 'Rosea'**

At the end of the trial plants were scored for size and colour. Plants were of a similar quality across all fertilisers.

Final biomass exhibited significant differences. Osmocote Plus, Osmocote Exact Hi-start and Ficote 180 TE produced the greatest biomass. Plantacote pluss and Multicote 8 produced the smallest biomass.

***Solanum jasminoides* 'Album'**

Sequential trimmings were bulked for each plot and weighed. At the end of the trial size and colour were scored.

All plants had a similar appearance following trimming back from the top of the canes. Plants grown with Osmocote Exact Standard and Multicote 12 produced the greatest weight of trimmings whereas plants grown with Ficote 180 TE produced the least weight of trimmings.

It can be seen from the trimming weights that the different CRFs stimulated different growth patterns. Osmocote Exact Hi-Start, Polyon and Multicote 12 had the most growth at the first trimming, but by the final trimming these three products had been overtaken by CRFs that had initially supported little growth e.g. Osmocote Plus, Osmocote Exact Standard and Vitacote (Figure 12a - d).

Total biomass of plants showed significant differences by spring, with plants grown with Osmocote Exact Standard, Vitacote and Multicote 8 having the greatest biomass and Ficote 180 TE, Plantacote pluss and Sincrocell 12 the least.

Summary

- With the short term autumn potted crops, all CRFs produced satisfactory results, with only small differences between them.

- As with other trials there were indications of improved flowering with Ficote 180 TE, Multicote 8, Vitacote and Sincrocell 12 (Lavender).

- More work is required to see whether the discolouring of the foliage on the *Hebe* was due to slower release of nutrients and subsequent re-distribution within the plants or other factors such as susceptibility to disease.

fig 11

fig 12

Discussion of CRF comparison trials

Before any discussion is made of the results it must be emphasised that the trials described in this study compared commercially available 12-14 month CRFs at ***manufacturer's recommended rates***. Differences between CRF treatments could be due to different rates of incorporation and/or different NPK analyses and/or different rates of release. This project is unable to establish the relative contribution of these three reasons towards the species responses. However, some indications can be drawn from the data and where possible these will be highlighted in this section.

These data are collected from one growing season only, which was relatively cool and wet. As such the conclusions may not apply to a hot and dry year, and must be viewed accordingly.

How do CRFs work?

Each CRF granule is coated with a layer of resin (e.g. Osmocote and Multicote) or polyurethane polymer (Polyon, Plantacote pluss, Sincrocell) or polyolefin polymer (Ficote 180 TE) (Rainbow, 1999). Water penetrates the granule and the nutrients dissolve, setting up a strong diffusion gradient over the resin layer. These nutrients then diffuse into the surrounding medium. The rate at which nutrients diffuse from the granule is limited by a) the thickness of the coating and b) temperature. Manufacturers can modify release rates through the thickness of the coating or the number of micropores in the membrane. At a higher temperature, nutrients diffuse faster from the granule, resulting in a shorter longevity period. The opposite is true at lower temperatures. Consequently, nutrient availability to the plant is mediated by the interaction of two factors: temperature and moisture (irrigation / rain).

CRFs may differ in their longevity, but also in their analysis (N:P:K). In addition to this the salts in the CRF are released at different rates relative to each other. The most soluble salts such as KNO_3 are released first, which is shown in the analyses from the residuals (Appendix B, Table 1 & 2). As a consequence analysis changes over time and plant responses may differ over time with the same CRF. The original salts used in the core granule differs between products; these salts also differ in their solubility which leads to differential release rates of individual elements over time (e.g. the phosphate source in Ficote 180 TE compared to Osmocote Plus).

Influence of geographical location.

The most immediate observation was that *Chamaecyparis,* and *Viburnum* plants grown at the Northern site were significantly smaller in biomass and size than those grown on the Southern site. In contrast, the final biomass of *Cotoneaster* was higher at the Northern site than the Southern site. This is an interesting response and compares to the results of HNS 43c, where Weigela was shown to be larger at the Northern site than the Southern site. It was not possible in this study to establish the reason for this response. The general response, with plants in the North producing less biomass than in the South, can be accounted for by the interaction of a number of factors: potting date, temperature and the release of nutrients from the CRFs. Plants were potted up in May at both sites, which was an acceptable potting date for the South, as the results/photographs show, but rather late in the North due to the shorter growing season.

Over the duration of the experiment, the average daily temperature at Johnson's of Whixley was 1.2 °C lower than HRI-Efford; and the average daily temperature was higher at Johnson's of Whixley in only 5 out of the 45 weeks that the experiment was concurrent on the two sites. This temperature difference affected the release rate of nutrients from the CRF granules. For each CRF the amount of nutrients (N, P and K) remaining in the granules at the end of the trial was significantly less at HRI-Efford than Johnson's of Whixley.

Differences between treatments were insignificant with C*hamaecyparis*. However, in general, with the other species studied, the same CRFs produced the greatest growth responses at HRI-Efford as Johnson's of Whixley, showing that the CRFs were behaving in a similar manner relative to each other albeit at lower release rates overall. This was most markedly shown with the trimming weight of *Weigela* which showed that although plant growth was reduced at the Northern site, the pattern of plant growth response among CRFs was the same.

Influence of growing regime

As different species were studied in each of the three growing regimes, direct comparison between species and their response to CRF treatments cannot be drawn. Nevertheless, the species that were potted in autumn, and grown on under glass, showed limited differences between CRF treatments, and all except *Lavandula* were of satisfactory quality. It would appear that with the shorter growing season, and at times relatively warm conditions, the CRFs were all releasing sufficient nutrients, and any differences in the release patterns were too small to markedly affect plant growth to the extent observed in the spring potted crops.

Influence of CRF

Size / weight

Some species produced similar quality plants with all CRFs eg *Euonymous, Cistus, Lavatera, Hebe, Solanum* and *Cotoneaster*, and in these species the choice of CRF would appear to be of less importance.

Not all CRFs have the same release pattern over a growing season and one manufacturer has produced CRFs with differing release profiles e.g. Osmocote Exact series. The inclusion of all three of the Osmocote Exact series allowed closer study of plant response to release rates. Only a few species showed significant differences in growth patterns: *Ceanothus* and *Cytisus* produced more growth with the early releasing Hi-Start (Hi-Start > Standard > Lo-Start). The same was seen in the weight of trimmings from *Weigela*. In contrast, *Photinia* produced the most growth prior to pruning with Lo-Start (Lo-Start > Standard = Hi-Start), although no significant difference was apparent after pruning. The sequential trimming from *Solanum* demonstrated the different times of release for Osmocote Exact Hi-start and Standard. Growth was initially greatest with the early releasing Hi-Start. Then as the season progressed the Standard started to produce greater growth. However, *Solanum* was grown as a short-term crop, under glass, and the trial ended before Lo-Start had time to start stimulating greater than average growth.

General trends are difficult to extract from the data due to the confounding of rates and species requirements but overall Osmocote Plus, Osmocote Exact Hi-Start and Multicote 12 produced large plants with the majority of species, notably *Viburnum, Weigela, Cytisus* and *Pieris*. It was also clear that Ficote 180 TE, Vitacote and Polyon generally produced smaller plants although some species produced greater than average growth with these CRFs (Ficote 180 TE – *Photinia* and *Jasminum*; Vitacote – *Pieris* and *Cytisus*; Polyon – *Chamaecyparis* and *Photinia*).

It would appear that Ficote 180 TE and Polyon were both releasing less nutrients than the other CRFs in the trial. It is known that Ficote 180 TE initially releases slowly (HNS 43b) and it is recommended by the supplier (Scotts/Levington) that single superphosphate (750 g/m^3) is incorporated at potting. In previous trials at HRI-Efford the nutrient release from Ficote 180 TE has been adequate without additional single superphosphate, and this wasn't added in the spring potted species. When added for the autumn potted species grown under protection, Ficote 180 TE, although relatively better, still produced significantly smaller plants with some species. The residual analyses clearly showed that in the cold growing year 1998/99 Ficote 180 TE released a lower proportion of the N, P and K originally in the granule than all the other CRFs. This lower release rate of *all* nutrients explains the smaller plants. However, it must be noted that the plants were still of saleable quality, and in some cases the more compact habit could be deemed preferential.

The Polyon studied here was a CRF used in North America, with a coating that released nutrients at temperatures > 12°C. Following results in the UK the coating has been altered to maintain nutrient release at lower temperatures, and it is these CRFs that are now on the market, and which require further comparative trialling.

Sincrocell 12 and Plantacote pluss gave acceptable results with all species. At the rates studied both CRFs generally produced slightly less growth than Osmocote Plus, Osmocote Exact Hi-Start and Multicote 12 throughout the growing season, and there was indications that the lighter foliage colour seen in *Choisya* grown with Plantacote pluss under protection may have been the result of less nutrients being available by the end of the trial, although this contrasts with the darker foliage colour observed with *Jasminum* grown with Plantacote pluss.

Early outdoor growth at Johnson's of Whixley benefited from the addition of Sincrostart to Sincrocell with *Viburnum* and *Weigela*. However, the late potting will have reduced the necessity for a soluble base fertiliser and high rainfall early on may have washed out some of the soluble fertiliser before it was utilised by the plants, limiting its effectiveness. Further work is needed to establish the role of soluble base fertiliser in stimulating early growth prior to nutrient supply being sufficient from the CRFs, especially in a cool spring.

