FINAL REPORT (APRIL 1995)

Project No FV41

STARTER FERTILIZER FOR DRILLED HORTICULTURAL CROPS

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RELEVANCE TO GROWERS AND PRACTICAL APPLICATION

APPLICATION

The project was aimed at improving fertilizer use efficiency and crop growth by the injection of small amounts of liquid fertilizer close to the seed at drilling. Starter fertilizers of different formulations were tested with a range of crops on soils of varying fertility and texture. The results of the work, taken together with similar work funded by MAFF Environmental Protection Division, show that the technique offers opportunities for maintaining yields of some crops with reduced fertilizer inputs, even on less fertile soils.

SUMMARY

Work at HRI Wellesbourne over several years has established that targeting small quantities of liquid fertilizer near the seed of some drilled crops can overcome the transient nutrient deficiencies associated with the use of conventional broadcast fertilizers. Broadcast and incorporated fertilizer granules enrich only a small fraction of soil. The delay before a seedling root intercepts an enriched zone can result in a depression in early growth and may irreversibly reduce final yield. To overcome these problems, current fertilizer advice for P and K is based on maintaining high levels of residual nutrients in the soil, and for N recommended rates are often greater than those required to meet crop demand. These strategies waste fertilizer, and the potential losses to the environment cause public concern. An alternative approach is to:

- satisfy early nutrient demand by injecting liquid starter fertilizer close to the seed, where it is readily available to the developing root system.
- meet later demand from reduced amounts of base or top-dressings, or from residual soil nutrients.

The aims of the current work were to examine the formulation of starter fertilizer and to examine the response to starter with a range of crops and soils.

Injection technique

The work made use of the HRI drill-mounted injection system (see final report of project no FV41a for more detail), which uses land-wheel driven peristaltic pumps to deliver adjustable rates of fertilizer to narrow injection tines (5 mm, tapering to 3 mm) working 25 mm below seed depth. Injection rates can be varied by changing the size of the silicon rubber tubes in the pumps. The rates used in the current project were:

INJECTION RATES WITH HRI SYSTEM		
TUBE BORE (MM)*	5.0	8.0
RATE (ML/M ROW)	9.3	18.6
* TUBING WALL THICKNESS 1.6 MM; DRILLING SPEED 3.2 KPH		

Summary of Results

- Ammonium phosphate starter fertilizer, in the presence of recommended levels of N, increased marketable yield of carrot, lettuce, onion and parsnip on a fertile sandy loam soil (P index 4, K index 2). The inclusion of K in the starter was not beneficial. Effects with calabrese, red beet and spinach were not significant.

- On a low fertility sandy loam soil (P index 2, K index 0) starter fertilizer, in the presence of recommended levels of N, increased marketable yields of carrot, lettuce, onion and Summer greens. The inclusion of some K in the starter was beneficial. The best treatments gave early growth of carrot and onion comparable to that on the high fertility soil.

- In subsequent work on the low fertility site with lettuce carrot and onion, a starter supplying 740-3720-1550 mg/m $N:P_2O_5:K_2O$ plus recommended levels of seedbed N gave yields equivalent to higher levels of broadcast PK.

- On a site with gradients of residual P (indices 2 to 9) and K (indices 0 to 5), a starter supplying 380-2230-1100 mg/m $N:P_2O_5:K_2O$ largely eliminated the effect of both the

P and K gradient on early growth of onion and carrot, and to a lesser extent with lettuce and French bean.

- A high phosphate starter (8-24-0, supplying 20 kgN/ha and 60 kgP_2O_5/ha) has enabled high yields of crisp lettuce, bulb onion and salad onion to be achieved with half the total N application, compared to broadcast ammonium nitrate used alone. At equivalent rates of N, grading was improved - 30% increase in onion bulbs >55 mm and 40% increase in lettuce iceberg heads.

- In trials on a peat soil, in a year in which response to broadcast N was small, yields of marketable lettuce, but not onion, were dramatically increased by starter fertilizer. On a high PK status silt soil there was no lasting benefit of starter fertilizer with either of these crops.

Points to note

1. Stanhay Webb Ltd markets versions of the HRI injection system that are suitable for their full range of precision vegetable drills. Alternative systems could be used, but care is needed to minimise soil disturbance beneath the seed that can affect drilling depth and disrupt soil water movement to the seed adversely affecting emergence.

2. It is important, with systems using peristaltic pumps that the tubes are correctly tensioned. If too tight across the pump rollers, the tubing will collapse, markedly reducing output. It is therefore advisable, until experience has been obtained, to check the rate by measuring the output from **each** injection line by turning the land wheel a fixed number of turns. Knowing the circumference of the wheel, the rate can be calculated in ml/m.

3. In HRI trials, one central injection tine per row has been found suitable for both single and twin line drilling but it has not been tested with triple lines.

4. The starter fertilizers used in these trials were donated by Hydo-Chafer. At the rates used there was no adverse effect on emergence when injected 25 mm below the seed.

Other liquid or soluble fertilizers are available commercially but were not tested. Experience would suggest caution in using those containing chloride or nitrate ions.

5. Previous work suggests that the benefits of starter P are likely to be greatest early in the season when soil temperatures are low, since root activity and release of soil P increase with increasing soil temperatures.

6. There has been little on-farm development work done on starter fertilizers, other than the specific examples noted in this report. We therefore suggest that growers wishing to evaluate starter fertilizers start with the application rates outlined here and then adjust according to experience gained under their own conditions.

Practical and financial benefits

The use of starter fertilizer offers a range of management options. For a given fertilizer application rate marketable yields are often increased when starter is used as part of the dressing, even on fertile soils. More importantly, from an environmental standpoint and the need to show due diligence in fertilizer use, starter fertilizers enable yields to be maintained with reduced fertilizer inputs, even on less fertile soils. With some crops additional benefits such as earlier maturity and improved grading have been demonstrated. Although not tested experimentally, it seems likely that the increased vigour of early growth will improve flexibility in timing of herbicide applications.

Uncertainties remain in predicting when the early benefits of starter fertilizer will persist to maturity. This is because of variations in the release of soil mineral N under different soil conditions and the effects of soil water content on the availability of residual soil P and K. MAFF funded work is continuing to explore these problems.

The cost of the starter fertilizers used in this work was about £125/1000 l for 8-24-0 and £160/1000 l for 0-17-17. The 0-17-17 is expensive compared to the potassium chloride component of granular fertilizers, and is unlikely to be cost effective as a starter in many situations. The cost of 8-24-0 used at a rate of 9.3 ml/m, based on a row length of 22,222 m/ha (4 rows at 38 cm spacing on 1.8 m beds), is broadly comparable to the cost of 75kgN/ha as ammonium nitrate. The potential financial benefit from starter fertilizer will vary with the aims (reduced inputs, increased yield, improved grading etc) of individual growers.

EXPERIMENTAL SECTION

INTRODUCTION

Studies have shown that the concentration of nutrients required in the soil to permit the maximum growth rate of young seedlings is much higher than that needed by older plants (Costigan, 1988). When fertilizer is broadcast and incorporated shortly before drilling in the conventional way, high rates are needed to meet nutrient requirements for maximum early growth. This is due to the limited size of the young root system in relation to the distribution of fertilizer granules in the soil (Costigan, 1987a; Greenwood *et al.*, 1989). If early demand is not met, crops suffer transient nutrient deficiencies that can lead to set backs in early growth and an irreversible reduction in final yield or delayed maturity (Burns, 1990).

To overcome these problems, current U.K. fertilizer advice for P and K is based on maintaining high levels of residual nutrients in the soil, while for N recommended rates are often more than those required to meet total crop demand. These strategies are inefficient in the use of fertilizer and potential losses to the environment cause public concern.

An alternative approach is to satisfy the early nutrient demand of drilled crops by injecting small amounts of liquid starter fertilizer close to the seed, where it is readily available to the emerging radicle (Costigan, 1988). To achieve this, novel drill-mounted injection equipment developed at HRI (Rowse *et al.*, 1988), was later modified to minimise soil disturbance beneath the seed. This equipment is now available commercially (Stanhay Webb Ltd) and fits a range of precision vegetable drills (Rowse, 1993).

Previous pot and field experiments at HRI showed that starter fertilizers could increase the early growth and final yield of some crops, even on fertile soil in the presence of ample dressings of broadcast fertilizer (Costigan, 1984; 1988). More recently, using the new equipment, it was shown that ammonium phosphate starter fertilizer, supplying 20kg N/ha, could dramatically increase early growth of bulb onion and crisp lettuce, while enabling broadcast nitrogen application rates to be halved without loss of final yield (Stone & Rowse, 1992). This improved the recovery of applied N fertilizer by the crop, and there was also some evidence that the rapid seedling development also led to earlier maturity and improved grading.

In most of the recent experiments ammonium phosphate was used as the starter fertilizer since it is known that ammonium and phosphate ions are both strongly absorbed on soil and cause little change in the osmotic concentration of the soil solution. However, since K uptake can be reduced by high concentrations of ammonium ions (Tromp, 1962), it was considered that inclusion of K in the starter solution might be advantageous. Early attempts at including K failed to show any benefits, however, because of seedling damage due to the osmotic effect of the chloride ions in the potassium chloride component of the compound fertilizers tested. With the increasing commercial availability of liquid potassium phosphate fertilizer, the objectives of the current project were to re-examine the formulation of starter fertilizer and to examine the response with an extended range of crops and soils.

Five experiments are described, which were aimed at:

1. examining starter formulation on soils of contrasting fertility (year 1)
2. maximising crop yields on low PK status soil (year 2)
3. assessing the benefits of starter in relation to soil PK status (year 2)
4. extending the range of crops tested with starter fertilizer (year 3)
5. extending the range of soils tested with starter fertilizer (year 3)

EXPERIMENT 1

MATERIALS AND METHODS

The experiments were carried out at Wellesbourne on a sandy-loam soil of the Wick series (Whitefield, 1974), in two adjoining fields of contrasting fertility. The two fields were Pump Ground (PG) (high fertility P index 4; K index 2) which also received 1 t/ha of 0-24-24 fertilizer incorporated in the seedbed and Wharf Ground (WG) (low fertility P index 2; K index 0) which did not receive additional PK fertilizer. All other cultural operations were identical in the two fields and carried out on the same day. Total mineral N in the soil to 30 cm at drilling was 31 and 25 kg/ha in PG and WG respectively. Four crops were grown, carrot cv Nandor, crisp lettuce cv Saladin, bulb onion cv Hysam and summer greens cv Dorado. These were sown, between 28 March and 10 April, into four single line rows 28 cm apart on 1.52 m beds, using a Stanhay belt seeder carrying the starter injection attachment. All crops were given nitrogen (ammonium nitrate) as an initial base dressing (80 kgN/ha lettuce, onion and summer greens; 60 kgN/ha carrot) followed, as appropriate to the crop, by top dressing.

The starter fertilizer treatments consisted of commercially available (Hydro-Chafer) ammonium phosphate (8-24-0, a mixture of mono- and di-ammonium phosphates) and potassium phosphate (0-17-17) diluted and mixed in various proportions (Table 1) to give solutions with constant P and varying N and K concentrations. Starter was injected 25 mm below sowing depth at a rate of 18.6 ml/m of row, giving rates equivalent to 0-20 kg N, 59 kg P_2O_5, 0-58 kg K_2O per ha. On control plots, tap water was injected at the same rate and position. Treatments were arranged in a randomized block design with three replicates.

Seedling emergence was recorded on 7 or 8 occasions on a 1.5 m length of each plot. Fresh and dry weight plant samples were taken on four or five occasions during the season between establishment and maturity.

Table 1. ***The experimental starter fertilizer treatments, and nutrient application rates.***

NP = ammonium phosphate at 50% dilution   KP = potassium phosphate at 68.75% dilution

Tmt No.	Starter - composition % of diluted NP and KP solutions	N mg/m row	P_2O_5 mg/m row	K_2O mg/m row
1	Control - water only			
2	100% NP	753	2250	0
3	75% NP + 25% KP	565	2250	553
4	50% NP + 50% KP	377	2250	1106
5	25% NP + 75% KP	188	2250	1659
6	100% KP	0	2250	2212

RESULTS

Treatments had no consistent effect on percent emergence or days to 50% emergence, although carrots were, on average, 1.1 days faster ($P<0.05$) to 50% emergence on the low fertility site with starter compared to the control.

The dry weight yields for the four crops from both the high and low fertility sites are shown for two selected harvests in Figs 1a - 4a (early) and in Figs 1b - 4b (final).

High fertility site

On the high fertility site (PG) starter fertilizer, irrespective of formulation, significantly increased early growth ($P<0.05$) of each crop, except summer greens. The magnitude of the dry matter increase, averaged across starter treatments, varied from 27-77%. Although these early benefits diminished with time, total dry matter at final harvest was still increased by 9-13% by starter fertilizer. This was reflected in significant ($P<0.05$) increases in marketable yield of 13% for onions (>25 mm), 7% for iceberg lettuce (heads >450 g) and 16% for carrot (>10 mm). Carrot was also graded on maximum diameter and this revealed a much larger increase (30%) in the 25-30 mm target size grade with the starter treatments (Fig 5). Formulation of the starter solution had no significant effect on the growth of onions or cabbage (the apparent poor growth with ammonium phosphate alone in the cabbage harvest shown in Fig 4a being attributed to pigeon damage on two of the replicates). With lettuce, a poor initial response was recorded with potassium phosphate alone, although this effect disappeared by maturity (cf. Figs 2a and 2b). With carrot, the inclusion of K at rates of 1106 mg K_2O, or above, per m of row was not as effective as ammonium phosphate alone (Figs 1a & b).

