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AUTHENTICATION

We declare that this work was done under my 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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GROWER SUMMARY

Headline

A list of current best practice guidelines detailing phosphate application techniques for watercress production has been produced (see Action Points for Growers). For consideration by the Watercress Growers Association, the guidelines will enable growers to address environmental issues whilst maximising production.

Background and expected deliverables

Phosphate is an important nutrient in plant growth, and oversupply in river water distorts the natural balance of species (eutrophication) through excessive vegetation growth. This typically causes growths of blanketweed and algae and the loss of other important plants such as water crowfoot. This can reduce numbers of small aquatic animals and fish that are dependent on them. It is therefore important to minimise discharges of phosphate, whilst growing healthy crops.

Collecting information on phosphate use by growers, will establish what the range of practices are in phosphate use- products, rates, timings, crop stage as well as determine what additional precautions growers are taking to minimise unutilised phosphate entering the watercourse namely use of settlement tanks/lagoons (Common Practice).

Existing available research from ADAS, Bath University, Hampshire Watercress Ltd and Vitacress on watercress's demand for phosphate will be used to determine the crops requirements during the various stages of the crops growth during the season in order to meet the high demand for both quality and yield.

Summary of the project and main conclusions

By examining the crops need for phosphate from the literature review and comparing Common Practice between the growers, it has been possible to establish Best Practice guidance for the growers to follow so that phosphate use is limited only to the demands of the crop. By applying phosphate only when the crop is in a receptive stage to take it up and utilise it, should lead to a reduction in the amount that is wasted and washed out of the watercress beds into the watercourses.

Based on the answers supplied by growers in the returned questionnaires, the survey has shown marked differences between individual growers regarding phosphate use.

The main conclusions were:

- Output of watercress per kg of P_2O_5 varies by a factor of four between different growers, demonstrating the wide difference between producers in their use of phosphate fertilizers. This is based on the estimated annual use of phosphate fertilizers and crop yields as given by producers in the survey. In conventional production systems, the highest yields appear not to be produced by those using the highest rates of phosphorus fertilizer applications. This suggests an opportunity to reduce the input of phosphate fertilizers by some producers.

- Use of phosphates per unit area varies by a factor of five in different production systems. Numerically, the total usage of phosphate varies from under 300 kg/ha/annum to almost 1,400 kg/ha/annum. This suggests considerable scope to reduce phosphate applications through a harmonisation of practice. It should be stated that only a limited number of watercress growers took part in the survey.

- The answers given by two of the six growers suggested that the Code of Practice annual maximum of 903 kg/ha/annum of P_2O_5 would appear to have been breached.

- Application rates of phosphate fertilizers to organic crops appear to vary widely, as do crop yields, which appear to indicate yield increases in line with phosphate applications and thereby that phosphorus is the most limiting nutrient.

- It is recommended that phosphate fertilizers are applied as early in the season or crop growth stage as possible to the growing crops to allow as much opportunity as possible for uptake in the early stages of crop growth.
- A second application of 50kg/1000m should be applied within 14 days of planting or a split application of 25kg/1000 applied twice but within the 14 day period. When the air temperature is less than 10c as in the winter, only apply half the total recommended rate in the base and as a top dressing.

Financial benefits

There are considerable financial savings to be made by some growers in their use of phosphate fertilizers by reducing the amount applied without affecting either yield or quality.

Action points for growers

The following guidelines are recommended for adoption by the Watercress Growers Association:

- A **MAXIMUM** application of 900 kg/ha/ of P_2O_5 in any one year should be adhered to. Growers should aim to apply less following guideline rates previously established by research.
- The first application, of 110 kg/ha of P_2O_5 (or 500 kg/ha of the preferred fertilizer Fibrophos 0.22.12 NPK) should be made pre-planting.
- Apply phosphate fertilizer to the beds after levelling. Avoid physical damage to pellets or granules. Some fertilizers including Fibrophos, may be best surface incorporated. Subsequent planting should anchor fertilizer in the bed gravel with the roots, growing medium and organic matter reducing discharges to watercourses.
- Always limit the bed area treated in any one day to a maximum of 5% of bed area at the site or one bed as this will minimise peak levels in discharge waters.
- Temporarily stop or reduce water flow rates to a minimum before, during and for 12 hours after all applications.
- A second application (top dressing) of 50kg/1000m (or a split application of 25kg/1000 applied twice) should be applied to the crop within 14 days of planting (or harvest), during its early stages of growth when water flow rates are low (and can be temporarily reduced further) as this will minimise phosphorus levels in discharge waters. Crops are most receptive to phosphate at the early stages of growth.
- Further applications of 110 kg/ha of P_2O_5 (or 500 kg/ha of the preferred fertilizer Fibrophos 0.22.12 NPK) can be made to stubble crops between 7 and 14 days after harvest.

- Consider mechanised application of fertilizers via spreaders (which can be accurately calibrated) to achieve greater uniformity of application for example SISIS fertilizer applicators.
- Limit summer application rates to 110kg P_2O_5, or 500kg/ha of Fibrophos, and a maximum of eight applications per year until more guidance is available. Lower rates may be applicable in winter.
- The Watercress Association Code of Practice guidance levels for the use of water soluble component of solid fertilizers should not exceed 3% and the citric acid soluble component should not exceed 7%, should be adhered to.
- Avoid application of phosphate fertilizers to crops reaching maturity, when flow rates are at their maximum and losses in discharge waters are likely to be at their greatest.
- Reduce phosphate fertilizer rates by half or frequency of application in winter, when the temperature drops below 10^0C to recognise the lower crop demand caused by a slower rate of growth.
- Analyse the following for phosphorus on a monthly basis:
    - water at site discharge points (which should not exceed 0.06 ppm orthophosphate)
    - representative plant samples (which should be around 0.7% to a maximum of 1.0% phosphorus.

