Project title	Watercress: evaluation of fertiliser regimes for the efficient and sustainable use of phosphate fertilisers by watercress growers.
Project number:	FV 338
Project leader:	Nigel MacDonald, ADAS
Report:	Final report, March 2010
Previous report	Annual report, January 2009
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Location of project:	The Watercress Company, Maxwell Farm, Alresford, Hampshire
Project coordinators:	Dr Steve Rothwell, Vitacress Salads, St Mary's Bourne, Hants. Charles Barter, The Watercress Company, Waddock Cross, Dorchester, Dorset.
Date project commenced:	1 March 2008
Date project completed:	31 December 2009
Key words:	Watercress, phosphate fertiliser, efficient use, monitoring, discharge levels, yield, quality, shelf life.

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

AUTHENTICATION

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

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CONTENTS

GROWER SUMMARY

Headlines

- Watercress crops grown from seedlings during the late spring and summer required 2,200 kg P_2O_5 per ha to ensure that adequate crop quality standards were achieved, though the effects of increasing phosphate fertiliser applications on crop yield were less apparent.
- Increasing the amount of applied phosphate (P) fertiliser increased the level of P in the discharge water from watercress beds. Using a soluble compound fertiliser produced much higher levels of P discharge than those following treatment with Fibrophos (a by-product of incinerating dried chicken manure).

Background and expected deliverables

Watercress plants require supplementary phosphate fertilization to produce marketable crops. Insufficient amounts are supplied by the spring or borehole groundwaters which supply watercress farms. Previous research indicated critical plant levels of phosphorus (P)[1] to be 0.52% in leaves and stems for plants with the potential to produce 90% of the maximum yield (Robinson & Cambus, 1977). However, production techniques, crop turnaround rates, yields and quality expectations have increased considerably since that research.

Matching crop phosphate requirements for maximum yield and high quality with supplementary applications of phosphate fertilisers requires skill and attention to detail. There is not a simple blueprint to follow, as factors such as water flow, temperatures and growth rates continually fluctuate. There has therefore been a tendency to apply an insurance amount of P to ensure adequate crop nutrition and prevent a fall-off in yield and quality. Ideally, a greater appreciation of the actual shortfall at various crop stages, flow rates and seasons of the year would allow a more precise approach to the use of phosphate fertilisers.

[1] To convert P_2O_5 to P, divide by 2.29

In order to meet crop needs, watercress growers apply mainly slow-release phosphate fertilisers such as Fibrophos to the bed base prior to planting and/or during the early stage of crop establishment. This maximises nutrient uptake by the crop and minimise the amount of P in discharge waters. However, early applications of P to watercress beds can lead to algal booms, so the timing of an application is an important consideration, as well as the rate used. Excessive phosphate fertilisation is to be avoided, as phosphate not taken up by the plant or adsorbed into the bed base will be lost into the discharge waters. Subsequent phosphate discharges into watercourses, i.e. any which are not 'captured' by the settlement tanks or lagoons in place on many farms, can lead to environmental consequences in the form of eutrophication.

In 2006, HDC funded a survey of watercress growers to determine the range of practices concerning phosphate fertiliser use and application throughout the industry (HDC project FV 302, completed February 2007). Data from this survey, and earlier research into crop requirements conducted in the 1980s, provided the NFU Watercress Association with further information in reviewing Best Practice guidelines for phosphate use. However, it was clear that in-depth experimentation would be required to evaluate how effective Best Practice guidelines could be in reducing phosphate discharges and any downsides in terms of crop performance. This required a comparison of phosphate application rates with intensive monitoring of P levels in discharge waters.

The expected deliverables from this project are to:

- Identify rates of phosphate fertilisers required to meet commercial requirements for optimum yield and quality including improvements to shelf life.
- Establish levels of phosphate in discharge waters from crops grown to acceptable commercial standards.
- Establish what opportunity there is for optimising application rates and timing to reduce discharges through more efficient use of phosphate.

Summary of the project and main conclusions

Three treatment rates of P fertiliser were compared in replicated watercress beds to determine the effects on crop yield and quality and the subsequent impact on P discharge levels, at Maxwell Farm, Alresford, Hampshire in three planted and three re-growth crops. The treatments were:

1. 'Minimise P' - limited to 900 kg/ha P_2O_5 per year (limit set in 1983) mostly applied to the bed base as Fibrophos.
2. Commercial Practice - 2,200 kg/ha P_2O_5 per year applied in *pro-rata* weekly applications.
3. Intermediate Rate - 1,500 kg/ha P_2O_5 per year applied *pro-rata* in twice weekly applications.

Watercress crops grown from seedlings during the late spring and summer required 2,200 kg P_2O_5 per ha to ensure adequate quality standards were achieved, i.e. to minimise aerial feeder roots and stem purpling, the major quality problems that result from lack of available phosphate.

Treatment effects on crop yield were less apparent. There was a trend for higher fresh and dry weight yields with increasing rates of P fertiliser applied to planted crops, but not in the late summer and autumn re-growth crops, where rooting into the gravel bed base provided a rich source of the nutrient with no response to additional applied P. Rooting into the bed base also leads to less stem purpling.

Higher P concentrations and P off-take were recorded following the higher fertiliser treatments. While 5.2 g/kg of P in plants is considered to be a critical level for 90% yield, it did not prevent some crops (i.e. late spring and early summer) from showing stem purpling. To achieve this level, an absolute minimum of 200 kg/ha P_2O_5 is required per crop, but this is only sufficient when all conditions are ideal. In reality, higher levels of phosphate are required per crop to produce plants of acceptable commercial quality. The lowest rate of P produced consistent stem purpling in all planted crops.

In summer crops, P concentrations of 7.0 g/kg in plants ensured no stem purpling was observed before harvest, providing that no other stress factors that could lead to purpling were imposed on the crop.

Rates of P fertiliser had no impact on shelf life quality after harvest.

Discharge levels of total reactive phosphate (TRP) are increased at bed clearing and after fertiliser application, peaking a few hours after fertiliser had been applied but returning to normal levels within 24 hours. Average and peak discharge concentrations of TRP are heavily dependent on both the type and the amount of fertiliser applied. Fibrophos produced lower levels of P discharge measured at the bed outflows compared with 19:14:14 NPK compound fertiliser. Where possible, it would be prudent to avoid the use of high rates of highly water-soluble P fertiliser.

Intensive sampling of water after bed clearing concluded that significantly lower P discharge was present from beds fertilised with the lowest P rate than intermediate and commercial rates.

Financial benefits

- The results of this series of experiments indicate that there is a sufficiently large reserve of P in the bed base for re-growth crops to exploit such that only small additions of P fertiliser may be needed during the growing period in situations where this ‘reserve’ has built up.
- Commercial practice could for example include three applications of fertiliser to re-growth crops: one of 19:14:14 at 320 kg/ha and two of Fibrophos each of 710 kg/ha. At the time of the project, the combined materials cost of these amounted to £1009 /ha (19:14:14 compound - £580 per tonne; Fibrophos - £320 per tonne). If the fertiliser rates for these crops were reduced by half, grower savings for the three crops would total ca. £1500 per hectare. Where more than three re-growth crops are grown in the season or where less than half the P fertiliser is applied, the savings could be greater, but it is likely that the reserves of P in the gravel base would decline more quickly.
- Growers who are not so confident in reducing P applications to re-growth crops to this degree may prefer to closely watch the growth of the crop and apply according to crop needs. Further investigation could elicit whether testing the bed base for P content prior to cropping or P application would be a useful indicator of crop requirement for regrowth crops.