Overall, Multicote 8 produced quality plants with most species, although with the spring potted *Ceanothus, Choisya, Jasminum,* and *Photinia* grown under protection, there were indications that the longevity was inadequate, compared to Multicote 12, and that nutrient reserves were exhausting by the end of the trial.

Flowering

In a number of species, CRF treatment influenced the amount of flowers (*Viburnum, Weigela* and *Lavandula*) and the timing of flowering (*Ceanothus* and *Cytisus*). These effects are summarised in Table 7.

Table7. CRF treatments that influenced flowering

	Osmocote Plus	Exact Hi-Start	Exact Standard	Exact Lo-Start	Ficote 180 TE	Vitacote	Polyon	Sincrocell 12 & Sincrostart	Sincrocell 12	Plantacote pluss	Multicote 8	Multicote 12
Lavandula angustifolia 'Hidcote'					□	□			□		□	
Viburnum tinus 'Eve Price'	□		□								□	□
Weigela 'Red Prince'					□							□
Ceanothus impressus 'Puget Blue'.				□	□					□		□
Cytisus x praecox				□	□		□					

Two groups of CRFs are involved: those associated with larger plants (e.g. Osmocote Plus, Multicote 8 and 12) and those associated with smaller plants (e.g. Exact Lo-Start, Ficote 180 TE, Polyon). It can be assumed that the response was due to differences in mineral nutrient supply among CRF treatments, as all other factors were constant. However, there are a number of possible explanations, as flowering can be affected by:

- nutrient deficiency
- salt stress (supra-optimal nutrient levels)
- optimal nutrient levels

Additionally, the timing of the 'influence' is important as flowering is the result of an interaction between flower initiation and flower expression; processes which are open to manipulation at specific times.

Correlations were calculated between flowering and nutrient measurements in the CRF granules and the foliage for the three species with the most significant flowering responses, namely *Viburnum tinus* and *Ceanothus* at HRI-Efford and *Weigela* at Johnson's of Whixley.

No significant correlations were observed between flowering and any variable for *Ceanothus*. In *Weigela* flowering was correlated negatively ($p<0.01$) with the amount of P and K in the CRF granule at time of potting and positively ($p<0.01$) correlated with the proportion of P remaining in the CRF granule by the end of the experiment (Figure 13a); i.e. flowering should be highest with those CRFs with a low initial P and K content, and which released the lowest proportion of P over the growth of the crop. It must be noted, however, that the spread of flowering across treatments, although significant, was small. Consequently small differences may have had a disproportionate influence on the correlations. Additionally, no correlations were observed between levels of nutrients in the CRFs at any time and levels in the foliage.

Flowering in *Viburnum tinus* was positively associated ($p<0.01$) with the ratio of P:K in the CRF at potting and negatively associated ($p<0.01$) with the proportion of N remaining in the CRF granule by the end of the experiment (Figure 13b); i.e. flowering should be greatest with those CRFs with a high initial P:K ratio and which release the most N over the course of the growing season. With *Viburnum tinus* a broader range of flowering response was observed, allowing greater weight to be attached to the correlations. Further work is needed to examine this response more closely.

Figure 13 & 14

Conclusion

- Overall, the results showed that at manufacturer's recommended rates all commercially available CRFs were capable of producing quality plants.

- Subtle differences were apparent between CRFs for different species, showing that specialist growers may benefit from a 'horses for courses' approach.

- It is not necessarily true that the best plants were those that were the largest, and in some cases it was apparent that growth was excessive and rates could probably be reduced e.g. *Lavandula* and *Choisya*.

- Further work is needed to study rates of CRF.

- The CRFs performed in a similar manner, relative to each other, at both the Northern and Southern sites, but plant growth was less at the Northern site.

- The CRFs at the Northern site released a lower proportion of their initial nutrients content showing that in order to supply the same level of nutrients to the plants, CRFs need to be incorporated at higher rates.

- As season has a potentially large effect on the release rates of CRF any further study on CRF rates needs to be carried out over *at least* two seasons.

- The flowering response created considerable interest and needs further work to examine responses more clearly, indeed to see if the results can be repeated.

Part 2

Zeolite Experiments

Part 2 Zeolite experiments

Zeolite is a natural alumino-silicate mineral with a skeletal structure containing voids occupied by various ions, and also molecules of water. These have considerable freedom of movement that lead to properties of both cation-exchange and reversible dehydration. The open framework provides zeolite with a large surface area, in some species >400 m^2 g^{-1}. The zeolite unit carries a negative electrical charge which is balanced by positively charged cations which are loosely held within the open framework. This electrical charge combined with the large surface area, gives zeolite a highly efficient cation exchange capacity.

Zeolite is a term that covers around 50 minerals species that differ in both structure and physical properties, and consequently cation exchange capacity. Clinoptilolite is one of the most prevalent and hence commercially utilised zeolite species. As such it has been studied widely, especially in the former Soviet Union where large deposits are located. It is clinoptilolite zeolite that is studied in the experiments described here.

There are two main potential uses of zeolite in nursery stock production:

- incorporated as a nutrient ***loaded*** zeolite (Ferticult) to supply nutrients to the plant (Experiment 1)

- incorporated as ***unloaded*** zeolite to retain soluble salts and reduce nutrient leaching (Experiment 2)

Experiment 1 Ferticult as a replacement for CRF

Introduction

It is possible to ‘load’ zeolite with the full range of nutrients required for plant growth (Challinor, le Pivert and Fuller 1994), theoretically allowing zeolite to be used as a direct replacement for conventional CRFs. Commercial products are becoming available on the UK market (e.g. Ferticult) and have been used for a number of years in Eastern Europe, where mineral deposits are found.

Following incorporation into growing medium, the release of nutrients is controlled along diffusion gradients (Allen, Ming, Hossner and Henninger, 1995). Hence, nutrients are released into the media when the levels of nutrients drop, either through root uptake or washing out, which gives rise to two potential benefits compared to CRFs:

- no risk of ‘flash-release’ of nutrients in an unusually warm spring, and

- minimal run-off of excess nutrients.

Work has been successfully carried out using zeolite in hydroponic systems (Challinor *et al*, 1994), but, as yet there has been no work looking at ‘loaded’ Zeolite in large scale containerised systems.

The objective of this experiment was to study the potential of a loaded zeolite (Ferticult) to provide plant nutrient requirements over a growing season in a number of environments.

Materials and Methods

The ferticult was incorporated at two rates: 5% and 10% v/v. and these rates were included as two additional treatments in all three CRF comparison trials. The experimental set-up and conditions were as described in Part 1 (see page 9). The plants were grown in a commercial system in the following environments:

- spring potted – outdoors (HRI-Efford and Johnson’s of Whixley)
- spring potted – protected (HRI-Efford)
- autumn potted – protected(HRI-Efford)

The plant growth and quality was compared at 5% and 10% Ferticult incorporation and Osmocote Plus 12-14 Spring at manufacturer’s recommended rate for each species (rates are shown in Table 1,5 and 6). Osmocote Plus represented the industry standard.

All growth scores and measurements of the Ferticult treatments were taken in the same manner and at the same time as those reported in Part 1. In addition, foliage nutrient analysis was undertaken for *Viburnum tinus* and *Ceanothus* (HRI-Efford) and *Weigela* (Johnson's of Whixley).

Ferticult had an 'analysis' of 18 : 12 : 60 & traces, in contrast to that of Osmocote Plus which was 15 : 9 : 11 & traces. Two points must be considered when comparing the analyses of Ferticult and Osmocote Plus (or any other CRF).

- Ferticult is a loaded zeolite and as such will retain very little (or no) anions such as phosphate, and the source of N will be NH_4-N.

- Chemical extraction of *available nutrients* is very difficult from a mineral with such high cation exchange capacity, and this Figure may be inaccurate.

Results

The plants were grown within the CRF comparison trials and with most species it was immediately obvious which two treatments were those incorporating Ferticult as they were of a poorer quality than plants grown with CRF treatments. The poorer growth was apparent with some species by the autumn assessment but with all species at the end of the experiment.

Differences were observed in species response for size, colour and biomass. Both *Cytisus* and *Photinia* suffered plant losses (Appendix C, Plate 3 & 4), and the plants that survived were small and approximately 25% of the weight of the plant grown with Osmocote Plus (see Table 8a). A few species produced similar biomass with Ferticult as with Osmocote Plus, namely *Cotoneaster* (HRI-Efford and Johnson's of Whixley), *Weigela* (Johnson's of Whixley only), *Pieris*, *Cistus* and *Lavatera*. However, only the *Weigela* grown at Johnson's of Whixley produced plants of *equal quality*, as foliage colour was paler in the other species e.g. *Ceanothus* and *Lavatera* (see Figure 14a & b). Additionally, the plants were in general more stretched and thin than those grown with Osmocote Plus (data not presented).

Table 8. Biomass of plants grown with Osmocote Plus, and Ferticult at 5 and 10 % v/v, spring 1999.

a) Spring potted - outdoor at HRI-Efford.