  These will act as a guide to the correct rate of phosphate fertilizers at individual sites.

1. SCIENCE SECTION

1.1 Background to current production

Watercress has been harvested and eaten since Roman times and has been cultivated since the early 1800's but has only been grown in purpose-made beds for approximately the last 80 years.

The major change in the watercress industry over the past two decades has been an increasing emphasis on summer production. Gone are the days when watercress was eaten only when there is an 'r' in the month. The crop is a major player in the leafy salads market and peak demand comes during the summer months.

Watercress is a long-day plant and flowers naturally in late May - this originally set the parameters for its marketing period in the UK. Technological advances and grower initiatives between 1970 and 1980 enabled the production of high quality summer watercress, largely from seed grown crops harvested before the onset of flowering. Although not universally practiced, a large proportion of the industry now produces summer watercress in this way. A few producers use a shy flowering strain instead of seed grown crops to produce summer watercress, and a few stop production altogether, as was traditionally the case.

Over the same period (1970-1980), the winter production strategy of the largest UK producers has also changed. Production in southern Europe (Spain and Portugal) and Florida (USA) has been developed in order to satisfy the quality requirements of major UK retailers and consumers. This development has largely halted previous attempts to produce high quality root-free watercress in the UK, using film plastics for winter crop protection. Cropping beds are now maintained in peak condition over the winter for the spring cropping period when the climate in southern England is ideal for watercress growth and development.

The great emphasis on summer production has increased demands for additional nutrients as growth rates are faster and water flow rates usually lower than in the winter. This makes it more critical for the supply of major nutrients to be supplemented during the summer, particularly at crop stages when the flow rate is low.

Watercress is normally grown to Code of Practice standards, which only permit the use of pure water, generally from springs or boreholes at source. Stream or river water cannot be used for the production of the crop, due to health risks and the general unsuitability of such supplies for watercress production, particularly in winter. In some very limited situations, water is re-circulated within a secure watercress production site in order to utilise nutrients more efficiently and benefit from higher summer water temperatures.

Watercress nutrition is a complex subject, due in part to the plant having both floating roots in the water and anchorage roots in the bed base. The two root systems are to some extent interchangeable for nutrient uptake as the crop can be grown in hydroponics systems, but in traditional bed systems an anchored root system is essential for successful crops.

Most nutrients, with the exception of phosphorus, are available in reasonable quantities from the water supply that flows through the beds where supplies are derived from chalk substrata. At certain crop stages, such as after planting or harvesting, flow rates are reduced to a level which severely limits nutrient availability and there is a demand for other nutrient supplements, e.g. nitrogen. At peak growing phases in the summer, low potassium availability can restrict growth if flow rates are poor, beds very long or bed levels inaccurate.

Phosphorus is the most demanded supplementary element in watercress production and for decades this has been provided by the addition of phosphate fertilizers. This practice is now being reviewed through this grower survey of Common Practice and the establishment of Best Practice that should assist growers with matching crop requirements with the timing and rates of appropriate phosphorus fertilizer.

Phosphorus levels fluctuate in borehole or spring sources but most sources originating from chalk aquifers contain very low levels of the nutrient. Analysis of water supplies from across Hampshire and Dorset in the 1970s showed the natural level to be either not detectable or in the range 0.01 to 0.05 ppm. The one exception is where the supplies arise from upper greensand, such as in Surrey (Abinger Hammer), where levels range between 0.4 and 0.8 ppm, but the production of watercress using such supplies is minimal.

Recent analyses of spring and borehole water in Dorset, Hampshire and Wiltshire, provided by participants in the survey indicate that little has changed in respect of phosphorus levels since the 1970s.

There is ample practical evidence from UK watercress producers that the levels of phosphorus generally found in water emanating from chalk substrata are inadequate for intensive crop production. Evidence from research studies confirms that natural levels of availability lead to phosphorus deficiency in watercress. (Robinson & Cumbus, 1977).

Watercress is virtually always grown in purpose-made beds that have a gradient of 1 in 240 to 1 in 300 down their length. Beds sizes vary but are traditionally 50 to 70 metres long and 6 to 9 metres wide. Water is supplied from boreholes or springs at source at a rate of 6,000 to 11,000 m^3 ha^{-1} day^{-1} in winter. Water enters at the top of beds and flows evenly down their length, before passing via a water carrier to further beds or to the site outfall point where it eventually enters a stream or river, generally via a settlement tank or lagoon.

Water depth in the bed may vary from 10 to 150 millimetres and is governed by two factors. Firstly by the flow rate, which may vary from 200 litres/ metre width/hour in the case of newly-planted beds or stubble crops, to 3,000 litres/metre/width in beds with crops reaching maturity that need maximum winter protection. Secondly, the density of the crop, which impedes flow as the crop thickens, thereby causing an increase in water depth.

Cropping cycles depend on the production system and time of year. In summer, seedlings planted out from a propagation unit can mature in as little as 4 weeks. At other times of year they may take as long as 12 weeks. Crops from returning stubbles can reach a marketable condition in 3 to 10 weeks depending on the time of year. The number of crops per year depends on the type of production system but is generally between three and five.

The aim in sustainable production systems is to match phosphate applications with crop requirements, improve efficiency of use and minimise loss of phosphate in outflow water.