Action points for growers

- Follow the NFU Watercress Code of Practice, applying fertiliser to match crop needs and adhering to advice which suggests helpful measures to reduce levels of P in discharge waters.
- Use the more soluble fertilisers only when necessary i.e. during periods of rapid growth/when rapid growth is required, when less soluble forms of phosphate may not supply P quickly enough, or when the crop is poorly rooted. P discharge levels will be considerably higher when soluble fertilisers are applied compared with a less soluble source of P (e.g. Fibrophos).
- Maintaining plant P levels above 0.52% as a minimum will reduce the incidence of stem purpling, but not eliminate it. To achieve this level, an absolute minimum of 200 kg/ha P_2O_5 is required per crop, and more when conditions are not ideal (see science section in full report). Increasing rates of P fertiliser will increase crop P levels.
- Take advantage of the high reserves of P in well-established gravel bed bases when growing late summer re-growth crops and reduce the amounts of applied P. This will not have detrimental effects on yield or quality. Applications rates as low as 125 kg/ha P_2O_5 had no detrimental effect on yield or quality of regrowth crops.
- Reduce water flow levels during and after fertiliser applications to enable the crop to recover as much fertiliser as possible, and so reduce overall P loadings from the beds.
- The findings from this project could contribute to the proposed development of a Code of Environmental Practice for Watercress Production, between Natural England, the Environment Agency and the NFU Watercress Growers Association.

SCIENCE SECTION

Introduction

Watercress is grown throughout the year, utilising the headwaters of springs in Hampshire, Dorset and Wiltshire. Watercress plants require supplementary phosphate (P) to produce marketable crops as there is an insufficient supply of P in groundwater. Previous research indicated that 0.52% P in leaves and stems was the 'critical' level for the crop (Robinson & Cumbus, 1977), defined as the concentration associated with 90% of the crop's maximum yield (Ulrich & Hills, 1967). However, since this research, crop turnaround rates, yields and quality expectations have increased considerably.

In order to meet crop needs, watercress growers apply mainly slow-release phosphate fertilisers such as Fibrophos to the bed base prior to planting and/or during the early stage of crop establishment. This maximizes nutrient uptake by the crop and minimises the amount of P in discharge waters. However, early applications of phosphate to watercress beds can lead to algal booms, so timing of application becomes critical as well as the P rates applied. Subsequent phosphate discharges into watercourses, i.e. any which are not 'captured' by the settlement tanks or lagoons in place on many farms can have environmental consequences in the form of eutrophication. This causes the growth of blanketweed and algae and the loss of important plants such as water crowfoot.

Watercress farms have been implicated in previous studies as contributing significant inputs of phosphate and sediment into river systems (Casey 1981; Casey *et al*. 1988, Casey & Smith 1994). A new and more significant challenge to UK watercress growers may come from the Environment Agency who will soon require discharge consents for phosphate, which is measured as total reactive P (TRP). The consents may require discharges to be as low as 40-60 µg TRP/litre as an annual average. It is likely that the present average discharge from watercress beds over the season is between 60–100 µg/litre, with spikes of phosphate discharge following fertiliser application well above the new suggested limits. The industry therefore urgently requires better guidance on phosphate use which will enable them to meet these limits whilst maintaining the ability to produce economically viable crops.

In 2006, HDC funded a survey of watercress growers to determine common practice in phosphate fertiliser use throughout the industry (FV 302, completed February 2007). Data from this survey and earlier research into crop requirements from the 1980s provided the NFU Watercress Association with a range of information on Best Practice guidelines for phosphate use, and an interim position on phosphate fertiliser application rates and methods. However, it was clear that further work would be required to evaluate the relevance and effectiveness of this data, in view of the many changes in production systems, cropping intensity, output and market requirements that have occurred in recent years. This required a comparison of phosphate fertiliser application rates, to assess their impact on crop yield and quality, with intensive monitoring of P levels in discharge waters.

In order to determine these, HDC project FV 338 commenced in February 2008 with the following specific objectives:

1. Determine which of three fertiliser practices produces the lowest TRP discharges,
2. Determine the lowest rate of phosphate fertiliser that will produce economically viable crops,
3. Determine if phosphate fertiliser rates have any impact on final product quality and shelf life,
4. Determine the rate of release of phosphate from an un-fertilised (NPK) watercress bed.

All four of the above objectives were addressed and trial results presented in the first year Annual Report FV338 (completed in January 2009). This Final Report includes an overview of these results and additional information not available at the time of the Annual Report relating to final bed base P concentrations and flow rates, along with the consequences on P loading of discharge waters.

Materials and methods

Site location and experiment design

This experiment was located at Maxwell Farm, Alresford, Hampshire and consisted of ten beds each measuring approximately 38m x 9m (350m^2), all fed from the same groundwater source. Three P fertiliser treatments (T1, T2 and T3) were replicated three times in a randomised block design, and a small portion (35m^2) of the tenth bed (actually bed 8 in the layout) was used to monitor yield and P offtake from the bed base in the absence of any NPK fertiliser.

Each bed was separated from its neighbour by a concrete wall on all sides. The inflow of pumped groundwater at the top of each bed was regulated by two or three inlet valves. A uniform gradient enabled the inlet water to flow slowly through the growing crop and discharge via a single standard outlet measuring 67 cm wide. Weirs were installed at the outfall by the Environment Agency to continuously monitor the water leaving each bed. As the beds are established on a very compact gravel/chalk base, it was assumed that there was no interaction between inflow water and groundwater over the bed area and amounts of inflow therefore equalled outflow.

The experiment was carried out from March 2008 to February 2009 on three summer watercress crops planted on 7 March, 13 May and 23 June and harvested on 12 May, 20 June and 31 July respectively. These were followed by three autumn/winter re-growth crops harvested on 27 August, 23 September and 21 November.

Bed, crop management and fertiliser treatments

Beds and crops were managed by The Watercress Company according to best commercial practice and the overriding need to produce a commercial saleable crop of high quality. Flow through the beds was controlled at strategic intervals to allow seedlings to establish themselves, to protect plants from frost stress and to allow harvest and cleaning out.

Three phosphate treatments were applied:

- T1: 'Minimise P' - 900 kg/ha P_2O_5 per year (limit set in 1983) mostly applied to the bed base as Fibrophos,
- T2: Commercial Practice - 2,200 kg/ha P_2O_5 per year applied *pro-rata* at weekly applications,
- T3: Intermediate Rate - 1,500 kg/ha P_2O_5 per year applied *pro-rata* at twice weekly intervals.

Straight and compound fertilisers were applied to each bed ensuring comparable rates of nitrogen and potash were applied (Table 1). Additional inputs of iron sulphate were added when appropriate to all beds to prevent yellowing.

Treatment applications and crop measurements were constrained by the need to achieve timely harvesting and a satisfactory crop for sale. Target rates of P were achieved on all treatments with the exception of T3 where a total of 1,300 kg P_2O_5 was applied instead of the target rate of 1,500 kg P_2O_5/ha. This shortfall was largely due to the timing of the final harvest date being too close to the target final fertiliser application date for crops 5 and 6. For T1, an <u>additional</u> input of 156 kg P_2O_5/ha and 85 kg K_2O/ha was applied to crop 2 on 13 June as an emergency application one week before harvest to help alleviate purple stems. Similar purple stems were present on T3 but before the final scheduled split fertiliser dressing.

Table 1. Rates of nitrogen (N), phosphorus (P) and potassium (K) fertiliser applied to each watercress crop.

	Crop 1	Crop 2	Crop 3	Crop 4	Crop 5	Crop 6	Total	Total P_2O_5 equivalent
Planting date	7 March	13 May	23 June	Re-growth	Re-growth	Re-growth		
Harvest date	12 May	20 June	31 Jul	27 Aug	23 Sep	21 Nov		
N (kg ha^{-1}) applied								
T1	166	141	128	58	58	0	551	
T2	182	122	122	61	61	0	548	
T3	180	134	122	58	48	0	542	
P [a] (kg ha^{-1}) applied								
T1	78	78	74[c]	54	54	55	393	899
T2	264	176	175	156	156	68	995	2278
T3 [b]	119	107	116	108	84	34	568	1300
K [a] (kg ha^{-1}) applied								
T1	266	186	199[c]	177	177	57	1062	
T2	326	217	217	179	179	71	1189	
T3	287	218	196	181	127	36	1045	

[a] To convert P to P_2O_5, multiply by 2.29. To convert K to K_2O, multiply by 1.205.
[b] Treatment 3 did not always receive all the allocated P for each crop depending on harvest date in relation to last fertiliser application.
[c] Figures exclude emergency application just prior to harvest (see p. 8)

Crop measurements were not allowed within 2 days of harvest and the integrity of water discharge measurements on the outlets of beds 3 and 4 were compromised after crop 3 due to collapse of a small bottom section of the concrete divide during harvesting. Inlet flow to beds 7, 9 and 10 (one block) was reduced during an extended period (crop 3 onwards) due to pump failure.

