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:	Annual report, Jan 2009
Previous report	
Key staff:	Dr Paul Withers, ADAS Adam Bates, ADAS Sean Ede, The Watercress Company Penny Ede, The Watercress Company
Location of project:	The Watercress Company, Maxwell Farm, Alresford, Hampshire
Project coordinator:	Dr Steve Rothwell, Vitacress Salads, St Mary's Bourne, Hamps. Charles Barter, The Watercress Company, Waddock Cross, Dorchester, Dorset.
Date project commenced:	1 March 2008.
Date project completed (or expected completion date):	30 November 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 carried out under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

Nigel MacDonald
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Signature .... Date ....

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Dr Bill Parker
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GROWER SUMMARY

Headlines

- The current commercial phosphate application rate on watercress (2,200 kg P_2O_5 per hectare) seems best practice to achieve good quality standards, minimise aerial feeder roots and stem purpling.

- Increasing phosphate application increases fresh and dry weight yields. However, discharge levels of total reactive phosphate (TRP) into watercourses are high at bed clearing and after fertiliser application though they return to normal levels within 24hrs.

Background and expected deliverables

To produce marketable crops, watercress plants require supplementary phosphate (P_2O_5)* that is not supplied in sufficient quantity from groundwater. Previous research indicated critical plant levels of phosphorus (P) to be 0.52% in leaves and stems for plants with the potential to produce 90% yield (Robinson & Cambus, 1977). Since this research, crop turnaround rates, yields and quality expectations have increased considerably.

Matching crop phosphate needs for maximum yields with supplementary applications of phosphate fertilisers requires skill and attention to detail. It cannot be a precise science, as factors such as water flow, temperature and growth rates are continually fluctuating. There has therefore been a tendency to apply an insurance amount of P to ensure adequate crop nutrition. A greater appreciation of the actual shortfall at various crop stages, flow rates and seasons of the year should allow a more precise approach to the use of phosphate fertilisers.

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 to maximise nutrient uptake by the crop and minimise 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 rates applied. Excessive phosphate application must be avoided as excess phosphate not taken up by the plant, or adsorbed into the bed base, will be lost into the discharge waters.

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* To convert P_2O_5 to P, divide by 2.29

Phosphate discharges into watercourses can lead to 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. This in turn can reduce the numbers of small aquatic animals and fish that are dependent on them.

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 done in the 1980s, provided the NFU Watercress Association with Best Practice guidelines for phosphate use, and an interim defence position on phosphate fertiliser use. However, it was clear that in-depth experimentation would be required to evaluate how effective the Best Practice guidelines were in reducing phosphate discharges. This required a comparison of approaches to phosphate use and intensive monitoring of P levels in discharge waters.

The expected deliverables from this project are:

- 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 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. Best Practice Guidelines (as in FV 302) 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.

- Although there was no significant difference in the fresh or dry weight yield from the three treatments, there was a general trend for the higher P rates to produce higher yields. This only applied to planted crops but not in re-growth crops where rooting into the bed base provides a rich source of the nutrient with no response to additional applied P. Rooting into the bed base also leads to less stem purpling. Consequently, re-growth crops require less applied P.

- In one crop a significant ($P < 0.1$) yield increase was produced by the highest P rate, both from the experimental samples and also from the commercial crop left after the trial was harvested.

- Higher P concentrations and P off-take are produced by 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 from showing stem purpling as experienced in late spring and early summer crops. . Maintaining plant P levels above 5.2 g/kg 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 are required per crop but only when all conditions are ideal. In reality nearer 400 kg/ha P_2O_5 are required per crop to produce plants of acceptable commercial quality. The lower 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 no other stress factors that could lead to purpling were imposed on the crop.

- The late summer and autumn re-growth crops did not respond to higher yields or improved quality with higher rates of P fertiliser. Adequate P reserves are present in the gravel base, sufficient to ensure optimum availability.

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

- The higher the rate of P fertiliser applied, the higher the levels of P in water discharges. Similarly, the more soluble the fertiliser, the higher the discharge rates; Fibrophos produced lower levels of discharge P compared with 19:14:14 NPK compound fertiliser.

- Discharge levels of TRP are increased at bed clearing and after fertiliser application but return 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. Large rates of highly water-soluble P fertiliser should be avoided.

