Project title:	**Hardy herbaceous perennials: a study of nutritional requirements**
Project number:	**HNS 43c**
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Report:	**Final report (January 2001)**
Previous reports:	**None**
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The results and conclusions in this report are based on an investigation conducted over one year. The conditions under which the experiment was carried out and the results obtained have been reported with detail and accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results especially if they are used as the basis for commercial product recommendations.

CONTENTS

Practical Section For Growers

Background and Objectives

Container grown hardy herbaceous perennials are a short-term crop, increasingly sold in flower. As a consequence, any crop husbandry that improves flowering and / or general quality of growth would be beneficial, especially for sales into the multiple outlets. A large body of anecdotal evidence supports the use of high K fertilisers with flowering perennials. However, the conclusions of previous scientific studies on the benefits of high K nutrition are contradictory. This project aimed to establish, through altering nutrient inputs in a liquid feed regime, whether high K nutrition, and interactions with nitrogen, had potential to improve growth and flowering of hardy herbaceous crops.

Summary of Results

This experiment studied the responses of three species of herbaceous perennial to a range of nutrient treatments. Five nutrient solutions of differing N:K ratios were used - 3:1, 2:1, 1:1, 1:2 and 1:3. Thirteen nutrient treatments were imposed using these solutions. Plants received one of these solutions alone (*main treatments*), or received 1:1 solution initially, changing to one of the 4 remaining solutions either in Autumn (week 40) or Spring (week 6) (*mixed treatments*).

Under the conditions of this trial, no clear and consistent benefits were observed in response to K nutrition in the growth and flowering of the three herbaceous species. This is in agreement with scientific reports but counter to the widely held belief that high potash benefits flowering.

Geranium macrorrhizum 'Ingwersens'

- Late growth benefited from high K nutrition. However, early growth required adequate N, as plants grown with high K solutions alone produced poor growth with pale foliage.

- The number of flowers produced by the *Geranium* plants was greatest with either a 1:1 or 3:1 feed and high K feeds reduced the number of flowers and delayed flowering.

Pulmonaria angustifolia ssp. *azurea*

- Pedicel length increased with high K treatments and gave the tallest plants, although biomass was unaffected.

- In contrast to *Geranium* the 1:1 feed solution reduced flower number and delayed flowering, with high K and high N solutions increasing flower number. Mixed treatments delayed flowering to a certain extent.

***Lithodora*'Heavenly Blue'**

- Changing the feed solution appeared to stimulate biomass production in the majority of mixed treatments. However, when the growth data was correlated with foliage nutrient levels, a reduction in dry weight was associated with high levels of K in the foliage.

- Both high N and high K solutions reduced flower number compared to a balanced 1:1 feed solution. However, the time to flowering was reduced using the high K solutions compared to either 1:1 or high N solutions.

<u>Overall</u>

No consistent effect of high K in either growth or flowering was observed in the three species studied in this trial. High K treatments did increase pedicel length in *Pulmonaria* but had no clear effect on flowering. Later application of high K feed produced greater growth in *Geranium* but higher foliage K was associated with reduced biomass in *Lithodora*. In both *Geranium* and *Lithodora* high K treatments reduced flower number, but hastened flowering in *Lithodora* and delayed flowering in *Geranium*.

Action Points

- In general, it is unlikely to be worthwhile manipulating K nutrition to influence flowering oe growth.

- Specialist growers may gain from 'fine tuning' of plant nutrition for single lines/species.

- Further, more extensive, work would be necessary to examine these responses (or lack of them) with greater replicate number and a wider range of species.

- Growers can produce quality plants with balanced feed regimes.

Practical and Financial Benefits

- At present there appears to be no advantage in growth or flowering in using high K feeds.

Science Section

Introduction

Containerised hardy herbaceous perennials are a short-term crop, increasingly sold in flower. As a consequence, any crop husbandry that improves flowering and / or general quality of growth would be beneficial, especially for sales into the multiple outlets. Currently the majority of hardy herbaceous perennials have nutrients supplied by controlled release fertilisers. Recommended rates and analyses are available from manufacturers, but it is recognised that these are based on limited trials.

In the pot and bedding sectors high K analysis fertilisers are used, mainly towards the end of the crop cycle, to improve flowering and flower quality, and to harden growth (Coutts, personal communication). A large body of anecdotal evidence supports the use of high K fertilisers, and manufacturers of fertilisers claim that a high K analysis fertiliser is suitable for improved flowering (as well as improved fruit development). Surprisingly few references that demonstrated the role of K in flower development and quality were uncovered in the initial literature search undertaken for this proposal. Potassium has been shown to influence flower formation in *Solanum sisymbrifolium* (Wakhloo, 1975) where reduced K was associated with reduced levels of cytokinin and an increase in sterile flower buds. However, at low levels of K plant height is often reduced and the general quality of growth is poor (Kageyama, Nakagawa & Konishi, 1993).

Potassium is the second most prevalent element in plant tissues after N and is essential for efficient water relations in plants, both in controlling water content of cells and movement of water through tissues, and in transpiration. Potassium is also involved in some enzyme activities and protein synthesis (Marschner, 1995). In general, cell extension is the consequence of the accumulation of K^+ in the cells, required for both stabilising the pH in the cytoplasm and increasing the osmotic potential in the vacuoles (Mengel & Kirkby, 1982). At adequate levels of N, expanded leaf area of *Phaseolus vulgaris* has been shown to be related to potassium status of the leaves (Mengel & Arneke, 1982). Potassium is acquired by the plant as K^+ which is the most abundant cation in the cytoplasm interacting with a number of elements at the site of uptake. The uptake of K^+ is inhibited by high levels of NH_4^+ but not by NO_3^-. However, high levels of K^+ do not inhibit the uptake of either form of N (Shaviv, Hagin & Neumann, 1987), but do inhibit uptake of magnesium and calcium (Engels & Marschner, 1993), and deficiencies of these elements may occur at high levels of applied K.

On the whole-plant scale, sub-optimal levels of N or K are both growth limiting. As the size of plant increases so does the need for K. Nitrogen interacts with K; low K will limit growth even if N is at optimal or supra-optimal levels (MacLeod, 1969). Additionally, adequate levels of K in the foliage is associated with reduced susceptibility to frost and disease (see review Marschner, 1995).

The timing of application of nutrients is a topic little studied in hardy ornamental plant production in the UK, as the majority of growers use CRFs to satisfy plant nutrient requirements. The plant requirement for specific nutrient elements varies with time, season and plant developmental stage. For example, in greenhouse roses the N uptake rate varies by a factor of five during different stages of growth, with average uptake rates in summer about twice of those in winter; and K, Ca, Mg and P follow the same pattern of uptake observed for N (Cabrera, Evans & Paul, 1995).

Many plants initiate flowers a number of months before flower expression, and it may be that these two stages have different optimal levels of certain nutrients. Manipulation of these levels through targeted inputs could lead to improved quality of plants at the marketing stage, and reduce fertiliser wastage.

Hardy herbaceous perennials to be sold in flower may benefit from a high potassium (K) regime. If the benefits of a high K feed were to be proven it would be possible to apply additional K as a liquid feed at specific points in the crop production cycle, in addition to a CRF base. Alternatively, high K analysis CRF blends that release nutrients at differential rates may be developed.

This project had two objectives:

1. Establish whether high K nutrition has potential to improve flowering of herbaceous crops

2. Determine the influence of timing of application throughout the growing season

Materials and Methods

(objective 1&2)

The work concentrated on the role of K nutrition and its interaction with N on flower production and development. This was investigated using liquid feed regimes.

Three indicator species were grown in containers for a period of 10 months, from August 1999 until May 2000. Plants were liquid fed, with solutions of different N:K ratio during active growth. Treatments were introduced and continued from potting (week 32). Nutrient treatments and timings of application are shown in Tables 1 and 2.

Treatments

Table 1. N:K ratio of liquid feed treatments

		Kg/100 litres		**mg/litre in final feed solution**		
Treatment	N:K ratio	Ammonium Nitrate	Potassium Nitrate	N	K_2O	Conductivity Ms/cm @ 20°C
	stock solution diluted at 1 in 200 to give feed solution					
A	1:3	0	14	100	300	875
B	1:2	2	9	100	200	700
C	1:1	4	4.5	100	100	575
D	2:1	10	4.5	200	100	750
E	3:1	16	4.5	300	100	1500

Fritted trace elements (0.3 kg/m^3; WM255) single super phosphate (1.5kg/m^3), and magnesium lime (1.8 kg/m^3) were incorporated in the growing medium as a base dressing. Treatment stock feeds were made up using potassium nitrate and ammonium nitrate as required. These were diluted at a rate of 1 in 200 prior to application. Treatments were applied by hand at weekly intervals. Plants were grown under protection. Irrigation between nutrient applications was by hand.

Table 2. Timing of liquid feed treatments

Treatment No.	Week number 32	40	6	
1	A	A	A	**Main treatments**
2	B	B	B	
3	C	C	C	
4	D	D	D	
5	E	E	E	
6	C	A	A	**Mixed treatments**
7	C	B	B	
8	C	D	D	
9	C	E	E	
10	C	C	A	
11	C	C	B	
12	C	C	D	
13	C	C	E	

Design:

The trial design was a randomised block layout with 3 replicates, and was analysed by the standard ANOVA analysis of variance to identify statistically significant treatment effects.

13 treatments
x
3 replicates
–
39 plots/species — *Plot = 3* recorded plants
x
3 species — *Plants required = 117 / species*
—
117 plots in total

Species

Geranium macrorrhizum 'Ingwersens'
Pulmonaria angustifolia ssp. *azurea*
Lithodora 'Heavenly Blue'

Cultural details

The pots of each plot were placed in shallow plastic trays lined with capillary matting. Each plot was therefore separated from the surrounding plots, ensuring no interference with adjacent treatments. Treatments were arranged in three randomised blocks repeated for each species. The *Geranium* and *Pulmonaria* were bought in as P9 plugs, then potted up into 3 litre containers. *Lithodora* bought in as cell tray plugs and potted into 1 litre containers. The potting mix was 75% Irish Premium peat and 25% Granulated pine bark. The roots of all species were washed to remove any residual CRF from the plugs. Plants were grown under well-ventilated polythene and a routine P&D regime was implemented.

Assessments

- Liquid feed stock was sampled weekly
- Days to appearance of first flower bud
- Days to appearance of first flower (defined as marketing stage)
- Flowers were counted weekly from first flower appearance
- At marketing stage, plants were scored* for size, pot cover and foliage colour, where appropriate.
- Photographs of treatment effects were taken as appropriate
- Biomass was calculated from all the plants at the end of the trial
- Foliage analysis of bulked samples was analysed at the end of the trial

*Score plants were selected for each assessed variable as follows: 5 plants displaying the full range of that variable were selected from all the plants (except guards). These plants were then termed score 1 to score 5, with the variable being the least for 1 and the greatest for 5. For example when assessing colour, score 1 was the plant with the lightest coloured foliage and score 5 was the plant with the darkest foliage. Score plants were photographed and measured. The score plants were grown under the same conditions as all the plants and were chosen from within the experimental plots and replaced into the body of plants after all plants had been scored. The score plants were selected anew each time plants were scored.

Results

Geranium macrorrhizum 'Ingwersens'

Flowering

- Main treatments

The maximum number of flowers produced was greatest with plants that received the 3:1 feed regime, with 24 flowers produced per plant (Fig. 1a). Those plants fed with the 1:1 feed had a similar number. The high K treatments applied throughout reduced the number of flowers produced with 14 and 13 flowers per plant for the 1:3 and 1:2 rates, respectively. Interestingly, the 2:1 feed reduced the number of flowers produced compared to 1:1 and 1:3 rates.

- All treatments

The timing of nutrient feeds had a significant effect on flower number (Fig. 1b). This effect was most marked where the feed changed from 1:1 to 1:3. The substitution of 1:1 feed with 1:3 feed led to a reduction in flower number. The earlier the change the greater the effect. Of note, where the feed changed from 1:1 there was always a reduction in the number of flowers produced, even where the 3:1 feed alone produced a large number of flowers a combination of 1:1 and 3:1 feeds reduced the flower number.