	Cotoneaster horizontalis	*Cytisus x praecox*	*Photinia x fraseri* 'Red Robin'	*Viburnum tinus* 'Eve Price'
Osmocote Plus (12-14) Spring	a 64.0	c 75.7	b 85.5	b 104.1
Zeolite 5%	a 64.5	b 24.4	a 16.7	a 40.2
Zeolite 10%	a 67.6	a 11.2	a 19.1	a 38.2
Mean	60.0	37.1	40.4	60.8
Significance	<0.001	<0.001	<0.001	<0.001
d.f.	22	21	15	22
SED	5.32	5.20	5.83	9.31

a) Spring potted - outdoor at Johnson's of Whixley.

	Cotoneaster horizontalis	*Viburnum tinus* 'Eve Price'	*Weigela* 'Red Prince'
Osmocote Plus (12-14) Spring	ab 83.4	b 75.4	a 62.2
Zeolite 5%	b 94.6	a 37.6	a 55.4
Zeolite 10%	a 76.9	a 30.6	a 56.2
Mean	84.9	47.9	58.0
Significance	<0.01	<0.001	ns
d.f.	21	22	16
SED	5.46	5.72	3.85

b) Spring potted – under protection at HRI-Efford

	Ceanothus impressus 'Puget blue'	*Choisya ternata* 'Sundance'	*Euonymous fortunei* 'Emerald 'n' Gold'	*Hedera colchica* 'Sulphur Heart'	*Jasminum nudiflorum*	*Pieris* 'Forest Flame'
Osmocote Plus (12-14) Spring	c 117.3	c 91.6	c 92.0	b 65.8	b 28.5	a 77.5
Zeolite 5%	b 95.6	b 66.4	b 78.2	a 33.6	a 11.5	a 64.3
Zeolite 10%	a 74.8	a 53.5	a 54.9	a 30.6	a 10.6	a 63.0
Mean	95.9	70.5	75.0	43.3	16.9	68.2
Significance	<0.001	<0.001	<0.001	<0.001	<0.001	ns
d.f.	22	22	22	22	22	22
SED	6.48	5.38	6.12	4.71	2.52	8.28

c) Autumn potted – under glass at HRI-Efford

	Cistus creticus	*Hebe pinguifolia* 'Pagei'	*Lavandula angustifolia* 'Hidcote'	*Lavatera thuringiaca* 'Rosea'	*Solanum jasmanoides* 'Album'
Osmocote Plus (12-14) Spring	a 33.4	b 45.9	ab 17.2	a 41.3	b 39.9
Zeolite 5%	a 34.2	a 37.1	a 12.8	a 37.6	a 34.7
Zeolite 10%	a 35.7	b 43.7	b 17.8	a 43.4	a 35.3
Mean	34.4	42.2	15.9	40.8	36.7
Significance	ns	<0.01	<0.05	ns	<0.05
d.f.	22	22	22	22	22
SED	1.93	2.58	2.17	4.70	1.89

Values are significantly different if no adjacent letter is common to both values.

fig 14

Foliage analysis

Data was available for three species only: *Viburnum tinus* and *Ceanothus* (HRI-Efford) and *Weigela* (Johnson's of Whixley). These data are presented in Table 9.

Table 9. Foliage analysis, spring 1999:

a) *Ceanothus impressus* 'Puget Blue' – HRI-Efford

	Osmocote Plus		5% Ferticult		10% Ferticult	
	%	g plant $^{-1}$	%	g plant $^{-1}$	%	g plant $^{-1}$
N	1.56	1.8	1.17	1.3	1.38	0.9
P	0.14	0.2	0.18	0.2	0.20	0.1
K	0.89	1.0	0.87	1.0	1.03	0.7

b) *Viburnum tinus* 'Eve Price' – HRI-Efford

	Osmocote Plus		5% Ferticult		10% Ferticult	
	%	g/plant	%	g/plant	%	g/plant
N	2.05	2.1	1.72	0.6	1.58	0.7
P	0.17	0.2	0.22	0.02	0.13	0.1
K	1.20	1.2	1.69	0.3	0.78	0.7

c) *Weigela* 'Red Prince' – Johnson's of Whixley

	Osmocote Plus		5% Ferticult		10% Ferticult	
	%	g/plant	%	g/plant	%	g/plant
N	3.05	1.9	2.66	1.6	2.85	1.5
P	0.31	0.2	0.36	0.2	0.36	0.2
K	1.82	1.1	1.54	0.8	1.48	0.9

The percentage of N in the foliage was lower in plants grown with Ferticult compared to those grown with Osmocote Plus for all three species. Potassium levels varied between treatments, with low values observed in V*iburnum* grown with 10% Ferticult. In contrast, phosphorous levels were similar regardless of treatment.

Discussion

Ferticult is a clinoptilolite zeolite that has been loaded with nutrients. This is achieved by placing the ground zeolite in a sequence of large vats containing nutrient solutions. Cations are retained by the negative charges in the mineral structure (see page 52), and anions which are not involved in cation exchange dry onto the surfaces of the granules. When the Ferticult was incorporated into the growing media, and the plants potted on, the anions which were loosely held would have quickly entered solution. Phosphate as an anion would have been released at high levels in the early stages of the experiment and this may explain the leaf drop and plant deaths observed in *Cytisus* and *Photinia*. This is supported by the fact that Cytisus is capable of acquiring phytotoxic levels of P in its tissues (Scott, 1981), whereas other species appear to limit P uptake (e.g *Juniperus*).

The reasons for the other symptoms: pale foliage, stretched and thin growth may be partly explained by the supply of N and K to the plants. All three species showed a decrease in N concentration in the foliage in plants grown with Ferticult. This could be due to a low total N added with the Ferticult and/or a retention of NH_4-N in the Ferticult. The tall plants observed with Ferticult could be due to a low N:K ratio (1.8, 1.3, 1.3 for Osmocote, 5% and 10% Ferticult respectively in *Ceanothus*). Consecutive foliage analyses were not included in the experiment so the cause can not be unequivocally established.

There are some indications in the data that plants were actually poorer at a rate of 10% compared to 5% incorporation (*Cytisus, Hebe, Lavandula*). With *Cytisus* this can be explained by high levels of P released early on. However with *Hebe* and *Lavandula* the higher rate of Ferticult led to smaller plants. This may be the result of the higher rate presenting a greater ‘sink’ of cations. Ferticult will retain cations regardless of their source and it may be that salts already in the peat were also retained. Alternatively a rapid release of P may have damaged roots and retarded root growth. Root growth was not assessed in this experiment and further work would be necessary to establish the cause of the reduced growth at the higher rate.

Conclusion

- The use of loaded Ferticult produced poorer quality plants than the industry standard CRF, Osmocote Plus.

- Before quality plants can be grown with Ferticult as a major nutrient source two issues need to be addressed: 1) the supply of phosphate is difficult to maintain over time; and 2) there is some indication that the balance of N:K is incorrect.

- Ferticult could yet be involved in plant nutrition as a nutrient buffer and source of cations, in association with other sources of nutrients (e.g. organic matter, rock phosphate).

- Further work is needed to improve the understanding of nutrient release kinetics from Ferticult before further progress can be made in this area.

Experiment 2. A study of zeolite as a means to reduce nutrient leaching from containers.

Introduction

Nutrient leaching from containerised growing medium occurs when the supply of nutrients in solution exceeds plant uptake. This can occur routinely with liquid feed systems, and more sporadically with CRFs. Highest rates of nutrient release would be expected from CRFs when high temperatures coincide with heavy rain fall / irrigation. Pressure is building within the horticulture industry to reduce the amount of nutrients in run-off. As such this experiment was undertaken to study the extent that zeolite could reduce nutrient leaching by adsorbtion onto the mineral. Additionally, the interaction with pH of irrigation water was studied.

The objectives of this experiment were:

- to determine the efficiency of nutrient absorption by zeolite;
- to study factors affecting nutrient absorption by zeolite.

Materials and Methods

Three experimental media were made up in bulk and wetted: 100% peat; 90% peat and 10% zeolite; 75% peat and 25% zeolite. Sub-samples of the experimental media were taken to establish moisture content, pH and EC level. In addition, sub-samples of the constituents were taken for analysis of available and total concentration of macro-nutrients (N, P & K). Soluble granular fertiliser (PG Mix) was incorporated into the experimental media at 1 g/l and 5 g/l but the control treatment received no additional fertiliser (see Table 10). The experiment was carried out using 9 cm pots suspended over 12 cm saucers. The pots were filled with experimental medium and placed in an incubator running at a constant temperature of 20°C. Pots were 'flushed' twice a week with 120 ml of de-ionised water of the designated pH, and the leachate collected. Water pH was adjusted with H_2NO_3 (pH 5) and KOH (pH 9). Leachate was analysed for nutrient analysis (NH_4-N, NO_3-N, P, K) at the start of the experiment, after two weeks and four weeks.