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

Financial benefits

Until we have all the information relating to flow rates and fully analysed the data, it is difficult to give specific benefits. To date the results look promising and it should be possible to provide guidance relating to rates of P fertiliser, utilisation of additional information on P concentrations and their impact on crop quality in the Final Report.

Action points for growers

- Use the more soluble fertilisers only when necessary i.e. during periods of rapid growth when less soluble forms of phosphate are not sufficiently available or when the crop is poorly rooted. P discharge levels will be considerably higher when soluble fertilisers are applied compared with the less soluble Fibrophos source of P.
- Adopt the NFU Watercress Code of Practice that suggests helpful measures to reduce levels of P in discharge waters.
- 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 are required per crop and only when conditions are ideal. Increasing rates of P fertiliser will increase crop P levels.
- Take advantage of the high reserves of P in the gravel base 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 78 kg/ha P_2O_5 had no detrimental effect on yield or quality of regrowth crops.
- Additional financial benefits made are highlighted in the Final Report to this project once the flow rate data not currently available is analysed and included in the results.

SCIENCE SECTION

Introduction

Watercress is grown throughout the year utilising the headwaters of springs in Hampshire, Dorset and Wiltshire. There are approximately 40 sites in these counties producing approximately 3,000 tonnes of watercress per year with a value of £55 million at retail level (including an additional 1,500 tonnes imported). Winter grown crops are supplemented with imported crops from Spain, Portugal and the USA.

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% of P in leaves and stems was critical if crops were to have the potential to produce 90% yield (Robinson & Cambus, 1977). Since this research, crop turnaround rates, yields and quality expectations have increased considerably.

Matching crop phosphate needs for maximum yields with supplementary applications of phosphate fertilisers requires skill and attention to detail. It cannot be a precise science, as factors such as water flow, temperature and growth rates are continually fluctuating. There has therefore been a tendency to apply an insurance amount of P to ensure adequate crop nutrition. A greater appreciation of the actual shortfall at various crop stages, flow rates and seasons of the year should allow a more precise approach to the use of phosphate fertilisers.

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. Excessive phosphate application must be avoided as excess phosphate not taken up by the plant, or adsorbed into the bed base, will be lost into the discharge waters. Phosphate discharges into watercourses can lead to 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. This in turn can reduce the numbers of small aquatic animals and fish that are dependent on them.

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).

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 Best Practice guidelines for phosphate use, and an interim defence position on phosphate fertiliser use. However, it was clear that in-depth experimentation would be required to evaluate how effective the Best Practice guidelines were in reducing phosphate discharges. This required a comparison of approaches to phosphate use and intensive monitoring of P levels in discharge waters.

A new and more significant threat 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 might 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 and produce viable crops.

The specific objectives of this experiment were:

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.

Materials and methods

Site location and experiment design

The watercress beds used in this experiment were located at Maxwell Farm, Alresford, Hampshire consisting of ten beds each measuring approximately 38 m x 9 m (350 m^2), and fed from the same groundwater source. Ten identical beds allowed three P fertiliser treatments (T1, T2 and T3) to be replicated three times in a randomised block design. A small portion (35 m^2) of the tenth bed 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 (Plate 1). 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.

Plate 1. Watercress beds at Maxwell Farm, Alresford, Hampshire being levelled off before planting of the P fertiliser treatment experiments, spring 2008

The experiment was carried out between 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. Weekly water samples will continue until March 2009.

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: Best Practice Guidelines (as in FV302) limited to 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 by an experienced operator to each bed ensuring comparable rates of nitrogen and potash were applied (Table 1). Additional inputs of sulphate of iron were added when appropriate to all beds to prevent yellowing.

Table 1. Rates of nitrogen (N), phosphorus (P) and potassium (K) fertiliser that were applied to each watercress crop 2008

	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* (kg ha^{-1}) applied								
T1	78	78	74	54	54	55	393	899
T2	264	176	175	156	156	68	995	2278
T3 ▲	119	107	116	108	84	34	568	1300
K* (kg ha^{-1}) applied								
T1	266	186	199	177	177	57	1062	
T2	326	217	217	179	179	71	1189	
T3	287	218	196	181	127	36	1045	

* To convert P to P_2O_5, multiply by 2.29. To convert K to K_2O, multiply by 1.205.
▲ Treatment 3 did not always receive all the allocated P for each crop depending on harvest date in relation to last fertiliser application.