Low fertility site

As anticipated on a soil with low residual PK and without broadcast fertilizer, starter fertilizer had a dramatic and significant effect on the early growth of each crop. With the best starter treatments, early growth was 100 - 1000 times better than the control. Not surprisingly, these large benefits persisted to final harvest resulting in increases in dry matter of 30% cabbage, 75% carrot, 130% onion and 260% lettuce. There was a significant advantage to the inclusion of K in the starter solution, with the mixed formulations containing 553 - 1106 mg K_2O per m of row generally best at all harvests.

A remarkable, and unexpected, feature of the results was the ability of a small amount of starter fertilizer to raise early yields of carrot and onion on the low fertility site to those given only broadcast fertilizer on the nutrient rich soil (Figs 1a and 3a). Although the effect did not persist beyond the early bunching stage of carrot or salad size of onion, the results nevertheless suggest that starter fertilizer might offer possibilities of achieving good yields on soils of lower residual PK than currently recommended.

EXPERIMENT 2

MATERIALS AND METHODS

Following the previous years results, the study at Wellesbourne was developed to see how far combinations of starter fertilizer with broadcast or injected fertilizer could maintain productivity on the low PK status soil. The experiment was carried out using three crops, carrot cv Nandor, crisp lettuce cv Saladin and onion cv Hysam. Total mineral-N in the soil to 30 cm at drilling was 37 kg/ha. The treatments are shown in Table 2.

The starter fertilizer consisted of mixtures of ammonium phosphate and potassium phosphate at two concentrations, 4-20.5-8.5 (%N-P_2O_5-K_2O, w/v), treatment 2 and half that concentration, treatment 3. These were injected at 18.6 ml/m row, 25 mm below the drill line. Treatment 2 provided 744 mg N, 3813 mg P_2O_5 and 1581 mg K_2O per m of row (equivalent to 20 kg N, 100 kg P_2O_5 and 42 kg K_2O per ha) and treatment 3 half these amounts. Starter fertilizer treatments were compared with broadcast P and K (as triple-superphosphate and potassium sulphate) incorporated in the seedbed at either the recommended rate for the crop, treatment 4, or at half the recommended rate, treatment 5 (MAFF, 1988). Starter fertilizer was also used in combination with the two rates of broadcast fertilizer (treatments 6 and 7), but the broadcast rate was reduced to allow for the P and K supplied by the starter. Nitrogen rates appropriate to the crop, and similarly adjusted, were also broadcast and incorporated in the seedbed for treatments 2-7.

Table 2. ***Treatments and recommended rates of broadcast PK fertilizer.***

Codes in parentheses refer to Figs 6-8.

TMT. NO.	TREATMENT		
1	Control - no NPK (zero)		
2	Starter high (SH)		
3	Starter low (SL)		
4	Broadcast at the recommended rate (B/RR) for the crop (see below)		
5	Broadcast at half the RR (B/.5RR)		
6	SH plus broadcast up to the RR (SB/RR)		
7	SL plus broadcast up to half the RR (SB/.5RR)		
8	SH plus point injected up to the RR (SI/RR)		
9	SL plus point injected up to half the RR (SI/.5RR)		
	Recommended rates (kg/ha):	P_2O_5	K_2O
	Carrot	175	250
	Onion	150	275
	Lettuce	250	175

To test an alternative technique of supplementing starter fertilizer, in treatments 8 and 9, liquid fertilizer was injected alongside the row using point injectors (Cady Systems, Inc., Ankenny, Iowa, USA) fitted to a Stanhay toolbar and fed by the same peristaltic pump system used on the starter injection drill. Four, spring-loaded injection wheels were attached to the toolbar, each offset 150 mm to the side of the drill line. Each wheel had twelve, 12.5 mm diameter spokes spaced 175 mm apart at the outer rim that penetrated the soil to a depth of 60 mm. The liquid fertilizer was fed by the pumps into a stainless steel axle fitted with ports which allow the liquid to flow out of the axle and into the spokes as they rotate around the hub. The liquid fertilizers, prepared from mixtures of urea, ammonium phosphate and potassium chloride, were made up to concentrations that enabled the total amount of supplementary NPK fertilizer to be point injected in two passes of the spoke wheel, one either side of the row, giving 37.2 ml/m of row (to achieve the recommended rate for onion two passes were required on each side of the row). Injection was carried out after crop establishment but before the roots had extended to the point of injection.

A control treatment receiving no NPK was included for comparison. On the control plots, and those receiving only broadcast fertilizer, tap water was injected at the same rate and position as the starter at the time of drilling. All treatments were replicated three times in a randomized block design.

Fresh and dry weight samples were taken on four occasions between establishment and maturity.

RESULTS

As in the previous year, there were no consistent treatment effects on the plant stand of any of the crops throughout the season. Data from selected harvests is shown in Figs 6a-8a for early dry weight harvests and Figs 6b-8b for the final mature fresh weight harvests.

Early growth of each crop was significantly enhanced by starter fertilizer, particularly at the higher rate, when compared with the recommended rate of broadcast fertilizer. This early starter effect was generally not enhanced by the addition of supplementary PK, irrespective of whether it was broadcast or point injected. Although the early benefits from starter fertilizer diminished with time, the final marketable yields were not significantly different from those obtained with the much higher rates of broadcast fertilizer. There were also no additional benefits at maturity from combining starter fertilizer with supplementary PK.

EXPERIMENT 3

MATERIALS AND METHODS

To assess the benefits of starter fertilizer to early seedling growth in relation to levels of residual soil nutrients, an experiment was carried out at Wellesbourne using land on which separate P and K gradients had previously been established. Five replicate gradients had been prepared in October 1990 by ploughing down eight levels of either triple superphosphate (0-3500 kg P/ha), or muriate of potash (0-4800 kg K/ha) in contiguous 6 x 6 m plots. All plots on the P gradient also received a uniform application of 3250 kg K/ha, and similarly on the K plots an application of 900 kg P/ha. By April 1992, natural leaching had reduced the conductivity of the plough layer (0-25 cm) to a level at which no restriction to plant growth was expected (2000 micro-siemans, ADAS index 0). Two beds 1.5 m wide were laid down on each gradient and sown with single rows, 28 cm apart, of carrot cv Nandor, lettuce cv Saladin, and onion cv Hysam on 16 April, plus one of French bean cv Label on 21 May. At drilling, half the beds were given starter fertilizer, consisting of a mixture of ammonium phosphate and potassium phosphate (as treatment 4, experiment 1), applied 25 mm below the drill line, and the other half tap water. In addition, each bed received 80 kg N/ha, as ammonium nitrate, broadcast and incorporated in the seedbed. A single harvest of total above ground dry matter (plus tap root of carrot) was taken from a 1.5 m length of row, about 30 days after 50% emergence of each crop. Soil samples, to 20 cm depth, were taken after harvest at each nutrient level on the gradient from the beds that had not received starter fertilizer. Each sample was analysed for sodium bicarbonate extractable P and ammonium acetate exchangeable K. Water soluble P and K were measured on a saturation extract by colorimetry and flame-photometry respectively. The analyses showed that the P gradients had uniformly high levels of available K (400 μgK/ml or ADAS index 3; and 4 μgK/ml of soil solution), with residual levels of available P of between 22-350 μgP/ml (ADAS index 2-9; and 0.4-98 μgP/ml of soil solution). Similarly, the K gradients had uniformly high levels of available P (85μgP/ml or ADAS index 5; and 25 μgP/ml of soil solution), with available K of between 45-830 μgK/ml (ADAS index 0-5; and 1-75 μgK/ml of soil solution). To identify the level of residual soil P and K above which there was no significant response to starter fertilizer a nonparametric method of statistical analysis, bootstrapping (Banks, 1989), was carried out using the Genstat BOOTSTRAP procedure.

RESULTS

For clarity, the effects of residual P and K, and of starter fertilizer, on mean plant dry weights are shown plotted against ADAS P (Figs 9-12) and K (Figs 13-16) indices, and the detailed statistical analyses are summarised in Table 3.

Mean plant dry weights of carrot (Fig 9) and onion (Fig 11) decreased 3 or 5-fold as levels of residual P fell from index 5 to 2. This effect was largely eliminated by starter fertilizer. With lettuce (Fig 10) the effect of declining levels of residual P over the same range was less marked (about 30%) but starter fertilizer increased early dry weights by an average of 20% irrespective of the initial level of soil P. In contrast to earlier work on a similar gradient of residual P in the same field (Costigan, 1987), French bean (Fig 12) did not respond to the level of residual P. Nevertheless, starter fertilizer still increased plant size by 30% when averaged across the range of indices available.

On the K gradient, mean plant dry weights of carrot (Fig 13), lettuce (Fig 14) and onion (Fig 15) declined by 60-100% as levels of residual K fell from index 2 to 0. With starter fertilizer mean weights were more or less constant whatever the level of residual K in the soil and were considerably higher by 18% lettuce, 30% carrot and 70% onion. With French bean there was no response to level of residual K but starter fertilizer increased early growth by an average 30%, irrespective of the level of K.

Table 3. ***Levels of residual soil P and K above which there were no significant effects of starter fertilizer (n.d. = not determined).***

	Phosphorus			Potassium		
Crop	ADAS index	Extractable µgP/ml	Soil solution µgP/ml	ADAS index	Exchangeable µgK/ml	Soil solution µgK/ml
Carrot	5	81	6	3	284	18
Lettuce	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Onion	6	141	14	4	572	>75
French Bean	n.d.	n.d.	n.d.	2	233	22

EXPERIMENT 4

MATERIALS AND METHODS

In the final year, the starter fertilizer investigation was expanded to cover a wider range of crops grown on a single high PK status soil at Wellesbourne (Experiment 4) and earlier work on lettuce and onion was extended to silt (HRI Kirton) and peat (ADAS Arthur Rickwood) soils (Experiment 5). The treatments, each replicated three times, were common to Experiments 4 and 5 and are summarised in Table 4 below.

In previous starter fertilizer work the ammonium phosphate had been used at half the supplied strength (treatment 2). This enabled the N application rate to remain constant whether the starter was diluted with water or potassium phosphate. To avoid carrying an unnecessary weight of liquid, it would be preferable, in practice, to apply the ammonium phosphate at full strength but at half the rate per metre of row. To ensure that this concentration was not detrimental, a full strength treatment (treatment 3) was included for comparison with past practice. Following on from year 1, the inclusion of K as potassium phosphate was tested with these crops and soils in combination with ammonium phosphate (treatment 4). Three rates of broadcast nitrogen (as ammonium nitrate) were included to compare nitrogen response curves in the presence (treatments 8-10) and absence (treatments 5-7) of starter fertilizer, as detailed in Table 4. Where broadcast nitrogen was used in combination with starter fertilizer, the rates were reduced to compensate for the 20 kg/N applied in the starter. Rates of broadcast N up to 80 kg N/ha were incorporated in the seedbed with the remainder top-dressed after crop establishment. All starter fertilizer was injected 25 mm below the drill line. In non-starter treatments, tap-water was injected instead.

Experiment 4, at Wellesbourne, was sited on a sandy loam soil (P index 3; K index 2; pH 6.3) following a one year, cut and unfertilized grass ley. Based on previous cropping, a soil nitrogen index of 0 was expected (MAAF, 1988). However, total mineral N to 60 cm after drilling was found to be much higher than expected, at 230 kg/ha. Parsnip cv Improved Marrow and red beet cv Bikores were drilled on 23 March into 9 m plots, containing four rows 28 cm apart in 1.52 m wide beds. Calabrese cv Hi-Calibur and spinach cv Spectrum were similarly drilled on 16 April. Yields were measured on two (calabrese and spinach), three (red beet) or four (parsnip) occasions during growth.

Table 4. Treatment summary (experiments 4 and 5).

TMT. NO.	TREATMENT			
1	Control - water only			
2	Ammonium phosphate starter (NP/H2O) - half strength (4-12-0) at 18.6 ml/m row			
3	Ammonium phosphate starter (NP only) - full strength (8-24-0) at 9.3 ml/m row			
4	Ammonium / potassium phosphate starter (NP/KP) - 50:50 mix of 8-24-0 and 0-17-17 (4-20.5-8.5) at 18.6 ml/m row			
5-7	Broadcast ammonium nitrate at three rates dependent on crop (see below)			
8-10	Ammonium phosphate starter (half strength at 18.6 ml/m) plus broadcast ammonium nitrate up to the levels of N in treatments 5-7			
	Broadcast rates of N (kg/ha):			
	Calabrese and Red beet	90	180	270
	Parsnip	40	80	120
	Spinach	60	120	180
	Onion - Kirton	40	80	120
	Onion - Arthur Rickwood	30	60	90
	Lettuce - Arthur Rickwood and Kirton	60	80	120

RESULTS

Plant fresh weights at selected harvests are shown in Figs 17-20. With each crop there were no consistent differences, across harvests, between the two concentrations of ammonium phosphate (NP & NP/H2O), nor any benefit from including potassium (NP/KP) in the starter formulation. Nitrogen response curves were also rather flat, presumably because of the high level of mineral-N in the soil at the start of the experiment. Of the four crops tested, parsnip was the most responsive to starter fertilizer. Averaged across rates of applied N, starter plus broadcast N increased total plant weight (shoot plus tap root) at an early harvest, by 70% in comparison with broadcast nitrogen alone (fig 17a). Although the benefit of starter decreased with time, a significant ($P<0.05$) 20% increase in root fresh weight persisted to final harvest (Fig 17b). Calabrese showed no increase in early growth (data not shown), and at final harvest (Fig 18) differences in trimmed head weights were generally not significant, except at the 160 kg N/ha rate where the combination of starter plus broadcast nitrogen was the best treatment. It was noticeable, however, that the ammonium phosphate starter alone gave good yields with much lower levels of N. Spinach (Fig 19) showed a small, but significant ($P<0.05$), depression in final yield of 7% from the use of starter that was not apparent at an earlier harvest. Red beet tops and roots were largely unresponsive to starter fertilizer in this high N soil (Fig 20a and b).