1.2 Concerns of the watercress industry and environmental bodies

Discharges from watercress beds have long been a sensitive environmental issue. The original concerns were suspended solids and sedimentation. However, these problems have been largely overcome by the introduction of sediment tanks and lagoons at the discharge point from watercress farms. These need maintenance for continued effectiveness but the problem with suspended solids appears to be largely under control.

Environmental concerns over the level of orthophosphate in water downstream from watercress beds rest mainly on the stimulation it gives to blanket weed and other algae and the suppression of other plants, such as water crowfoot. This can reduce the numbers of small aquatic animals and fish that are dependent on them. For this reason, maintaining healthy crops while reducing the levels of phosphate discharged into watercourses to levels as close to natural background levels as possible is a high priority.

In recent years, levels of soluble reactive phosphate (SRP), which is broadly similar to orthophosphate and does not include bound or biologically unavailable phosphate, has come under increasing scrutiny by the

Environment Agency (EA) and other environmental bodies. As effluent discharges from industry and sewage treatment works are being reduced in line with EC Directives, the discharges from agricultural systems are required to follow suit. Although the watercress industry contributes only a small proportion (5.4%, based on mean flow data and the long term SRP average for the River Itchen).of SRP being deposited in rivers, (Jonathan Cox Associates, 2005), the situation needs addressing.

There is now increasing pressure from the Environment Agency for the watercress industry to take action to more closely manage SRP levels discharging from watercress beds. The greater emphasis on summer production with faster growth rates and lower flows requiring larger nutrient supplements may have exacerbated the problem, as peaks are occurring during the critical biologically active period of flora and fauna in rivers.

The effect of best practice in phosphate use can be measured either by average monthly outflow concentrations over the course of a year, or by peak concentration levels of phosphorus. Natural England favours the latter indicator. (P. Kelly, Environment Agency. Personal communication).

1.3 Phosphorus requirements and uptake

Research at the University of Bath indicated that phosphorus uptake is independent of diurnal and light intensity effects. Uptake is strongly influenced by temperature; summer requirements are therefore likely to be much higher than in the winter. Winter uptake of phosphorus has been shown to be only 10% of summer uptake. A linear response to phosphorus uptake was found with 0.3 mg/kg in the fresh weight at 5° C increasing to 1.3 mg/kg at 15° C (Rothwell, 1983). Critical levels of phosphorus were found to be 0.52% P in leaves and stems when the plant had the potential to produce 90% yield (Robinson & Cumbus, 1977).

Maximum demand for phosphorus by a watercress crop is 1.29 kg ha^{-1} day^{-1} (Rothwell, 1983). This amount cannot be supplied at normal flow rates from chalk aquifers. A theoretical flow rate of 130,000 m^3 ha^{-1} day^{-1} would be needed to supply sufficient phosphorus. These calculations assume there is no contribution by the substrate/bed base. Although this is not the case, it highlights the need for a contribution both from the water through adventitious floating roots in the water and the rooting medium through the roots anchoring the plant.

Matching crop phosphorus needs for maximum yields with supplementary applications of phosphate fertilizer requires skill and attention to detail. It cannot be a precise science, as factors such as water flow and growth rate are continually fluctuating. There has therefore been a tendency to apply an excessive 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 fertilizers.

1.4 The watercress association code of practice

The Watercress Code of Practice provides the following guidance on phosphate fertilizer use: -

- An annual maximum of 903 kg P_2O_5 / ha (ADAS, 1983). NB. Phosphate in fertilizers is quoted as P_2O_5, which varies from phosphorus (P) by a factor of 2.29.
- Use of insoluble or low solubility forms or the use of soluble forms under careful control.
- Water soluble component of solid fertilizers should not exceed 3% and the citric acid soluble component should not exceed 7%.
- Liquid feeds should not be applied at a rate exceeding 1kg total P_2O_5/ha/day and at a maximum hourly rate not exceeding 110 g total P_2O_5/ha.
- Solid phosphate fertilizers should not be applied to more than 25% of the bed area of any farm on any one day, subject to a minimum area of one bed.

1.5 Phosphorus fertilizers

Traditionally, it has been the practice to supplement the water supply feeding the crop with substrate-incorporated phosphate fertilizers or top dressings. For many years basic slag provided an ideal product as it had slow-release properties and also supplied a range of beneficial trace elements, particularly iron. Changes in the steel industry, from which basic slag is a by-product, have halted the supply of slag containing appreciable amounts of phosphorus.

In the 1970's and 80's when the availability of basic slag began to decline, trials done by ADAS in conjunction with Hampshire Watercress Ltd. looked at alternatives including:

- rock phosphate

- superphosphate
- mono-ammonium phosphate
- phosphoric acid

Observation trials at standard rates indicated that rock phosphate was too insoluble in the alkaline water in watercress beds where the pH is invariably 7.5 to 8.0. The use of mono-ammonium phosphate (MAP) and phosphoric acid involved careful dosing of the water supply. This is an expensive technique which could not be readily implemented by the industry, although it is understood that MAP is widely used in France, where the industry is mostly more traditional and less well developed than in the UK. Superphosphate was too soluble and although used sparingly on a regular basis, results were not comparable to the properties and benefits offered by basic slag.

Watercress plants have been shown to be capable of exploiting enhanced levels of phosphorus in substrates via their anchorage roots. Levels of phosphorus in bed bases have also been shown to be far greater than those in feeding waters, although this is historic data and may not be valid following the cessation of use of basic slag.