Table 10 Experimental design

Treatment no.	Experimental media Peat:zeolite	Nutrient concentration PG mix incorporated into experimental media (g/l)	pH of water
1	100:0	0	5
2	100:0	0	7
3	100:0	0	9
4	100:0	1	5
5	100:0	1	7
6	100:0	1	9
7	100:0	5	5
8	100:0	5	7
9	100:0	5	9
10	90:10	0	5
11	90:10	0	7
12	90:10	0	9
13	90:10	1	5
14	90:10	1	7
15	90:10	1	9
16	90:10	5	5
17	90:10	5	7
18	90:10	5	9
19	75:25	0	5
20	75:25	0	7
21	75:25	0	9
22	75:25	1	5
23	75:25	1	7
24	75:25	1	9
25	75:25	5	5
26	75:25	5	7
27	75:25	5	9

Results

The pH of irrigation water had no consistent effect on the concentration of K, P or NH_4 in the leachate. The level of NO_3 in the leachate was significantly higher with the treatments irrigated with water of pH 5 at all three nutrient levels. Consequently the pH data was pooled.

The treatments with no added soluble fertiliser produced leachates with similar concentrations of nutrients at each sampling date. The addition of PG mix to the experimental media increased the concentration of nutrients in the leachate proportionate to the rate of incorporation. This level decreased over the three sampling dates as the soluble fertiliser was washed from the experimental media.

NO_3-N and P showed no differences in the leachate concentration with proportion of zeolite in the experimental medium, whereas NH_4-N and K showed clear reduction in leachate concentration, with the addition of zeolite to the experimental medium.

NO3-N

At the first sample there was no significant interaction between the rate of incorporation of zeolite and fertiliser (Figure 15 & Table 11). The leachate from the 25% rate of zeolite had a significantly higher concentration of NO3-N in the leachate with fertiliser incorporated at 1 g/l and 5 g/l than the 0 or 10% zeolite treatments.

The second sample showed no interaction between zeolite and fertiliser incorporation. Differences in the NO3-N concentration in the leachate were observed for the treatments with no added fertiliser, with the leachate from the 25% rate of zeolite had the highest values.

By the third sample there was a significant interaction between zeolite and nutrient rate. There were no significant differences within nutrient rates but values overlapped between nutrient rates, in contrast to the previous two samples.

NH4-N

There was a highly significant ($p<0.001$) interaction between zeolite and nutrients with sample one (Figure 16 & Table 12). Where no nutrients had been added the values were the same. The addition of 1 g/l fertiliser gave the highest concentration in the leachate from the medium containing no zeolite, with the concentration significantly reduced with the 10% zeolite rate, and at the 25% rate of zeolite the leachate concentration was significantly lower than either the 0% or 10% rate. The same pattern was repeated at the 5 g/l rate of fertiliser.

The treatments produced similar results in the second sample although the values were slightly smaller reflecting the leaching out of the experimental media. One exception was the concentration in the leachate from the 5 g/l rate of fertiliser incorporation with no zeolite, which was higher than sample one.

The third sample showed no significant interaction between zeolite and nutrient rate. No differences were observed in the values from the treatments with no fertiliser added. The leachate concentrations were significantly lower at the 25% zeolite rate at both 1 g/l and 5 g/l of fertiliser addition.

P

The interaction between nutrient rate and zeolite was not significant at the first sample date (Figure 17 & Table 13). The level of P in the leachate was significantly higher from the 25% zeolite rate with the no added nutrient treatment.

A significant interaction ($p<0.01$) between nutrient rate and zeolite was observed in the second sample. The level of P in the leachate was significantly higher with the 25% zeolite treatment when no nutrients were added. However, when nutrients were added the highest level of P was observed in the leachate from the treatments that had no zeolite in the medium.

By the third sample the interaction between nutrient rate and zeolite was non significant and no differences were observed with zeolite within nutrient rates.

K

Significant interactions ($p<0.001$) were observed between nutrient rate and zeolite at all three samples (Figure 18 & Table 14).

The concentration of K in the leachate collected from the treatments that received no added nutrients increased with the proportion of zeolite in the experimental medium. This trend was reversed in the treatments with added nutrients, where there was a significant reduction in the concentration of K associated with the incorporation of zeolite, and at the highest rate of nutrient addition there was a significant reduction in the concentration of K in the leachate at 25% compared to 10% zeolite.

The second and third samples produced similar results although there was a marked reduction in K concentration at the high nutrient rate with 100% peat. The incorporation of zeolite was associated with significantly high levels of K in the leachate from the treatments that received no added nutrients. Significant differences were again observed following the addition of nutrients with a significant reduction in the concentration of K associated with the proportion of zeolite incorporated in the medium.

Table 11. Concentration of NO_3-N in the leachate from experimental media containing 3 levels of zeolite. The left hand column contains the log_{10} values used in the statistical analysis; the right hand columns the anti-logged values in bold (mg/l).

Proportion of zeolite in experimental mix (%)	*Sample number* 1		2		3	
			Water			
0	a 3.703	**40.6**	ab 3.584	**36.0**	ab 3.310	**27.4**
10	a 3.576	**35.7**	b 3.653	**38.6**	ab 3.294	**27.0**
25	a 3.833	**46.2**	a 3.484	**32.6**	a 2.934	**18.8**
			1 g/l PG mix			
0	b 5.150	**172.4**	c 5.022	**151.7**	bc 3.695	**40.2**
10	b 5.264	**193.3**	c 5.045	**155.2**	b 3.803	**44.8**
25	c 5.568	**261.9**	c 5.043	**154.9**	c 3.679	**39.6**
			5 g/l PG mix			
0	d 6.682	**797.9**	d 6.353	**574.2**	e 4.536	**93.3**
10	d 6.762	**864.4**	d 6.294	**541.3**	de 4.228	**68.6**
25	e 7.183	**1316.9**	d 6.260	**523.2**	cde 4.072	**58.7**
SED	0.1379		0.0663		0.2702	
df	50		52		49	
Zeolite x Nutrient	ns		ns		<0.05	

fig 15

Table 12. Concentration of NH_4-N in the leachate from experimental media containing 3 levels of zeolite. The left hand column contains the log_{10} values used in the statistical analysis; the right hand columns the anti-logged values in bold (mg/l).

Proportion of zeolite in experimental mix (%)	*Sample number*					
	1		2		3	
			Water			
0	a 0.212	**1.3**	a 0.029	**1.0**	a 0.675	**2.0**
10	a 0.074	**1.1**	a 0.141	**1.2**	a 0.618	**1.9**
25	a 0.323	**1.4**	a 0.00	**1.0**	a 0.516	**1.7**
			1 g/l PG mix			
0	d 5.415	**224.8**	e 5.096	**163.4**	c 3.274	**26.4**
10	c 2.697	**14.8**	c 3.291	**26.9**	b 2.686	**14.7**
25	b 1.969	**7.2**	b 2.536	**12.6**	b 2.334	**10.3**
			5 g/l PG mix			
0	f 6.71	**820.6**	g 6.767	**868.7**	e 4.74	**114.4**
10	e 6.01	**407.5**	f 5.757	**316.4**	e 4.54	**93.7**
25	d 5.189	**179.3**	d 4.762	**1170**	d 3.971	**53.0**
SED	0.1536		0.1439		0.2702	
df	48		51		50	
Zeolite x Nutrient	<0.001		<0.001		ns	

fig 16

Table 13. Concentration of P in the leachate from experimental media containing 3 levels of zeolite. The left hand column contains the log_{10} values used in the statistical analysis; the right hand columns the anti-logged values in bold (mg/l).

Proportion of zeolite in experimental mix (%)	*Sample number*					
	1		2		3	
			Water			
0	a 1.199	**3.3**	a 0.664	**1.9**	a 0.782	**2.2**
10	a 1.162	**3.2**	a 0.817	**2.3**	a 0.744	**2.1**
25	b 1.862	**6.4**	b 1.057	**2.9**	a 0.707	**2.0**
			1 g/l PG mix			
0	c 5.426	**227.2**	d 5.065	**158.4**	b 3.210	**24.8**
10	c 5.507	**246.4**	cd 5.004	**149**	b 3.585	**36.1**
25	c 5.516	**248.6**	c 4.833	**125.6**	b 3.196	**24.4**
			5 g/l PG mix			
0	d 7.001	**1097.7**	f 6.626	**754.5**	c 4.718	**111.9**
10	d 7.041	**1142.5**	e 6.432	**621.4**	c 4.828	**125**
25	d 7.366	**1581.3**	e 6.256	**521.1**	c 4.758	**116.5**
SED	0.2282		0.0927		0.2294	
df	49		50		52	
Zeolite x Nutrient	ns		<0.01		ns	

fig 17

Table 14. Concentration of K in the leachate from experimental media containing 3 levels of zeolite. The left hand column contains the log_{10} values used in the statistical analysis; the right hand columns the anti-logged values in bold (mg/l).