EXPERIMENT 5

MATERIALS AND METHOD

The experiment at Arthur Rickwood was on a light peat-loamy soil of the Prickwillow series (P index 3; K index 4; pH 6.7) and at Kirton on a coarse silty alluvial soil (P index 6; K index 2-3; pH7.6-7.8). Onion cv Hysam and lettuce cv Saladin R100 were drilled on 31

Mar and 19 Apr respectively at Kirton, and together on 7 Apr at Arthur Rickwood. To fit in with existing equipment, the crops were grown at both sites on 1.8 m beds but were drilled, as at Wellesbourne, in four rows 28 cm apart in the centre of the bed. Yields were measured at early and final harvests with the later, for lettuce, divided into two harvests a week apart.

RESULTS

As at Wellesbourne, there were no consistent differences between starter formulations or between the two concentrations of ammonium phosphate. At Kirton, neither lettuce nor onions responded significantly to starter fertilizer and the data is not presented. Although visual assessments of early growth of onions suggested an initial starter benefit, this did not persist to salad onion size, possibly because of the high level of residual P in the soil. At Arthur Rickwood, a similar increase in early vigour of onions lasted to salad size (Fig 22a) giving a significant ($P<0.05$) 13% increase in total dry matter (averaged across rates of applied N), but this effect did not persist to dry bulb harvest (Fig 22b). Nevertheless, starter fertilizer did give high yields with low levels of nitrogen. Lettuce at Arthur Rickwood showed a clear positive response to starter fertilizer that, in the absence of a broadcast nitrogen response, was not enhanced by combining starter fertilizer with broadcast N (Figs 21a and b). At 77 days from sowing, the use of starter fertilizer approximately doubled individual plant dry weight (Fig 21a), and the benefit was maintained until final harvest. Fig 21b shows the highly significant ($P<0.001$) increase with starter fertilizer in fresh weight yield of trimmed heads above the supermarket minimum of 450g for iceberg lettuce at the first of the mature harvests. A week later, at the second of the final harvests, starter fertilizer treatments were still outyielding the conventional treatments by 43%. At both mature harvests, starter fertilizer alone gave similar yields to starter plus supplementary broadcast N.

CONCLUSIONS

Experiment 1 supported early findings that showed that small amounts of starter fertilizer could enhance early growth of some crops, even on soils with high available nutrient status and in the presence of ample freshly applied fertilizer. More surprisingly, it was discovered that certain starter fertilizer formulations enabled young crops on the low fertility soil to grow as rapidly as those without starter fertilizer on the high fertility soil. It is perhaps not surprising that this equality of growth was not maintained as the crops matured, because the quantity of P and K in the starter would not have been sufficient for the demands of the mature crop. It has previously not been possible, by fresh application of PK fertilizer, to raise the productivity of a low PK status soil to that of a high PK status soil (Costigan et al., 1983: Costigan & McBurney, 1983). While seedlings require small total amounts of nutrients, the demand per centimetre of root is high and this can only be met by maintaining a high concentration of nutrients in the soil solution. If this can be achieved by using starter fertiliser in localised areas close to the seed, then satisfactory yields might still be achievable if the bulk soil is maintained at a lower nutrient status than currently advised. This was demonstrated by Experiment 2 when final marketable yields with starter fertilizer were not significantly different from those obtained with the much higher recommended rates of broadcast P and K. This finding offers considerable scope for reducing fertilizer inputs in situations where it would be uneconomic to raise levels of residual soil nutrients to non-limiting amounts or where nutrient pollution was a potential problem.

The treatments in Experiments 1, 4 and 5 that investigated the inclusion of K in the starter solution suggest that this is unlikely to be beneficial on soils with high levels of residual K. Results from the gradient work (Experiment 3) suggest that starter fertilizer can largely eliminate the depression in early growth of some crops that occurs on low P or K status soils but shows that the effects of starter fertilizer on early growth will be small at P indices above 5/6 or K indices above 3/4. The response to starter fertilizer is likely to vary with soil water conditions; the wetter the soil the greater the availability of residual soil nutrients. To account for this interaction, work is continuing, under MAFF funding, to extend the HRI nitrogen response model to P and K.

Previous work (Stone & Rowse, 1992) showed that ammonium phosphate starter fertilizer supplying 20 kg N/ha, enabled nitrogen application rates for bulb onion and lettuce to be at least halved without loss of yield. In the current work (Experiments 4 and 5), in a difficult season in which response to broadcast nitrogen was very small, the yields with starter fertilizer alone were not enhanced by supplementary nitrogen. To permit nitrogen inputs to be predictably reduced without loss of yield it would be necessary to identify those situations where additional N is required to sustain the early benefits of starter fertilizer through to maturity. However, because of the large variations in soil mineral N under different soil conditions, there are uncertainties in estimating exactly how much additional N is required to provide recommendations that avoid excessive use of fertilizer. MAFF Environmental Protection Division are currently funding work aimed at sustaining the benefits of starter fertilizer to maturity by combining its use with either foliar applications of N or N top-dressings. The latter are based either on simple 'on-farm' measurements of soil mineral N made at the start of the grand period of growth, or on recommendations from the HRI nitrogen response model WELL_N. If successful, the reliability of this work will require testing on different soils under a wide range of weather conditions if it is to be adopted by the industry.

It should be borne in mind that each experiment in the current project extended over one growing season only and that the results consequently may differ under different environmental conditions. Nevertheless, taken collectively, and with past starter fertilizer work, the conclusions are believed to be valid. Growers should be aware that there has been little on-farm testing of starter fertilizers. We suggest that those wishing to evaluate the technique base their application rates on those used in these experiments and then make further adjustments based on experience gained in their own particular growing situation.

ACKNOWLEDGEMENTS

Much of the early development work on starter fertilizers and the subsequent work on the environmental aspects of their use formed part of a research programme commissioned by the Ministry of Agriculture, Fisheries and Food.

We are grateful to Hydro-Chafer for supplying, free of charge, the starter fertilizers used in this work, and to ICI plc for the free loan of the spoke-wheel injector. We also wish to thank Mr C Dawson of Dawson Associates for arranging the above supplies and for helpful discussion on the potential use of starter fertilizers.

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CAPTIONS TO FIGURES

Note. Scales vary between graphs.

Figs 1-4. Effect of starter fertilizer formulation on dry weight yield at two harvests (**a.** early **b.** final) of carrot (Fig 1), crisp lettuce (Fig 2), onion (Fig 3) and summer greens (Fig 4) on two sites (Pump Ground - high fertility, Wharf Ground - low fertility). Treatment codes are given in Table 1. (Experiment 1)

Fig 5. Effect of starter fertilizer (averaged across formulations) on size grade of carrot on Pump Ground - high fertility site. (Experiment 1)

Figs 6-8. Effect of starter fertilizer, with and without supplementary broadcast or injected PK, at two harvests (**a.** early **b.** final) of carrot (Fig 6), crisp lettuce (Fig 7), and onion (Fig 8) on a low fertility site. Treatment codes are given in Table 2. (Experiment 2)

Figs 9-12. Effect of starter fertilizer on early seedling growth of carrot (Fig 9), lettuce (Fig 10), onion (Fig 11) and French bean (Fig 12) on soil with a gradient of residual P. (Experiment 3)

Figs 13-16. Effect of starter fertilizer on early seedling growth of carrot (Fig 13), lettuce (Fig 14), onion (Fig 15) and French bean (Fig 16) on soil with a gradient of residual K. (Experiment 3)

Figs 17-20. Response of parsnip (Figs 17a & b), calabrese (Fig 18), spinach (Fig 19) and red beet (Figs 20a & b) at selected harvests to starter fertilizer alone or in combination with broadcast ammonium nitrate, in comparison with broadcast ammonium nitrate alone. Treatments codes are shown in Table 4. (Experiment 4)

Figs 21-22. Response of lettuce (Figs 21a & b) and onion (Figs 22a & b) at selected harvests to starter fertilizer alone or in combination with broadcast ammonium nitrate, in comparison with broadcast ammonium nitrate alone on a peat soil. Treatments codes are shown in Table 4. (Experiment 5)

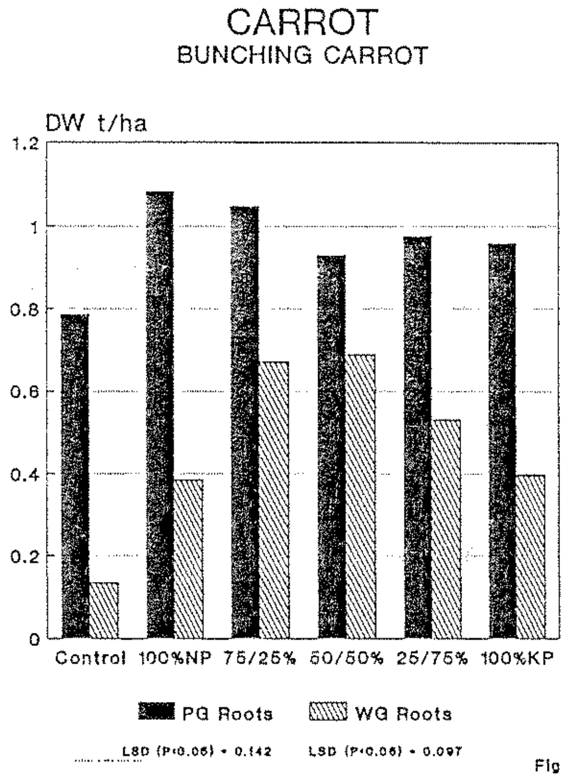

CARROT
BUNCHING CARROT
DW t/ha
1.2
1
0.8
0.6
0.4
0.2
0
Control 100%NP 75/25% 50/50% 25/75% 100%KP
PG Roots
WG Roots
LSD (P<0.05) = 0.142
LSD (P<0.05) = 0.097

Fig 1a

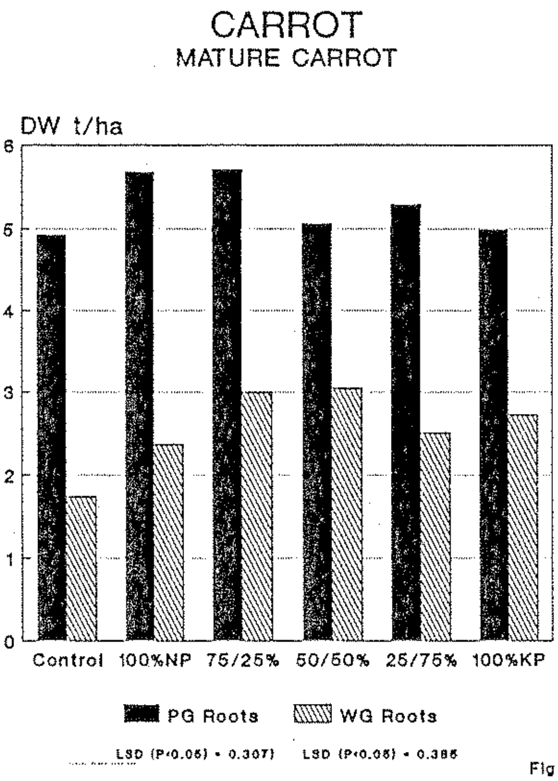
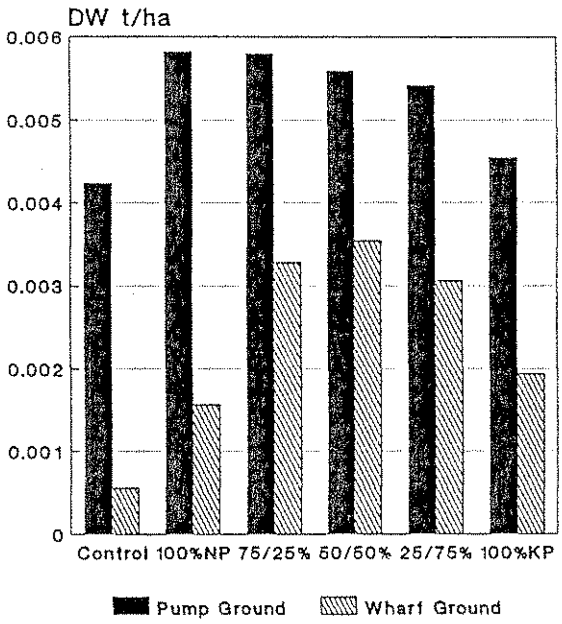

CARROT
MATURE CARROT
DW t/ha
6
5
4
3
2
1
0
Control 100%NP 75/25% 50/50% 25/75% 100%KP
PG Roots
WG Roots
LSD (P<0.05) = 0.307)
LSD (P<0.05) = 0.386