Treatment applications and crop measurements were constrained by the need to achieve timely harvesting and a satisfactory crop for sale. For T3, some bi-weekly fertiliser applications were omitted because they were too close to the harvest date (e.g. crop 5) and for T1, an additional ‘emergency’ fertiliser application was made to improve the colour of crop 2 at harvest. 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.

Assessments

Bed base

On the 26 February, the over-wintered crop was removed, the base cleaned and re-leveled and its physical and chemical composition characterised. Representative samples of both the gravel base and the underlying chalk base were sampled for determination of total P (TP), plant-available (Olsen) P (OP) and water-extractable P (WEP) to provide an initial estimate of the P available to the rooted crop. For each bed, the gravel/chalk from ten 0.04 m^2 quadrats was sieved through a 5 mm mesh, bulked and sub-sampled for analysis. Additional samples of the turbid solution produced by this process (mimicking cleaning out) were also taken for analysis of total P. Further replicate samples of stored (heaped) gravel base material that is usually used to replenish the gravel base at the end of each crop was also analysed for TP, OP and WEP. This gravel base store was never used by the grower during the experimental year but nevertheless represents what might have been used in practice in another year. The initial concentrations of P measured in the bed base will be compared with a final sample taken at the end of the experiment in March 2009.

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. Sampling was generally carried out on the same day each week.

Intensive sampling of the discharge water from each bed was carried out on three occasions: on 12 May (during bed cleaning), 2 June (after application of Fibrophos fertiliser) and on 7 July (after application of 19:14:14 NPK compound fertiliser). 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 and at the start of cleaning and every 15 minutes for a period of 6 hours. This was usually the period taken for the discharge water to become clean. 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 also 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 after fertiliser application were analysed for TRP only since little bed sediment is dispersed during fertilisation.

Plant tissue samples and yield

To allow crop performance comparisons between phosphate treatments, plant samples from 5 x 0.1 m^2 quadrats were taken every week from all beds (including the unfertilised control area of bed 10) to determine fresh weight yield, dry matter content, crop P concentration and crop P uptake. Sampling commenced when there was sufficient material to sample and the samples were taken randomly from areas of the bed that showed full crop cover. 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 tops: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 from each bed as part of the commercial harvesting procedure with the watercress from each bed being weighed separately into 11 kg plastic bins after quadrat samples and shelf life samples had been taken.

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 in total. The samples were scored by The Watercress Company (TWC) for appearance using a colour chart (score 1-5, 1= dark, 5=pale), percentage purple stems and percentage aerial rooting (>3 mm), percentage mottling and percentage leaf diseases (principally *Septoria*) according to commercial specifications. Defects were weighed to give a percentage in each category. Oversize product related to leaf greater than 40 mm or stem longer than 100 mm and wider than 6 mm. Undersize product related to leaf less than 20 mm width. Percentage aerial roots produced greater than 3 mm were scored after the second harvest to improve treatment differentiation. The harvested product from each bed was then placed in sealed polythene bags in a refrigerator and assessed for shelf-life after 3, 5 and 8 days for appearance (leaf colour) and disease. Statistical analysis was used to determine any quality and shelf life differences between the harvested material from the different phosphate fertiliser regimes.

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, crop management and treatments

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 compared to 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 (e.g. crop 5). For T1, an additional 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.

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. The inlet flow through beds 7, 9 and 10 was noticeably reduced after a breakdown of the borehole pump during crop 3 causing lower flows at the outlet after this period. This seemed to have a significant effect on the discharge TRP concentrations measured from these beds, especially beds 9 and 10 (furthest away). When made available by the Environment Agency, flow data will help to quantify these effects.

Removal of plants during crop measurements necessarily involved some patching of bare spaces with seedlings for the re-growth crops. The establishment of these seedlings was variable and re-growth crops generally appeared more uneven than the seedling crops.

Generally temperatures were below the long-term average for much of the period causing slower growth than normal. The first and to a lesser extent the second crop had a very prolonged growing period due to a cold spring.