There is no doubt that bed bases with enhanced levels of phosphorus can contribute significantly to meet crop needs and compensate for the amount required in the water supply needed to provide healthy growth and good crop yields.

1.6 Common practice in phosphate use in the survey

In 2006 a survey of common practices in phosphate fertilizer use was conducted on a sample of small, medium and large watercress producers as a first step towards developing an approved code of best practice for the use of phosphate fertilizers in the watercress industry (see Appendix 1). The survey was initiated by the Environment Agency requirement for watercress growers to reduce phosphate levels entering rivers from discharge points at watercress sites. A total of six growers participated in the survey, which was done by ADAS. The participants were chosen to represent typical growing practices in the UK watercress industry, particularly in their use of phosphate fertilizers. The growers were based in Dorset, Hampshire, Wiltshire and West Sussex and comprised different sized enterprises, some with several sites. In broad terms, by size, two small, two medium and two large producers were interviewed. At least two of these producers have production sites outside the UK for producing high quality watercress in the English winter for the UK market, when quality standards required by multiple retailers are difficult to maintain. This has an impact on the way their UK sites are managed during the winter.

The following information was supplied by growers in confidence as part of the survey.

1.6.1 Range of phosphate fertilizers in current use

The following materials are in current use:-

- Fibrophos 0:22:12 - a by-product of the poultry industry and the most widely used proprietary compound fertilizer
- Organic Fibrophos 0:24:14 – another by-product of the poultry industry, now being phased out
- Specialist compound mixes – made to order for specific producers
- Pennine Organic Chicken Manure Pellets – for organic crops.
- Soluble phosphorus in propagation growing media. Soluble phosphate fertilizers are included in proprietary multipurpose growing media used for the propagation of watercress seeds prior to planting in beds. Taking the volume of growing media used by individual growers and the standard phosphate content, the phosphorus loading does not appear to constitute a significant contribution to the soluble reactive phosphorus leaving watercress beds.

Liquid feed injected into the water supply is used by one producer but in an attempt to reduce phosphorus levels in outflows, this method of phosphate application ceased in 2006.

1.6.2 Methods of use and rates of application

Fibrophos (0:22:12) is normally top-dressed over the crop with emphasis on application early in the production cycle. Application procedures varied and included the following:

- to stubble crops 7 days post-harvest or soon after the planting of a new crop, and a further application 2 weeks later at a rate of 71 kg/,1000m^2. The second application is omitted by some growers.

- early on in the crop's life, with one application per crop at 40 kg/1000 m^2

- as a base dressing pre-planting at a rate of 50-60 kg/1000m^2 followed by a further application every 4 weeks at the same rate.

Specialist mixes are used by two producers. The phosphate level in these mixes varies from 6-14% P_2O_5.

In one case, a base dressing of an 8% P_2O_5 product is used routinely, prior to planting at a rate of 50 kg/914 m^2

Other specialist products are used as top dressings at the following rates of application:-

- 14% P_2O_5 product – at 32 kg/1000 m^2 – 7 days post planting
- 6% P_2O_5 product at 100 kg/914 m^2 – 10 days post planting

Pennine Organic Chicken Manure, a pelleted product, containing 3-5% P_2O_5 is used specifically for organic watercress production. It is used at a rate of 71 kg/1,000 m^2 but application times vary, with one producer using it from March to December two weeks after cutting or planting and two weeks later. In another case the product is used weekly from mid-March to mid-September.

Later applications of phosphate fertilizers to crops nearing maturity are made by visual assessment rather than on a routine pre-determined basis, but at similar rates to those quoted above.

One producer uses liquid feeding through a pulsed applicator on a daily basis (April-October). Although originally including phosphates, this was omitted in 2006 in an attempt to reduce phosphorus application.

1.7 Conclusions of the survey of phosphate use in the industry

The main conclusions were:

- There is a four fold difference in the amount of P_2O_5 applied by watercress growers demonstrating the wide difference between producers in their use of phosphate fertilizers. This is based on the estimated annual use of phosphate fertilizers and estimated crop yields as given by producers in the survey. In conventional production systems, the highest yields appear not to be produced by those using the highest rates of phosphorus fertilizer applications. This suggests an opportunity to reduce the input of phosphate fertilizers by some producers.
- Use of phosphates per unit area varies by a factor of five in different production systems. Numerically, the total usage of phosphate varies from under 300 kg/ha/annum to almost 1,400 kg/ha/annum. Comparisons between production systems are difficult as the same types of fertilizers were not used and errors are possible in the responses to questions on yields. This suggests considerable scope to reduce phosphate applications through a harmonisation of practice.
- The answers given by two of the six growers suggested that the Code of Practice annual maximum of 903 kg/ha/annum of P_2O_5 would appear to have been breached. The survey is dependent on growers providing accurate responses to questions.

- Application rates of phosphate fertilizers to organic crops appear to vary widely, as do crop yields, which appear to indicate yield increases in line with phosphate applications and thereby that phosphorus is the most limiting nutrient.

1.8 Methods used to maximise efficient use

Practices employed varied widely and include some of the following:

1.8.1 Water flow rate adjustment

Water supply adjustment at the time of phosphate fertilizer application varies according to producer (numbers complying are in brackets) and ranges from:

- No adjustment at all (3)
- Water supply shut off during application (1)
- Water supply reduced at the time of application (1)
- Water supply reduced on the day after application (except in hot weather) (1)

1.8.2 Application timing

Application of fertilizer early in the establishment of the crop, when flow rates are low (and the consequences of crop damage are less serious) is being widely practiced. (6)

1.8.3 Limitation of application

The Code of Practice limits application to 25% of total bed area or one bed on any one day. Adherence to this requirement was not checked in the questionnaire but one participant in the survey volunteered information that he restricts phosphate use and other husbandry operations, e.g. bed clearing, to 5% of bed area in any one day to reduce phosphorus in the outflow.