Proportion of zeolite in experimental mix (%)	***Sample number*** 1		2		3	
			Water			
0	a 1.702	**5.5**	a 0.980	**2.6**	a 1.571	**4.8**
10	b 2.403	**11.1**	b 2.338	**10.4**	b 2.322	**10.2**
25	c 2.717	**15.1**	b 2.300	**10.0**	b 2.143	**8.5**
			1 g/l PG mix			
0	e 5.861	**351.1**	e 5.552	**257.8**	e 4.086	**59.5**
10	d 4.150	**63.4**	d 4.077	**59.0**	d 3.283	**26.7**
25	d 4.069	**58.5**	c 3.766	**43.2**	c 2.967	**19.4**
			5 g/l PG mix			
0	g 7.637	**2073.5**	g 7.474	**1761.6**	h 5.418	**225.4**
10	f 6.644	**768.2**	f 6.329	**560.6**	g 4.92	**137**
25	e 5.937	**378.8**	e 5.414	**224.5**	f 4.565	**96.1**
SED	0.1035		0.0628		0.1234	
df	50		52		52	
Zeolite x Nutrient	<0.001		<0.001		<0.001	

fig 18

Discussion

The most marked observation from this experiment was that zeolite appeared to have little or no effect on the rate of leaching of NO_3-N or P and a clear effect on the rate of leaching of NH_4-N and K. This can be explained by the cation exchange capacity of zeolite as nitrate and phosphorous are both anionic in solution and ammonia and potassium are both cationic. Consequently, NO_3-N or P were unaffected by the nutrient retaining mechanisms in zeolite. However, the physical properties of zeolite e.g. effects on air filled porosity (AFP) and hence increased drainage would still have an effect and can explain the lower concentration of P in the leachate at sample 2. The effect of zeolite incorporation on NO_3-N leaching is a rather more complex one as there is an interaction with NH_4-N. Nitrifying bacteria in the moist and relatively warm experimental medium would have been converting NH_4-N to NO_3-N. Zeolite has a high affinity for NH_4^+ ions and the ability to hold NH_4-N internally, where it is physically protected from nitrifying bacteria (Ferguson, 1984). This would predict that nitrification rates are slowed in the presence of zeolite reducing the 'pool' of NO_3-N available to be leached. This effect was not observed in this experiment. In contrast, the levels of nitrate in sample 1 were highest with the highest rate of zeolite, significantly so when fertiliser had been added to the experimental medium. It may be that the physical properties had a greater effect than the de-nitrifying effect. Further work would be necessary to establish the relative contributions of these mechanisms.

The cations NH_4^+ and K^+ were both rapidly retained by the zeolite. With available levels of ~ 250 ppm NH_4-N and 400 ppm K, zeolite incorporated at a rate of 10% maintained similar levels of concentration in the leachate as a rate of 25%, showing that no more than 10% incorporation would be necessary at these levels of run-off. At the higher rate of ~ 1000 ppm NH_4-N and 2000 ppm K zeolite incorporated at a rate of 10% was no longer sufficient and the leachate concentration was initially higher. Hence, in situations where high EC solutions were leaching from pots, rates as high as 25% incorporation would be necessary to limit run-off of nutrients. Over the time course of this experiment it was not possible to study the re-release of nutrients that had been initially retained by the zeolite. This could have an important role in efficiency of nutrient supply to container grown crops and in part is examined in the previous experiment.

Conclusion

- Zeolite has the ability to markedly reduce the loss of cations such as ammonia – N and potassium, but loss of anions such as nitrate and phosphate (the two main pollutants of waterways) are uncontrolled.

- This limits the effectiveness of this approach as a means to reduce nutrient leaching *on its own*.

- The use of zeolites *as a component* of a larger leachate controlling strategy may have benefits for the horticulture industry as a whole.

References

Allen ER, Ming DW, Hossner LR and Henninger DL, (1995) Modelling transport kinetics in clinoptilolite-phosphate rock systems. *Soil Science Society of America Journal* **59:1** pp 248-55

Challinor PF, le Pivert JM and Fuller MP (1994) The production of standard carnations on nutrient loaded zeolite. *Acta Horticulturae* **401** pp 293-99

Rainbow, A (1999) Speciality mineral and organo-mineral fertilisers – products and markets. *Proceedings of the International Fertiliser Society. No.* **432**, York, UK

Scott MA (1981) The role of phosphate in the production of quality container grown nursery stock. *MAFF Leaflet number 2*.

HDC reports quoted:

HNS 43. Container grown nursery stock: Investigation of use of controlled release fertilizers under protection. Final report 1991-1993. (Scott MA, and Davies EM, 1994)

HNS 43a. An investigation into the use of controlled release fertilizers for spring potting of container nursery stock grown outdoors. Final report 1994-1996. (Scott MA, Davies EM, and Girard 1997)

HNS 43b. To evaluate the use of computer simulation models for advice on the availability of nutrients from controlled release fertilisers. Final report 1994-1997. (Burns I, 1998)

Appendices

A – Part 1. Data and photographic plates

Plate 1. *Chamaecyparis lawsoniana* 'Ellwoodii' exhibiting symptoms of tip scorch, HRI-Efford. Treatment -Ficote 180 TE. Photograph taken 10/7/98.

Appendix A

Plate 2. *Viburnum tinus* 'Eve Price' showing the marked difference in flowering with CRF treatment, HRI-Efford. Left – Osmocote Plus, Right – Multicote 12. Photograph taken 30/10/98.

Appendix A

Spring potted - outdoor at HRI-Efford.

Table A-1 ***Chamaecyparis lawsoniana*** **'Ellwoodii'**

	Autumn 98		Spring 99	
	Plant height increase (cm)	Foliage scorch*	Plant height increase (cm)	Foliage scorch*
Osmocote Plus 12-14 Spring	17.1	1.2	8.5	1.0
Osmocote Exact Hi-Start 12-14	18.1	1.3	5.9	2.3
Osmocote Exact Standard 12-14	18.8	2.3	5.4	2.4
Osmocote Exact Lo-Start 12-14	21.4	1.8	4.6	1.1
Ficote 180 TE	15.6	2.3	4.7	2.4
Vitacote	18.9	1.4	6.6	1.0
Polyon	22.9	1.1	5.9	1.0
Sincrocell 12 & Sincrostart	17.5	1.6	6.2	1.2
Sincrocell 12	16.7	2.4	6.4	2.6
Plantacote pluss 12M	18.4	1.2	8.2	0.9
Multicote 8	18.4	1.6	8.2	1.0
Multicote 12	23.7	1.5	5.1	1.1
Mean	18.9	1.6	6.3	1.5
Significance	<0.01	<0.01	<0.01	<0.01
d.f.	202	202	202	202
SED	0.63	0.28	1.45	0.37

* 5 = greatest, largest, darkest; 0 = least, smallest, lightest

Table A-2 ***Cotoneaster horizontalis***

	Autumn 98	Spring 99	
	Size score *	Size score *	Biomass (g)
Osmocote Plus 12-14 Spring	3.0	2.8	67.6
Osmocote Exact Hi-Start 12-14	3.5	3.1	80.1
Osmocote Exact Standard 12-14	3.9	3.1	68.1
Osmocote Exact Lo-Start 12-14	3.2	3.7	55.7
Ficote 180 TE	2.9	3.0	62.3
Vitacote	3.5	3.1	59.4
Polyon	3.0	2.8	57.5
Sincrocell 12 & Sincrostart	-	-	-
Sincrocell 12	-	-	-
Plantacote pluss 12M	3.6	3.2	63.1
Multicote 8	3.0	3.1	62.0
Multicote 12	3.5	3.0	77.9
Mean	3.3	3.1	65.4
Significance	ns	ns	<0.01
d.f.	167	167	78
SED	0.24	0.31	6.73

* 5 = greatest, largest, darkest; 0 = least, smallest, lightest

Appendix A

Spring potted - outdoor at HRI-Efford.

Table A-3 *Cytisus x praecox*

	Autumn 98		Spring 99		
	Size score *	Foliage colour score *	Size score *	Flower score *	Biomass (g)
Osmocote Plus 12-14 Spring	3.8	3.4	3.9	1.7	75.7
Osmocote Exact Hi-Start 12-14	3.8	2.8	4.1	0.3	74.3
Osmocote Exact Standard 12-14	3.2	3.4	3.7	0.7	58.3
Osmocote Exact Lo-Start 12-14	2.6	4.2	2.9	2.3	48.0
Ficote 180 TE	1.9	4.8	2.3	2.3	31.4
Vitacote	3.8	2.4	3.5	1.3	71.6
Polyon	2.1	4.9	2.4	3.0	33.6
Sincrocell 12 & Sincrostart	-	-	-	-	-
Sincrocell 12	-	-	-	-	-
Plantacote pluss 12M	3.0	1.6	3.3	1.7	57.3
Multicote 8	2.9	3.9	3.3	1.7	53.8
Multicote 12	3.8	3.0	3.9	1.7	87.5
Mean	3.09	3.4	3.3	1.7	59.1
Significance	<0.01	<0.01	<0.01	ns	<0.01
d.f.	167	167	167	167	78
SED	0.39	0.59	0.38	0.87	8.87

* 5 = greatest, largest, darkest; 0 = least, smallest, lightest

Table A-4 *Photinia x fraseri* 'Red Robin'

	Autumn 98			Spring 99			
	Size score*	Quality score *	Foliage colour score *	Trimming biomass (g/3 plants)	Size score *	Foliage colour score *	Biomass (g)
Osmocote Plus 12-14 Spring	3.5	4.6	2.2	181.7	3.7	4.3	85.5
Osmocote Exact Hi-Start 12-14	3.1	4.6	1.9	155.4	3.3	2.6	77.0
Osmocote Exact Standard 12-14	3.1	4.4	1.7	147.9	3.4	3.8	69.1
Osmocote Exact Lo-Start 12-14	3.8	4.6	2.5	171.7	3.4	3.9	77.1
Ficote 180 TE	3.7	3.8	3.7	131.1	3.7	4.7	71.6
Vitacote	3.2	4.4	2.2	180.3	3.7	2.9	75.5
Polyon	3.6	4.0	4.4	103.3	3.6	3.8	67.2
Sincrocell 12 & Sincrostart	-	-	-	-	-	-	-
Sincrocell 12	-	-	-	-	-	-	-
Plantacote pluss 12M	3.1	4.2	2.3	143.4	3.2	2.2	66.5
Multicote 8	3.7	4.2	2.4	153.9	3.3	2.3	66.8
Multicote 12	2.6	3.9	2.1	80.4	3.0	2.5	78.2
Mean	3.3	4.3	2.6	144.9	3.4	3.3	73.5
Significance	<0.01	0.10	<0.01	<0.01	ns	<0.01	ns
d.f.	167	167	167	18	167	167	78
SED	0.21	0.33	0.28	15.01	0.24	0.37	5.99

* 5 = greatest, largest, darkest; 0 = least, smallest, lightest

Appendix A

Spring potted - outdoor at HRI-Efford.