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 were very high following a long history of P inputs. 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.

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

	TP	**OP**	**WEP**
Gravel base			
T1	8550	88	17.6
T2	7387	63	12.9
T3	8140	76	13.5
F test (2 d.f.)	0.832	0.324	0.306
Significance	NS	NS	NS
Chalk rubble			
T1	1397	14	3.1
T2	1297	16	2.8
T3	1011	14	2.2
F test (2 d.f.)	0.212	0.751	0.494
Significance	NS	NS	NS

NS, not significant

The stored bed base gravel used in re-levelling the gravel after cleaning out seedlings also showed very high concentrations of P. Mean values of TP, OP and WEP were 10,800, 107 and 20 mg/kg respectively and are slightly above those measured in the beds themselves at the start of the trial.

Water samples

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) and was therefore very consistent. However, at the bed outfalls, weekly concentrations of TRP over the monitoring period to date varied considerably, ranging from 20-20,000 µg/litre depending on flow, when fertiliser was last applied and harvesting operations. The largest concentrations were recorded just after fertiliser application while concentrations were often below 100 µg/litre in between fertiliser application. Treatment effects on discharge TRP concentrations cannot be fully assessed until flow data are made available by the Environment Agency.

Preliminary trends in average weekly concentrations at discharge are shown in Table 3. Concentrations tend to be greater for T2 than T3 which is greater than T1 with exception of crop 2 where T1 concentrations are highest because average values are heavily influenced by one sampling date directly after a fertiliser application, and crop 6 where little fertiliser was applied. Once flow data are available further analysis of flow effects can be undertaken.

Table 3. Average weekly concentrations of total reactive P (TRP, µg/litre) 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	749	1053	43	49	391	239
T2	2016	547	114	114	955	255
T3	511	251	69	69	691	232

Intensive sampling during cleaning out (Crop 1)

Intensive sampling of the discharge during cleaning out of the beds after crop 1 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 1).

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 between 29

April and 11 May. Differences in flow rates across the beds will influence these concentrations and these data are still awaited from the Environment Agency.

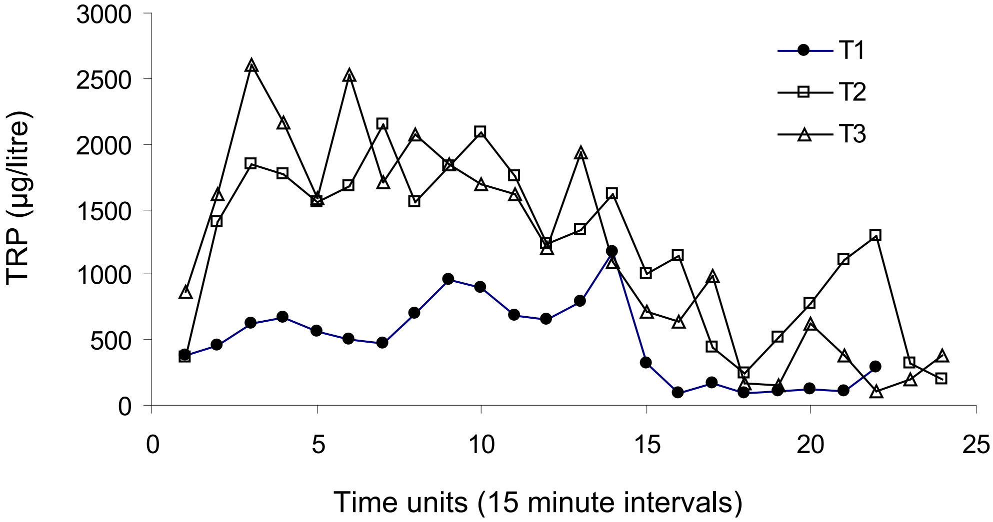

Figure 1. Changes in the concentrations of total reactive P (TRP) during the cleaning out of the beds on 12 May 2008. Time intervals were every 15 minutes.

TRP concentrations were consistently above SRP concentrations because the Environment Agency method of analysis will include a proportion of easily desorbed P from the particulate fraction. There was no significant difference between treatments in the concentrations of other measured P forms; either as soluble unreactive (organic) P or particulate P, although values were always greater on T2 and T3 than T1 (Table 4).