1.8.4 Sampling and analysis

The use of routine sampling on a monthly basis to provide water and plant analyses is being undertaken, but generally by larger producers only. Results are used to confirm the adequacy or otherwise of rates and frequency of phosphate applications.

1.8.5 Methods of application

Most (5 out of 6) producers apply fertilizer by hand from a bucket while traversing beds. Generally the number of buckets per bed is specified on a schedule, which is based on a standard rate of application and bed size, so all that remains is for staff to apply it evenly on specified dates. In only one case is the operation mechanised with bed base dressings applied by mini tractor and top dressings by means of a quad bike. A fertilizer spreader applies the fertilizer and is calibrated at regular intervals to ensure accurate application across the beds.

1.8.6 Outflow and waste procedures

The use of settlement tanks and lagoons to prevent deposition of suspended solids, organic matter and nutrients into streams and rivers is now well established and an essential requirement of the Code of Practice. Measures of this type were in use in all cases. The use and maintenance of these facilities is an ongoing requirement for all producers.

The use of reed beds or bio-beds to reduce chemical effluent levels at discharge points is being investigated by one producer only. Recirculation to utilise high nutrient levels is also being used intermittently in a small way by two producers.

Packhouse waste (except in two cases where watercress is packed by others) and bed clearings also present a potential contribution to phosphorus effluent levels. In the main, they are composted on adjacent land and then spread on agricultural land, where they pose little problem. In a new development, the re-introduction of composted watercress waste to watercress beds prior to planting is being trialled by one producer.

There appears to be a limited risk of watercourse pollution at two sites from long term compost heaps that are sited close to river or stream boundaries and allowed to rot over the long term without regular removal.

1.8.7 New beds

Four participants in the survey have renovated old beds in recent years, involving new layouts, bed gradients and concrete walls on existing sites. During the renovation, no special measures were taken to minimise the release of phosphates from the bed bases while they were being levelled and graded.

In one case, new bed bases were sealed with a sand / clay mix to provide an impermeable layer; this may have helped to reduce phosphorus leakage.

In one case out of the four, a heavy base dressing was applied to provide a high residual phosphorus level, akin to those traditionally found in 'mature' watercress beds. The amount of fertilizer applied was not based on analytical data but was purely a 'rule of thumb' heavy application rate.

In three cases, application rates of phosphate fertilizers and timing of use on new beds were the same as those used on established beds.

The building of new beds on a new site is an infrequent event and in most cases is not considered to cause a significant release of phosphorus into discharge waters. The renovation and reconstruction of existing beds happens once every 20 to 30 years and poses some risks of phosphate discharge. However, this is probably not a significant source of phosphorus release into streams and rivers, due to its relative infrequency.

The application of high rates of phosphate fertilizers to new beds prior to cropping is not widely practiced but appears to be the main risk of heavy contamination of discharge waters. The justification of carrying out this process rather than using normal rates appears to be in question.

1.9 Best practice for phosphate use

Items for consideration in an approved code of best practice for phosphate fertilizer use are considered here.

1.9.1 Water and plant analysis

Water and plant analysis has the potential to form a key role in providing efficient use and rates of phosphate required by watercress if done at monthly intervals. Sample results could be used to guide phosphate fertilizer applications when combined with knowledge of previously applied fertilizer rates and other bed operations such as crop clearance. For greatest benefit the sampling process needs to be standardised, such that sampling is carried out:

- from the same location on each occasion;
- at the same time of day i.e. early morning before bed operations begin or at the end of the day;
- following similar husbandry operations but avoiding crop clearance or fertilizer application, which provide transient phosphorus spikes and are better included as a separate undertaking;
- when the flow rate is measured, taken into account or is a constant factor.

Water analysis may fluctuate considerably according to crop actions but remains a useful guide. A maximum figure of 0.06 ppm orthophosphate should be the target at site discharge points.

Plant analysis will reflect management procedures over a longer length of time, including fertilizer use and may potentially indicate over- or under-use of phosphate fertilizers. Here a guide figure for plant tissue analysis should be 0.70% phosphorus.

Smaller growers appear to rely on the Environment Agency to carry out water analysis, whereas larger producers have their own sampling schedule. A pro-active approach to sampling and analysis is to be recommended for all growers irrespective of size.

1.9.2 Fertilizer type

In the short term, the industry is likely to continue to be largely dependent on Fibrophos for phosphorus enrichment. Other purpose-made fertilizers used by specific companies meet general requirements. The use of mono-ammonium phosphate or phosphoric acid may also have potential when metered into the water supply at a low rate, probably on a pulsed (intermittent) basis to avoid wastage and pollution of rivers and streams at discharge points. These materials and the method of use are potentially hazardous in application. It is recommended later in this report that an evaluation of a number of available forms of phosphate fertilizers should be done to determine optimum rates at different periods of the growing cycle and their efficiency of uptake.

1.9.3 Time of use

There are important guidelines in fertilizer use, which need to be followed, especially for summer crops.