Table A-5 *Viburnum tinus* 'Eve Price'

	Autumn 98		Spring 99	
	Size score *	Flowering score	Size score *	Biomass (g)
Osmocote Plus 12-14 Spring	4.2	5.0	4.2	104.1
Osmocote Exact Hi-Start 12-14	3.9	2.3	4.2	81.1
Osmocote Exact Standard 12-14	3.9	4.3	3.7	94.2
Osmocote Exact Lo-Start 12-14	3.6	2.3	3.9	98.7
Ficote 180 TE	2.0	1.3	2.8	72.4
Vitacote	2.3	0.6	2.5	50.0
Polyon	2.2	0.0	2.3	61.4
Sincrocell 12 & Sincrostart	2.9	0.0	2.8	62.0
Sincrocell 12	2.9	0.0	3.2	74.3
Plantacote pluss 12M	3.1	0.3	3.2	68.4
Multicote 8	3.6	3.7	3.9	86.0
Multicote 12	4.0	4.3	3.2	72.5
Mean	3.2	2.0	3.3	77.1
Significance	<0.01	<0.01	<0.01	<0.01
d.f.	202	202	202	94
SED	0.22	0.42	0.25	10.60

* 5 = greatest, largest, darkest; 0 = least, smallest, lightest

Table A-6 *Weigela* 'Red Prince'

	Autumn 98	
	Size score*	Trimming biomass (g/3 plants)
Osmocote Plus 12-14 Spring	4.2	59.9
Osmocote Exact Hi-Start 12-14	4.2	62.8
Osmocote Exact Standard 12-14	3.7	44.6
Osmocote Exact Lo-Start 12-14	3.9	38.3
Ficote 180 TE	2.8	27.5
Vitacote	2.5	62.9
Polyon	2.3	29.8
Sincrocell 12 & Sincrostart	2.8	59.7
Sincrocell 12	3.2	51.1
Plantacote pluss 12M	3.2	69.1
Multicote 8	3.9	34.7
Multicote 12	3.2	69.8
Mean	3.3	50.9
Significance	<0.01	<0.01
d.f.	202	22
SED	0.25	8.82

* 5 = greatest, largest, darkest; 0 = least, smallest, lightest

Spring potted - outdoor at Johnson's of Whixley

Table A-7 ***Chamaecyparis lawsoniana*** **'Ellwoodii'**

	Autumn 98		Spring 99	
	Plant height increase (cm)	Foliage scorch*	Plant height increase (cm)	Foliage scorch*
Osmocote Plus 12-14 Spring	15.4	1.2	3.4	1.1
Osmocote Exact Hi-Start 12-14	16.2	1.3	3.2	1.3
Osmocote Exact Standard 12-14	14.4	1.3	4.1	1.4
Osmocote Exact Lo-Start 12-14	14.8	1.9	4.2	1.8
Ficote 180 TE	15.3	2.3	3.9	1.6
Vitacote	15.0	1.4	3.6	0.9
Polyon	16.6	1.1	2.5	0.8
Sincrocell 12 & Sincrostart	16.8	2.2	2.3	1.4
Sincrocell 12	17.1	1.6	2.6	1.6
Plantacote pluss 12M	14.5	1.9	3.0	1.3
Multicote 8	14.0	1.6	5.3	1.5
Multicote 12	15.2	1.5	3.6	1.6
Mean	15.5	1.6	3.4	1.4
Significance	0.99	<0.01	ns	0.02
d.f.	202	202	202	202
SED	0.45	0.29	1.34	0.36

* 5 = greatest, largest, darkest; 0 = least, smallest, lightest

Table A-8 ***Cotoneaster horizontalis***

	Autumn 98	Spring 99	
	Size score *	Size score *	Biomass (g)
Osmocote Plus 12-14 Spring	3.0	2.8	84.5
Osmocote Exact Hi-Start 12-14	3.5	3.1	69.9
Osmocote Exact Standard 12-14	3.9	3.1	82.2
Osmocote Exact Lo-Start 12-14	3.2	3.7	74.6
Ficote 180 TE	2.9	3.0	62.6
Vitacote	3.5	3.1	68.7
Polyon	3.0	2.8	67.9
Sincrocell 12 & Sincrostart	-	-	-
Sincrocell 12	-	-	-
Plantacote pluss 12M	3.6	3.2	78.9
Multicote 8	3.0	3.1	71.1
Multicote 12	3.5	3.0	102.6
Mean	3.3	3.1	76.3
Significance	ns	ns	<0.01
d.f.	167	167	78
SED	0.24	0.31	8.05

* 5 = greatest, largest, darkest; 0 = least, smallest, lightest

Appendix A

Spring potted - outdoor at Johnson's of Whixley

Table A-9 *Viburnum tinus* 'Eve Price'

	Autumn 98	Spring 99	
	Size score *	Size score *	Biomass (g)
Osmocote Plus 12-14 Spring	2.6	3.5	75.4
Osmocote Exact Hi-Start 12-14	2.7	3.2	76.4
Osmocote Exact Standard 12-14	2.4	3.3	76.6
Osmocote Exact Lo-Start 12-14	2.0	3.2	74.7
Ficote 180 TE	1.9	2.6	64.3
Vitacote	2..4	3.4	70.1
Polyon	1.8	2.4	58.4
Sincrocell 12 & Sincrostart	2.7	3.3	75.6
Sincrocell 12	2.1	2.9	66.3
Plantacote pluss 12M	2.2	3.3	66.0
Multicote 8	1.8	2.8	60.2
Multicote 12	2.3	3.3	68.9
Mean	2.2	3.1	69.4
Significance	<0.01	<0.01	<0.01
d.f.	202	202	94
SED	0.21	0.29	5.41

* 5 = greatest, largest, darkest; 0 = least, smallest, lightest

Table A-10 *Weigela* 'Red Prince'

	Autumn 98		
	Size score*	Flower score*	Trimming biomass (g)
Osmocote Plus 12-14 Spring	3.1	2.6	62.2
Osmocote Exact Hi-Start 12-14	3.2	2.4	65.0
Osmocote Exact Standard 12-14	2.3	2.3	60.2
Osmocote Exact Lo-Start 12-14	2.2	2.6	60.6
Ficote 180 TE	0.7	3.3	55.9
Vitacote	1.7	3.0	56.7
Polyon	1.2	2.6	53.6
Sincrocell 12 & Sincrostart	2.8	2.4	60.9
Sincrocell 12	2.7	2.2	57.3
Plantacote pluss 12M	3.1	2.3	60.7
Multicote 8	1.9	2.9	54.4
Multicote 12	3.0	2.4	59.4
Mean	2.3	2.6	58.9
Significance	<0.01	ns	ns
d.f.	202	202	22
SED	0.27	0.46	3.89

* 5 = greatest, largest, darkest; 0 = least, smallest, lightest

Spring potted – under protection at HRI-Efford.