Concentrations of particulate P were nearly an order of magnitude greater than dissolved P forms due to the transport of sediment and fine crop debris during cleaning out. Hence TP concentrations discharged from the beds during the period were very large, ranging from 7-11 g TP/litre.

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.

Concentrations of SS ranged from 0.04 to 22 g/litre on different occasions during the cleaning out process but average values were *c*. 1.7 g/litre and very consistent across all treatments, as was the concentration of P within the SS (SS-P) with average values of 5.5 TO 5.9 g/kg. The latter values are of a similar order to those measured in the bed base at the start of the experiment (Table 2).

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 2).

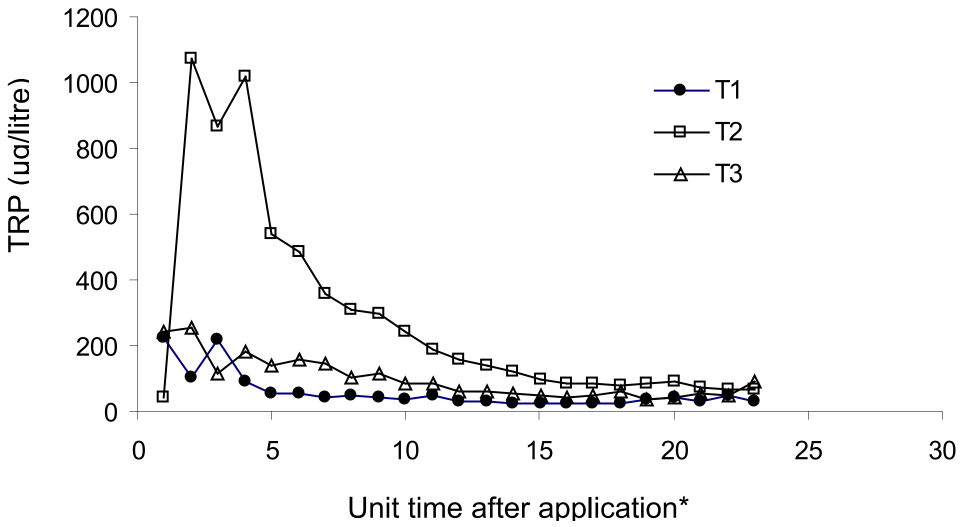

Figure 2. Changes in the concentrations of total reactive P (TRP) in bed discharge water following treatment applications of Fibrophos fertiliser. *Samples were taken every 30 min for the first 4 hours, every 60 min for the next 3 hours, every 3 hours for the next 24 hours and every 6 hours for the next 24 hours.

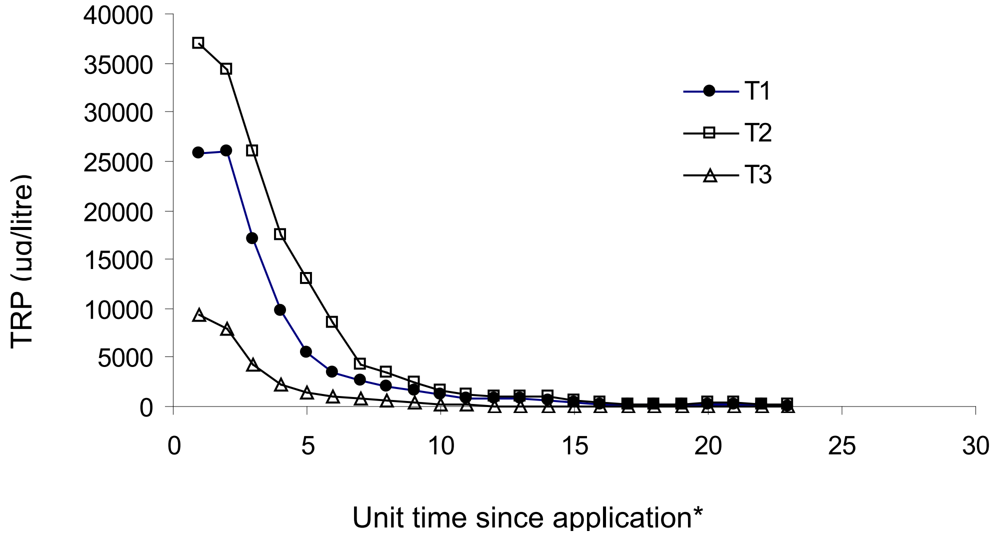

Figure 3. Changes in the concentrations of total reactive P (TRP) in bed discharge water following treatment applications of compound fertiliser. *Samples were taken every 30 min for the first 4 hours, every 60 min for the next 3 hours, every 3 hours for the next 24 hours and every 6 hours for the next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

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 3). 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.