1.9.3.1 Pre planting application options

Pre-planting applications of Fibrophos are used only by one producer at present, however one large producer uses a bespoke product in this way. Application when the water flow has ceased and the bed virtually dry can provide a safe and efficient way of surface incorporation. A gradual increase in flow rate, as required by the crop in its early stages, is likely to minimise any immediately soluble phosphorus leaving in discharge water. In the absence of firm recommendations, a rate of use of 50 kg/1,000m^2

appears a good basis to work on, as on a practical level it is sufficient to be able to be applied uniformly and somewhat less than is currently being applied by many producers. At this rate of use, eight applications of a 22% P_2O_5 product could be used during the course of a year without breaking the Code of Practice specified maximum of 903 kg/ha/annum, which is based on the 1983 guideline given by ADAS.

1.9.3.2 Early crop application options

Early crop stage application 3 to 10 days after cutting or planting, according to production systems, is another sound option where no base dressing has been applied pre-planting. Flow rates should be temporarily stopped or maintained at a low level with the crop canopy 'open', thereby allowing the fertilizer to sink to the bed base. In most cases, with summer crops taking only 4-6 weeks to reach harvesting/marketing, one application may suffice. An application rate of 50 kg/1,000 m^2 should suffice on the same basis as given above for pre-planting treatments.

1.9.4 Method of application

The method of application and uniformity of application can affect crop performance and affect efficiency of phosphate uptake. The following proposals for mechanisation should be considered:

Pre-planting: treatments can be mechanised using a mini-tractor or handheld machine, which will provide a more uniform and accurate rate of application. Tractor -mounted hoppers with drop arms provide a safe and accurate method of application, where the scale of operation justifies it. On a smaller scale, 'Sisis' type pedestrian operated machines can be used with accuracy.

Post planting: pedestrian-operated machines are preferable to manual methods using buckets, although the latter is currently the most widely-used method. On a larger scale, spinner type machines may have a place but care is needed to ensure that contamination of water channels does not occur. Low ground pressure tyres will minimise crop damage. Machines give a greater accuracy in application and distribution compared with hand application, although the total amount applied may be the same in both cases.

1.10 Suggestions for future research

A proposed Code of Good Practice for the use of phosphorus fertilizers based on current practices can only go so far in informing and encouraging husbandry measures that meet the demands of both producers and environmental bodies. Development work is required to refine existing techniques and identify and test new methods and materials. Much of this work can be done 'on-farm' with support from the HDC.
The following work could be undertaken: -

- Full evaluation of the efficiency and use of Fibrophos
- An evaluation of controlled release fertilizers, such as the Osmocote Agroblend range and Basacote (BASF) in watercress bed situations. The requirement in watercress beds is for a fertilizer which allows release of its nutrients slowly and constantly, thus avoiding the peaks that occur with the current fertilizers in use or even historically with basic slag. Fertilizers which do this are available but this type of fertilizer is expensive and currently largely unproven in watercress beds, although fertilizers of this type were used in trials in the late 1970's. These have variable release rates depending on changes in temperature but as water temperatures increase down bed lengths in summer, the release pattern may fit the increased crop demand down the bed.

  There are two ways in which such materials could be used: -

  - Incorporation of a mini-granule in the propagation medium, which would be placed in the bed at planting time and continue to provide nutrition for a pre-determined time post-planting.

- Application as a pre-planting bed base dressing of a material with the capability to last the duration of the crop.

In both cases, uptake would largely be through the anchorage roots in the surface gravel layer.

- Evaluation of a method of precipitation of SRP by adding iron (Fe) or Aluminium (Al) before discharge water enters the river. This could be done in the lagoon or settling tank. The precipitate could be removed at regular intervals and recycled to land or landfill. It is possible that between 50% and 75% of the discharging phosphorus could be removed by this method. Such work would need to consider the potential for discharges of Al and Fe into the watercourse that could be an additional and unwanted threat and would need EA approval. The financial costs of such a removal method could prohibit its use.
    - Define and test a minimum phosphorus regime, which might provide sufficient phosphorus for an overwintered crop followed by two summer crops. Carry out a commercial test under controlled conditions.

2. REFERENCES

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3. APPENDICES

3.1 Appendix 1: grower questionnaire

Common Practice in Phosphate use in Watercress Production

We are conducting a survey of watercress growers to establish common practice in the use of phosphate fertilizers. We would appreciate your help in answering the questions below as accurately as possible.

Questionnaire to be completed with named growers.

1.0 Identification

Name of Company

Address of Company

Production Manager

Interviewee

Location, number of production sites and area.

Source of water and volume supplied to each site

2.0 Overview of your production

Describe the production system on each unit (including propagation method and harvesting period)

3.0 Phosphate use and yields achieved.

We need to know the total amount of phosphate used on each unit throughout the year, how the rates of phosphate use change with season and what total yields are achieved.

3.1 Propagation

a. Is propagation carried out in a glasshouse or tunnel? If so, during which months of the year?

b. Is a proprietary growing medium used for propagation. If so which one? If a home mix is used please provide details of composition.

c. What is the volume of growing medium used to plant up 0.1 ha

d. Are any other systems used e.g. direct sowing in beds, planting cuttings

e. What rate of liquid fertilizer is applied during the propagation phase that contains phosphate in any of its forms? Please provide details.

3.2 Production

a. What is the annual consumption / use of phosphorus fertilizers on each unit

b. Provide details of the procedures for applying phosphorus fertilizer to each unit.

c. Include details of application of phosphorus fertilizer during the life of each crop

d. List all the products applied normal rates of use and times of application in the table below.

Please include all forms some of which we have mentioned here.

Superphosphate 19-21% P20
Fibrophos
Phosphoric acid
Rock phosphate (state % P2O
Mono ammonium phosphate P61% P2O
Basic slag
Other forms of P (state %P).