Flowering time

- Main treatments

The time taken from the appearance of coloured buds to open flowers was similar for all main treatments (Fig. 2a). The earliest flowers were observed in plants that had received the 1:1 or 3:1 feeds. The high K treatments delayed flowering.

- All treatments

No clear pattern emerged with the timing treatments. In general, the switch to high K treatments delayed flowering compared to the 1:1 treatment (Fig. 2b). No treatment flowered significantly sooner than the 1:1 treatment.

Growth

Size and colour

- All treatments

Mixed treatments were similar in size with the exception of those that received only 1:2 and 1:3 feeds, which were significantly smaller (Fig. 3a & b). The same pattern was seen with plant colour. Interestingly, the effect of the high K feed was not apparent where the initial feed was 1:1, suggesting the effect was a result of nutrition during early growth.

Foliage dry wt

- Main treatments

There was no significant difference between main treatments (Fig. 4a).

- All treatments

Significant differences were observed depending on when the higher K ratio was applied. Plants that changed to a 1:3 feed in week 6 (Fig. 4b) produced the greatest biomass. A similar response was observed in the plants that changed to a 1:2 feed in week 6. However, this effect was reduced where the change to the new feed occurred in week 40, especially with the 1:2 feed. A significant increase in biomass also occurred where the feed changed from 1:1 to 3:1, both from week 40 and week 6.

Foliage nutrient analysis

The main treatments showed an increase in the amount of K relative to N in the foliage in response to increased K relative to N in the feed applied (Table 3). The 1:3 feed produced a ratio of 1:2.3 in the foliage. However, a reduction in the ratio of K in the feed reduced the ratio of K in the foliage but at a lower rate, with the minimum foliage analysis of 1:1.4 when the feed solution had a ratio of 3:1

Table 3. Showing the N:K ratio of the feed solutions and foliage of plants receiving only the main treatments.

N:K	
Feed	***Foliage***
1:3	1:2.3
1:2	1:1.8
1:1	1:1.7
2:1 (1:0.5)	1:1.5
3:1 (1:0.3)	1:1.4

Correlation of variables

The correlation of physiological variables and foliage nutrient analyses highlighted significant relationships (Table 4). As the same data was used to derive N:P, N:K and N the correlations between these variables were very high, but can be ignored as artefacts. Of interest was the significant positive correlation between the ratio of N:P in the foliage and foliage dry weight. Additionally, the number of days to bud in colour was significantly positively associated with the number of days to flower.

Table 4. Showing correlations between nutrient variables and growth and flowering variables.

		1	2	3	4	5	6	7
1	N:P	1						
2	N:K	0.70 **	1					
3	N	0.91 **	0.82 **	1				
4	K	ns	ns	ns	1			
5	P	ns	ns	ns	ns	1		
6	dry wt	0.51 *	ns	ns	ns	ns	1	
7	days to bud colour	ns	ns	ns	ns	ns	ns	1
8	days to flower	ns	ns	ns	ns	ns	ns	0.92 **

* and ** indicate significance of correlation at p=0.05 and 0.01, respectively.

***Geranium macrorrhizum* 'Ingwersens'**

Figure 1a. Maximum flower - Main treatments
Bar = LSD(0.05)

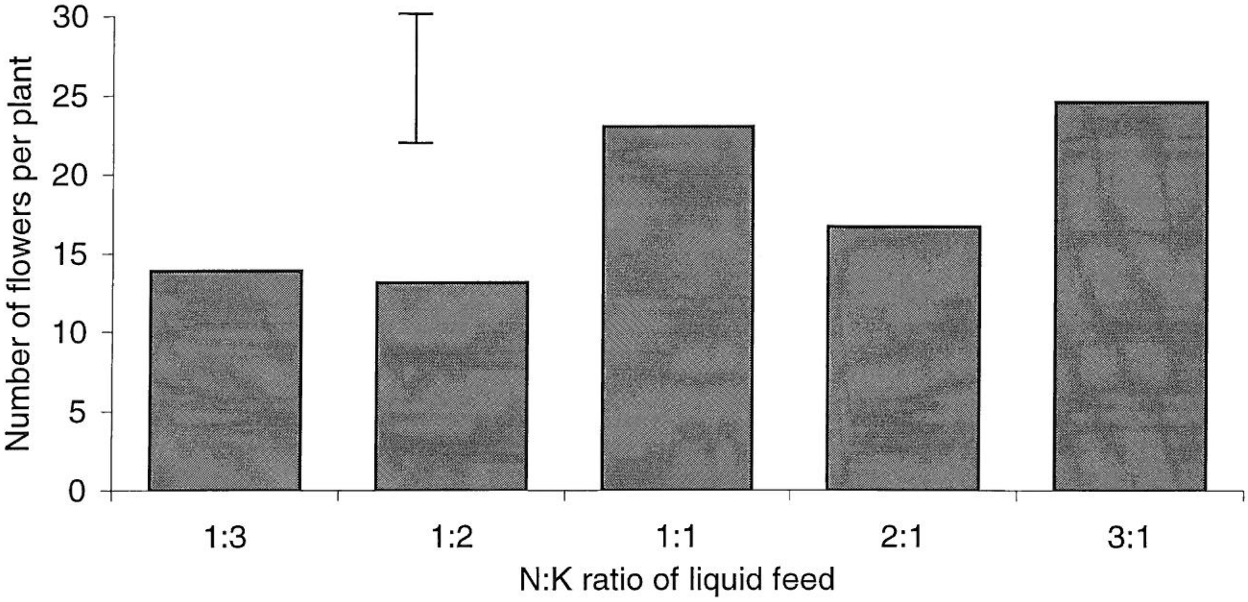
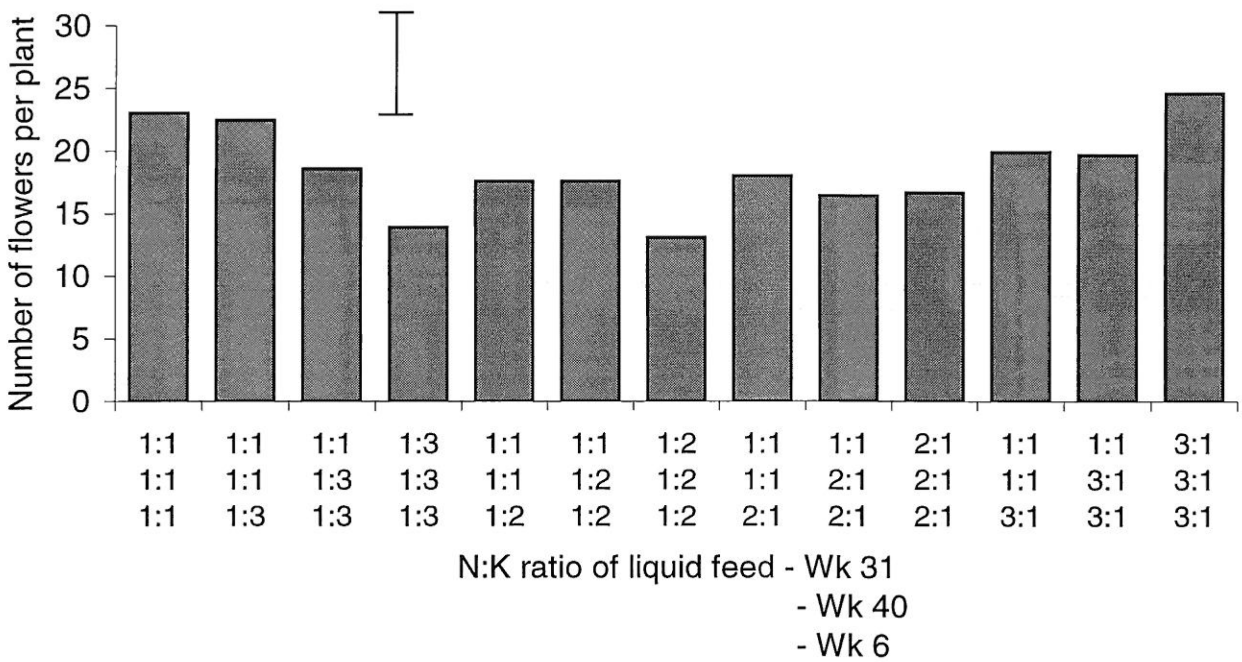


Figure 1b. Maximum flower - All treatments
Bar = LSD(0.05)



***Geranium macrorrhizum* 'Ingwersens'**

Figure 2a. Average day of first coloured bud and open flower - Main treatments. Bar = LSD(0.05)

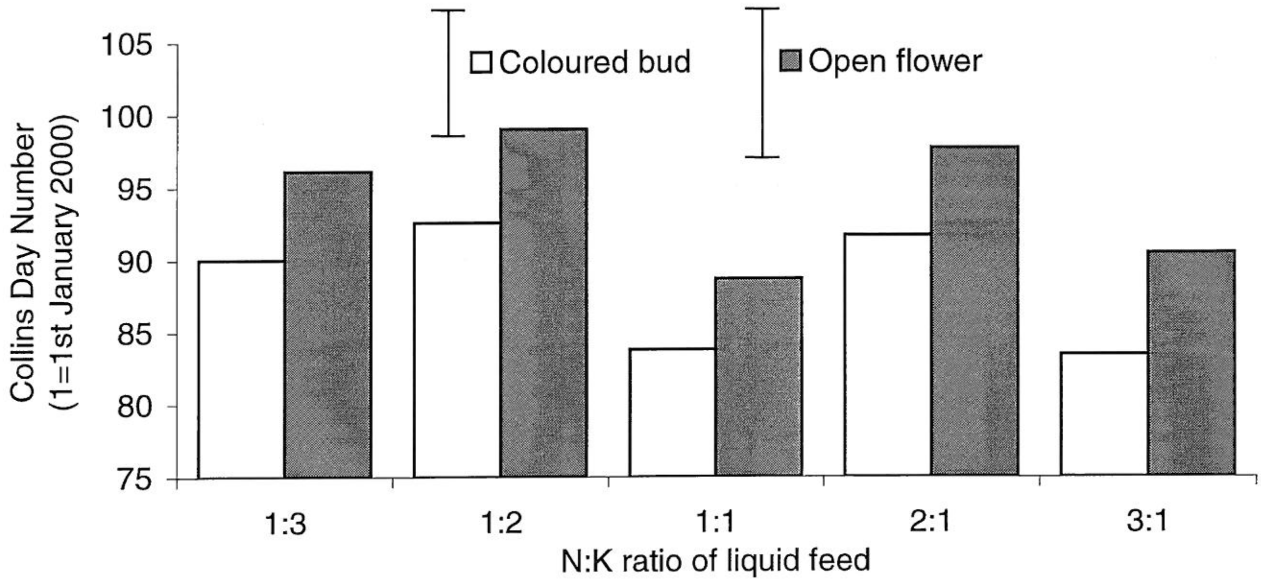
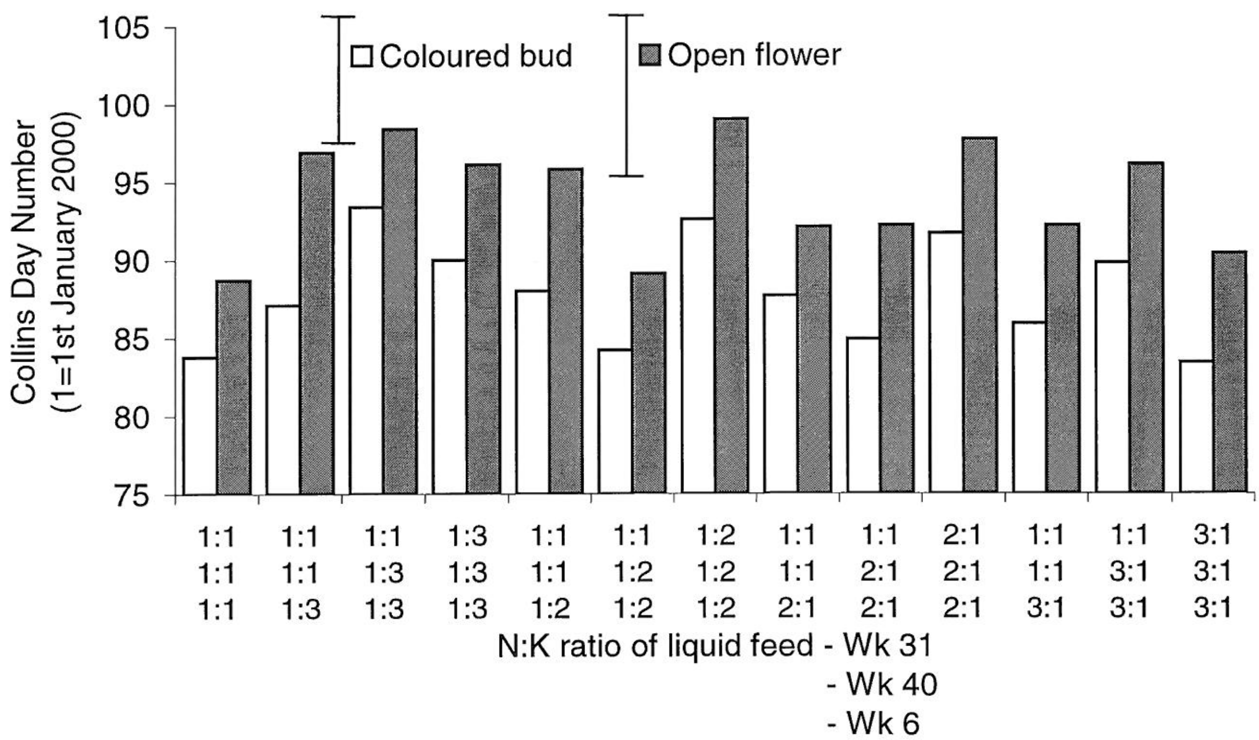