Installation of the weirs by the Environment Agency at the bed outfalls caused a certain amount of water to back up the beds and cause loss of seedlings across the lower portion of the beds. This area was subsequently avoided for crop measurements but affected yield measurements undertaken by The Watercress Company. Similarly, the cold temperature of the groundwater (11°C) reduced crop growth at the very top of beds during summer and these areas were also avoided.

Assessments[2]

Bed base

In February 2008, after removal of the over-wintered crop and cleaning of the bed base, and at the end of the experiment in March 2009, representative samples of both the gravel base and the underlying chalk base were collected. Samples were taken from 10 x 0.01 m^2 quadrats within each bed, bulked and sub-sampled for determination of total phosphate (TP), plant-available (Olsen) phosphate (OP) and water-extractable phosphate (WEP). The initial concentrations of P in the bed base were compared with those at the end of the experiment.

Flow rates

Flow rates were determined by measuring the depth of water flowing over a shallow weir of known cross-sectional area installed at the outlet of each bed. Flow depth was recorded electronically every 15 minutes onto a datalogger and downloaded at regular intervals. There were some gaps in the data record, particularly for beds 3 and 7, whilst bed10 (T3) was only monitored up to June 2008. The flow record provided the opportunity to examine temporal patterns in flow and relationships between flow and discharge P concentrations.

Water samples

Water entering three common inlet channels and leaving each bed were sampled weekly for total reactive phosphate (TRP) to provide an estimate of the P entering and leaving the beds.

Intensive sampling of the discharge water from each bed was carried out on three occasions: on 12 May (during bed cleaning after crop 1), 2 June (after application of Fibrophos fertiliser to crop 2) and on 7 July (after application of 19:14:14 NPK compound fertiliser to crop 3). On each occasion, ISCO automatic sampling equipment was used to trigger sampling of the discharge water at regular intervals. For the intensive sampling during bed cleaning, water samples were collected when flow was resumed after harvest, at the start of cleaning and then every 15 minutes for a period of 6 hours. For the intensive sampling after fertiliser application, water samples were collected every 30 min for the first 4 hours, every 60 min for the next 3 hours, every 3 hours for the next 24 hours and every 6 hours for the next 24 hours. Two additional samples were taken before the fertiliser was applied. Samples collected during bed cleaning were analysed for true soluble reactive phosphate (SRP), soluble un-reactive phosphate (SUP) and particulate phosphate (PP) in addition to TRP, but only on every other sample (i.e. every 30 minutes). Samples collected

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[2] For definitions of the various phosphate measurements, please see Glossary, page 22.

after fertiliser application were analysed for TRP only since little bed sediment is dispersed during fertilisation.

Plant tissue samples and yield

Plant samples from 5 x 0.1 m^2 quadrats were taken every week from all beds to measure fresh weight yield, dry matter content, and crop P concentration. For seedling crops 1-3, whole plants including roots were sampled while only tops were harvested for the re-growth crops. The 'tops' are harvested cut stems, no longer than 10 cm in length. For crop 3, the yield of both whole plants and tops were measured to provide an index of top:root yields. Sampled plant material was shaken to remove any adhering gravel/sediment on root material and allowed to drain of water before weighing. Crop P contents of re-growth crops 4 and 5 were not analysed.

Yield measurements were also undertaken by The Watercress Company as part of the commercial harvesting procedure, with the watercress from each bed being weighed separately into 11 kg plastic bins.

Quality assessments and shelf life determinations

When the watercress was due to be harvested, 10 samples were taken at random from each bed and bulked to make a sample of *c*. 100 g. The samples were scored by The Watercress Company (TWC) for appearance using a colour chart (1-5 scale, where 1= dark and 5=pale), percentage purple stems, percentage aerial rooting (>3 mm), percentage mottling, percentage leaf diseases (principally *Septoria*), percentage oversize (leaf greater than 40 mm or stem longer than 100 mm and wider than 6 mm) and percentage undersize (leaf less than 20 mm width), according to commercial specifications. The harvested products from each bed were then placed in sealed polythene bags in a refrigerator and assessed for mottling, leaf colour and disease after 3, 5 and 8 days.

Statistical analysis

Experiment design and analysis were under the supervision of Mr Chris Dyer (ADAS statistician). Data were analysed parametrically using analysis of variance (ANOVA) and use of appropriate mean separation tests (e.g. Least Significant Difference).

Results

Objective 1. Determine which of three fertiliser practices produces the lowest TRP discharges.

Bed base

The bed base was composed of 0-3 cm of loose gravel overlying a compacted layer of gravel and small chalk flints (3-10 cm). This in turn overlaid a very compact layer of chalk rubble and large flints (10-30 cm) overlying peat (>30 cm). The chalk rubble layer was too compact to enable sampling below 30 cm.

The concentrations of total and extractable P in the sediment present within the gravel layer at the start of the experiment were very high following a long history of P inputs (Table 2). Concentrations of TP, OP and WEP ranged from 4,680 to 13,100 mg/kg, 41 to 115 mg/kg and 9.7 to 16.4 mg/kg respectively. Bed 6 had the highest concentrations and Bed 1 the lowest, but there was no significant difference in average values between treatments suggesting there was a large supply of available P present in each bed. Concentrations of TP in the turbid interstitial gravel water created during disturbance (mimicking cleaning out) were also very high and very variable, ranging from 4 to 67 g TP/litre.

Concentrations of P in the deeper chalk rubble layer were considerably lower than in the gravel layer but nevertheless can be considered enriched in P (Table 2). Concentrations of TP, OP and WEP ranged from 892-1700, 11-17 and 2.0-4.4 mg/kg, respectively. These data suggest there has been movement of P downwards through the bed base over time.

Concentrations of TP, OP and WEP in the gravel base and chalk rubble remained high throughout the trial. At the end of the experiment, P concentrations were typically in the order T1<T3<T2 but these differences were not statistically significant. Interestingly, P concentrations for treatment 1 appeared to fall over the course of the experiment, possibly indicating release of P from the bed base, although again these differences were not statistically significant.

Table 2. Mean concentrations of total P (TP), Olsen-extractable P (OP) and water-extractable P (WEP) in the gravel base and in the chalk rubble at the start and end of the experiment, according to treatment.

	TP		**OP**		**WEP**	
	START	**END**	**START**	**END**	**START**	**END**
GRAVEL BASE						
T1	**8550**	**5803**	**88**	**56**	**17.6**	**7.6**
T2	**7387**	**7153**	**63**	**75**	**12.9**	**15.1**
T3	**8140**	**6603**	**76**	**66**	**13.5**	**12.8**
F TEST (2 D.F.)	**0.832**	**0.595**	**0.324**	**0.505**	**0.306**	**0.404**
SIGNIFICANCE	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
CHALK RUBBLE						
T1	**1397**	**1177**	**14**	**16**	**3.1**	**<2**
T2	**1297**	**1537**	**16**	**20**	**2.8**	**<2**
T3	**1011**	**2393**	**14**	**28**	**2.2**	**<2**
F TEST (2 D.F.)	**0.212**	**0.200**	**0.751**	**0.113**	**0.494**	**-**
SIGNIFICANCE	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

NS = not significant;
T1 = 900kg P_2O_5 ha/annum, T2 = 2,280kg P_2O_5 ha/annum, T3 = 1,300kg P_2O_5 ha/annum,

Flow volumes

Spot flow rates varied from zero (flow too low to be detected) to 80 litres/sec. A typical flow record is illustrated in Figure 1. Peak flow rates were mostly below 10 litres/sec and generally did not exceed 20 litres/sec except during cleaning out of the beds for crops 1 (12 May) and 2 (20 June). Flow was increased during November and December 2008 to help protect the crop from frost. Otherwise there was a consistent pattern of flow gradually increasing during the single crop cycle once the seedlings had fully established a rooting system, giving a characteristic cyclical pattern in the flow record (Figure 1). Flow did not vary significantly between treatments.