One table should be completed to represent all crops grown on the unit.

Stage of crop growth when application made	Time of year.	Product (P content %)	Rate of use at each application	Total P (kg/ha)

Provide details of the yields achieved at each unit.

4.0 Application of phosphate fertilizers.

a. What is the base level of P in the water as determined from analysis.

b. How is it ensured that the crops requirements for phosphate fertilizer are matched to the amounts applied?

c. What is the procedure for applying phosphate fertilizers to the watercress beds by hand and by machine?

d. What equipment is used?

e. How often is application equipment calibrated or rates of use checked which are applied manually by staff?

f. In the case of top dressed materials i.e. over the crop, how is the fertilizer removed from the foliage?

g. Are flow rates reduced at the time of application to minimise losses into outflows?

h. How do you maximise the efficient uptake of applied phosphate?

5.0 Results of analysis

a. Do you have any results of water analysis for phosphate or Soluble Reactive Phosphate on entry to or exit from the watercress beds? Please provide copies.

b. Do you have the results of plant analysis throughout the year giving the level or % of P in the plant? Please provide copies

6.0 Outflow procedures

Do you operate any of the following before discharging water into watercourses to minimise deposition of P into streams and rivers?

a. Short term cessation of flow Y/N

b. Recirculation of water back into beds Y/N

c. Reedbeds or biobeds Y/N

d. Settlement lagoons / tanks Y/N

e. Wetland plots Y/N

f. Watercress beds with no fertilizer additions Y/N

g. Do you have any evidence that that these measures are successful? Please provide any analytical sample results to back up your comments.

7.0 New Beds

a. Have you constructed new beds or reconstructed old beds recently? If so, what measures did you take to minimise the amount of P release from the old bed base entering the watercourse?

b. How did you determine the amount of P required for the new bed base?

c. How much did you apply and what form did it take?

8.0 Crop waste

a. What happens to crop wastage i.e. packhouse trimmings, surplus crop and bed clearings?

b. Is effluent from composting contained or can it leach into the substrata?

c. How is the waste dredged from the settling lagoons and tanks disposed of?

Many thanks for your co operation.

3.2 Appendix 2: survey results

WATERCRESS PRODUCTION - PHOSPHORUS USE SURVEY

Details of P use in propagation

Grower code	Period	Method	Modular compost	Volume compost used to plant / 0.1ha (litres)	P_2O_5 content @70 mg/litre P_2O_5 (g)	Total compost use - litres	Total P_2O_5 use / annum (kg)	Other methods of propagation
1	Direct sowing in beds only	Org. Fibrophos used @25 g/m2	N/A	N/A	N/A	(0.5 tonnes Org. Fibrophos)	110.00	Direct sowing in beds, cuttings, plants
2	March - June	Trays on ground in tunnel	Seed / potting	6006	420.42	23100	1.62	Cuttings
3	Jan - Oct	Plug trays in tunnels	Sinclair modular	150	10.5	72000	5.04	Tops, cuttings, whole plants
4	Mid-Feb to mid-July	Trays on ground in glasshouse / polytunnel	Sinclair modular	850	59.5	469200	32.84	None
5	Feb - March	Plug trays in tunnels	SHL	1000	70.0	2000	0.14	Direct sowings. Some plants

6	March - June	Trays on ground in tunnel	Evergreen Irish	2250	157.5	175500	12.29	Cuttings / plants

Outflow Procedures

Are any of the following procedures used to minimise P deposition into streams and rivers?

Grower code	Short cessation of flow	Re-circulation back into beds	Reedbeds or biobeds	Settlement lagoons/ tanks	Wetland plots	No fertilizer additions to beds	Evidence of success?
1	Yes	No	No	Yes	No	No	Environment agency analysis
2	No	No	No	Yes	No	No	Water authority analysis – low P (generally 0.02-0.05)
3	Divert to settlement tank	Small amount from settling tanks	Applying to use and allow natural reedbeds to develop	Yes	No	No	Years of analysis has confirmed benefits
4	No	Yes – a few and half rate fertilizer application	No	Yes	No	No	Reduction in suspended solids. No evidence where recirculation in use
5	No	No	No	When	No	No	No evidence apart from water authority

				clearing beds only			satisfaction?
6	Partial – often low flows when used	No	No	Yes	No	No	No evidence

New Beds

Grower code	Have new beds been built recently? If so what measures were used to minimise P release entering the watercourse?	How was base dressing of P determined?	How much was applied?
1	Yes. None as beds are dry.	By visual assessment after planting the first crop	None before planting
2	No new construction	N/A	N/A
3	Yes. Seal bed base with sand/clay then use standard base dressing.	No extra – as for all new plantings	100 kg/1000 yd2 8% P_2O_5
4	2004. No special measures	Heavy base dressing – rule of thumb.	Redzlagg Fibrophos – 10 times normal rate
5	No new construction	N/A	N/A
6	Yes. No special measures	Standard P dressings	Standard

Water and plant analysis

Grower code	Water analysis - entry	Water analysis - exit	Plant analysis
1	Yes - EA	Yes - EA	None available
2	Yes - EA	Yes - EA	No
3	Yes monthly	Yes monthly	Yes regularly
4	Yes monthly	Yes monthly	Yes regularly
5	No	No	No
6	Yes	Yes - EA	Yes