Figure 2b. Average day of first coloured bud and open flower - All treatments. Bar = LSD(0.05)



***Geranium macrorrhizum* 'Ingwersens'**

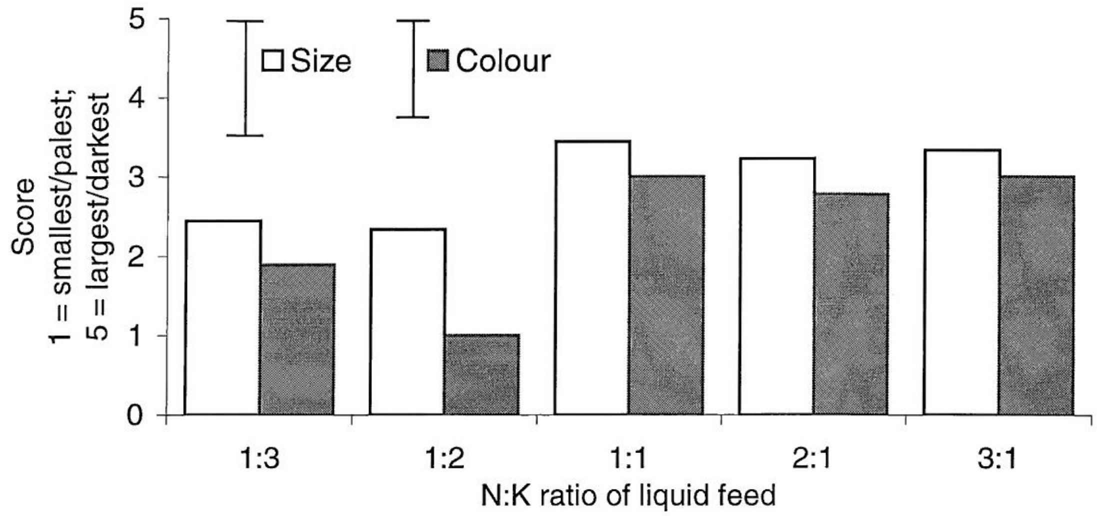


Figure 3a. Size and Colour score - Main treatments
Bar = LSD(0.05)

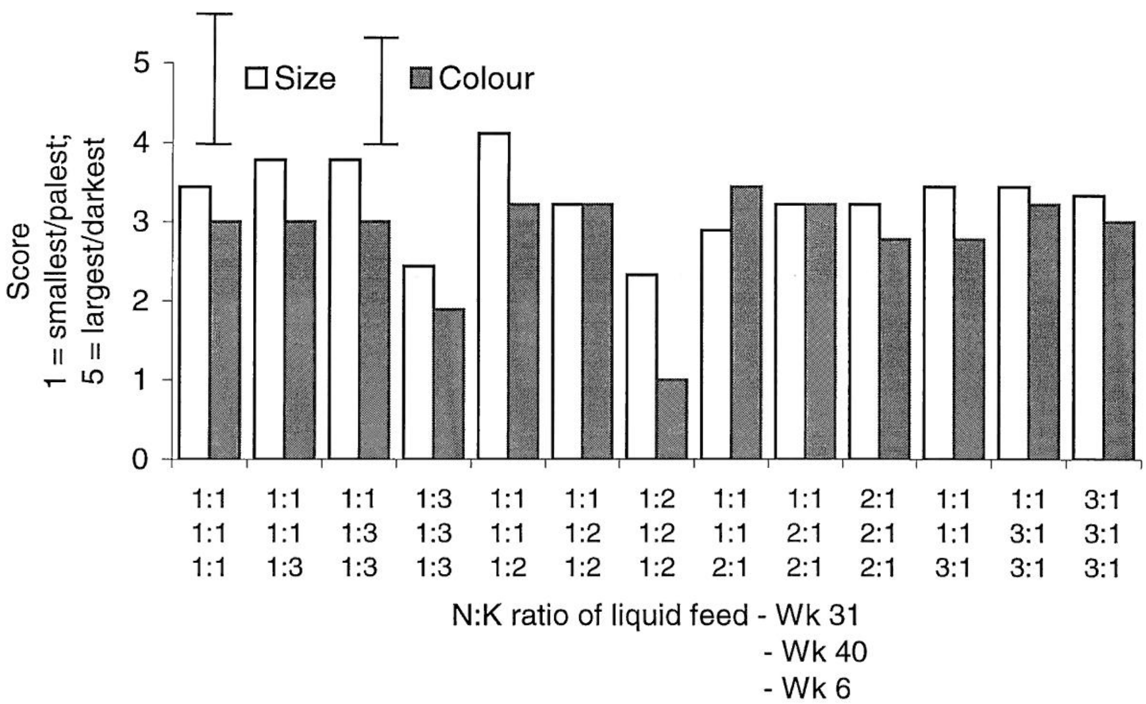


Figure 3b. Size and Colour score - All treatments
Bar = LSD(0.05)

***Geranium macrorrhizum* 'Ingwersens'**

Figure 4a. Foliage dry weight (g) - Main treatments
Bar = LSD(0.05)

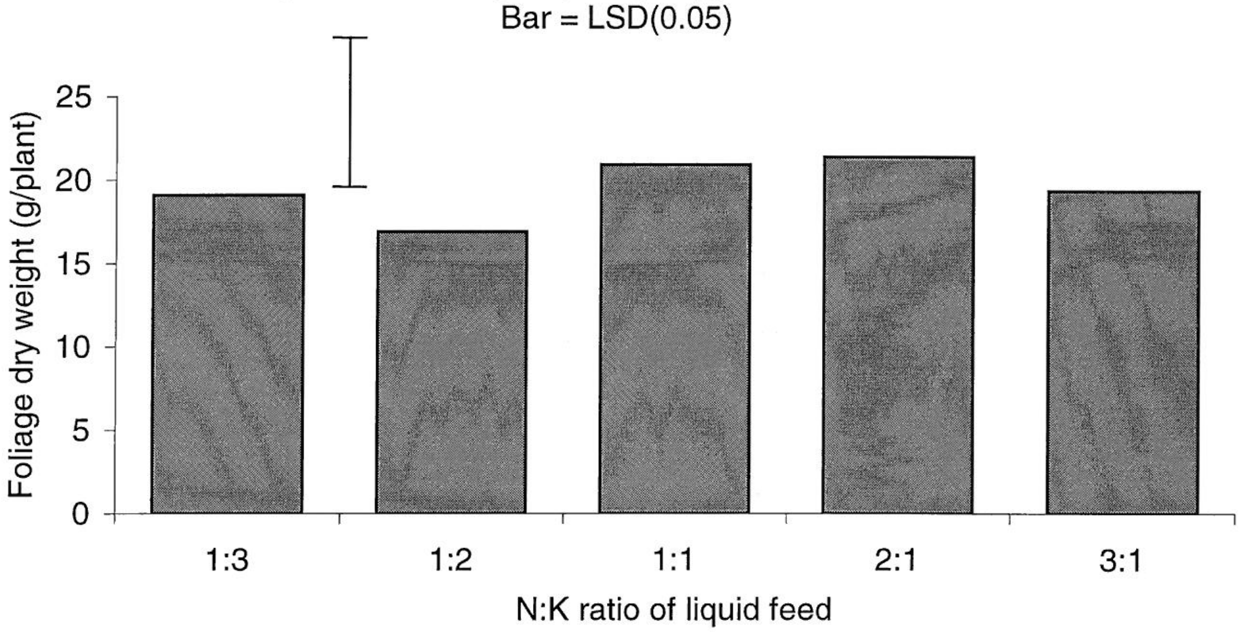
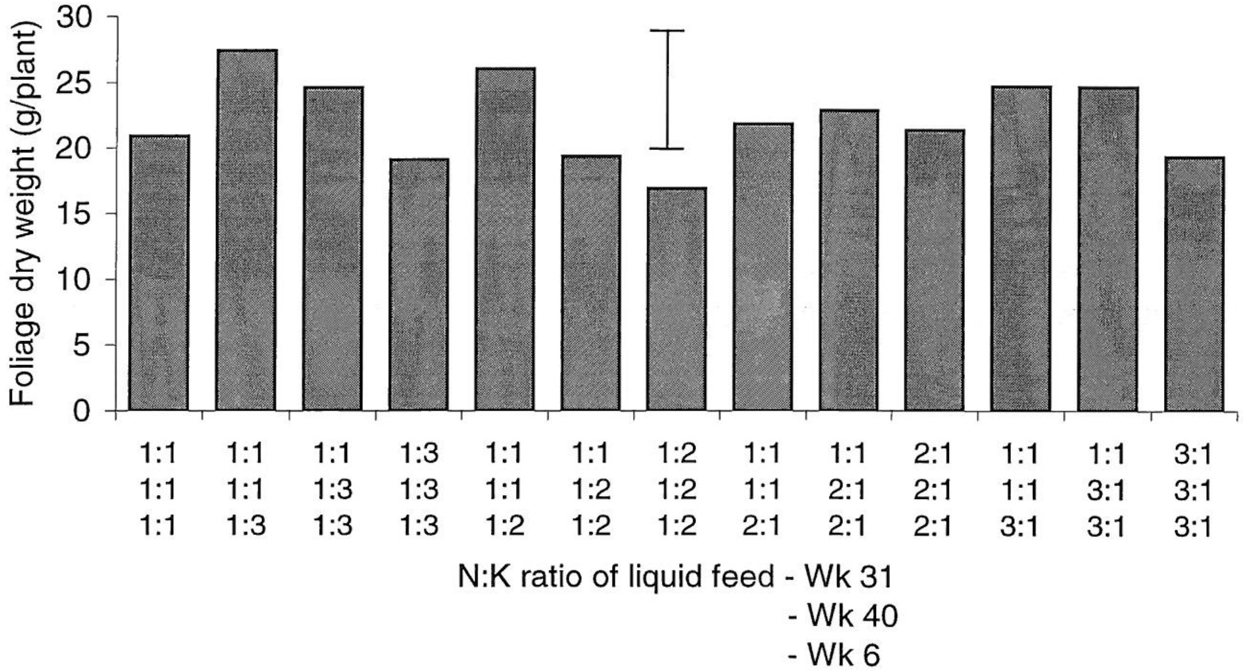


Figure 4b. Foliage dry weight (g) - All treatments
Bar = LSD(0.05)



Pulmonaria angustifolia ssp. *azurea*

Maximum flowers

- Main treatments

The high N, 3:1 feed alone produced the greatest number of flowers with an average of 15.6 flowers per plant (Fig. 5a). The fewest flowers, an average of 9.7 per plant, were produced with the 1:1 feed.