There was a strong linear relationship between the average increase in TRP discharge concentrations over the 24 hour monitoring period and the amount of fertiliser P applied (Figure 4). The average values represent time-weighted concentrations over the sampling period. The gradient of these relationships was notably different. While discharge concentrations of TRP (µg/litre) after Fibrophos application were about two-thirds of the amount of fertiliser P applied (kg/ha), the discharge concentrations of TRP after 19:14:14 NPK compound fertiliser application were 37 times greater than the amount applied.

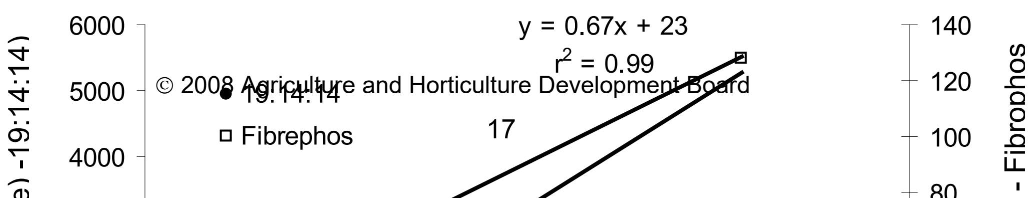

Figure 4. The effect of P application rate on time-weighted average concentrations of total reactive P (TRP) in bed discharge for two types of fertiliser. Note the large difference in scale between Fibrophos and the 19:14:14 NPK compound fertiliser.

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. Further analysis of the effects of flow rate on the weekly and storm concentration data is required.

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 for analysis of dry matter to determine if differences in phosphate rates had any effect on yield at the harvest of each crop. 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 3-5) of nil and three phosphate fertiliser treatments (NS – not significant. * denotes significance at P=0.05; statistical significance does not include the control area which was not replicated. LSD = least significant difference)

	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	-

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. Differences in flow rates across the beds may partly account for this but flow data have not yet been provided by the Environment Agency.

For crop 2, fresh weight yield on T2 was significantly higher than T1 and T3 at the 10% level but not the 5% level. For crops 1, 3 and 5, dry weight yield was significantly greater on T3 at the 10% level. 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 (t ha^{-1}), 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.

Harvesting of the individual beds after sampling the experimental beds was carried out by the farm staff using commercial harvesting methods. The crop in each bed was cut with a stalk length of between 70 and 100 mm as per quality standards. The harvested crop from each bed weighed separately. The results are presented in Table 6.

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.

There were no significant differences in yield between the various treatments. 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.

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; average crop P at harvest in relation to the amounts of P received by the crop during the growing period are shown in Figure 5. 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).

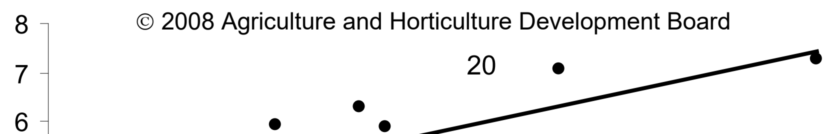

Figure 5. The effect of fertiliser P inputs on the P concentration in whole plants at harvest. Data cover the first 3 crops.

The measured crop P content and uptake of P by the plants (roots and tops) for the first three crops treated with different rates of P fertiliser is illustrated in Table 7. Higher crop P and P offtake values were recorded for the fertilised crops than the control crops 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 this was statistically significant only for crop 3 where the greater P off take 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 (Fig. 5).