Fig 1b

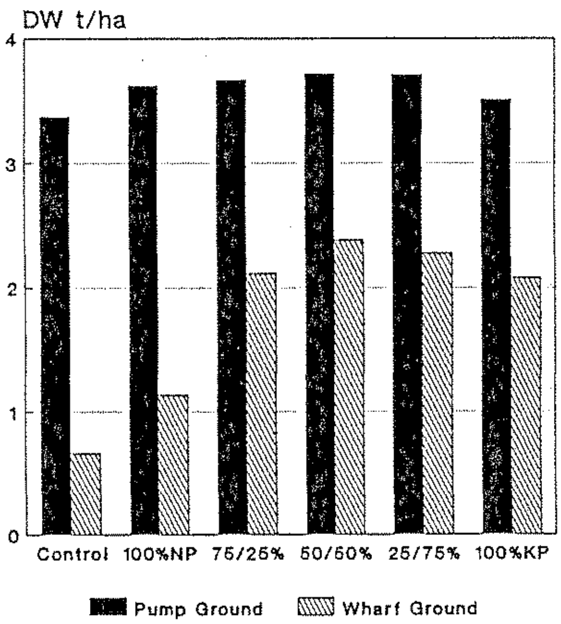
LETTUCE
THINNING STAGE



LSD (P<0.05) = 0.0003 LSD (P<0.05) = 0.0010

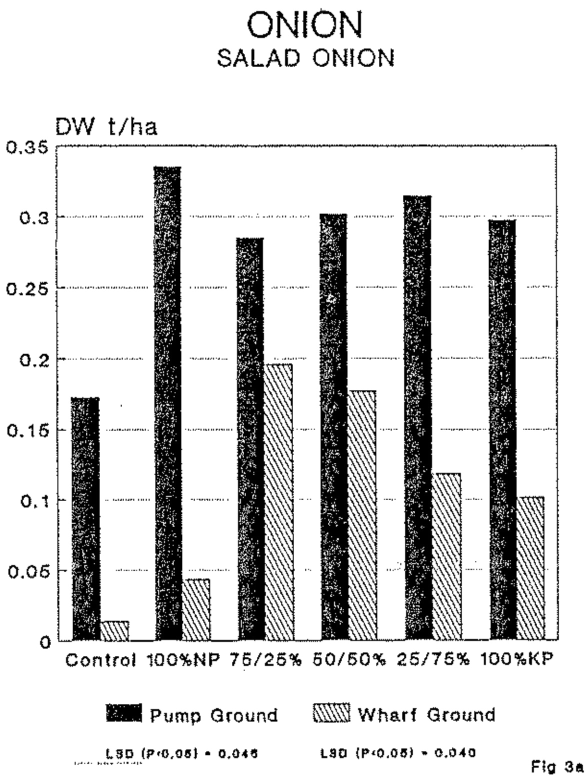
Fig 2a

LETTUCE
MATURE HEADS



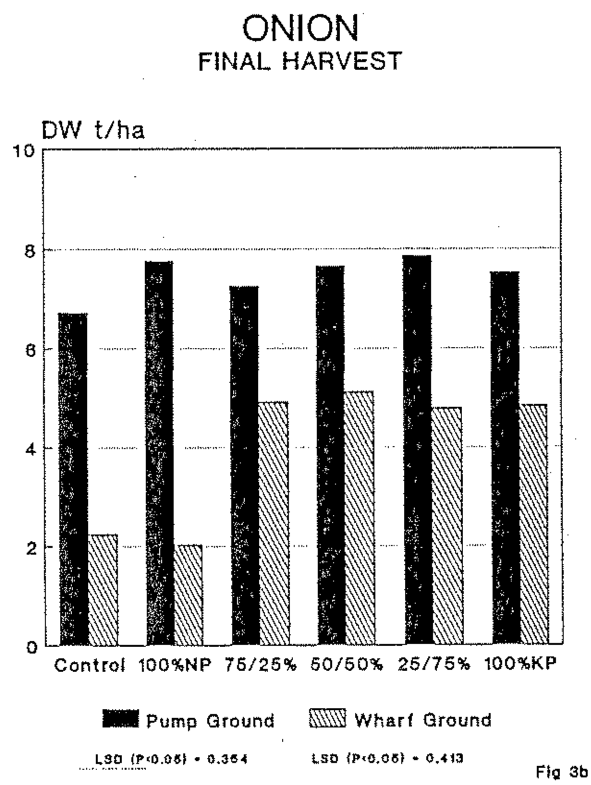
LSD (P<0.05) = 0.473 LSD (P<0.05) = 0.348

Fig 2b



ONION
SALAD ONION
DW t/ha
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Control 100%NP 75/25% 50/50% 25/75% 100%KP
Pump Ground
Wharf Ground
LSD (P<0.05) = 0.046
LSD (P<0.05) = 0.040

Fig 3a



ONION
FINAL HARVEST
DW t/ha
10
8
6
4
2
0
Control 100%NP 75/25% 50/50% 25/75% 100%KP
Pump Ground
Wharf Ground
LSD (P<0.05) = 0.354
LSD (P<0.05) = 0.413

Fig 3b

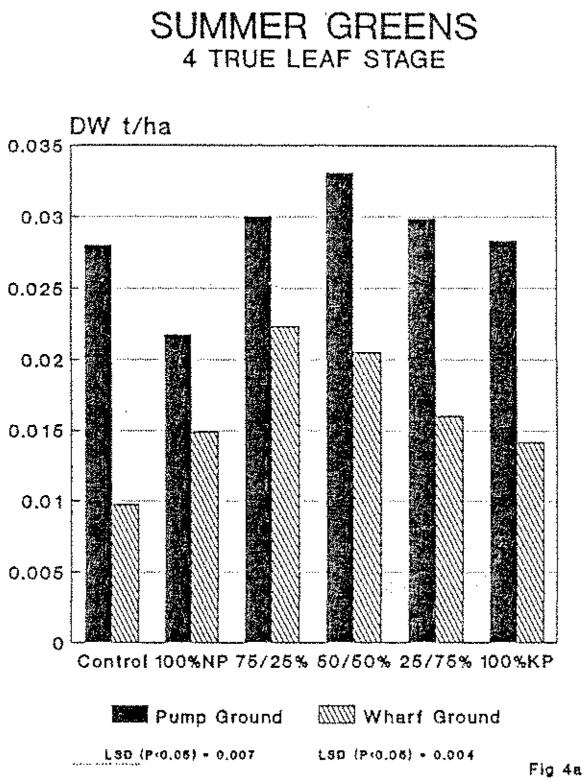

SUMMER GREENS
4 TRUE LEAF STAGE
DW t/ha
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
Control 100%NP 75/25% 50/50% 25/75% 100%KP
Pump Ground
Wharf Ground
LSD (P<0.05) = 0.007
LSD (P<0.05) = 0.004

Fig 4a

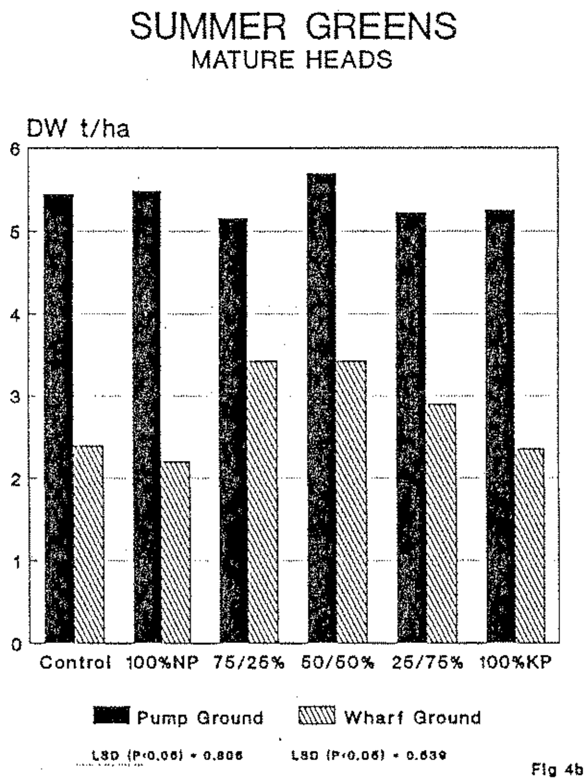
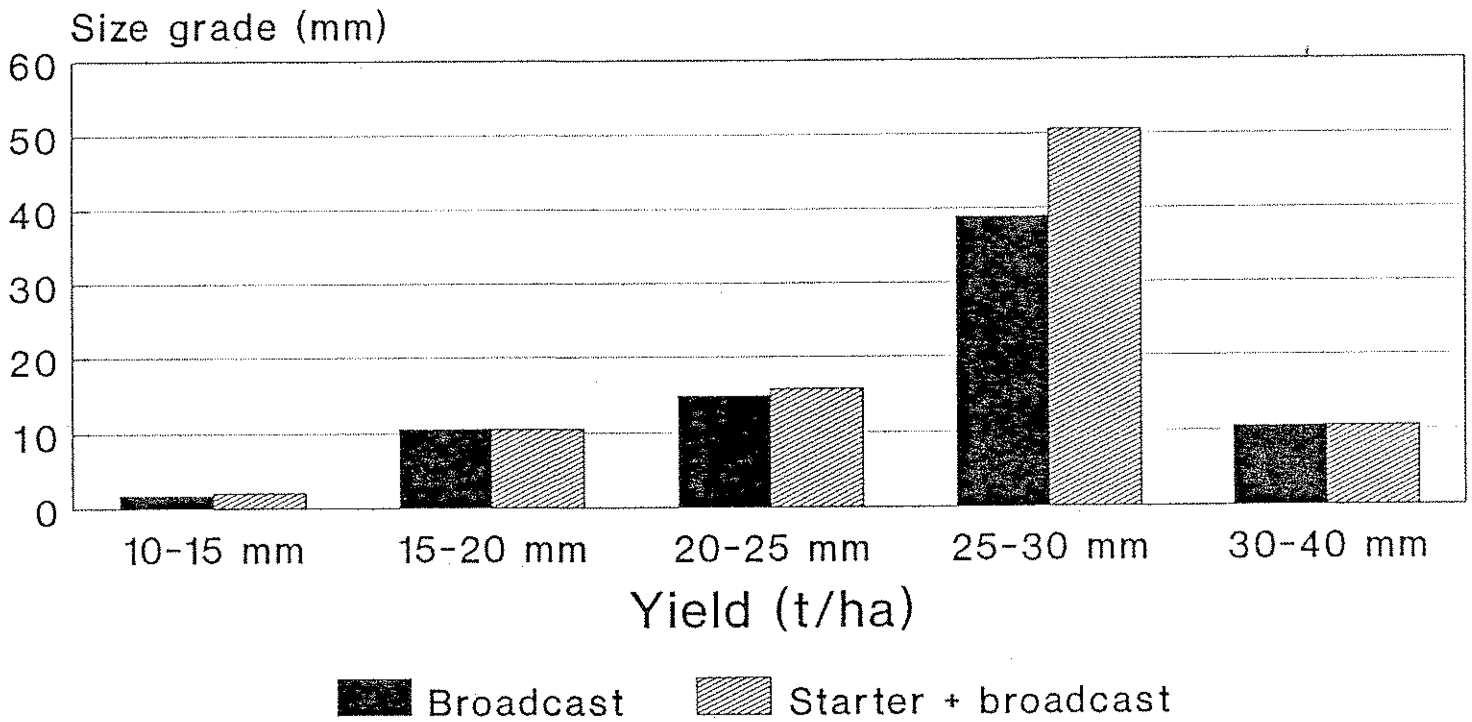

SUMMER GREENS
MATURE HEADS
DW t/ha
6
5
4
3
2
1
0
Control 100%NP 75/25% 50/50% 25/75% 100%KP
Pump Ground
Wharf Ground
LSD (P<0.05) = 0.806
LSD (P<0.05) = 0.639

Fig 4b

CARROT

FW ROOTS BY GRADE
HIGH FERTILITY SITE



BENEFITS OF STARTER

30% INCREASE IN ROOTS 25-30 mm

Fig 5

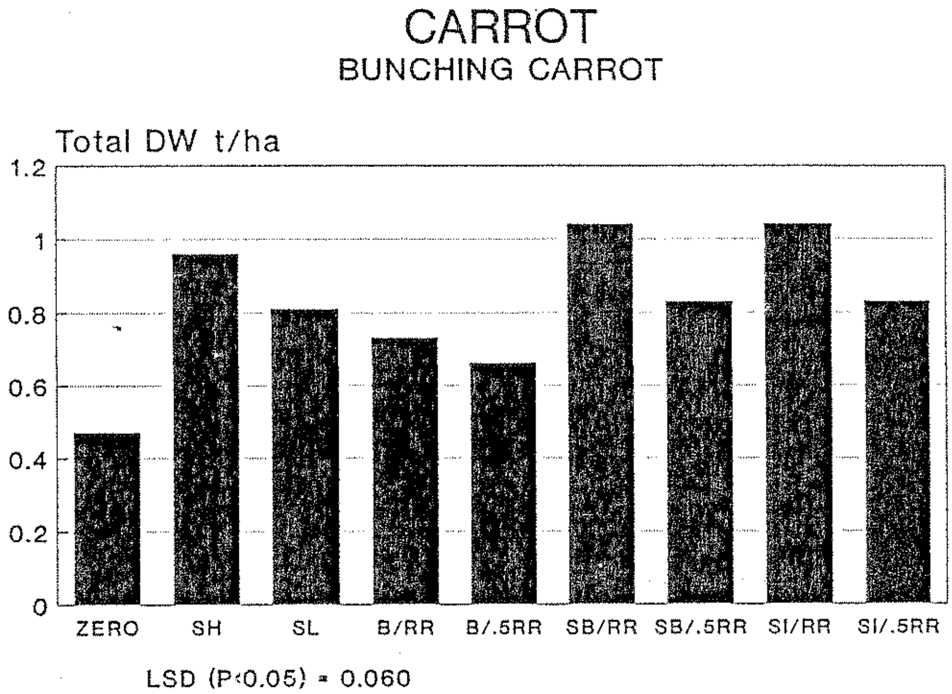

CARROT
BUNCHING CARROT
Total DW t/ha
1.2
1
0.8
0.6
0.4
0.2
0
ZERO
SH
SL
B/RR
B/.5RR
SB/RR
SB/.5RR
SI/RR
SI/.5RR
LSD (P<0.05) = 0.060