- All treatments

Changes in the feed regimes significantly affected the number of flowers produced by the plants. The greatest number of flowers was counted on the plants that received a 1:2 feed from week 40 (Fig. 5b). Plants that received 3:1 feed from week 40 produced the fewest flowers. However, no clear pattern emerged in response to treatments.

Flowering time

- Main treatments

The earliest flowers were observed on those plants receiving the 3:1 feed (Fig. 6a). Plants receiving 1:2 produced flowers on average 1 day later. Those plants receiving the 1:1 feed flowered latest, on average 6.5 days after those receiving the 3:1 feed.

- All treatments

A change in nutrient feed regime promoted earlier flowering compared to the respective main treatment except where plants received 3:1 feed from week 40 (Fig. 6b). The effect of changed nutrient feed was especially marked with the 1:3 and 2:1 mixed feed treatments. Changing the nutrient feed from 1:1 to 1:3 at weeks 40 and 6 hastened flowering by 5.4 and 7.1 days respectively, compared to the constant 1:1 feed, and 3.0 and 4.7 days compared to the constant 1:3 feed.

Growth

Stem height and pot cover

- Main treatments

Stem heights differed significantly between main treatments with plants receiving the 1:2 feed being the tallest at 9.2 cm (Fig. 7a). This was significantly taller than plants produced with the 1:1 and 3:1 feeds, with heights of 6.3 and 6.9 cm, respectively. No significant differences in pot cover were observed between treatments.

- All treatments

Stem heights were similar for most treatments. However, three treatments were significantly taller: 1:3 only, 1:2 only and 3:1 from week 6 (Fig. 7b). No significant differences in pot cover were observed between treatments.

Foliage dry wt

- Main treatments

There were no significant differences among treatments in foliage biomass (Fig. 8a).

- All treatments

A number of treatments significantly reduced the foliage biomass compared to the main treatments. Plants receiving 1:3 feed after week 6 produced the least foliage biomass with 0.76 g/plant, significantly less than plants receiving either 1:1 or 1:3 only (Fig. 8b). A similar response was observed in plants that received 3:1 feed after week 40, producing significantly less foliage than plants receiving either 1:1 or 3:1 only.

Foliage nutrient analysis

The main treatments showed an increase in the amount of K relative to N in the foliage in response to increased K relative to N in the feed applied (Table 5). The 1:3 feed produced a ratio of 1:2.8 in the foliage. However, a reduction in the ratio of K in the feed reduced the ratio of K in the foliage but at a lower rate, with the minimum foliage analysis of 1:1.1 when the feed solution had a ratio of 3:1.

Table 5. Showing the N:K ratio of the feed solutions and foliage of plants receiving only the main treatments.

N:K	
Feed	***Foliage***
1:3	1:2.8
1:2	1:2.1
1:1	1:1.8
2:1 (1:0.5)	1:1.9
3:1 (1:0.3)	1:1.1

Correlation of variables

The correlation of physiological variables and foliage nutrient analyses highlighted significant relationships (Table 6). As the same data was used to derive N:P, N:K and N, P and K, the correlations between these variables were very high, but can be ignored as artefacts. No other significant correlations existed.

Table 6. Showing correlations between nutrient variables and growth and flowering variables.

		1	2	3	4	5	6
1	N:P	1					
2	N:K	0.74 **	1				
3	N	0.82 **	0.91 **	1			
4	K	ns	-0.84 **	-0.56 *	1		
5	P	-0.70 **	ns	ns	ns	1	
6	dry wt	ns	ns	ns	ns	ns	1
7	days to flower	ns	ns	ns	ns	ns	ns

* and ** indicate significance of correlation at p=0.05 and 0.01, respectively.

***Pulmonaria augustifolia* ssp. *azurea**

Figure 5a. Maximum flower number - Main treatments
Bar = LSD(0.05)

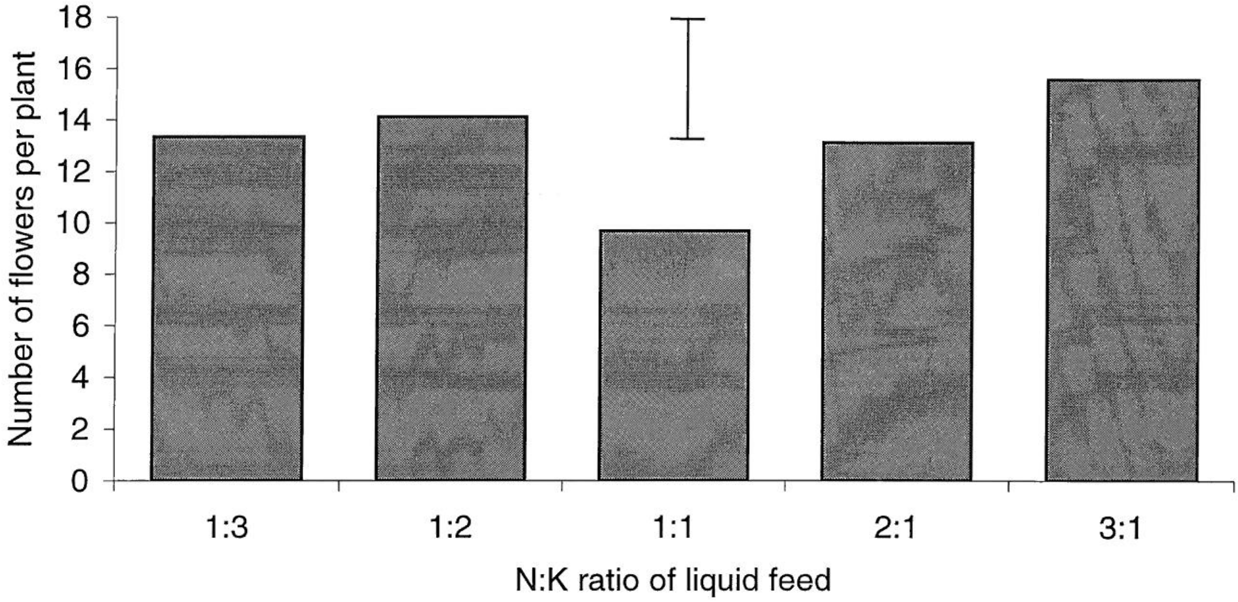
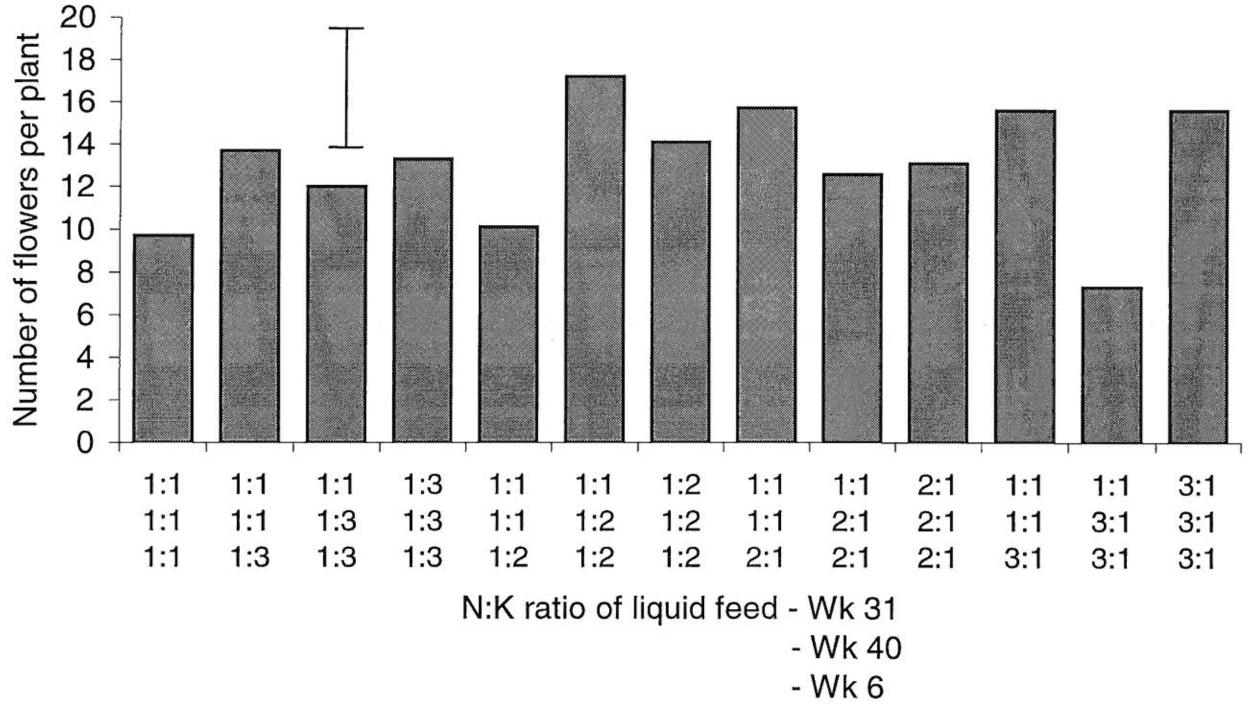


Figure 5b. Maximum flower number - All treatments
Bar = LSD(0.05)



***Pulmonaria augustifolia* ssp. *azurea**

Figure 6a. Average day of first open flower - Main treatments
Bar = LS(0.05)