Average flow from the beds over the monitoring period ranged from 2.8 - 5 litres/sec. Average flows per treatment were 4.4, 4.3 and 3.2 litres/sec, respectively. However, the slightly lower flow rates from T3 than the other two treatments may reflect the absence of a full flow record for bed 10.

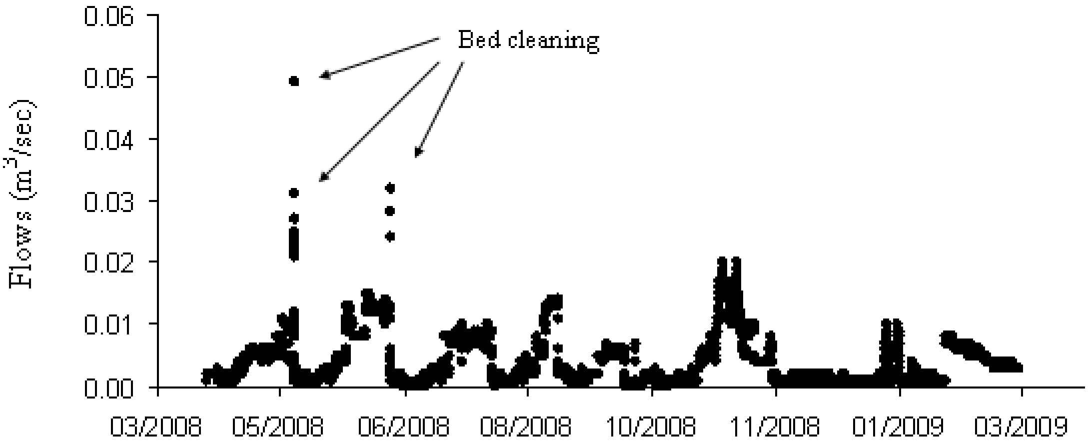

Figure 1. Patterns of flow from bed 2 over the experimental period.

Weekly sampling of bed discharge

Weekly concentrations of TRP in the groundwater as measured at the inflow to the beds, fell within a very narrow range 24-30 µg/litre (mean of 26 µg/litre). However, at the bed outfalls, weekly concentrations of TRP over the monitoring period varied considerably, ranging from 20-20,000 µg/litre depending fertiliser applications and harvesting operations. The largest concentrations were recorded just after fertiliser application while concentrations were often below 100 µg/litre between fertiliser applications.

Spot flow discharge rates for each sampling date were compared with the corresponding TRP concentrations, but there was no consistent pattern (Figure 2). TRP concentrations tended to be greater at the lower flows, but this reflects the practice of limiting flow rates during and immediately after fertilisation to help prevent the fertiliser powder/granules from being washed away. Any effect of flow is therefore small in relation to the effects of fertiliser application and there was no overall statistically significant effect of flow on discharge TRP concentrations.

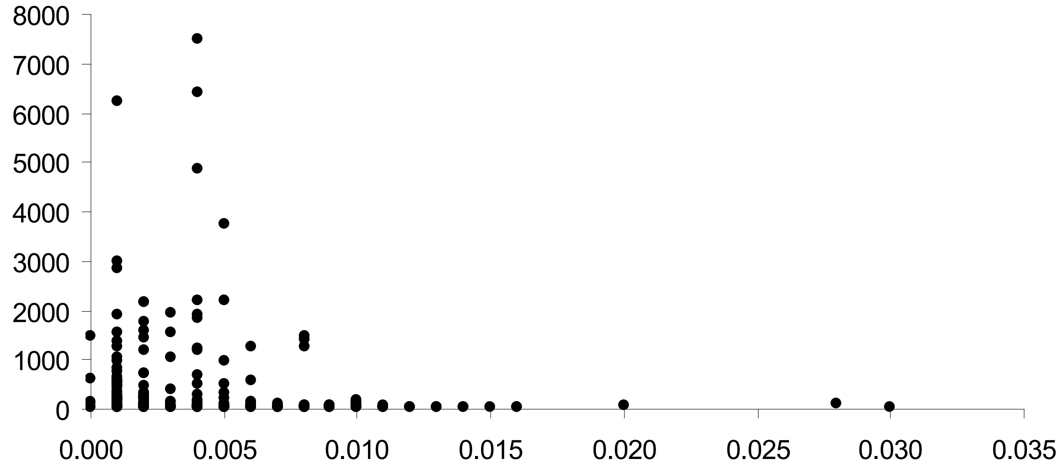

Figure. 2. Variation in weekly TRP concentrations discharged from beds with spot flow rates.

Spot loads of TRP discharged from each bed were calculated by multiplying spot flows and weekly concentrations for every weekly sampling occasion. Values were then averaged for each crop to give the range in loads of P discharged. Spot loads varied from zero (no flow recorded) up to 10 kg/day where fertiliser had just been applied, but average values across the treatments were also very variable (Table 3). A significant treatment effect on average daily P discharge was obtained only for crop 3, when the highest P load was obtained from the beds receiving the highest rate of P fertiliser.

Table 3. Average weekly loads of total reactive P (TRP, kg/day) discharged from the beds according to treatment and for each crop.

TREATMENT	CROP 1	CROP 2	CROP 3	CROP 4	CROP 5	CROP 6
T1	0.31	0.26	0.02	0.02	0.06	0.14
T2	1.02	0.21	0.03	0.07	0.13	0.05
T3	0.10	0.11	0.02	0.02	0.06	0.04
F TEST (6 D.F.)	0.320	0.649	0.039	0.084	0.104	0.576
SIGNIFICANCE	NS	NS	*	NS	NS	NS

NS = not significant; * denotes significance at the 5% level; Least significant difference for crop 3 was 0.01 kg/day.

Overall average TRP loads discharged across the whole season for T1, T2 and T3 were 0.14, 0.13 and 0.06 kg/day, respectively. The lower value for T3 reflects the lower flows due to the lack of flow record for one of the replicates, bed 10. Hence, these loads provide an indication only of the large temporal variation in P load that can occur from a watercress bed, largely due to the effects of fertiliser application and harvesting operations.

Intensive sampling during cleaning out (Crop 1)

Intensive sampling of the discharge during cleaning out of the beds after crop 1 was harvested on the 12 May showed concentrations of TRP ranging from *c*. 0.1 to 3 mg/litre for all treatments. However, TRP concentrations measured from T1 were much lower over at least the first 4 hours of sampling, whilst concentrations from T2 and T3 were very similar (Figure 3).