Fig 6a

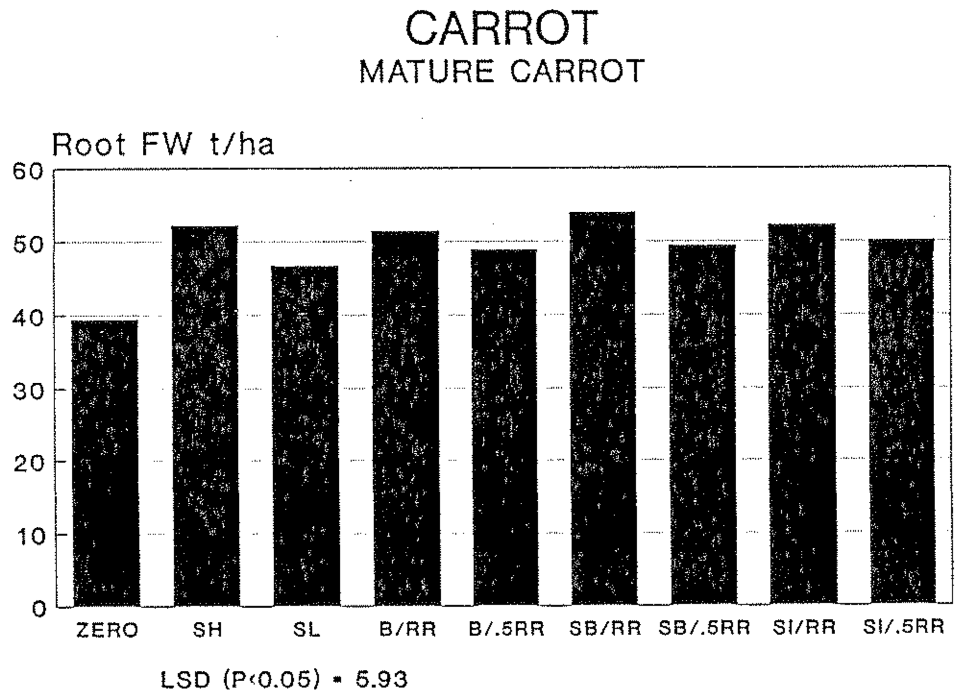

CARROT
MATURE CARROT
Root FW t/ha
60
50
40
30
20
10
0
ZERO
SH
SL
B/RR
B/.5RR
SB/RR
SB/.5RR
SI/RR
SI/.5RR
LSD (P<0.05) = 5.93

Fig 6b

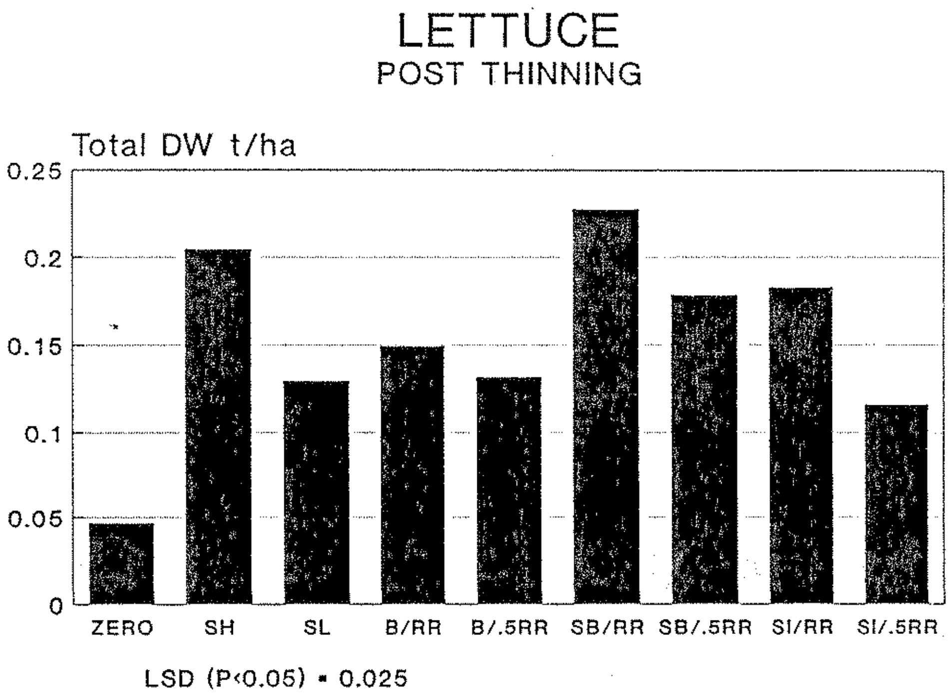

LETTUCE
POST THINNING
Total DW t/ha
0.25
0.2
0.15
0.1
0.05
0
ZERO
SH
SL
B/RR
B/.5RR
SB/RR
SB/.5RR
SI/RR
SI/.5RR
LSD (P<0.05) = 0.025

Fig 7a

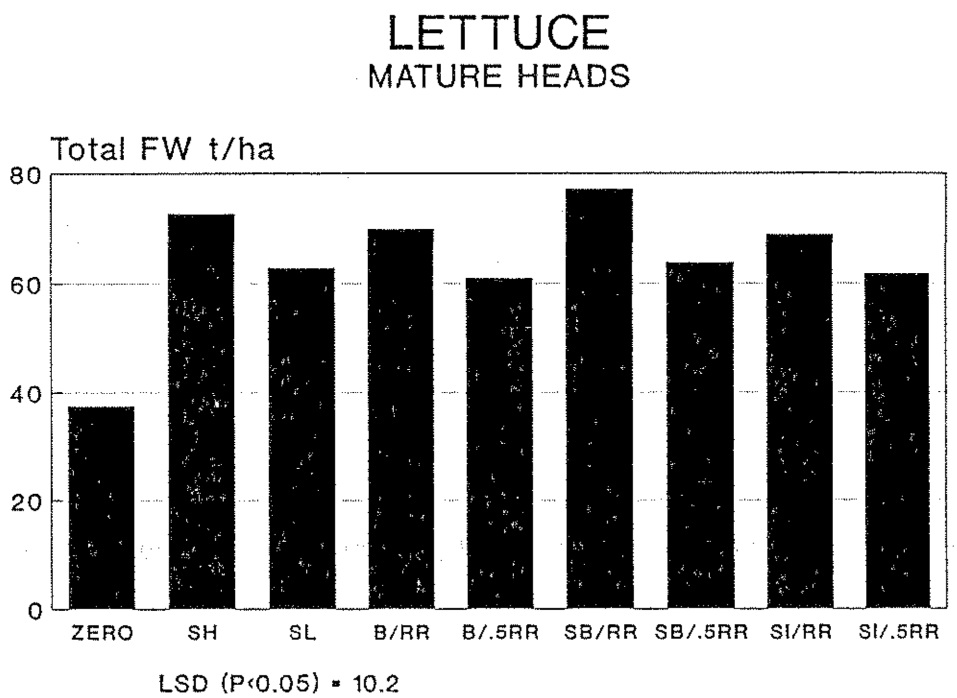

LETTUCE
MATURE HEADS
Total FW t/ha
80
60
40
20
0
ZERO
SH
SL
B/RR
B/.5RR
SB/RR
SB/.5RR
SI/RR
SI/.5RR
LSD (P<0.05) = 10.2

Fig 7b

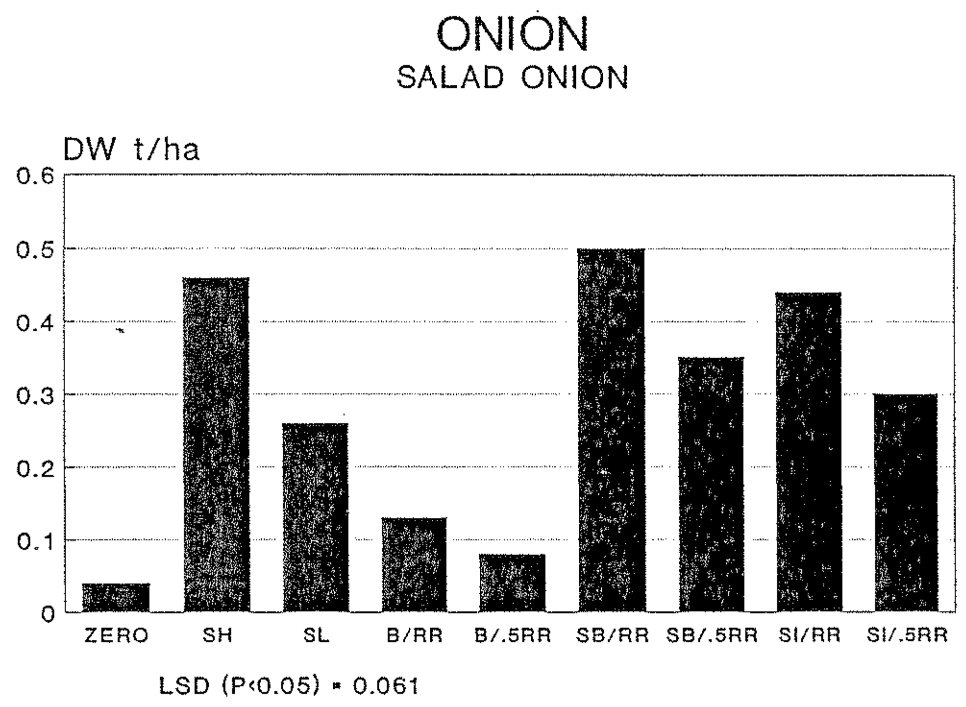

ONION
SALAD ONION
DW t/ha
0.6
0.5
0.4
0.3
0.2
0.1
0
ZERO
SH
SL
B/RR
B/.5RR
SB/RR
SB/.5RR
SI/RR
SI/.5RR
LSD (P<0.05) = 0.061