Table 7. Treatment effects on the P content and P uptake by whole plants for seedling crops 1-3 (NS = not significant. * = significant at *P*=0.05; LSD = least significant difference)

	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})[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
P	NS	NS	*
LSD	13.9	30.1	9.3

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

Quality assessments and shelf life determinations

In order to determine if there were any effects of phosphate treatments on plant quality at harvest, random samples representing harvested material were taken from across each bed to produce a bulked 100 g sample for assessment. Samples were taken as close as possible to the optimum harvest date with due consideration for the slower growth rate of T1 compared with T2 and T3.

Table 8 presents the quality assessments at the commercial harvest dates and after shelf life of crops 1 to 4 for the different phosphate treatments. There is very limited significant difference between the treatments, with significant differences only in crop 3, percentage mottling being significantly higher in T1 and T3 compared with the Control (Nil-P) and T2. Control (Nil–P) results are included in the results 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 or leaf diseases. Purple stems were recorded in all planted crops with very high levels in crop 3 in all treatments at harvest. Aerial rooting can be the cause for rejection if the length of aerial roots exceeds 3 mm as in crop 3 probably due to the levels of over-maturity. Levels of mottling and disease were generally low.

Crop 1 was initially slow to develop due to the low spring temperatures requiring additional growing days compared to normal crops at this time of year. By 12 May, it had produced enough volume to harvest. All treatments produced pale leaves at harvest which did not deteriorate during shelf life over the eight day assessment period.

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. .

Relatively high levels of purpling were recorded in all treatments. Purpling (anthocyanin) is considered to be indicative of stress on the plant and may be caused by insufficient phosphate uptake. While the levels of purpling were consistent in all three replicates in T1, one of the three replicates of both T2 and T3 both scored zero for purpling suggesting some variation in P availability within the beds. This may be due to plant density effects, the accuracy of fertiliser placement across the beds or the uneven flow of water around the plants. Very low levels of leaf disease were recorded in T1 in different replicates but did not progress during shelf life.

Crop 2 took longer than expected to reach marketable size due to lower than average temperatures for the time of year. Colour score differences between treatments were only small and not significantly different. Purple stems were present at a level close to crop rejection even though Crop P uptake (Table 3) was adequate. Significant levels of mottling were found in harvested samples from T1 and T3 compared with T2 but cannot be associated with any particular nutrient deficiency. All replicates were affected in both treatments but the defect did not worsen over the shelf life period.

Crop 3 was over-mature at harvest with flower bud onset, resulting in lower quality and the subsequent abandonment of harvest. In plant samples taken from crop 3 one week before harvest, concentrations of N, P and K in T2 plants with little or no purpling (61.0, 7.1 and 5.2 g/kg NPK, respectively) and T1 plants with extensive purpling (56.4, 4.6 and 3.8 g/kg NPK, respectively) showed large differences in P and K content. This was reflected in leaf size (Plate 3).

Plate 2. Crop 3. T2 plants (left) with no stem purpling 7.1% P and T1 plants (right) severe stem purpling 4.6% P on 22 July.

Plate 3. Crop 3 taken on 22 July, T2 (left) larger leaved and T1 (right).

One week later, the levels of P in T2 had dropped to 5.3 g/kg (Table 3) possibly due to severe stress caused by the onset of flowering. Not only was purpling an issue (Plate 2) but aerial roots were very evident in all treatments but at variable levels between replicates and within beds making any treatment effects impossible to distinguish. A low level of leaf disease was present in one replicate of T1and T3.

Crop 4, harvested on 27 August had very little over or undersize material. The darker green colour of this crop was an improvement on previous paler crops. Colour was consistent between replicates of treatments unlike in previous crops. Purple stem colouration was generally low from all treatments but as in previous crops, variable between replicates. All treatments produced a similar low level of aerial rooting with broadly consistent results between replicates of the same treatment. Leaf disease symptoms were present on samples of all treatments and tended to increase as the shelf life period extended to eight days.

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

The smaller 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 for the first three crops only when 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 of increasing the dry weight yield above values on fertilised beds (e.g. crop 2, Table 5).

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), with the exception of crop 1 (Table 7). Crop P offtake was similar for crops 1 and 2 (*c.* 25 kg P/ha) and 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 the base contains.