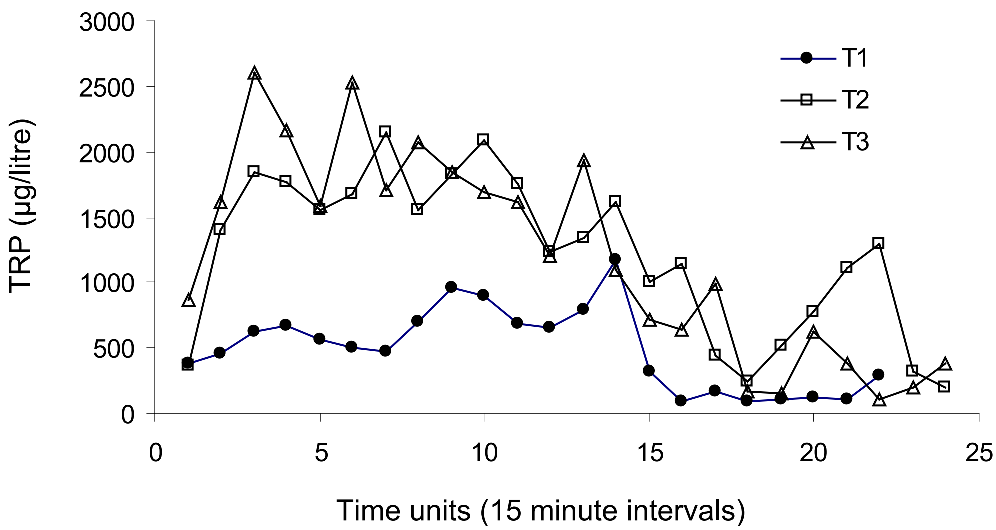

Figure 3. Changes in the concentrations of total reactive P (TRP) during the cleaning out of the beds on 12 May 2008. Time intervals were every 15 minutes.

Average TRP concentrations from T1 over the whole sampling period were 60 to 65% less than those measured from T2 and T3. A highly significant ($P < 0.001$) difference between SRP concentrations from T1 and those from T2 and T3 was also observed when samples were analysed for the full P suite (Table 4).

This large difference in dissolved P concentrations occurred despite the lack of any fertiliser application for 12 days before harvest and cleaning out. There was no overall effect of flow on TRP concentrations during cleaning out. Some significant trends were observed for four individual beds (e.g. treatments 2 and 3) but the trends observed were both positive (i.e. TRP increasing with flow) and negative (i.e. TRP decreasing with flow). Hence it is concluded that differences in flow did not confound the effects of the treatments on TRP concentrations.

Table 4. Treatment effects on the numeric average concentrations (µg/litre) of the various P forms, suspended solids (SS, mg/litre) and P content of the suspended solids (SS-P, mg/kg) measured during the intensive sampling of bed discharge during cleaning out on the 12 May 2008.

Determination	**T1**	**T2**	**T3**	**F test (2 d.f.)**	**Significance**
TRP	513	1277	1451	0.039	*
SRP	342	1045	1071	0.002	**
SUP	343	761	891	0.294	NS
PP	6595	9133	9337	0.547	NS
TP	7280	10939	11299	0.339	NS
SS	1715	1724	1669	0.998	NS
SS-P	5534	5911	5781	0.991	NS

NS = not significant; * and ** denote significance at the 5% and 1% levels, respectively.

Intensive sampling after fertiliser application (Crops 2 and 3)

Intensive sampling was undertaken following application of both Fibrophos (0:22:12) and compound (19:14:14) fertiliser. Fibrophos is a slow-release fertiliser and discharge P concentrations should therefore be lower than the highly water-soluble compound fertiliser. The amounts of Fibrophos applied directly before monitoring started were 10 (T1), 19 (T3) and 68 (T2) kg P/ha. Average concentrations peaked at 1,100 µg/litre for T2 while peak concentrations for T1 and T3 were 225 and 255 µg/litre, respectively (Figure 4).

The amounts of 19:14:14 NPK compound fertiliser applied directly before monitoring started were 17 (T1), 27 (T2) and 10 (T3) kg P/ha. Average concentrations peaked at 26 mg/litre for T1, 37 mg/litre for T2 and 9 mg/litre for T3 (Figure 5). Although the rates of 19:14:14 applied were much smaller than the rates of Fibrophos applied, the peak concentrations recorded after application of 19:14:14 were considerably greater.

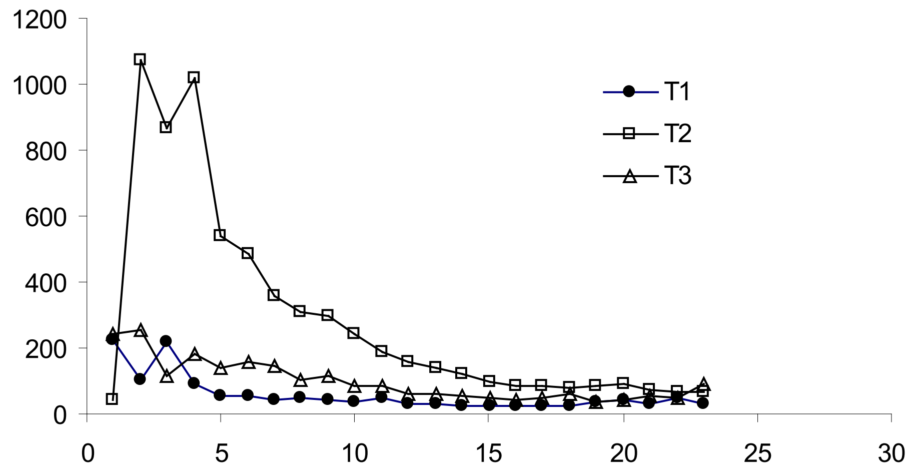

Figure 4. Changes in the concentrations of total reactive P (TRP) in bed discharge water following treatment applications of Fibrophos fertiliser. *Samples were taken every 30 min for the first 4 hours, every 60 min for the next 3 hours, every 3 hours for the next 24 hours and every 6 hours for the next 24 hours.

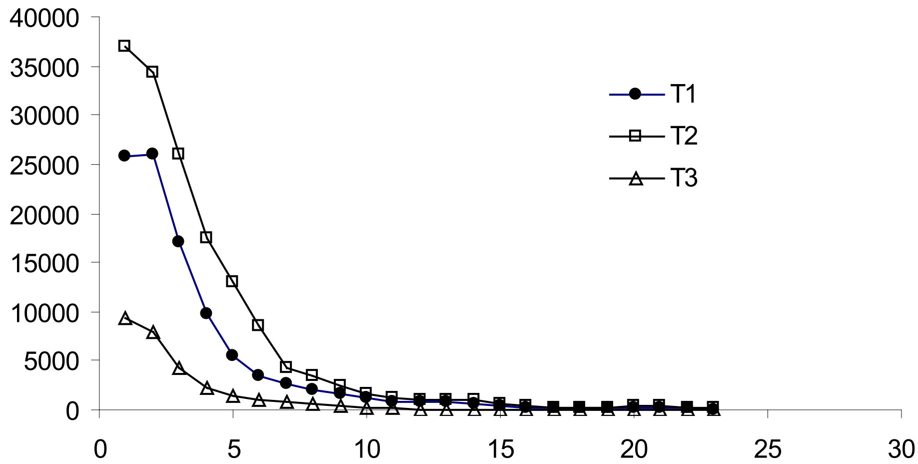

Figure 5. Changes in the concentrations of total reactive P (TRP) in bed discharge water following treatment applications of compound fertiliser. *Samples were taken every 30 min for the first 4 hours, every 60 min for the next 3 hours, every 3 hours for the next 24 hours and every 6 hours for the next 24 hours.

There was a strong linear relationship between the average increase in TRP discharge concentrations over each of the 24 hour monitoring periods (for Fibrophos and 19:14:14) and the amount of fertiliser P applied (Figure 6). The average values represent time-weighted concentrations over the sampling period. The gradients of the relationships between TRP concentration and fertiliser P rate were notably different for Fibrophos and 19:14:14 NPK compound fertiliser.