Table A-11 *Ceanothus impressus* 'Puget Blue'

	Autumn 98	Spring 99			
	Size score *	Size score *	Foliage colour*	Flowering score*	Biomass (g)
Osmocote Plus 12-14 Spring	3.2	3.3	3.1	3.4	117.3
Osmocote Exact Hi-Start 12-14	3.8	4.2	3.1	3.9	132.5
Osmocote Exact Standard 12-14	3.2	4.0	3.4	3.8	124.6
Osmocote Exact Lo-Start 12-14	2.7	3.3	3.7	3.9	113.3
Ficote 180 TE	2.4	2.8	5.0	4.7	93.5
Vitacote	3.0	3.3	3.0	3.7	118.3
Polyon	2.8	3.3	3.6	4.4	92.5
Sincrocell 12 & Sincrostart	3.1	3.4	2.3	3.2	125.1
Sincrocell 12	2.3	2.6	3.0	3.7	89.5
Plantacote pluss 12M	2.9	3.1	3.9	4.6	134.0
Multicote 8	3.2	3.5	2.4	2.2	116.0
Multicote 12	3.8	3.9	3.6	4.5	123.8
Mean	3.0	3.4	3.1	3.4	115.0
Significance	<0.01	<0.01	<0.01	<0.01	<0.01
d.f.	202	202	202	202	94
SED	0.27	0.25	0.28	0.29	9.05

* 5 = greatest, largest, darkest; 0 = least, smallest, lightest

Table A-12 *Euonymous fortunei* 'Emerald 'n'Gold'

	Autumn 98	Spring 99	
	Size score *	Size score *	Biomass (g)
Osmocote Plus 12-14 Spring	3.4	4.1	92.0
Osmocote Exact Hi-Start 12-14	3.2	3.8	83.4
Osmocote Exact Standard 12-14	3.7	4.1	84.8
Osmocote Exact Lo-Start 12-14	2.8	3.9	79.7
Ficote 180 TE	3.6	4.2	88.4
Vitacote	3.8	4.2	87.0
Polyon	3.3	3.8	84.8
Sincrocell 12 & Sincrostart	3.8	3.9	88.6
Sincrocell 12	3.6	3.7	80.4
Plantacote pluss 12M	3.2	3.6	68.7
Multicote 8	3.7	3.7	77.8
Multicote 12	3.7	4.0	90.6
Mean	3.5	3.9	83.9
Significance	ns	ns	0.02
d.f.	202	202	94
SED	0.26	0.23	6.98

* 5 = greatest, largest, darkest; 0 = least, smallest, lightest

Spring potted – under protection at HRI-Efford.

Table A-13 *Hedera colchica* 'Sulphur Heart'

	Autumn 98	Spring 99	
	Height (cm)	Height (cm)	Biomass (g)
Osmocote Plus 12-14 Spring	86.6	133.3	65.8
Osmocote Exact Hi-Start 12-14	83.3	139.0	63.6
Osmocote Exact Standard 12-14	91.4	139.0	70.7
Osmocote Exact Lo-Start 12-14	95.3	135.2	74.3
Ficote 180 TE	85.9	134.2	55.3
Vitacote	93.4	136.1	62.7
Polyon	79.6	119.8	40.7
Sincrocell 12 & Sincrostart	98.9	139.1	67.6
Sincrocell 12	84.3	135.1	59.6
Plantacote pluss 12M	94.0	135.2	62.6
Multicote 8	86.3	131.3	54.2
Multicote 12	93.1	138.0	63.0
Mean	89.3	134.6	61.7
Significance	<0.01	<0.01	<0.01
d.f.	202	202	94
SED	4.70	3.42	5.94

* 5 = greatest, largest, darkest; 0 = least, smallest, lightest

Table A-14 *Pieris* 'Forest Flame'

	Autumn 98		Spring 99			
	Size score *	Flowering score*	Size score *	Flowering score*	New growth score*	Biomass (g)
Osmocote Plus 12-14 Spring	3.4	2.6	3.3	3.7	4.1	77.5
Osmocote Exact Hi-Start 12-14	3.2	2.3	3.4	3.0	4.0	73.4
Osmocote Exact Standard 12-14	3.6	3.0	3.2	3.8	3.0	69.5
Osmocote Exact Lo-Start 12-14	3.2	2.4	2.9	4.1	3.4	58.3
Ficote 180 TE	2.9	2.6	3.2	3.4	3.9	68.5
Vitacote	4.1	2.8	3.7	3.6	3.6	80.6
Polyon	2.9	2.7	2.9	3.4	3.7	59.0
Sincrocell 12 & Sincrostart	-	-	-	-	-	-
Sincrocell 12	-	-	-	-	-	-
Plantacote pluss 12M	2.9	2.7	2.9	3.8	3.2	50.3
Multicote 8	3.1	2.8	3.1	4.4	3.4	65.4
Multicote 12	3.3	2.0	4.0	2.2	4.7	77.2
Mean	3.3	2.6	3.3	3.5	3.7	67.9
Significance	0.02	ns	<0.01	<0.01	<0.01	<0.01
d.f.	167	167	167	167	167	78
SED	0.31	0.32	0.27	0.41	0.43	6.68

* 5 = greatest, largest, darkest; 0 = least, smallest, lightest

Spring potted – under protection at HRI-Efford.

Table A-15 *Choisya ternata*

	Autumn 98	Spring 99			
	Size score*	Size score*	Foliage colour score*	Flowering score*	Biomass (g)
Osmocote Plus 12-14 Spring	3.9	3.9	3.4	2.4	91.6
Osmocote Exact Hi-Start 12-14	3.7	3.7	3.7	2.4	99.9
Osmocote Exact Standard 12-14	3.8	3.8	3.3	2.6	93.4
Osmocote Exact Lo-Start 12-14	3.1	3.1	3.4	2.9	74.6
Ficote 180 TE	2.1	2.3	4.1	3.0	71.5
Vitacote	3.8	3.9	2.4	2.2	87.1
Polyon	1.9	2.2	2.9	3.1	64.4
Sincrocell 12 & Sincrostart	-	-	-	-	-
Sincrocell 12	-	-	-	-	-
Plantacote pluss 12M	3.3	3.1	2.5	3.2	70.3
Multicote 8	3.7	3.4	2.5	2.9	87.6
Multicote 12	3.6	3.7	3.7	1.3	90.6
Mean	3.3	3.2	3.1	2.6	83.1
Significance	<0.01	<0.01	<0.01	<0.01	<0.01
d.f.	167	167	167	167	78
SED	0.33	0.25	0.25	0.49	5.09

* 5 = greatest, largest, darkest; 0 = least, smallest, lightest

Table A-16 *Jasminum nudiflorum*

	Autumn 98	Spring 99		
	Height (cm)	Height (cm)	Foliage colour *	Biomass (g)
Osmocote Plus 12-14 Spring	48.0	51.1	4.8	28.5
Osmocote Exact Hi-Start 12-14	47.6	48.2	4.4	21.5
Osmocote Exact Standard 12-14	46.2	52.6	4.8	22.7
Osmocote Exact Lo-Start 12-14	49.1	49.7	4.6	21.8
Ficote 180 TE	49.9	59.1	4.2	30.6
Vitacote	46.6	44.1	1.5	15.2
Polyon	38.9	41.3	1.2	13.7
Sincrocell 12 & Sincrostart	-	-	-	-
Sincrocell 12	-	-	-	-
Plantacote pluss 12M	48.6	47.5	3.7	18.2
Multicote 8	53.8	46.0	1.2	16.2
Multicote 12	44.6	38.8	1.7	13.3
Mean	48.3	47.9	3.2	20.2
Significance	<0.01	<0.01	<0.01	<0.01
d.f.	167	167	167	78
SED	3.84	3.39	0.27	3.25

* 5 = greatest, largest, darkest; 0 = least, smallest, lightest

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Autumn potted – under protection at HRI-Efford.

Table A-17 ***Cistus creticus***

	Spring 99		
	Size score *	Foliage colour*	Biomass (g)
Osmocote Plus 12-14 Spring	2.6	4.3	33.4
Osmocote Exact Hi-Start 12-14	3.1	3.3	34.1
Osmocote Exact Standard 12-14	3.1	4.2	35.2
Osmocote Exact Lo-Start 12-14	2.8	4.0	31.3
Ficote 180 TE	2.7	4.7	31.1
Vitacote	3.1	4.1	35.6
Polyon	2.8	3.3	34.0
Sincrocell 12	3.0	3.6	32.7
Plantacote pluss 12M	2.8	3.6	32.2
Multicote 8	3.2	3.4	38.5
Multicote 12	2.9	4.1	33.2
Mean	2.9	3.9	33.7
Significance	ns	<0.01	0.02
d.f.	185	185	86
SED	0.24	0.29	2.32

* 5 = greatest, largest, darkest; 0 = least, smallest, lightest

Table A-18 ***Hebe pinguifolia*** **'Pagei'**

	Spring 99		
	Size score *	Quality score*	Biomass (g)
Osmocote Plus 12-14 Spring	4.7	4.4	45.9
Osmocote Exact Hi-Start 12-14	4.2	4.6	41.1
Osmocote Exact Standard 12-14	4.3	4.7	49.4
Osmocote Exact Lo-Start 12-14	4.2	4.3	40.3
Ficote 180 TE	3.9	3.9	40.1
Vitacote	4.1	4.9	45.6
Polyon	4.4	4.6	43.0
Sincrocell 12	4.1	4.6	39.9
Plantacote pluss 12M	4.1	3.4	43.2
Multicote 8	4.3	4.8	43.8
Multicote 12	4.2	4.3	40.8
Mean	4.2	4.4	43.0
Significance	ns	<0.01	0.01
d.f.	185	185	86
SED	0.32	0.31	4.87

* 5 = greatest, largest, darkest; 0 = least, smallest, lightest

Autumn potted – under protection at HRI-Efford.