Fig 8a

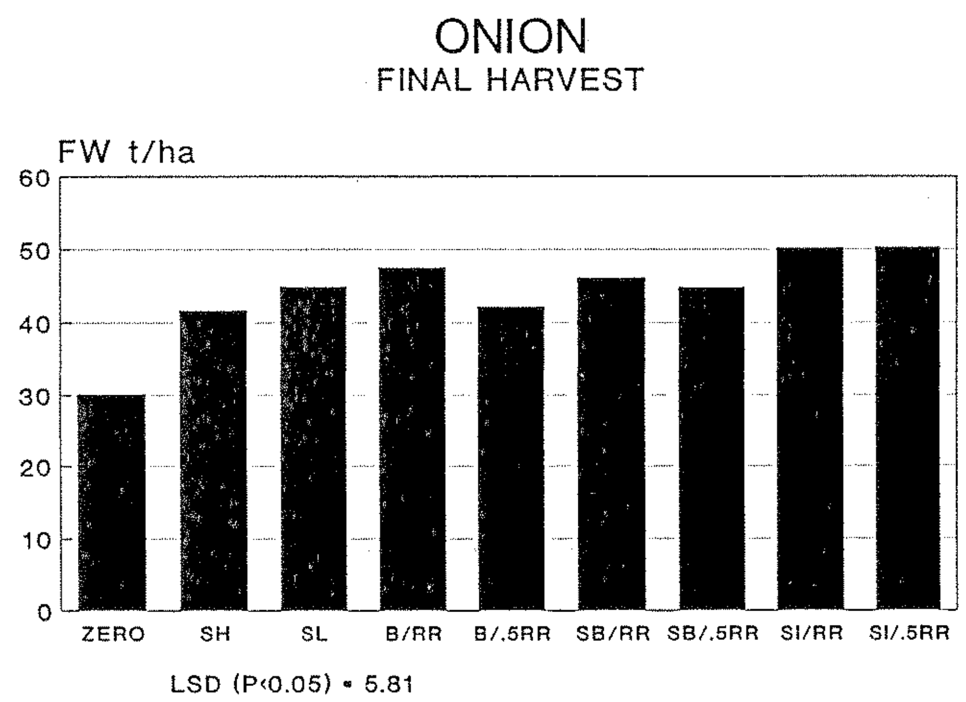

ONION
FINAL HARVEST
FW t/ha
60
50
40
30
20
10
0
ZERO
SH
SL
B/RR
B/.5RR
SB/RR
SB/.5RR
SI/RR
SI/.5RR
LSD (P<0.05) = 5.81

Fig 8b

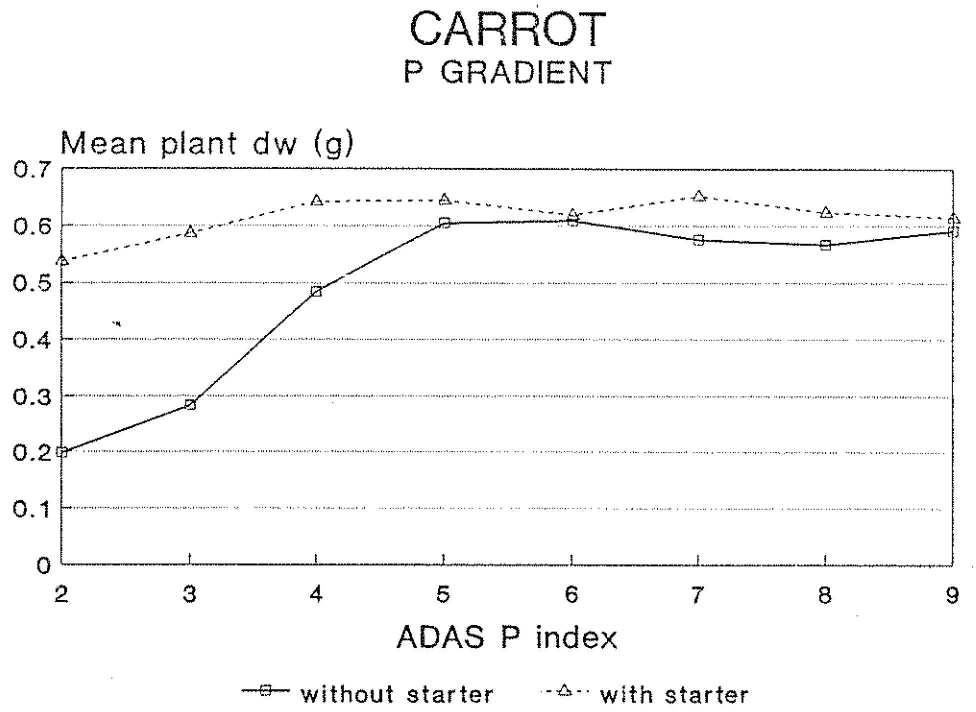

CARROT
P GRADIENT
Mean plant dw (g)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2
3
4
5
6
7
8
9
ADAS P index
without starter
with starter

Fig 9

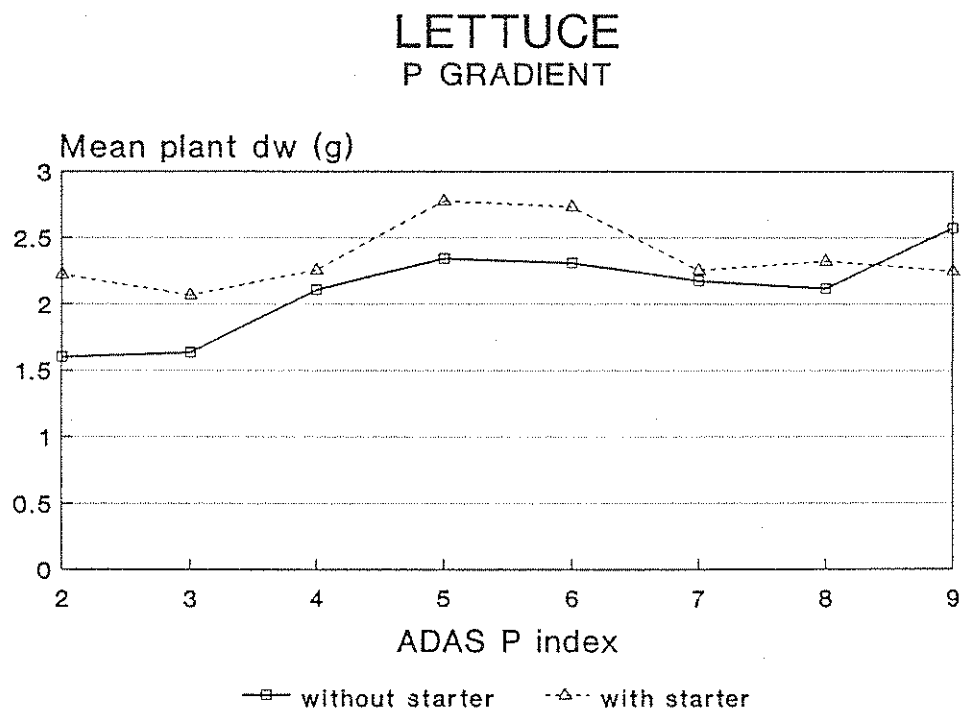

LETTUCE
P GRADIENT
Mean plant dw (g)
3
2.5
2
1.5
1
0.5
0
2
3
4
5
6
7
8
9
ADAS P index
without starter
with starter

Fig 10

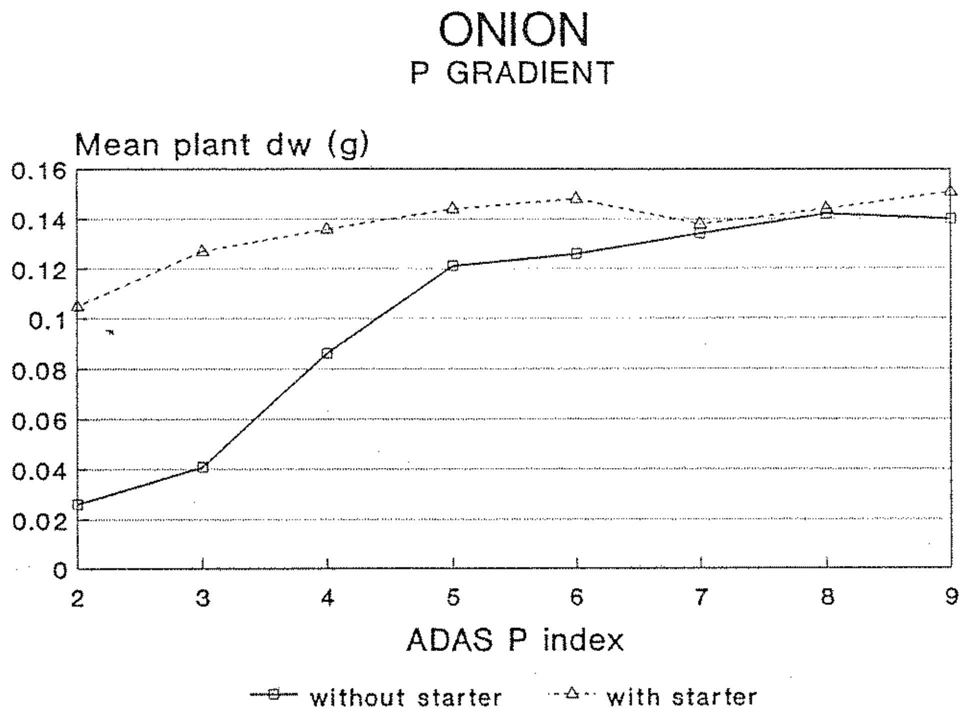

ONION
P GRADIENT
Mean plant dw (g)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
2
3
4
5
6
7
8
9
ADAS P index
without starter
with starter

Fig 11

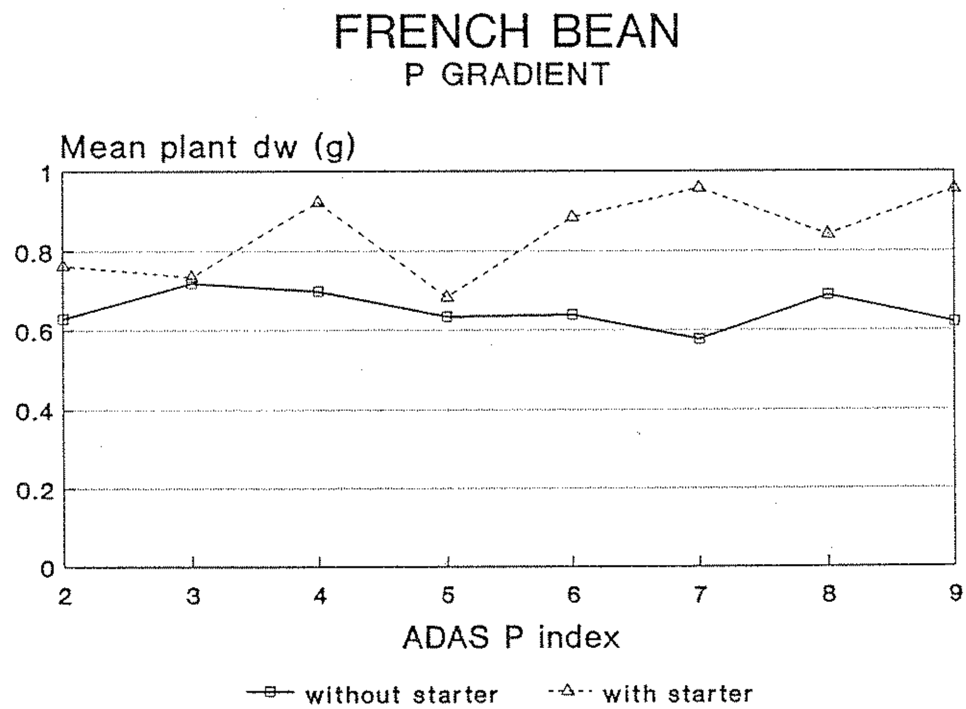

FRENCH BEAN
P GRADIENT
Mean plant dw (g)
1
0.8
0.6
0.4
0.2
0
2
3
4
5
6
7
8
9
ADAS P index
without starter
with starter

Fig 12

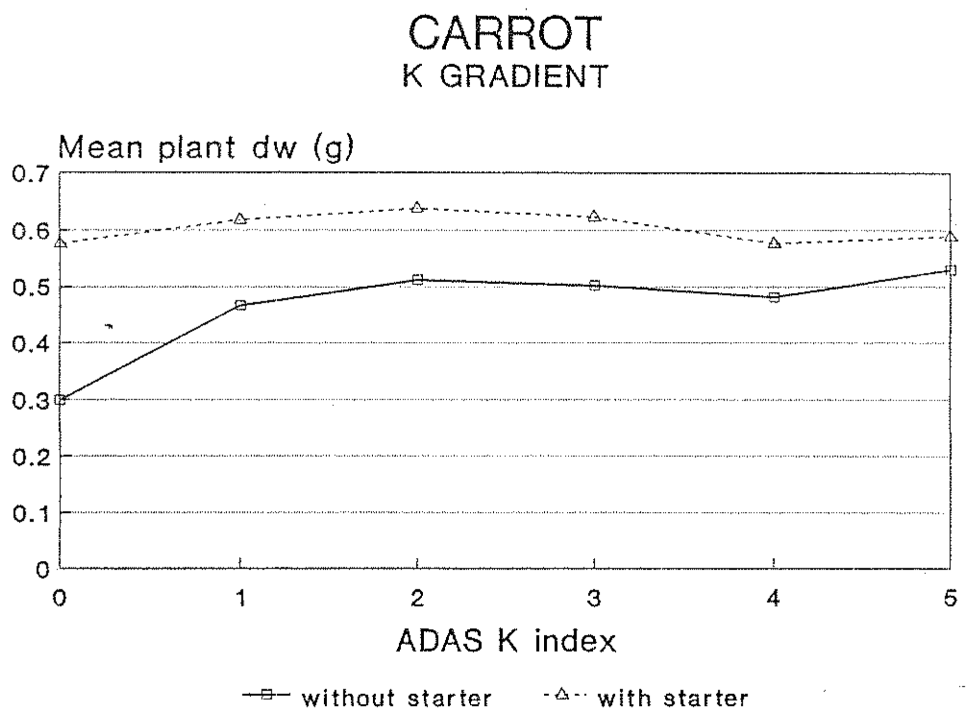

CARROT
K GRADIENT
Mean plant dw (g)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
ADAS K index
without starter
with starter

Fig 13

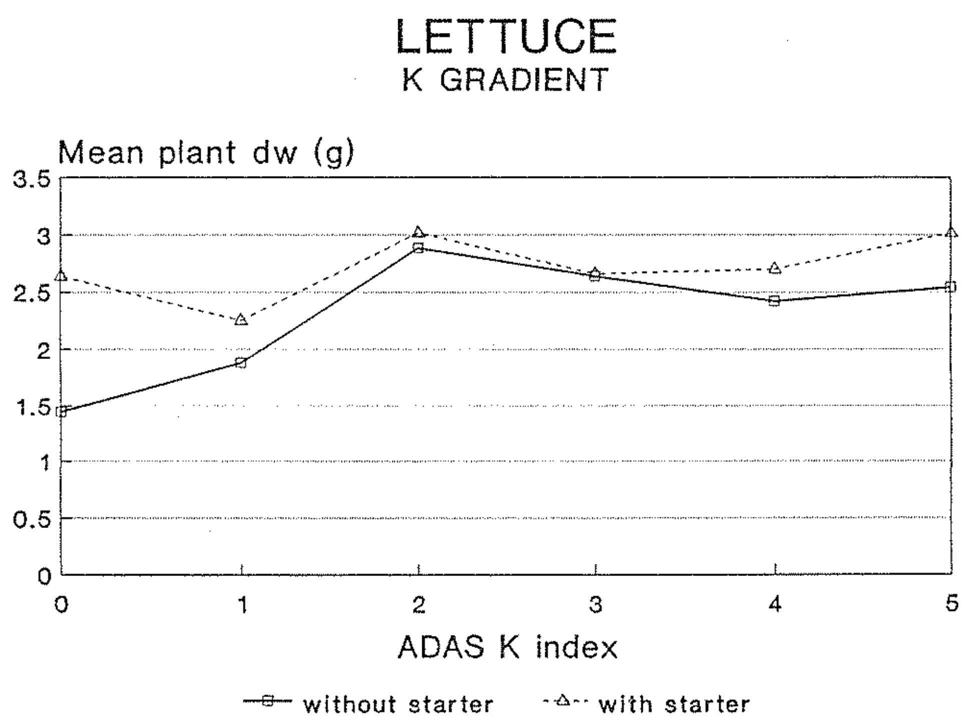

LETTUCE
K GRADIENT
Mean plant dw (g)
3.5
3
2.5
2
1.5
1
0.5
0
0
1
2
3
4
5
ADAS K index
without starter
with starter