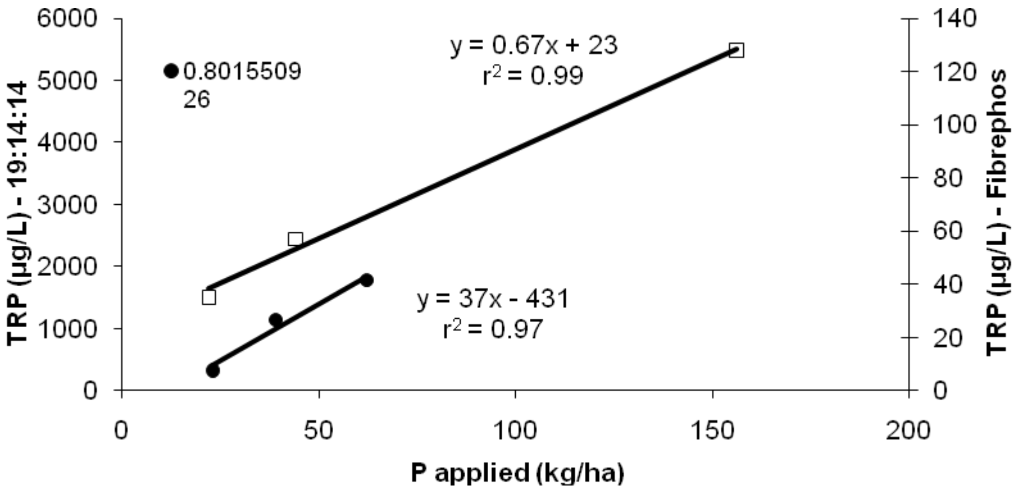

Figure 6. The effect of P application rate on time-weighted average concentrations of total reactive P (TRP) in bed discharge for two types of fertiliser. Note the large difference in scale between Fibrophos and the 19:14:14 NPK compound fertiliser.

Whilst flow rates are reduced during and directly after bed cleaning, flow rate data suggest that there was no significant effect of flow rate on TRP concentrations over the intensive sampling period. Hence it is concluded that differences in flow did not confound the effects of the treatments on TRP concentrations. The results suggest that both the type and rate of P applied has a large influence on the discharge TRP concentrations at the bed outfalls. The higher the rate of P applied and the more water-soluble the fertiliser, the greater the discharge concentrations will be. In terms of the experimental objective, the T1 treatment would therefore be expected to produce the lowest TRP discharge levels.

Objective 2. Determine the lowest rate of phosphate fertiliser that will produce economically viable crops.

Plant tissue samples

Weekly plant samples from each watercress bed were taken to determine the effects of phosphate rates on crop yield. Table 5 shows the fresh weight and dry matter yields (t ha^{-1}) as close as possible to the actual harvest date of the three planted summer crops and the three autumn/winter re-growth crops.

Table 5. Effects on the fresh weight yield (FW, t ha^{-1}) and dry matter yield (DM, t ha^{-1}) at harvest of whole plants (crops 1-3) and tops only (crops 3-6) of nil and three phosphate fertiliser treatments.

	Crop 1 (Whole)	**Crop 2 (Whole)**	**Crop 3 (Whole)**	**Mean**	**Crop 3 (Tops)**	**Crop 4 (Tops)**	**Crop 5 (Tops)**	**Crop 6 (Tops)**	**Mean**
FW yield (t ha^{-1})									
Control (nil P)	75.0	81.9	85.2	80.7	27.1	21.0	13.8	17.9	19.9
T1	101.9	111.6	112.8	108.7	48.8	29.9	18.4	20.5	29.4
T2	107.3	135.2	115.7	119.4	51.3	25.6	14.6	19.0	27.6
T3	103.4	124.6	136.5	121.5	47.7	28.8	17.5	21.4	28.8
F test (2 d.f.)	0.498	0.096	0.029		0.716	0.915	0.157	0.554	
Significance	NS	NS	*		NS	NS	NS	NS	
LSD	11.6	22.0	16.3		12.2	7.8	4.5	8.3	
DM yield (t ha^{-1})									
Control (nil P)	4.5	8.7	4.1	5.7	1.7	0.8	0.7	0.3	0.87
T1	5.5	7.3	5.0	5.9	2.5	1.0	1.1	1.0	1.40
T2	6.5	7.7	5.0	6.4	2.6	0.9	0.9	1.0	1.30
T3	7.1	7.5	6.0	6.8	2.4	1.0	1.1	1.1	1.40
F test (2 d.f.)	0.056	0.910	0.091		0.643	0.796	0.066	0.258	
Significance	NS	NS	NS		NS	NS	NS	NS	
LSD	1.24	2.87	0.99		0.56	0.28	0.17	0.24	-

(NS = not significant; * denotes significance at the 5% level; statistical significance does not include the control area which was not replicated; LSD = least significant difference).

There was no significant (*P* <0.05) treatment effect on either fresh weight or dry weight yield, with the exception of T3 for crop 3 which was entirely due to an unusually high yield measurement on Bed 1. This apparent yield difference on Bed 1 was absent in previous plant measurements for this crop and at harvest crop 3 generally showed greater variability in yields than crop 1 and 2 across the trial site. There is a also a general trend in the planted crops (1 to 3) for the whole plant fresh and dry weight to increase as the rates move towards the two higher rates of P application, but differences were not significant. Yields of re-growth crops were very consistent across all treatments and were always slightly lower on the T2 treatment.

Comparison of commercial and experimental yields

Watercress grown to commercial standards in an average year will produce in the region of 10 t/ha (1 kg/m^2). In 2008, the growing conditions for watercress were considered difficult with low spring temperatures followed by a lack of sunshine hours through the summer growing season, leading typically to a 30% reduction in average yields across many watercress farms in Hampshire and Dorset compared with previous years.

There were no significant differences in commercial yield between the various treatments (Table 6). Crop 3 was not marketable as it was over-mature by the time a commercial harvest was possible (delayed for marketing reasons). Crop 6 required fleecing to prevent early frost damage and complete loss of crop and then only produced a low yield of reduced quality. While the first three crops appeared to produce above average commercial yields for the year, yields from re-growth crops were lower, probably due to loss of plant population for reasons mentioned earlier. The commercial yields were substantially lower than those of the experimental samples (Table 5), possibly because experimental samples were not taken from the poorest parts of the beds.

Table 6. Mean yield (t ha^{-1}) of commercial harvest of watercress from crops 1 to 6 treated with different P fertiliser regimes (excluding yield of crop 3).

Treatment	**Crop 1**	**Crop 2**	**Crop 3**	**Crop 4**	**Crop 5**	**Crop 6**	**Mean***
T 1	9.7	10.0	No yield	6.2	7.4	2.7	7.2
T2	10.9	10.5	No yield	8.3	6.6	2.1	7.7
T3	6.9	9.7	No yield	5.9	6.5	2.8	6.3
F test (2 d.f.)	0.183	0.532	-	0.235	0.706	0.673	0.288
Significance	NS	NS	-	NS	NS	NS	NS

NS = not significant.

Crop P concentration and uptake

Crop P concentrations (whole plants) varied from 4 to 9 g/kg across the different sampling occasions, largely depending on the amounts of P applied (Figure 7). Separate sampling of tops and roots for crop 6 suggested P concentrations in tops are only slightly greater (factor of 1.1) than those in roots. These data suggest that the minimum amount of fertiliser P required to meet the recommended target leaf P concentration for maximum yield of 5.2 mg/kg (Robinson & Cambus, 1977) is 85 kg P/ha (*c*. 200 kg P_2O_5/ha).

Higher crop P and P offtake values were recorded for the fertilised crops than the control crops (Table 7), but on T1 P concentrations in crops 2 and 3 were still below the 5.2 mg/kg target. Higher levels of crop P and P offtake were generally produced by the highest level of P application (T2) compared with T3 and T1, although the only statistically significant result was for crop 3 where the greater P offtake on T3 reflected both the higher recorded yield and a relatively high crop P concentration. Levels of both crop P and P offtake in T2 were often double the level in Control (nil P) with intermediate levels in T1 and T3 as might be expected.