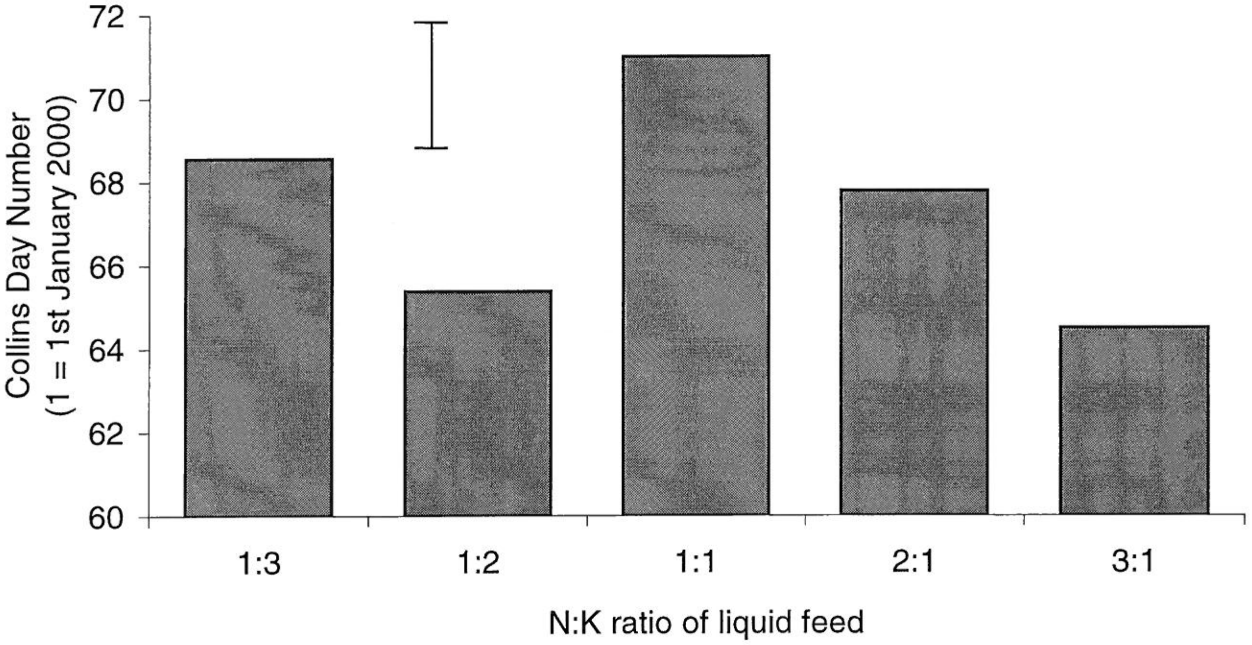
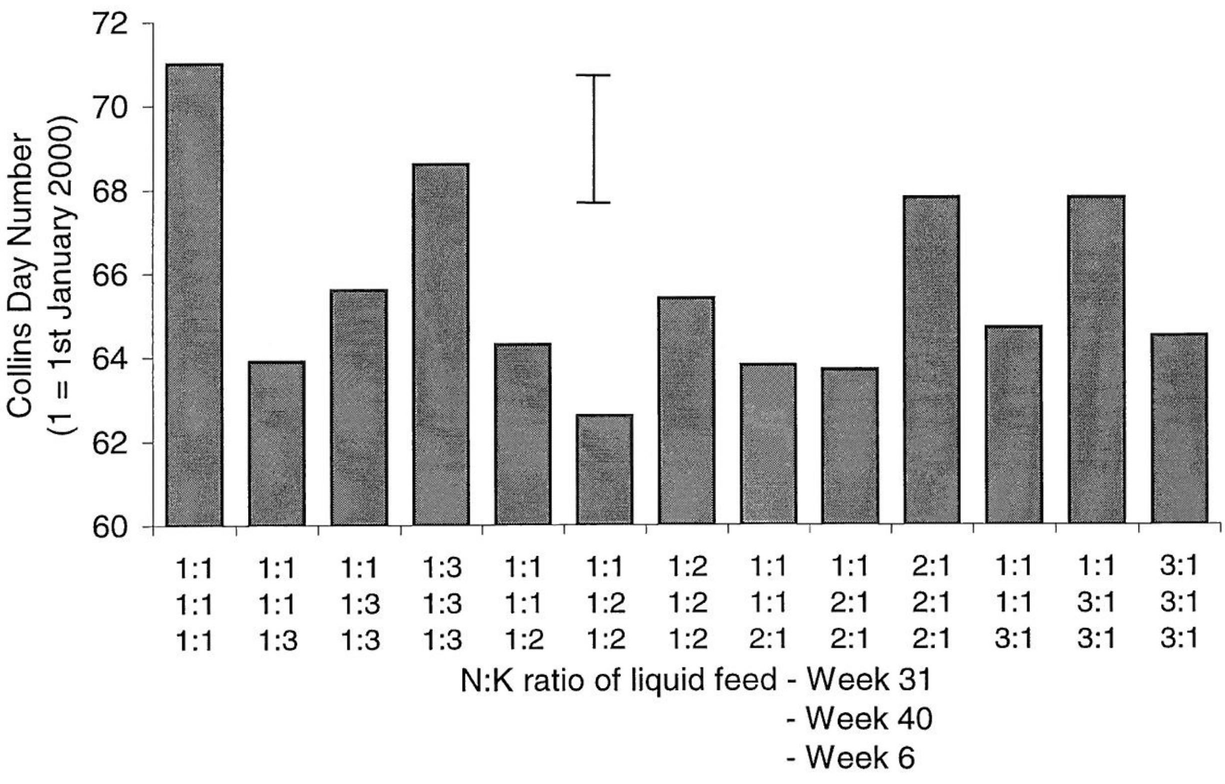


Figure 6b. Average day of first open flower - All treatments
Bar = LSD(0.05)



***Pulmonaria augustifolia* ssp. *azurea**

Figure 7a. Stem height and pot cover at marketing stage - Main treatments. Bar = LSD(0.05)

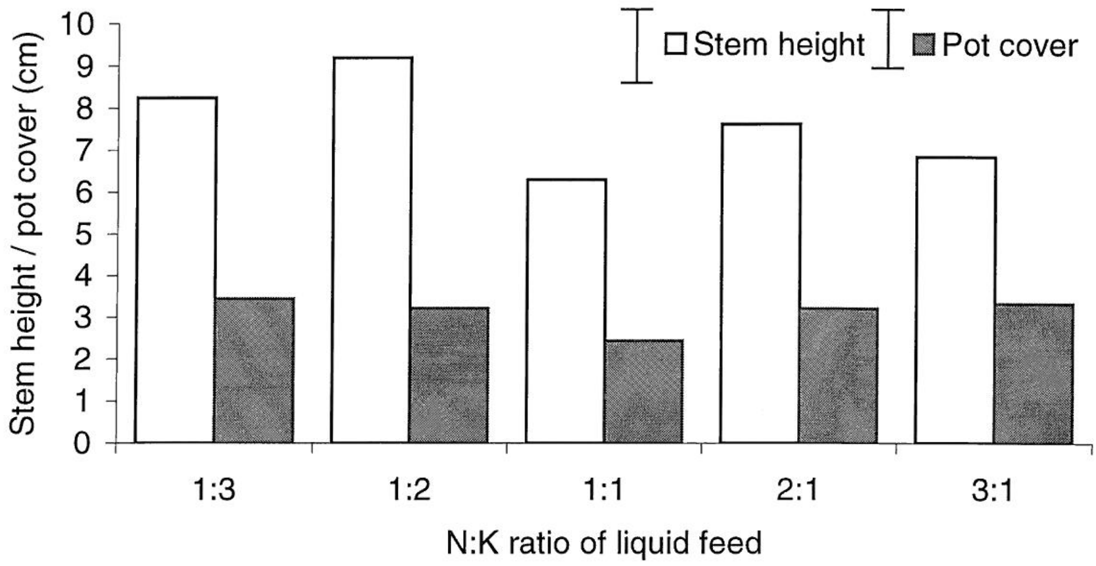
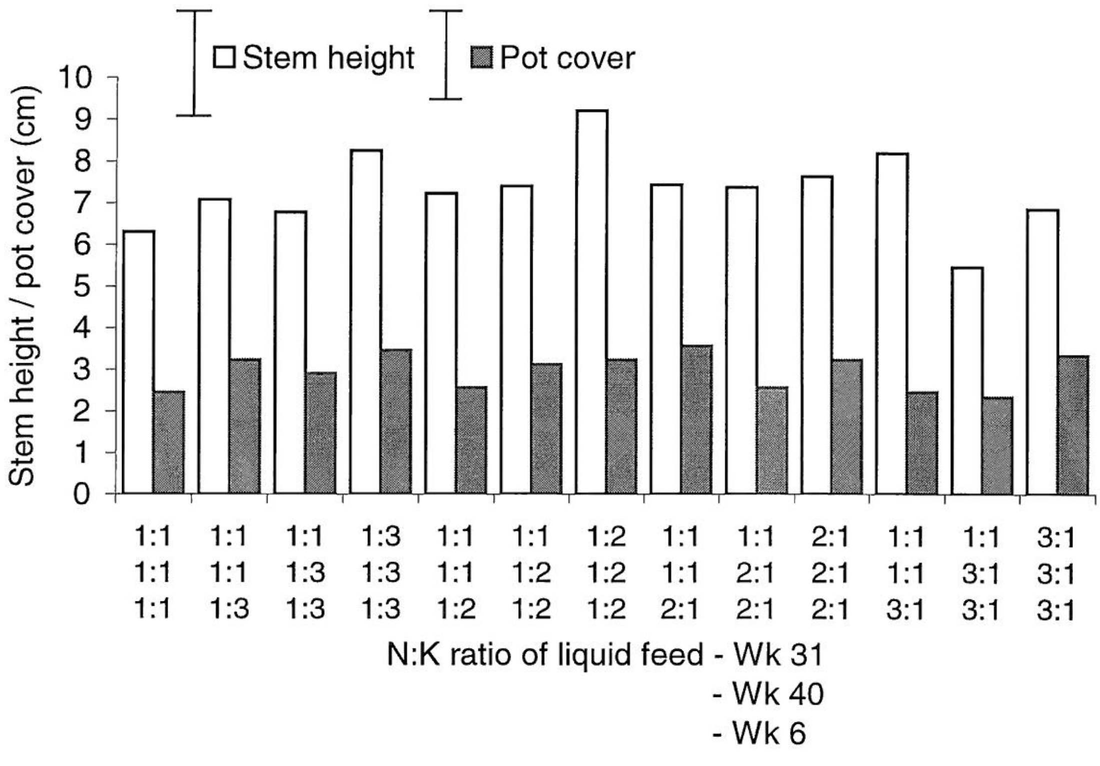


Figure 7b. Stem height and pot cover at marketing stage - All treatments. Bar = LSD(0.05)



***Pulmonaria augustifolia* ssp. *azurea**

Figure 8a. Foliage dry weight (g) - Main treatments
Bar = LSD(0.05)