Fig 14

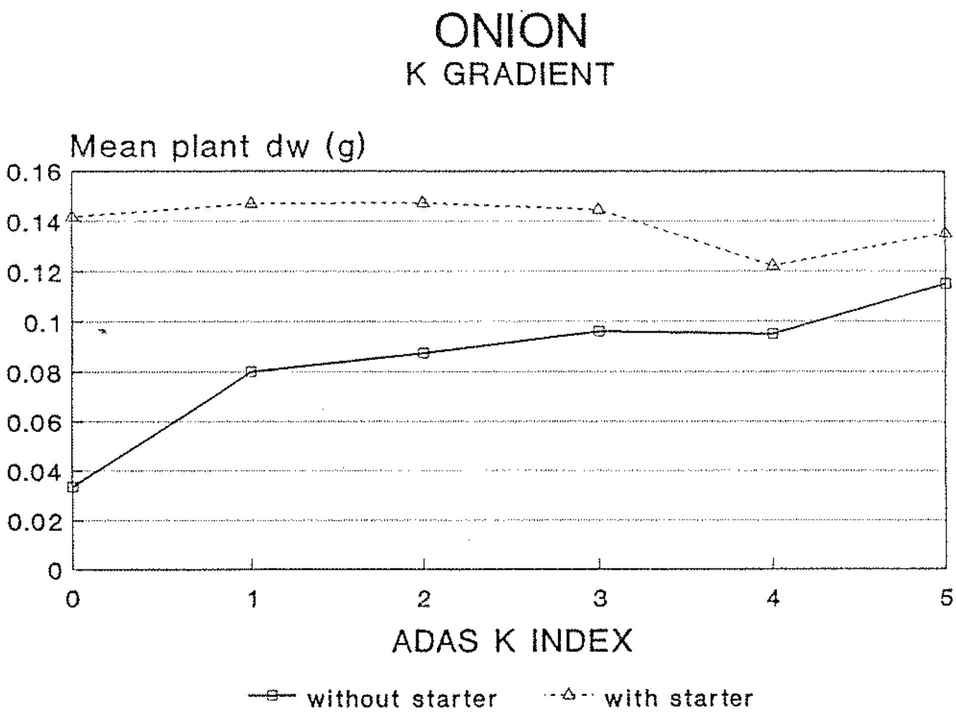

ONION
K GRADIENT
Mean plant dw (g)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
1
2
3
4
5
ADAS K INDEX
without starter
with starter

Fig 15

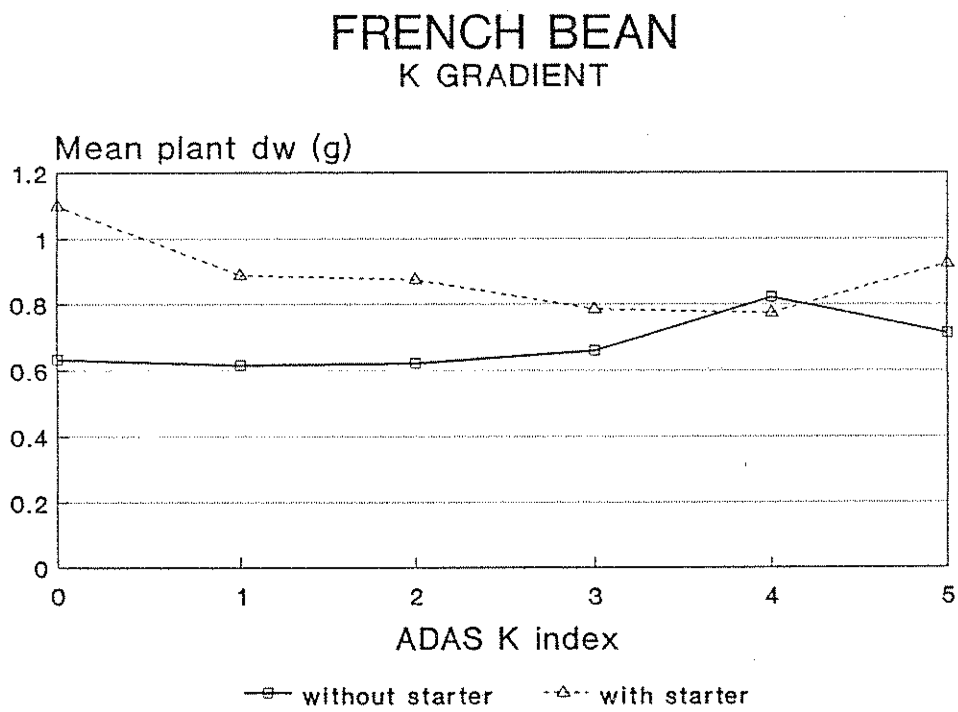

FRENCH BEAN
K GRADIENT
Mean plant dw (g)
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
ADAS K index
without starter
with starter

Fig 16

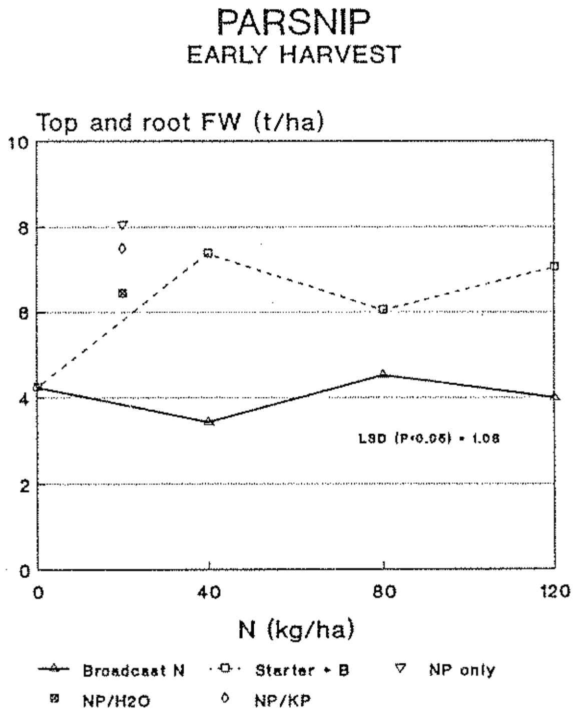


Fig 17a

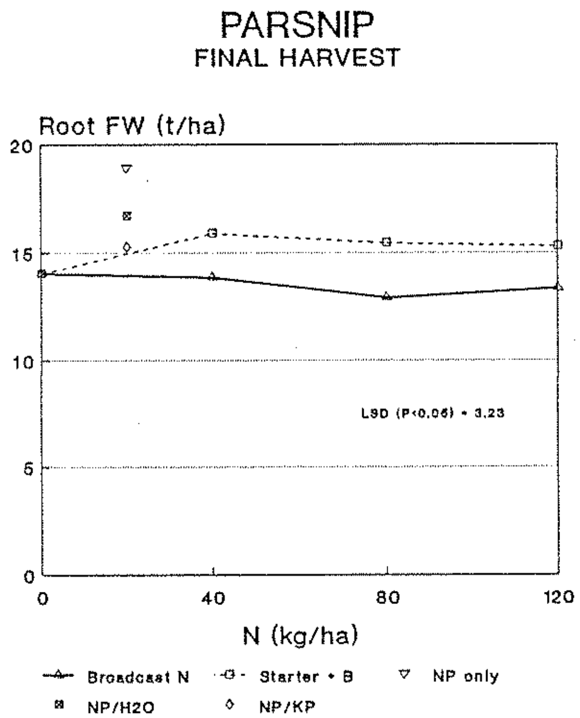


Fig 17b

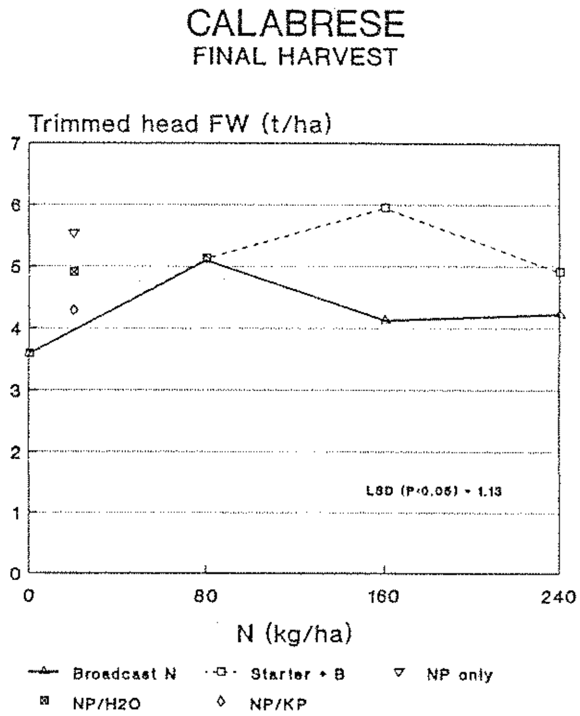

CALABRESE
FINAL HARVEST
Trimmed head FW (t/ha)
7
6
5
4
3
2
1
0
LSD (P<0.05) = 1.13
0
80
160
240
N (kg/ha)
Broadcast N
Starter + B
NP only
NP/H2O
NP/KP

Fig 18

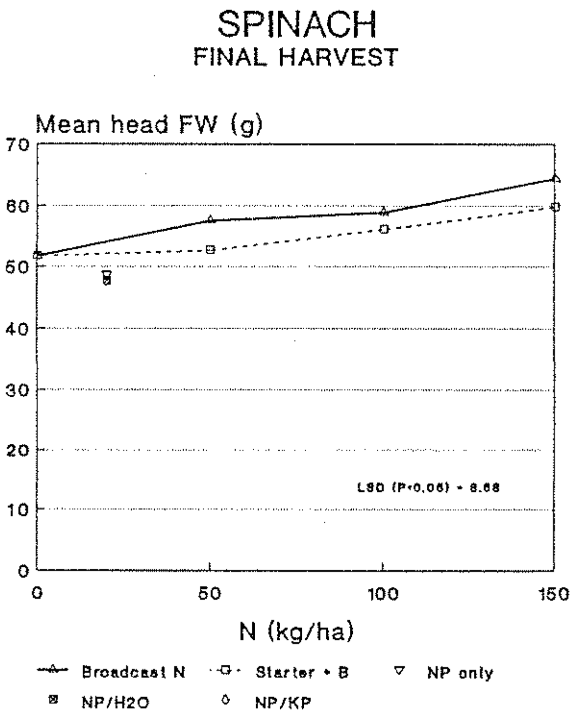

SPINACH
FINAL HARVEST
Mean head FW (g)
70
60
50
40
30
20
10
0
LSD (P<0.05) = 8.68
0
50
100
150
N (kg/ha)
Broadcast N
Starter + B
NP only
NP/H2O
NP/KP