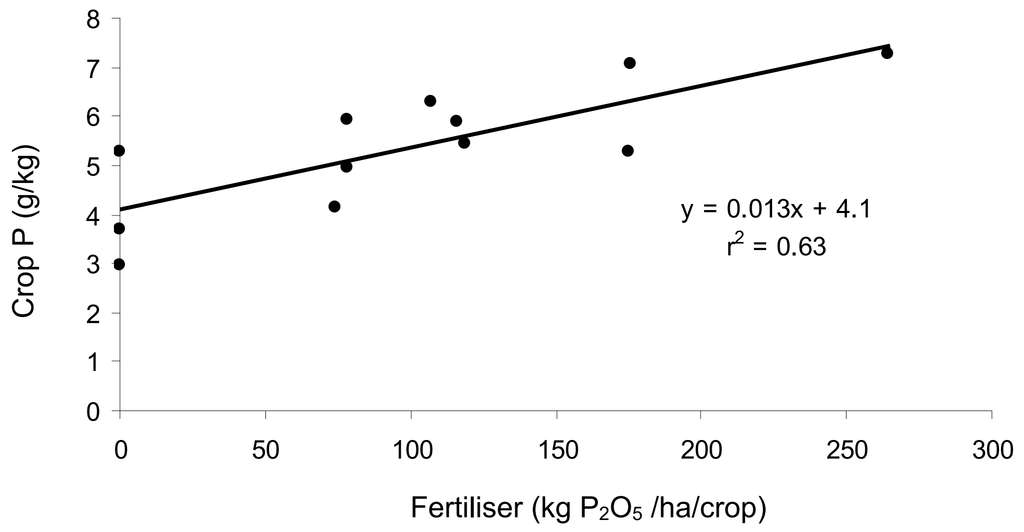

Figure 7. The effect of fertiliser P inputs on the P concentration in whole plants at harvest. Data cover the first 3 crops.

Table 7. Treatment effects on the P content and P uptake by whole plants for seedling crops 1-3.

	Crop 1	**Crop 2**	**Crop 3**
Crop P (mg kg^{-1})			
Control (nil P)	5.3	3.0	3.7
T1	5.9	5.0	4.1
T2	7.3	7.1	5.3
T3	5.5	6.3	5.9
F test (2 d.f.)	0.215	0.224	0.069
P	NS	NS	NS
LSD	2.37	2.80	1.48
P offtake (kg ha^{-1})			
Control (nil P)	23.7	25.8	15.1
T1	32.8	35.9	20.7
T2	46.4	54.5	26.2
T3	38.4	47.7	34.9
F test (2 d.f.)	0.122	0.325	0.033
Significance	NS	NS	*
LSD	13.9	30.1	9.3

NS = not significant; * = significant at the 5% level; LSD = least significant difference.

Objective 3. Determine if phosphate fertiliser rates have any impact on final product quality and shelf life.

Quality assessments and shelf life determinations

There were very limited differences between the treatments in crop quality and shelf life. The only significant differences were in crop 2, for which percentage mottling was significantly higher in T1 and T3 than in the Control (Nil-P) and T2. Control results are included despite being un-replicated.

All crops were grown to satisfactory standards with no significant amounts of over- or under-size product produced at any of the harvest dates. The earlier harvested crops 1 and 2 tended to be paler in colour than crops 3 and 4, possibly reflecting the lack of temperature and light earlier in the season. Holding the samples in the refrigerator as part of the shelf life study appeared to have no detrimental effects on reducing the leaf colour but may have slightly increased the levels of mottling and leaf diseases. Purple stems were recorded in all planted crops with very high levels in all treatments of crop 3. Aerial rooting can be a cause for rejection if the length of aerial roots exceeds 3 mm, as in crop 3 probably due to over-maturity. Levels of mottling and disease were generally low.

Table 8. Quality assessments on 100 g samples taken at harvest (day 1) and after 3, 5 and 8 days shelf-life. Data for crops 1 to 4, assessed 12 May, 20 June, 31 July and 27 August 2008 respectively

		Crop 1				Crop 2				Crop 3				Crop 4			
		Treatments				Treatments				Treatments				Treatments			
Day	**Assessment**	**T1**	**T2**	**T3**	**Nil -P**	**T1**	**T2**	**T3**	**Nil-P**	**T1**	**T2**	**T3**	**Nil-P**	**T1**	**T2**	**T3**	**Nil-P**
	Over spec (%)	11.3	10.3	4.7	15.0	0	0	0	0	0	0.7	0	0	0	2.0	0	0
	Under Spec (%)	2.7	4.0	6.0	2.0	6.3	2.7	7.6	3.0	18.3	1.6	5.0	0	0	0	0	0
1	Colour rating	4.3	4.7	4.3	5.0	3.3	4.3	3.7	4.0	2.7	2.7	2.7	3.0	2.3	2.3	2.0	2.0
3	Colour rating	4.3	4.7	4.3	5.0	3.3	4.3	3.7	4.0	2.7	2.7	2.7	3.0	2.3	2.3	2.0	2.0
5	Colour rating	4.3	4.3	4.0	5.0	3.3	4.3	3.3	4.0	2.7	2.7	2.7	3.0	2.3	2.3	2.0	2.0
8	Colour rating	3.7	3.7	4.3	4.0	2.7	3.3	3.0	3.0	2.7	2.7	2.7	3.0	2.3	2.7	2.7	3.0
	Purple stems (%)	20.7	10.0	15.3	16.0	22.6	14.3	16.3	15.0	42.3	43.0	35.3	25.0	6.3	2.3	5.0	3.0
	Aerial rooting > 3 mm (%)									40.0	28.7	35.0	17.0	3.3	3.7	3.7	0
1	Mottling (%)	0	0	0.7	0	2*	0	1.7*	0	0	0	0	0	0	0	0	0
3	Mottling (%)	0	0	0.7	0	2*	0	1.7*	0	0	0	0	0	0	0	0	0
5	Mottling (%)	0	0	1.0	0	2*	0	1.7*	0	0	0	0	0	0	0	0	0
8	Mottling (%)	1	1	2.0	1	2*	0	1.7*	0	0	0	0	0	0	0	0	0
1	Leaf disease (%)	0.3	0	0	0	0	0	0	0	1.0	0	0.3	0	3.3	1.0	1.7	4.0
3	Leaf disease (%)	0.3	0	0	0	0	0	0	0	1.0	0	0.3	0	3.7	1.0	1.7	4.0
5	Leaf disease (%)	0.3	0	0	0	0	0	0	0	1.3	0	0.3	0	5.7	1.3	2.7	5.0
8	Leaf disease (%)	0.3	0	0	0	0	0	0	0	1.3	0	0.7	0	5.7	1.3	2.7	6.0

* Denotes significant ANOVA result at *P*<0.05. There are no significant differences between all other results. .

Objective 4. Determine the rate of release of phosphate from an un-fertilised (NPK) watercress bed.

The small control area which did not receive any NPK fertiliser provided an opportunity to quantify the uptake of P from the bed base. This is the primary source of P available to the plant as concentrations of soluble P in the groundwater are very low. Uptake assessments are based on data from the first three crops, from which both roots and tops were collected.

Fresh weight yields on the control area were consistently *c*. 70% of those obtained in the fertilised beds (Table 5). However, plants from the control area generally had a greater percentage dry matter than fertilised plants which had the effect on one occasion (crop 2) of increasing the dry weight yield above values on fertilised beds.

With the exception of crop 1, crop P concentrations on the control area were well below the level of 5.2 g/kg required for satisfactory crop growth according to Robinson & Cambus (1977). Crop P offtake was similar for crops 1 and 2 (*c.* 25 kg P/ha) but declined to only 15 kg/ha in crop 3 (Table 7). Without inputs of P from fertiliser, crop P concentrations and offtake might be expected to decline if the ability of the crop's anchorage roots to utilize the large available P reserves in the bed base was limited. However, P uptake across the control area was still 50 to 60% of the average P offtake across the three fertilised treatments.

It was not possible to collect discharge water from the control area but bed base analyses suggested concentrations of soluble P of 1.3 to 1.8 mg/litre, reflecting the large amounts of available P reserves in the base.