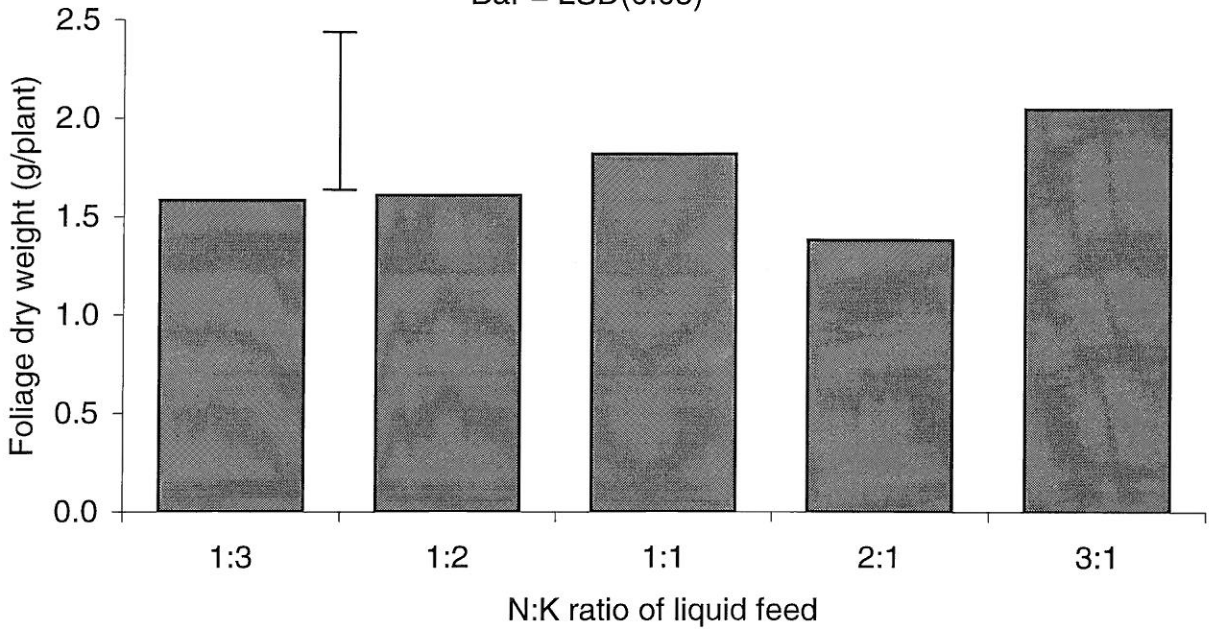
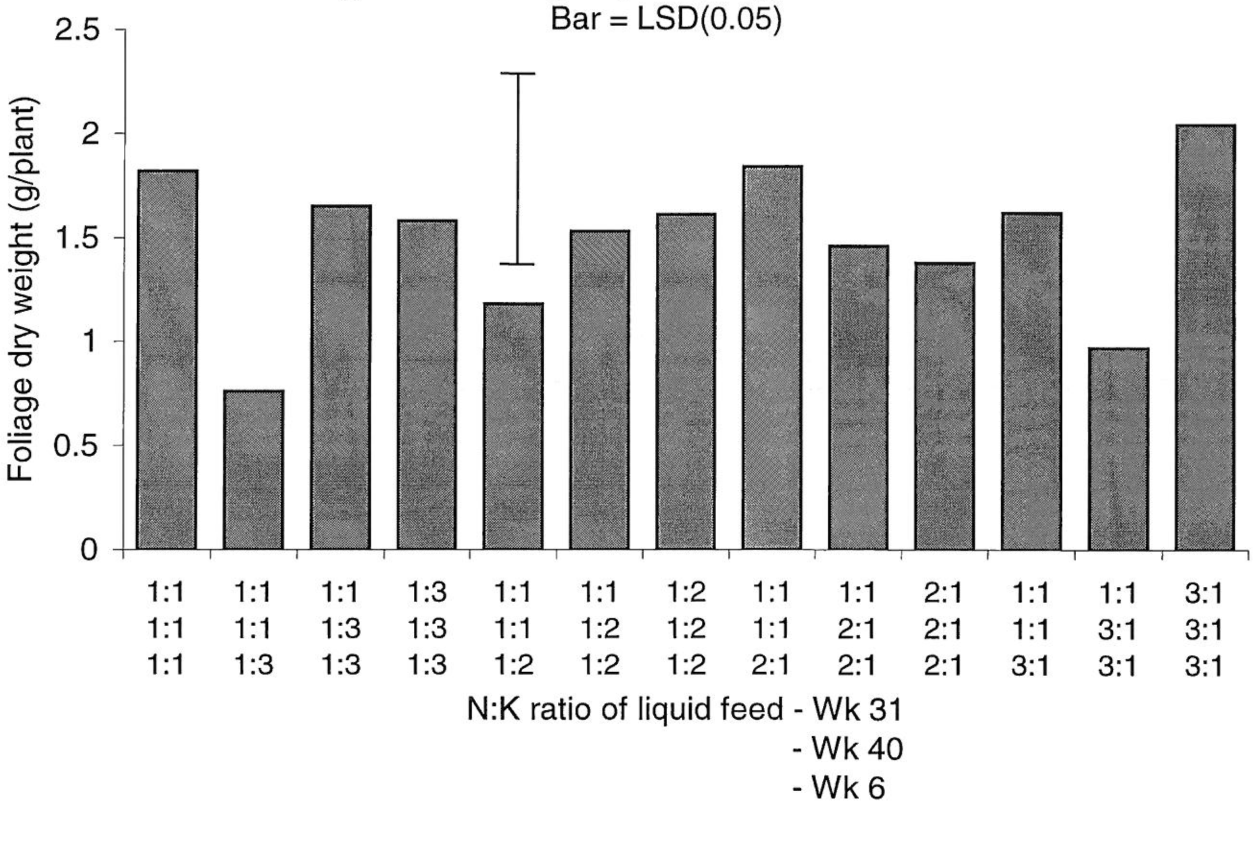


Figure 8b. Foliage dry weight (g) - All treatments.
Bar = LSD(0.05)



Lithodora 'Heavenly Blue'

Maximum flowers

- Main treatments

Significantly more flowers (37.3 per plant) were produced with the 1:1 feed (Fig. 9a). The least were produced with the 2:1 and 3:1 feeds with 23.2 and 23.0 flowers/plant respectively.

- All treatments

Significant differences occurred among treatments but a pattern was hard to distinguish. Overall, a combination of feeds produced more flowers (although rarely significantly so) than the relevant main treatments (Fig. 9b). Of note was the response of the 3:1 mixed treatments where those plants receiving a 3:1 feed from either week 40 or 6 produced almost twice as many flowers as plants receiving a 3:1 feed throughout production.

Flowering time

- Main treatments

The time taken between first coloured buds and first flowers was similar for all treatments. On average, plants receiving the high K feed (1:2 and 1:3) produced coloured buds 4.1 days earlier and open flowers 4.7 days earlier than the other treatments (Fig. 10a).

- All treatments

Changing nutrient ratios hastened flowering in the majority of treatments compared to the relevant main treatments. No flowering was significantly delayed by changing the feed solutions (Fig. 10b).

Growth

Size score

- Main treatments

Differences between main treatments were not significant, but the data suggested that plants that had received the 1:1 feed were, on average, the largest (Fig. 11a).

- All treatments

No clear pattern emerged in response to changing the ratio of N:K in the feed solution. Nevertheless, it was noticeable that the main treatments of 1:3 and 2:1 were the smallest plants, and that a change in feed regime significantly increased growth in the majority of treatments (Fig. 11b).

Foliage dry wt

- Main treatments

The foliage biomass followed a similar pattern to the size score, with 1:1 feed producing the greatest foliage biomass of 7.2 g/plant (Fig. 12a).

- All treatments

As with the size score no clear pattern emerged in response to changing the ratio of N:K in the feed solution. The main treatments, except 1:1, were smaller than average and a change in feed regime increased foliage biomass in the majority of treatments; significantly so with the 3:1 and 1:2 mixed treatments (Fig. 12b).

Foliage nutrient analysis

The main treatments showed a small increase in the amount of K relative to N in the foliage in response to increased K relative to N in the feed applied (Table 7). The 1:3 feed produced a ratio of 1:3.3 in the foliage. However, a reduction in the ratio of K in the feed reduced the ratio of K in the foliage but at a much-reduced rate, with the minimum foliage analysis of 1:2.4 when the feed solution had a ratio of 3:1.

Table 7. Showing the N:K ratio of the feed solutions and foliage of plants receiving only the main treatments.

N:K	
Feed	***Foliage***
1:3	1:3.3
1:2	1:3.0
1:1	1:2.5
2:1 (1:0.5)	1:2.5
3:1 (1:0.3)	1:2.4

Correlation of variables

The correlation of physiological variables and foliage nutrient analyses highlighted significant relationships (Table 8). As the same data was used to derive N:P, N:K and N, P and K, the correlations between these variables were very high, but can be ignored as artefacts. Interestingly, the concentration of K in the foliage was negatively associated with the ratio of N:P. Foliage dry weight was significantly positively associated with the N:K ratio and also negatively related to the concentration of K in the foliage. The number of days to flower was negatively correlated with dry weight and positively correlated to the number of days to bud colour.

Table 8. Showing correlations between nutrient variables and growth and flowering variables.

		1	2	3	4	5	6	7
1	N:P	1						
2	N:K	ns	1					
3	N	ns	0.88 **	1				
4	K	-0.65 **	-0.82 **	ns	1			
5	P	-0.91 **	ns	ns	ns	1		
6	dry wt	ns	0.60 *	ns	-0.66 **	ns	1	
7	days to bud colour	ns	ns	ns	ns	ns	ns	1
8	days to flower	ns	ns	ns	ns	ns	-0.51 *	0.58 *

* and ** indicate significance of correlation at p=0.05 and 0.01, respectively.

Lithodora 'Heavenly Blue'

Figure 9a. Maximum flower number - Main treatments.
Bar = LSD(0.05)

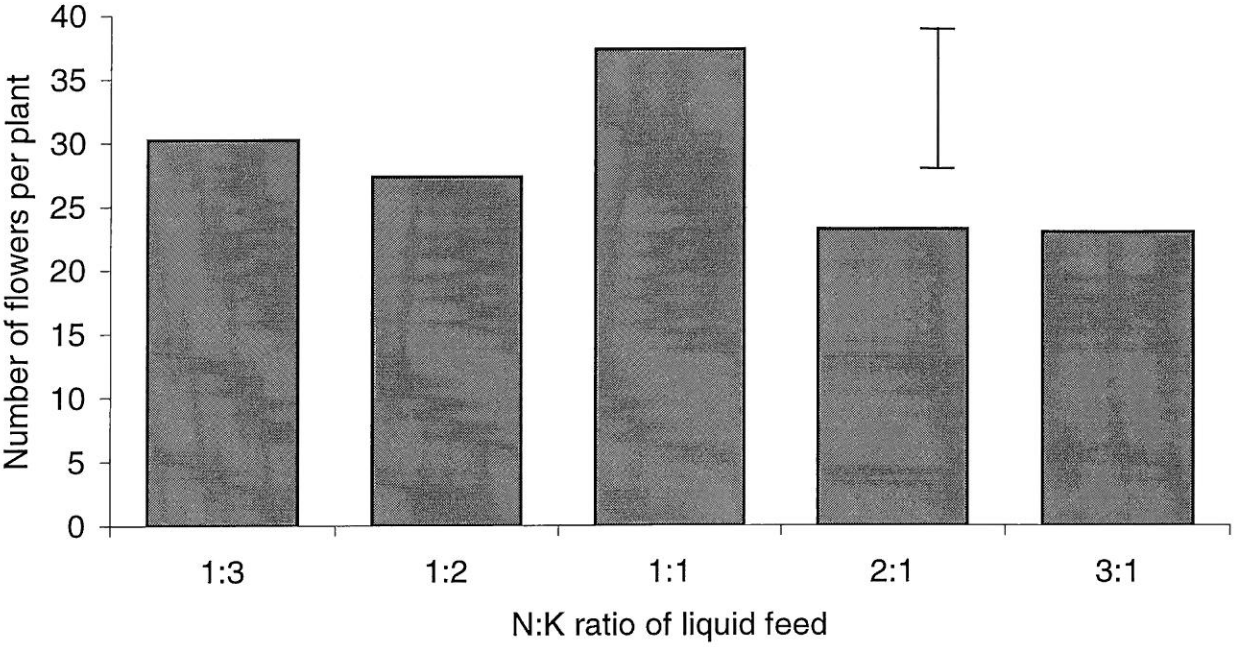
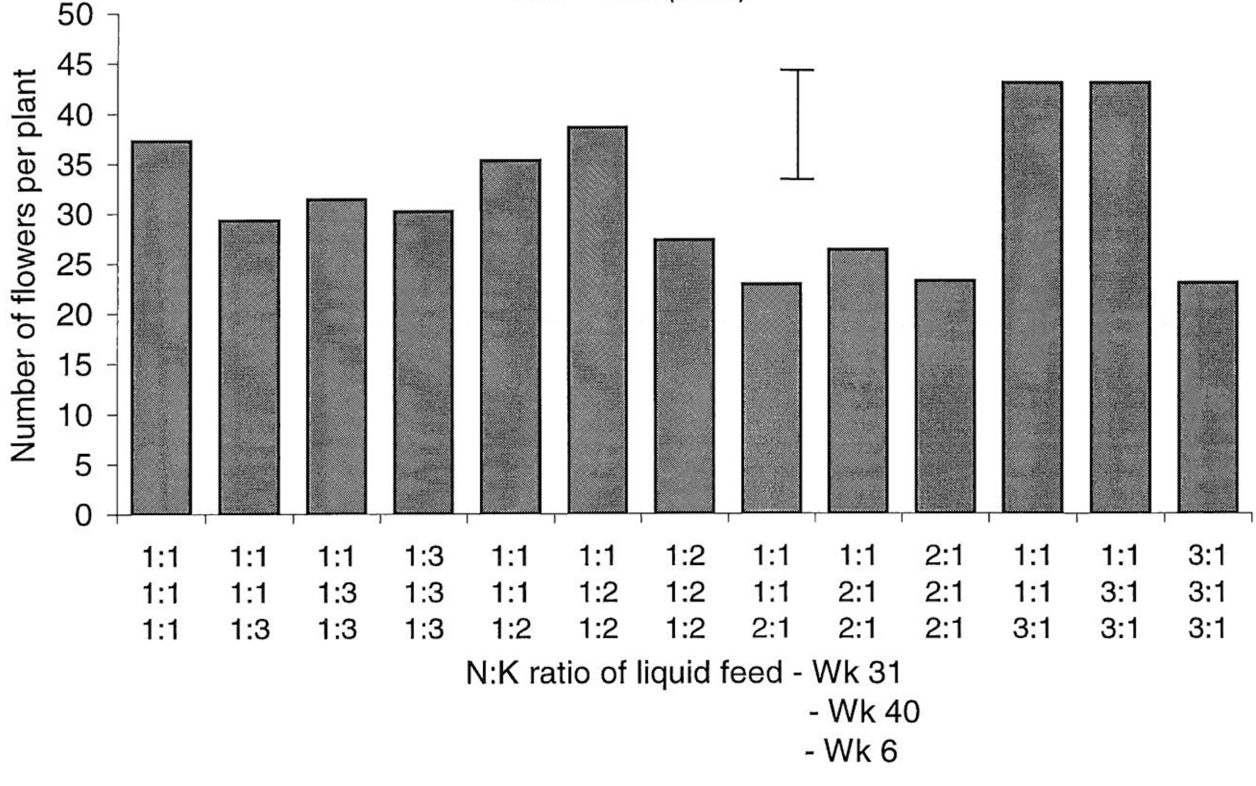