Discussion

The beds at Maxwell Farm offered ideal conditions for comparing the different rates of P. The three rates of P used in the trial were based on current commercial practise (T2) for the growth of all year round crops; T3 at 75% of commercial rate T2 at more frequent applications in an attempt to improve uptake efficiency; and T1 the lowest rate, derived from ADAS trials in early 1980 when watercress was grown predominantly for winter production and considered the Best Practice rate of P for UK watercress production. Considerable effort was made to ensure uniform growing conditions and control of the treatments. Variation in flow rates, adverse weather leading to loss of plant populations in some beds combined with treatments maturing at different times all lead to challenging conditions for the experiment.

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 the experiment, the yield of each treatment was recorded weekly and the harvest carried out on a simultaneous date. In commercial practise, the beds would be harvested as soon as they were mature to maximise yield and quality and allow a new crop to be established as soon as possible. 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, the delayed harvest having consequences on quality and potential to knock back yields. The effects of this delay are compounded when the annual production cycle is considered. Faster developing crops allow the following crop to be established sooner permitting more crop and yield per year. .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.
Simultaneous harvesting of the treatments produced results that mirrored the yields obtained at the harvest of each bed by the farm albeit the yields were substantially lower than those in the experimental samples.

Higher crop P concentrations and P off-take were produced by the higher fertiliser treatments with levels in T2 high in crops 1 and 2 (above 5.2 g/kg threshold) but still producing some purple stemmed plants at harvest. Purpling can be attributed to a deficiency of P but ensuring levels are maintained at a satisfactory levels throughout the crop is essential as illustrated in crop 3 where high levels of stem purpling were present (Plate 2). In this crop, a week before harvest, T1 scored high for purpling against no purpling in T2 (P crop 4.6 and 7.1 g/kg respectively). A week later, the dynamics of P uptake changed with all treatments turning purple with T1 and T2 down to 4.1 and 5.3 g P/kg respectively. Closely monitoring plant P concentrations and ensuring a level well above 5.2 at all stages of growth is essential for minimising 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 the same crop, 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 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 probably masking 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 reduce the fertiliser management by applying less P fertiliser without any yield or quality penalty. All treatments received target levels of P in crop 5 but yields dropped off compared with crop 4. Crop 6 fresh weight yields were marginally higher than crop 5, but received substantially less P and K. This higher yield increase was not apparent in the dry weight yields. The farm harvested yield for crop 6 that showed a large reduction compared to crops 4 and 5 and may be explained by the generally poor overall state of the crop that needed fleecing due to the low temperature leading to lower overall weights.

Quality assessments were carried out on samples taken at harvest of each bed and consequently match the commercial yields. Assessments made 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.

In the weekly water sampling schedule, the largest concentrations of TRP were recorded after fertiliser applications with concentrations greatest after T2 and T3 compared with T1. This comment needs further qualification after flow rate data has been received from the Environment Agency. Peak concentrations occurred within a few hours of application and were much lower when the slow-release Fibrophos fertiliser was applied. The large difference in average discharge TRP concentrations between the two fertilisers (Fibrophos and compound fertilise 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.

Intensive sampling of the discharge during bed cleaning produced similar results with T1 having significantly lower TRP than T2 and T3. However, concentrations of particulate P were more dominant at this time and were relatively uniform across all treatments.

Conclusions

- From the data collected so far, maintaining current commercial levels of P are necessary for meeting quality standards through crop P up-take and the requirement to minimise stem purpling. The evidence that commercial levels of P are required for maximising yield are 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 away from commercial levels of fertilizer for re-growth crops would lower discharge levels especially where the more soluble fertilizers are applied at higher rates of application.

- Discharge levels 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 ug/litre in 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 differences between beds.

- The Final Report due at the end of 2090 will include the water flow rate measurements through the beds, their impact on the P discharge levels, yield and harvest data for the remaining period of the trial not covered in this Annual Report.

Technology transfer

Article for HDC News after the trials are completed in summer 2009.

Glossary

Phosphate forms

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

Ortho- phosphate - Ortho phosphate is the dissolved inorganic form of phosphorus.

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.

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

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

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. Is the main method used by the EA.

Water-extractable P (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.

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).

Fertiliser conversions

To convert P to P_2O_5, multiply by 2.29.

To convert K to K_2O, multiply by 1.205.P_2O_5

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