Discussion

Bed base concentrations over the one year period of the experiment remained high and did not fluctuate with treatment, potentially providing a large supply of available P for root uptake. Similarly, levels of P in the deeper rubble base remained fairly constant except that total phosphate levels in T3 appeared to double over the length of the experiment suggesting that the more frequent applications were not necessarily more efficient for crop uptake.

In the weekly water sampling schedule, the largest discharge concentrations of TRP were recorded after fertiliser applications with larger concentrations measured after T2 and T3 than T1. The addition of flow rate data provided since the Annual Report indicated that the loading of P (but not the concentration of P) discharged from each bed is influenced by the flow. Reducing flow during periods of fertiliser application will help to minimise the loads of P discharged, even though discharge P concentrations will remain high during the first 24 hours after application. As reported previously, peak concentrations occurred within a few hours of application and were much lower when the slow-release Fibrophos fertiliser was applied compared with compound fertilisers. The large difference in average discharge TRP concentrations between the two fertilisers (Fibrophos and compound fertiliser 19:14:14 NPK) raises questions over the need to use water-soluble fertilisers except in situations where higher rates of available P need to be applied during cold temperatures to prevent purpling and during warm periods of rapid growth when only more soluble fertilisers will provide sufficient available P. Twenty-four hours after fertiliser had been applied, discharge levels of P had returned to normal. The practise of reducing flow levels during and after fertiliser applications to allow the crop every opportunity to recover as much fertiliser as possible clearly has benefits in reducing overall P loadings from the beds.

Intensive sampling of the discharge during bed cleaning and after fertiliser applications produced similar results with T1 having significantly lower TRP concentrations than T2 and T3. Flow rate differences between beds did not influence treatment effects on discharge P concentrations after either fertiliser application.

The results indicated that there were no statistically significant yield differences between P treatments for any of the crops, although there was a numeric trend for the fresh and dry weights of the planted crops (1 to 3) to increase with increasing rates of P fertiliser. In commercial practice, the beds would be harvested as soon as they were mature (subject to demand) to maximise yield and quality and allow a new crop to be established as soon as possible, but in the trial it was necessary for all treatments to reach maturity before harvest could commence. T2 reached a harvestable condition sooner than the other treatments and the delayed harvest had consequences for quality and the potential to knock back yields. The effects of this delay could be compounded when the annual production cycle is considered. Sequential harvesting treatments according to maturity may have been preferable to differentiate treatment yields. The impact of this faster growth rate on total marketable yield per year could be significant for farm profitability.

There was a trend for higher crop P concentrations and P off-take to be produced by the higher fertiliser treatments, although the differences were mostly not significant. Levels of crop P in T2 were particularly high in crops 1 and 2 (above the 5.2 g/kg threshold), but this did not prevent some purple stemmed plants at harvest. Levels of stem purpling were highest in crop 3, showing that close monitoring of plant P concentrations to ensure a level well above 5.2 at all stages of growth is essential to minimise stem purpling as a reason for crop rejection. Other stress factors such as over-maturity and aerial rooting were both implicated in the reasons for this crop being rejected.

During the harvest of crop 3, thicker stemmed plants were observed to have increased levels of purple colouration compared to those with thinner stems. Thicker stemmed plants may establish quicker at planting than those with weaker, thinner stems. Differences in plant type and crop density are associated with the way the crop is established leading to competition and plant to plant variations that can last through until harvest. It was observed that the onset of stem purpling can appear rapidly and intensify accompanied by a shortening of the internode length.

While a trend appeared to exist in the planted crops for increasing yields with increased rates of fertiliser this was not evident in the results of the lower yielding re-growth crops (4 to 6). This is probably due to the plant roots being more strongly anchored into the gravel base which was shown to be high in available phosphate (76 mg Olsen-P/kg of gravel sediment) and so may have masked the effects of treatment on yield. Recorded levels of stem purpling were very much lower in all treatments of re-growth crops suggesting sufficient available P even at the low rates of applied P.

The lack of any trend in crop yields between the treatments in the re-growth crops may suggest that growers could improve fertiliser management by applying less P fertiliser to re-growth crops, without any yield or quality penalty.

Quality assessments were carried out on samples taken at harvest of each bed and consequently match the commercial yields. Assessments at this late stage in maturity made differentiation between the treatments difficult. Ideally quality assessments made twice weekly as harvest approached would record progressive quality problems. P treatment had no detectable effects on quality during the 3, 5 and 8 day shelf life trials at The Watercress Company.

Conclusions

- From the data collected so far, maintaining current commercial levels of P is necessary to meet quality standards, through crop P uptake and the requirement to minimise stem purpling. The evidence that commercial levels of P are required for maximising yield is less compelling, especially for re-growth crops where a reduction in P may not impact on final yield. Crop P levels can be maintained at 0.52% with 200 kg/ha P_2O_5 per crop, but this level may not be sufficient to prevent quality problems such as purple stems.

- A reduction in commercial rates of fertiliser application for re-growth crops would lower discharge P concentrations and loads, especially where the more soluble fertilizers are applied and at higher rates of application.

- Discharge concentrations and loads of TRP are highly dependent on both the rate and type of P fertilizer applied with highest concentrations (up to 40 mg/litre) occurring within a few hours after soluble fertilizer use but reducing to <100 µg/litre between fertilizer events. Correspondingly, concentrations of TRP were much greater in discharges from commercial levels of P application (2,200 kg/ha per year) compared with 900 kg/ha P_2O_5 per year. However, even at current recommended rates of P application, discharge concentrations are well above the low limits required to protect water quality suggesting alternative methods of control are required.

- These results indicate that although there were clear visual differences in crop quality between the treatments, the apparently more saleable product obtained under current commercial practice (T2) could not be translated into significantly greater yields in this trial. This suggests that the variability in crop growth across the beds is greater than the treatment differences between beds.

- Water flow rate measurements across the beds were relatively uniform and consistent between beds and did not greatly influence treatment effects on P discharge levels, crop yield or harvest quality.

Technology transfer

Article for HDC News December 2009, including reference to HDC Project FV 338a: "Review and evaluation of two phosphate stripping materials for reducing phosphate concentrations in watercress discharge outflows."

Glossary

Phosphate forms

Olsen Phosphate (OP), – estimates plant available inorganic P levels (mg/kg)

Orthophosphate – the dissolved inorganic form of phosphorus.

Particulate Phosphate (PP) – the phosphate attached to suspended solids. Calculated as the difference between TP and TDP.

Soluble Reactive Phosphate (SRP) – a measure of orthophosphate, the filterable (<0.45 μm), soluble, inorganic fraction of phosphorus, the form directly taken up by plant cells (μg/litre).

Soluble Un-reactive Phosphate (SUP) – dissolved (<0.45 μm) phosphate that is not inorganic. This fraction contains dissolved P in organic and polyphosphate forms.

Suspension Solids (SS) - solids held in suspension of a liquid (SS mg/litre).

Suspension Solids – Phosphate (SS-P) – phosphate bound to the solids held in suspension of a liquid (SS-P, mg/kg).

Total Dissolved Phosphate (TDP) – the sum of SRP and SUP.

Total Phosphate (TP) - a measure of all the forms of phosphorus, dissolved and particulate, that are found in a sample (mg/kg). It represents the sum of SRP, SUP and PP.

Total Reactive Phosphate (TRP) – the inorganic phosphate that is present in an unfiltered sample without preliminary hydrolysis or digestion (μg/litre). It represents the sum of SRP and that portion of PP which is easily extracted and hence bioavailable to aquatic organisms. The main method used by the EA.

Water-extractable Phosphate (WEP) – the portion of total P in a sample which is extracted by water in inorganic form at a given sample:water ratio (mg/kg). It is a measure of the ease with which P might be released to runoff during a storm event.

Fertiliser conversions

To convert P to P_2O_5, multiply by 2.29.

To convert K to K_2O, multiply by 1.205.

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