Table A-19 *Lavandula angustifolia* 'Hidcote'

	Spring 99				
	Size score*	Quality score*	Flowering score*	Plant deaths (%)	Biomass (g)
Osmocote Plus 12-14 Spring	3.2	4.4	4.5	22	17.2
Osmocote Exact Hi-Start 12-14	3.2	4.5	4.2	6	17.1
Osmocote Exact Standard 12-14	3.7	4.6	4.3	39	17.4
Osmocote Exact Lo-Start 12-14	3.6	4.4	4.5	6	18.8
Ficote 180 TE	3.1	4.2	3.9	6	17.2
Vitacote	4.1	4.9	4.7	22	19.4
Polyon	3.3	4.6	4.1	17	16.9
Sincrocell 12	3.2	4.9	4.8	0	16.9
Plantacote pluss 12M	3.2	4.6	4.4	0	16.2
Multicote 8	3.7	5.0	5.0	22	18.4
Multicote 12	3.3	4.7	5.0	33	16.3
Mean	3.4	4.4	4.4	15	17.4
Significance	0.02	<0.01	<0.01	0.01	0.4
d.f.	185	185	185	185	86
SED	0.29	0.29	0.38	11.5	1.64

* 5 = greatest, largest, darkest; 0 = least, smallest, lightest

Table A-20 *Lavatera thuringiaca* 'Rosea'

	Spring 99		
	Size score *	Foliage colour*	Biomass (g)
Osmocote Plus 12-14 Spring	2.9	4.8	49.6
Osmocote Exact Hi-Start 12-14	3.7	5.0	50.6
Osmocote Exact Standard 12-14	3.7	4.7	37.6
Osmocote Exact Lo-Start 12-14	3.7	4.6	39.0
Ficote 180 TE	3.6	4.8	43.2
Vitacote	3.3	3.6	39.6
Polyon	3.6	4.3	36.4
Sincrocell 12	3.3	4.4	39.2
Plantacote pluss 12M	3.3	4.4	34.4
Multicote 8	3.0	4.6	34.8
Multicote 12	3.0	3.9	39.9
Mean	3.36	4.5	40.2
Significance	ns	<0.01	<0.01
d.f.	185	185	86
SED	0.37	0.29	4.55

* 5 = greatest, largest, darkest; 0 = least, smallest, lightest

Autumn potted – under protection at HRI-Efford.

Table A-21 ***Solanum jasmanoides* 'Album'**

	Spring 99							
	Size score*	Foliage colour score*	Trimming biomass (g / 3 plants)					Biomass (g)
			Aug - Nov	Nov - Jan	Jan - Mar	Mar - Apr	Total	
Osmocote Plus 12-14 Spring	3.7	3.0	0.91	1.60	3.78	5.20	11.49	39.9
Osmocote Exact Hi-Start 12-14	3.9	3.1	1.56	1.96	3.25	3.85	10.62	38.9
Osmocote Exact Standard 12-14	4.2	3.0	1.28	2.09	3.56	4.94	11.88	41.8
Osmocote Exact Lo-Start 12-14	3.6	3.1	1.33	1.25	3.40	4.04	10.02	36.6
Ficote 180 TE	2.9	4.3	0.94	0.96	2.59	4.28	8.77	35.5
Vitacote	4.2	3.8	0.74	1.52	3.82	6.22	12.30	42.0
Polyon	3.3	3.1	1.69	1.84	2.70	4.14	10.37	38.6
Sincrocell 12	3.1	2.9	1.41	1.45	2.76	3.44	9.06	35.0
Plantacote pluss 12M	3.0	2.6	1.31	1.82	2.54	3.56	9.24	34.3
Multicote 8	3.6	3.1	1.12	1.46	3.16	4.52	10.25	39.4
Multicote 12	3.6	2.9	1.90	2.03	3.17	4.65	11.75	37.4
Mean	3.5	3.2	1.29	1.63	3.16	4.44	10.52	38.1
Significance	<0.01	<0.01	0.17	0.03	0.20	0.02	<0.01	<0.01
d.f.	185	185	20	20	20	20	20	86
SED	0.30	0.21	0.388	0.308	0.529	0.657	0.724	1.75

* 5 = greatest, largest, darkest; 0 = least, smallest, lightest

B - Part 1. CRF residual analyses

Table B-1. N, P and K analysis of CRFs included in experiment, at potting (Spring 98), Autumn 98 and Spring 99 - HRI-Efford.

CRF product	*	Spring 98	(%)Ψ	Autumn 98	(%)	Spring 99	(%)
Osmocote plus (12-14) Spring	***N***	16	(100)	7	(46)	2	(13)
	P	7	(100)	4	(55)	4	(56)
	K	12	(100)	6	(48)	3	(22)
Osmocote Exact 12-14 Hi-Start	***N***	16	(100)	7	(44)	2	(12)
	P	7	(100)	4	(50)	3	(42)
	K	12	(100)	6	(47)	3	(22)
Osmocote Exact 12-14 Standard	***N***	16	(100)	8	(53)	2	(11)
	P	7	(100)	4	(52)	3	(42)
	K	12	(100)	6	(53)	2	(19)
Osmocote Exact 12-14 Lo-Start	***N***	15	(100)	7	(48)	3	(18)
	P	7	(100)	3	(45)	3	(45)
	K	11	(100)	6	(51)	3	(30)
Ficote 180	***N***	11	(100)	10	(85)	2	(17)
	P	2	(100)	2	(120)	2	(104)
	K	6	(100)	6	(103)	2	(41)
Vitacote	***N***	18	(100)	8	(43)	3	(15)
	P	4	(100)	3	(77)	2	(56)
	K	13	(100)	6	(64)	4	(33)
Polyon	***N***	17	(100)	11	(65)	7	(40)
	P	4	(100)	2	(67)	2	(69)
	K	11	(100)	7	(71)	7	(63)
Sincrocell 12	***N***	14	(100)	8	(62)	6	(47)
	P	5	(100)	4	(72)	3	(60)
	K	17	(100)	14	(82)	7	(39)
Plantacote pluss	***N***	13	(100)	8	(59)	3	(26)
	P	5	(100)	2	(49)	2	(40)
	K	17	(100)	11	(66)	8	(46)
Multicote 8	***N***	9	(100)	6	(69)	2	(24)
	P	2	(100)	2	(129)	2	(114)
	K	7	(100)	6	(92)	4	(63)
Multicote 12	***N***	16	(100)	7	(45)	4	(23)
	P	5	(100)	3	(63)	2	(46)
	K	11	(100)	7	(65)	6	(51)

*N = total N (%), P = P_2O_5 (%), K = K_2O (%)

Ψ value in parentheses is percentage of initial measured quantity of nutrient

Table B-2. N, P and K analysis of CRFs included in experiment, at potting (Spring 98), Autumn 98 and Spring 99 - Johnson's of Whixley.

CRF product		Spring 98		Autumn 98		Spring 99	
	*		(%)Ψ		(%)		(%)
Osmocote plus (12-14) Spring	***N***	16	(100)	8	(52)	7	(44)
	P	7	(100)	5	(68)	6	(81)
	K	12	(100)	7	(57)	7	(60)
Osmocote Exact 12-14 Hi-Start	***N***	16	(100)	8	(54)	7	(41)
	P	7	(100)	5	(69)	5	(63)
	K	12	(100)	7	(60)	7	(56)
Osmocote Exact 12-14 Standard	***N***	16	(100)	8	(53)	6	(38)
	P	7	(100)	4	(61)	4	(57)
	K	12	(100)	7	(62)	6	(50)
Osmocote Exact 12-14 Lo-Start	***N***	15	(100)	10	(66)	5	(34)
	P	7	(100)	5	(68)	5	(60)
	K	11	(100)	8	(70)	6	(56)
Ficote 180	***N***	11	(100)	12	(105)	6	(55)
	P	2	(100)	2	(145)	2	(113)
	K	6	(100)	7	(113)	5	(83)
Vitacote	***N***	18	(100)	9	(48)	4	(23)
	P	4	(100)	3	(75)	2	(55)
	K	13	(100)	8	(61)	6	(44)
Polyon	***N***	17	(100)	10	(59)	11	(64)
	P	4	(100)	3	(75)	3	(79)
	K	11	(100)	8	(78)	10	(91)
Sincrocell 12	***N***	14	(100)	9	(64)	7	(50)
	P	5	(100)	6	(111)	4	(76)
	K	17	(100)	12	(71)	11	(64)
Plantacote pluss	***N***	13	(100)	9	(71)	7	(52)
	P	5	(100)	5	(109)	2	(44)
	K	17	(100)	13	(80)	12	(70)
Multicote 8	***N***	9	(100)	10	(108)	5	(54)
	P	2	(100)	3	(159)	2	(121)
	K	7	(100)	9	(128)	7	(98)
Multicote 12	***N***	16	(100)	8	(52)	6	(36)
	P	5	(100)	4	(74)	3	(59)
	K	11	(100)	9	(84)	8	(71)

*N = total N (%), P = P_2O_5 (%), K = K_2O (%)
Ψ value in parentheses is percentage of initial measured quantity of nutrient

C – Part 2. Ferticult photographic plates

Plate 3. *Cytisus x praecox* showing growth reduction with Ferticult, HRI-Efford. Treatments from left to right – Osmocote Plus, Ferticult 10% (v/v) and Ferticult 5% (v/v).
Photograph taken 30/10/98.

Appendix C

Plate 4. *Photinia x fraseri* 'Red Robin' showing the loss of leaves associated with the incorporation of Ferticult, HRI-Efford. Left hand treatment block – Ferticult incorporated at 5% v/v, Right hand treatment block – Osmocote Exact Hi-Start. Photograph taken 10/7/98.