Figure 9b. Maximum flower number - All treatments.
Bar = LSD(0.05)



Lithodora 'Heavenly Blue'

Figure 10a. Average day of first coloured bud and open flower - Main treatments. Bar = LSD(0.05)

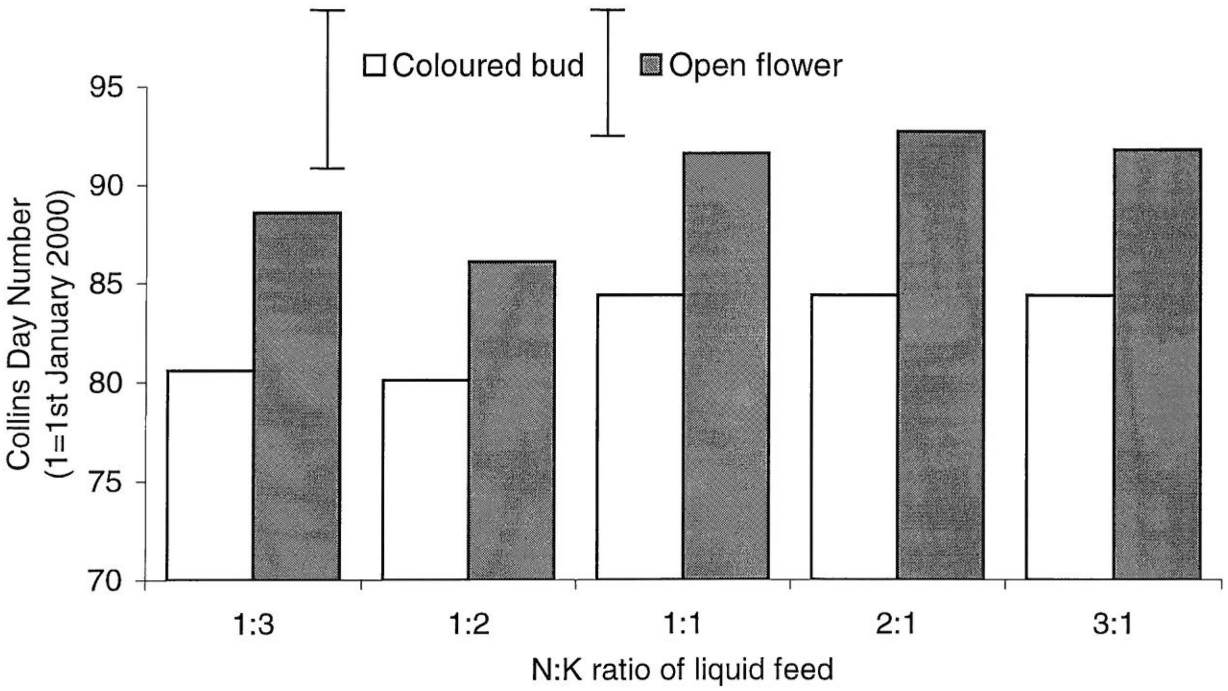
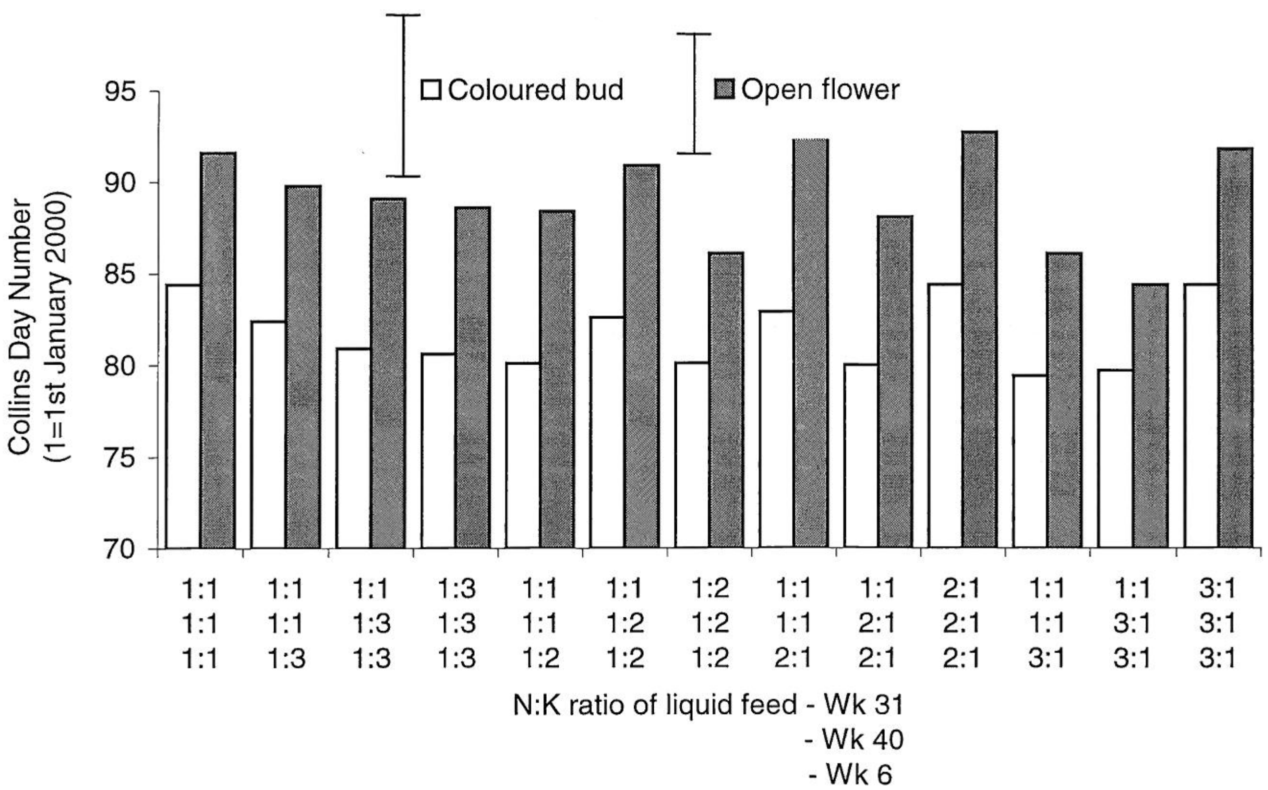


Figure 10b. Average day of first coloured bud and open flower - All treatments



Lithodora 'Heavenly Blue'

Figure 11a. Size score - Main treatments. Bar = LSD(0.05)

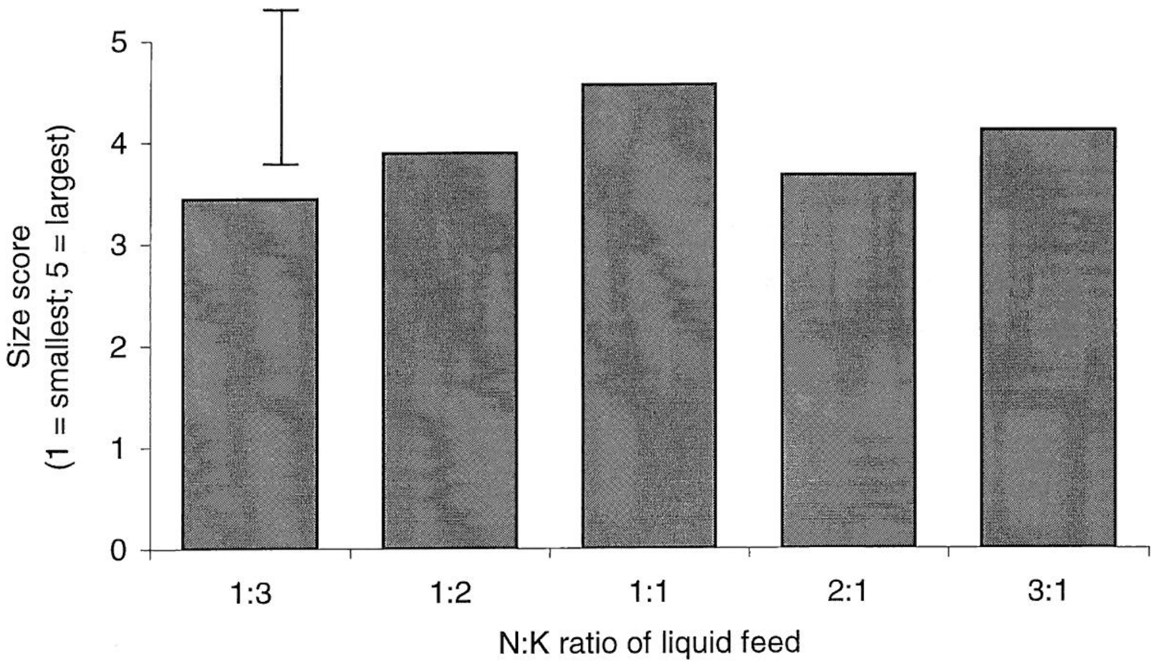
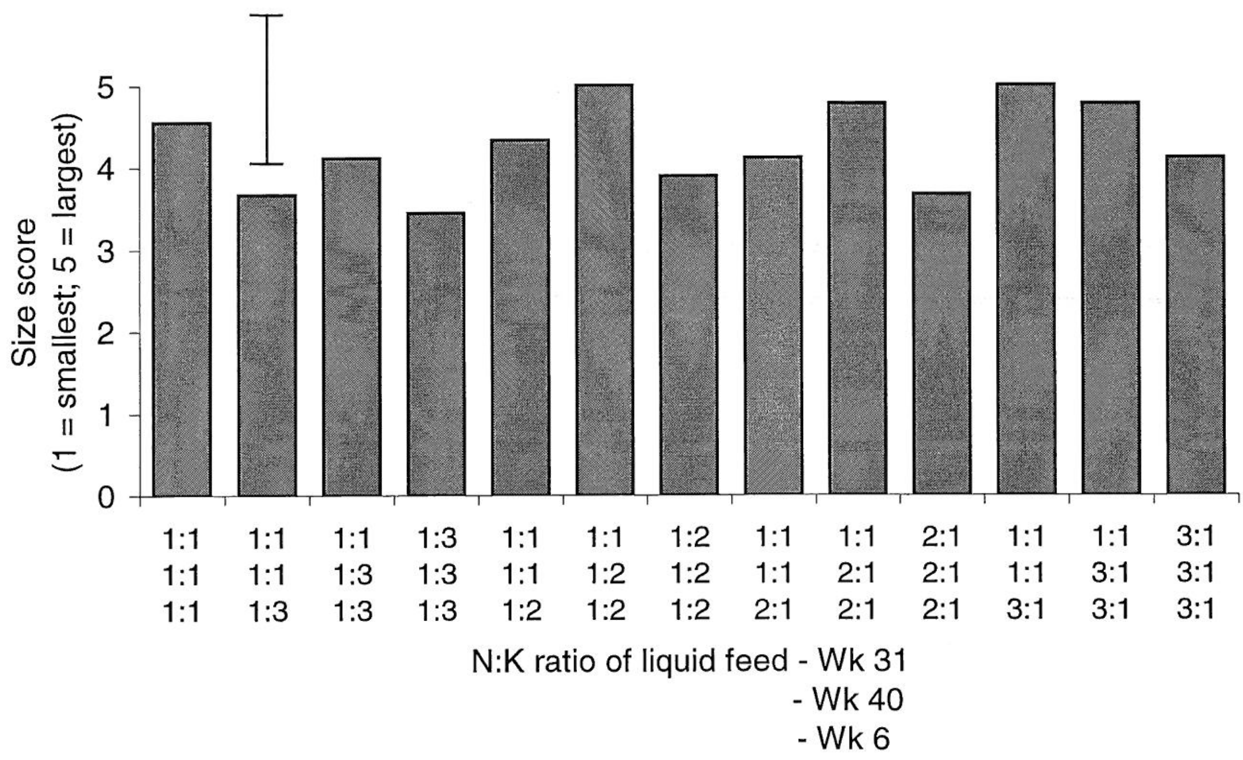