Crop wastage

Grower code	What happens to packhouse waste / crop clearings?	Can effluent leach into substrate / river?	How is waste from lagoons etc. disposed of?
1	Put on tip to rot down and spread on organic ground	HD site – contained behind soil bank and removed every 2 years. S. site – stored on dry bank, some leaching possible in heavy rain.	Pumped out once a year and spread on organic farmland.
2	Packhouse waste - stored in pit and moved once a year to agri. land. Bed waste stacked on bank	Possibility of leachates reaching R. Ebble just below heap	Natural decomposition occurs
3	No packhouse waste. Bed clearings tipped in areas and composted. Some recycling to bed bases (new)	Some soaks into ground but no evidence of contamination of water supply	S. tanks - Spread on agricultural land 2-3 times a year. Ponds emptied every 3 years
4	Crop and gravel cleaned out and composted on agri. land until February then wash, grade and reuse	No leachates from compost heaps. During washing – tanker used to take washings and spread on agri. land.	Cleared annually – usually in August. Sediment pit used for drying out and then spread on agri. land in following year
5	Composted in earth bund from both sites	Isolated from stream and borehole	SG site – waste dredged with digger into trailer, then tipped at composting site. H. site – pumped on to agri. land
6	Very little packhouse waste.	Not contained – small amount of	Flow diverted and dredged into

	Crop residues composted.	leachate unlikely to reach river	pit. Spread on agri. land from pit after 1 year.

Application of phosphate fertilizers

Grower code	Base level of P	How is application matched to demand?	Application procedure?	Equipment	Frequency of calibration of application (hand or machine)	After top dressing how is fertilizer removed from foliage?	Are flow rate reduced at time of application?	How is uptake maximised?
1	0.02 – 0.05 ortho)	By eye and experience	By hand	Buckets	Manager checks buckets per bed.	Rolled off crops	Water shut off	Keep the water low.
2	0.03 (ortho)	Visual / experience	By hand	Buckets	No specific checks	Patting / rolling	No only preplanting / sowing	Patting / rolling
3	0.01-0.02	In / out water analysis and plant analysis	Base dressing – drop spread by tractor. Top dressing – quad bike	Tractor / quad bike	Regular calibration	Applied when immature – generally no rolling needed	When top dressing, flow rate cut back at time of application	Analysis check Use early in crops life Reduce flow rates
4	0.01- 0.03	Application matched to quality and speed of growth required	By hand	Buckets	Staff monitored. Buckets per bed specified	Rolled off crops near to harvest	No reduction	After application and removal from foliage – flow rates reduced for 24 hours (except in hot weather)
5	0.01-0.03	Appearance /	By hand	Buckets	No specific	Knocking off with	Generally yes.	No specific

		stage of growth			checks	wooden rake		technique
6	0.02 (ortho)	Experience	By hand	Buckets	By staff but rates under review	Rolled / bashed off near to harvest	No	Apply little and often

Fertilization during production

Grower code	Annual use of P fertilizer	Procedure	Stage of growth	Products used	Yield achieved (tonnes)
1	TD - Seedlings / plants – 0.50tonnes TD - Crops – 30-40 tonnes	May – July – 25 g/m2 Mar - Dec – 71 g/m2	Seedbeds – early growth stage. 2 weeks after planting 1 month after planting 2 weeks after cutting	Organic Fibrophos Pennine Org. Chicken manure – 3.72:3.35:1.82	
2	TD – 2 tonnes	Applied to stubble. Applied to seedlings / plants	After cutting to stubbles then by visual assessment. After planting then two weeks later	Fibrophos	
3	Base – 70 tonnes	Base dressing – drop	Base – day before or	Product - 8% P (total)	

	TD – 50 tonnes	spread by tractor. Top dressing – quad bike Liquid feeding pulsed every day – April to Oct but no P in 2005.	day of planting (April – July) TD – 10 days after planting (March – Sept)	– rate 50 kg / 1000 yd2 Product - 6% P – rate 100 kg / 1000 yd2	
4	TD -Fibrophos – 72 tonnes TD -Bespoke – 40 tonnes TD - Chicken manure pellets – 35 tonnes	Mar-Jul – 71 g/m2 Aug-Nov – 71 g/m2 Mar-Jul – 32 g/m2 Aug-Nov – 32 g/m2 Mar-Sept – 71 g/m2	5-14 days post plant 7 days post harvest 7 days post plant Post harvest Weekly during summer	Fibrophos Bespoke product – 19:14:14 Pennine Org. Chicken manure – 2:5:5	
5	TD - 2.64 tonnes	Top dressing by hand	Usually one per crop, early on.	Fibrophos 4 kg / 100 m2	
6	Base and TD – 20 tonnes	Application by hand Base – 0.05 – 0.06 kg/m2	Preplanting and every 4 weeks	Fibrophos	

		TD – 0.05 – 0.06 kg/m2			

Site and production overview

Grower code	Sites	Area (Ha)	Water source	Water volume (million gals/day)	Production System	Propagation method
1		3.23	Boreholes small springs	4.5	Traditional methods. All organic.	Direct sowing in beds. Summer strain
2		1.6	Boreholes / springs	1.29	Traditional. No crop – mid-July to 1st Sept.	Limited sowing ex. beds in tunnel to renew annual crops.
3		16.0	Boreholes /	18.73	Progressive AYR production	Sowing in tunnels

			springs			away from beds.
4		18.4	Boreholes / springs	27.15	Progressive AYR production	Sowing in tunnels away from beds.
5		1.65	Boreholes / springs	1.56	Traditional but some summer production from seed / seedlings	Limited sowing ex. beds in tunnels. Some direct sowing in beds
6		4.79	Boreholes / springs	3.49	Moving up the ladder to more intensive modern production, including organics at one site.	Sowing in tunnels away from beds.