Fig 19

RED BEET
MATURE HARVEST

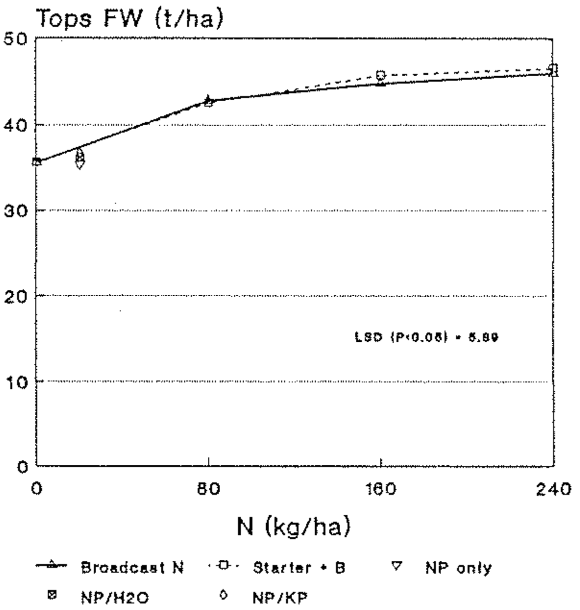


Fig 20a

RED BEET
MATURE HARVEST

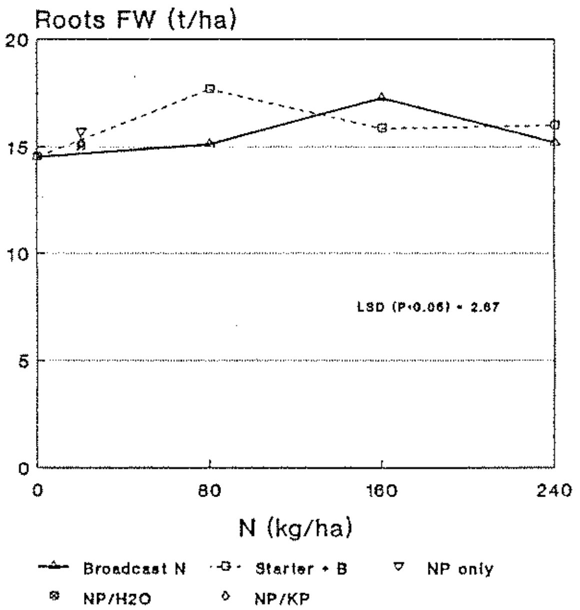


Fig 20b

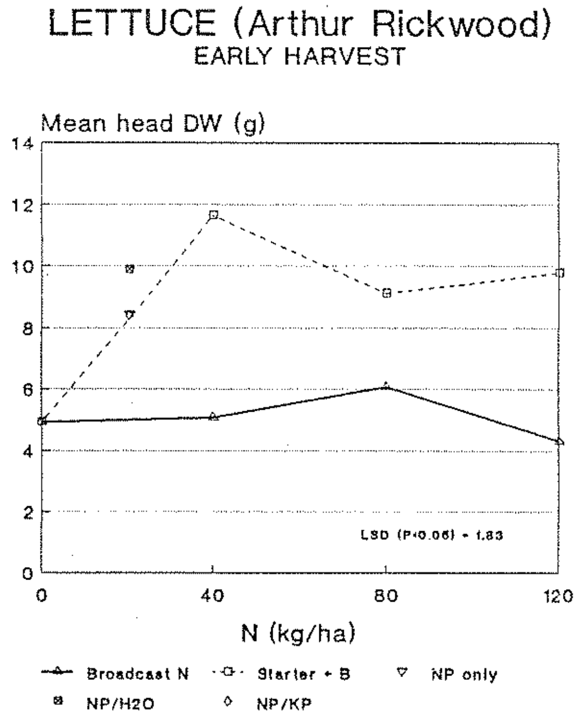


Fig 21a

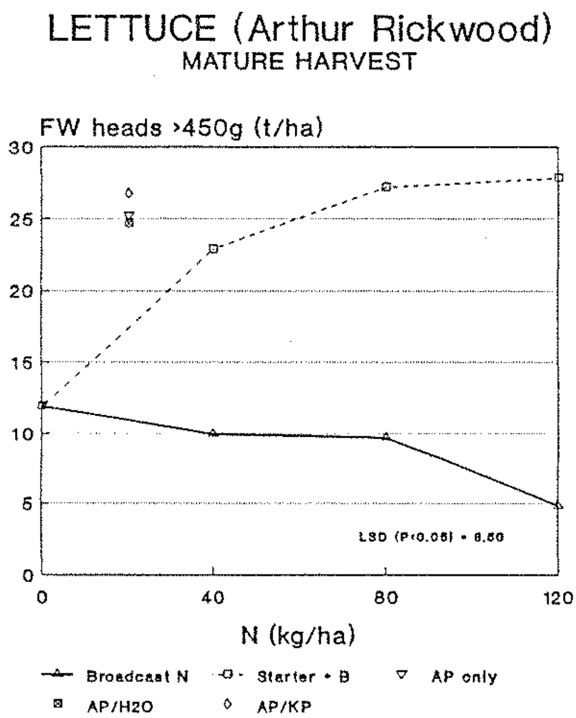


Fig 21b

ONION (Arthur Rickwood)
SALAD ONION

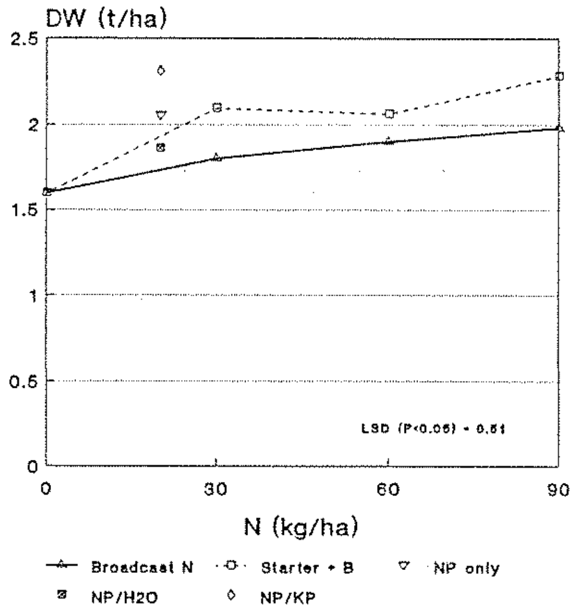


Fig 22a

ONION (Arthur Rickwood)
FINAL HARVEST

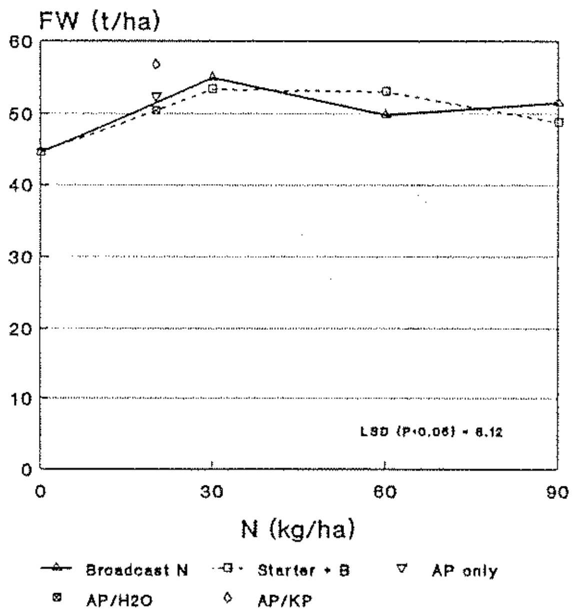


Fig 22b

Contract between HRI (hereinafter called the "Contractor") and the Horticultural Development Council (hereinafter called the "Council") for a research/development project.

1. TITLE OF PROJECT **Contract No: FV 41**

Drilled horticultural crops: starter fertiliser

2. BACKGROUND AND COMMERCIAL OBJECTIVE

Yields of vegetable crops vary enormously from field to field even with the recommended fertiliser application, irrigation and control of pests and diseases. It has been discovered that much of this variation results from transient deficiencies of nitrogen, phosphate and, to a lesser extent, potassium, in the early stages of growth. One way to overcome the early nutrient deficiency is to raise the nutrient supplying power of the soil by repeated heavy applications of farmyard manure or fertiliser, but this is expensive and can lead to pollution. For drilled crops an alternative approach which is both cheaper and less harmful to the environment, is the precision injection, of small amounts of the correct formulation of a liquid fertiliser close to the seed. Initial problems associated with the "salt effect" of the fertiliser, and the interruption of the capillary flow of water to the seedling have been overcome by changing the formulation of the fertiliser and by improving the design of the soil-engaging components. Used with conventionally applied fertiliser, small amounts of injected fertiliser have produced higher yields than any level of conventionally applied fertiliser by itself. Moreover this technique has greatly improved the recovery by the crop of the added fertiliser.

3. POTENTIAL FINANCIAL BENEFIT TO THE INDUSTRY

Depending on the crop and soil, the proper use of starter fertiliser will result in more even, larger and/or earlier yields. The benefits will also include a reduced number of field operations and a reduction in fertiliser usage.

4. SCIENTIFIC/TECHNICAL TARGET OF THE WORK

1 To investigate the rate, formulation and position of injection of liquid fertiliser on early growth and final yield.

2 To ascertain the soil conditions when transient early nutrient deficiencies, especially of phosphorus and potassium are likely to occur and thus when a response to starter fertiliser can be expected.

5. CLOSELY RELATED WORK - COMPLETED OR IN PROGRESS

The equipment to be used has been developed at Wellesbourne with MAFF funding and has been copied by several other research organisations. In conjunction with HRI entomologists it has also been used to inject liquid insecticides either with or without liquid fertiliser.

6. DESCRIPTION OF WORK

The objectives of the work will be reviewed annually and will depend on the results from the previous year's work. Initially all work will be carried out at Wellesbourne but when suitable treatments have been devised, experiments may be carried out at Kirton or other sites.

In recent work potassium has not been included in the starter fertiliser because it would have involved using potassium chloride, and chlorides cause salt damage to the germinating seed. Recently two firms have offered to formulate fertiliser with potassium phosphate which should be a much safer source of potassium. The objective of the first years experiments will be to investigate the effectiveness of various mixtures of ammonium and potassium phosphates as a starter fertiliser. Experiments will be carried out with onions, carrots, spring cabbage and lettuce on high and low fertility soils.

7. COMMENCEMENT DATE AND DURATION

Work to commence in 1.4.1991 and last for three years.

8. STAFF RESPONSIBILITIES

Project Leader: Dr H.R.Rowse, HRI Wellesbourne
Experiment Leader: Mr D.A.Stone, HRI Wellesbourne
Other staff involved: Prof D.J.Greenwood, Dr I.G.Burns

9. LOCATION

During the first year (1991 season) all experiments will be done at HRI Wellesbourne. Location of experiments in subsequent years will be decided by the experimental requirements of the research. Full use will be made of the unique plots at Wellesbourne on which gradients of nutrient status have been established over the past 7 years.

Contract between HRI (herinafter called the "Contractor) and the Horticultural Development Council (herinafter called the "Council") for research/development project.

1. TITLE OF PROJECT **Contract No: FV 41**

(Modification to year 3 of the contract)

DRILLED HORTICULTURAL CROPS: STARTER FERTILIZER

2. BACKGROUND AND COMMERCIAL OBJECTIVE

The main objective in the first year was to investigate various formulations of liquid starter fertilizer on the growth of carrot, onion, iceberg lettuce and summer greens on two sandy loam soils of contrasting fertility. On a high PK soil, starter fertilizer increased early growth and final yield of each crop, except summer greens, irrespective of formulation. On a low PK soil, starter dramatically increased early growth and marketable yield of each crop, with solutions containing ammonium and potassium phosphates being better than either used alone. The results demonstrated that starter fertilizer can give substantial improvements in yield, and often improved grading, even on a high fertility soil. An important additional finding was that the use of starter fertilizer on a low fertility soil produced early growth comparable to that on the high fertility soil. This opens up the possibility of reducing pollution by permitting the maintenance of a lower soil nutrient status without loss of yield.

In the second year, the study was developed to see how far combinations of starter fertilizer with broadcast or injected fertilizer could maintain productivity on the low PK status site. The benefits of starter were also assessed in relation to initial soil fertility using gradients of residual soil P & K which had been established at Wellesbourne. The interpretive and environmental aspects of the work were funded by a contribution from a MAFF research contract. This work was particularly promising, with starter fertilizer giving yields which were not significantly different from the high rates of broadcast fertilizer recommended by ADAS for soil of low PK indices, and will continue in 1993 under MAFF funding alone.

Previous starter fertilizer work has demonstrated the potential of ammonium phosphate starter solution for improving nitrogen use efficiency of bulb onion and iceberg lettuce on the sandy loam soils at Wellesbourne. High yields were achieved with reduced levels of nitrogen fertilizer inputs with concomitant benefits of improved grading and, in some cases, earlier maturity. Under MAFF funding, the work on onions was extended to the coarse sandy soils at ADAS Gleadthorpe with similar benefits. A need was identified at the 1992 Project Review to extend the investigation to a wider range of crops and soil types. To facilitate this, HDC funded (under FV41A) collaboration between HRI and Stanhay-Webb Ltd with the aim of producing a commercial prototype of the Wellesbourne injection system. Four sets of 4-row equipment are now available.

3. POTENTIAL FINANCIAL BENEFIT TO THE INDUSTRY

As for FV41

4. SCIENTIFIC/TECHNICAL TARGET OF THE WORK

As for FV41

5. CLOSELY RELATED WORK - COMPLETED OR IN PROGRESS

As for FV41

6. DESCRIPTION OF WORK

In 1993 the new equipment will be used to:-

1 Examine the effect of ammonium phosphate starter (and ammonium phosphate/potassium phosphate mixture) on the fertilizer use efficiency, early growth, maturity, grading and crop nitrate content (as appropriate) of parsnip, red beet, calabrese and spinach at Wellesbourne.

2 Extend the earlier work on onions and lettuce to silt (HRI Kirton) and peat (ADAS Arthur Rickwood) soils. Results to be collated at Wellesbourne.

Treatments would be identical in 1 and 2 above viz:

1 Control (Zero starter and nitrogen - to enable calculation of N uptakes).
2 Ammonium phosphate starter - full strength at 9.3 ml/m.
3 Ammonium phosphate starter - half strength at 18.6 ml/m.
4 Ammonium phosphate/Potassium phosphate starter - 50:50 mix of commercial concentrates at 18.6 ml/m.
5-7 Ammonium nitrate as nitram at three rates dependant on crop to provide response curve.
8-10 Ammonium phosphate (as treatment 3) plus ammonium nitrate up to the same rates as treatments 5-7.

7. COMMENCEMENT DATE AND DURATION

Start date 01.04.91; duration 3 years. The final report will be produced by end of April, 1994. It is likely that it will be necessary to disseminate some of the more important results before the beginning of the season in 1994 and an article for Project News will be produced in winter 1993/94. In addition, it may be appropriate for a fact sheet to be produced for all FV HDC levy payers.

8. STAFF RESPONSIBILITIES

As for FV41

9. LOCATION

As for FV41