Figure 11b. Size score - Main treatments. Bar = LSD(0.05)



Lithodora 'Heavenly Blue'

Figure 12a. Foliage dry weight (g) - Main treatments. Bar = LSD(0.05)

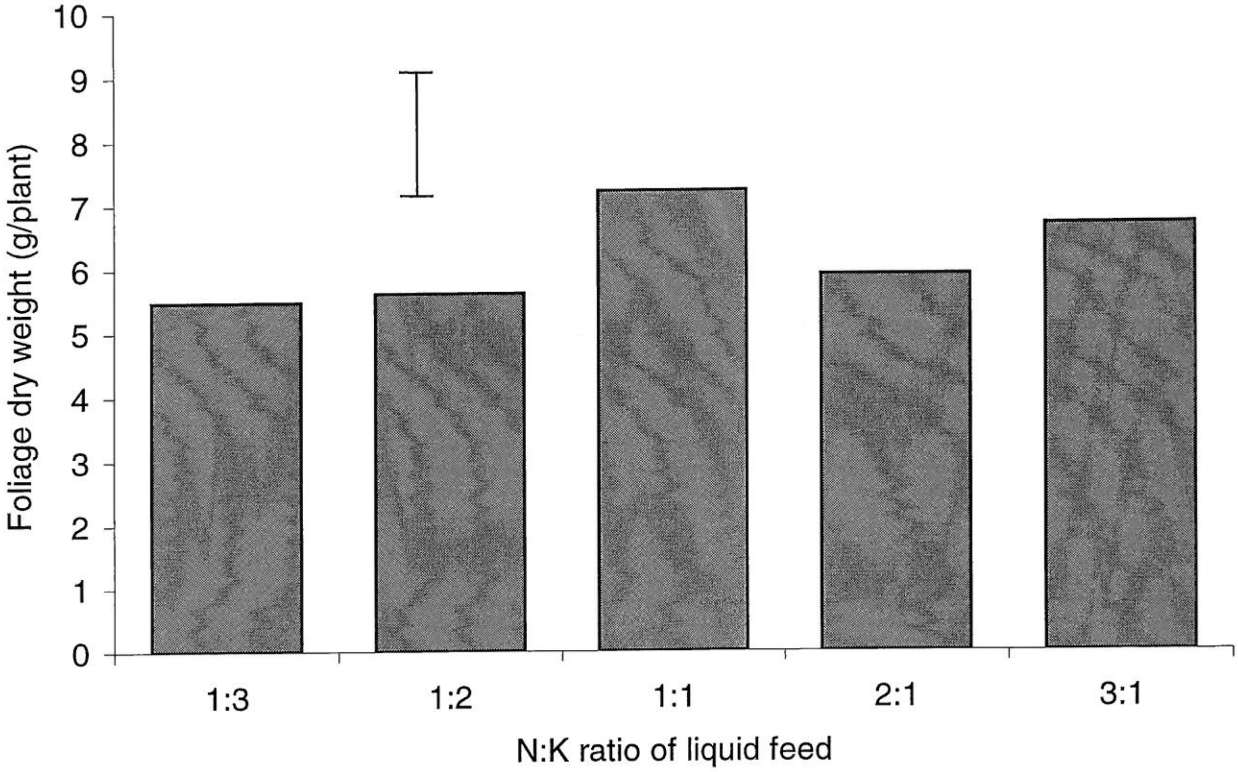
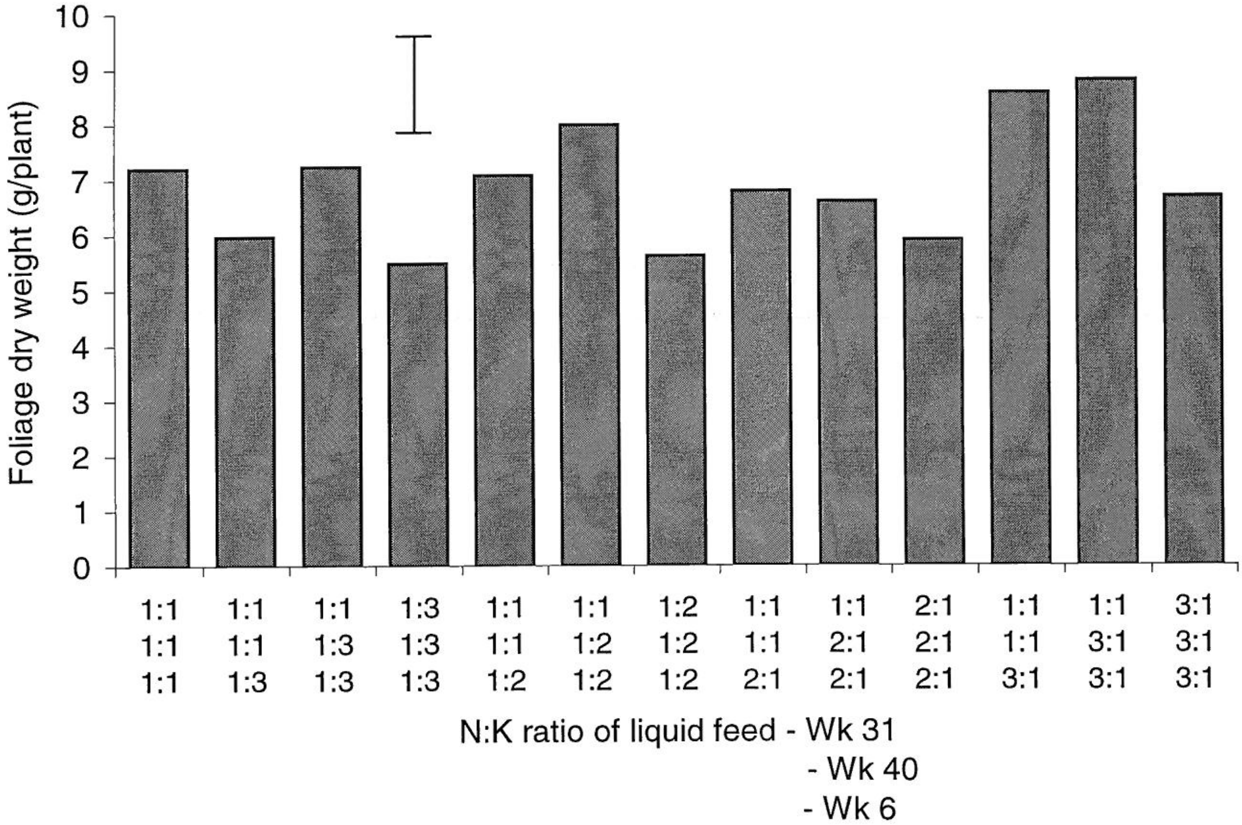


Figure 12b. Foliage dry weight (g) - All treatments. Bar = LSD(0.05)



Discussion

This work investigated the role of nutrition in the number and time of flower production. The study was carried out from August to May and covered the period of flower development (expression). The initiation of flowers may also have occurred during this period. However, no physiological studies were undertaken to establish the phase of meristem growth (ie vegetative of floral growth) and one can only speculate on this issue. The role of environmental conditions in flower initiation and expression has recently been reviewed in HNS 103 and the findings discussed here should not be viewed in isolation of those interactions. Nutrition is one of a number of factors influencing flowering.

Nutrient accumulation

A range of nutrient treatments were applied to the plants, from low K (3:1) to high K (1:3) liquid feed solutions. Interestingly, although the N:K ratio in the foliage (ranging from 1:2.3 to 1:3.3) was similar to the feed concentration at the high K treatment, the foliage N:K ratio never dropped below 1:1, even when the feed solution was 3:1. This suggests that N and K are accumulated at a fixed ratio close to 1:1 with deficiencies in K limiting the uptake of N. Where K was supplied in excess of this ratio, accumulation increased relative to the amount available in solution. This is in agreement with the observations of Mengel & Arneke, 1982. This response was similar for the three species studied and must be borne in mind when considering plant response to treatment as large treatment differences may lead to small 'perceived' differences in the plant.

Plant growth

In *Geranium* biomass was greatest where plants were grown with the 1:1 solution until week 6 and then changed to either high K solution (1:2 or 1:3), showing that late growth benefited from high K nutrition. However, early growth required adequate N, as plants grown with high K solutions alone produced poor growth with pale foliage. In contrast to *Geranium*, *Pulmonaria* growth was similar regardless of treatment, but the two main high K treatments (1:2 and 1:3) gave the tallest plants. K is involved in water relations within the cell and it has been suggested that high K treatments lead to increased cell expansion (Mengel & Kirkby, 1982) and hence longer pedicels as observed. With *Lithodora* no clear response to K was observed although a change in the feed solution appeared to stimulate biomass production in the majority of combination treatments. However, when the growth data was correlated with *foliage* nutrient levels a reduction in dry weight was associated with high levels of K in the foliage.

Flowering

The number of flowers produced by the *Geranium* plants was greatest with either a 1:1 or 3:1 feed. High K feeds reduced the number of flowers and delayed flowering, as a main treatment or a mixed treatment and changing feed solutions from 1:1 reduced the number of flowers produced even when changing to high N solutions. There was a lot of variation in *Pulmonaria* flowering among treatments and no clear pattern emerged. In contrast to *Geranium* the 1:1 feed solution reduced flower number and delayed flowering, with high K and high N solutions increasing flower number. Mixed treatments delayed flowering to a certain extent. There was also a lot of variation in the *Lithodora* flowering results. Both high N and high K solutions reduced flower number compared to a balanced 1:1 feed solution. However, the time to flowering was reduced using the high K solutions compared to either 1:1 or high N solutions.

Benefit of K in herbaceous flowering plants

No consistent effect of high K in either growth or flowering was observed in the three species studied in this trial. High K treatments did increase pedicel length in *Pulmonaria* but had no clear effect on flowering. Later application of high K feed produced greater growth in *Geranium* but higher foliage K was associated with reduced biomass in *Lithodora.* In both *Geranium* and *Lithodora* high K treatments reduced flower number but hastened flowering in *Lithodora* and delayed flowering in *Geranium.*

A large body of anecdotal evidence supports the use of high K fertilisers, and manufacturers of fertilisers claim that a high K analysis fertiliser is suitable for improved flowering, yet few scientific studies have demonstrated benefits of increased K in flower development and quality. It may be that the anecdotal evidence is unreliable, and high potash (high K) is not of clear benefit to flowering. Benefits may be due to lower N concentration reducing soft growth and improving cold tolerance and also increased pedicel length enhancing flower 'presentation' (as shown with *Pulmonaria).*

Conclusions

Under the condition this trial was completed, no clear and consistent benefits were observed in response to K nutrition in the growth and flowering of three herbaceous species. This is in agreement with scientific reports but counter to the widely held belief that high potash benefits flowering. Further, more extensive, work is necessary to examine these responses (or lack of them).

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