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|---|---|
| **Project title:** | Identification of critical soil P in vining pea crops |
| **Project number:** | FV 380 |
| **Project leader:** | Nathan Morris, NIAB<br>(NIAB TAG) |
| **Report:** | Final report 2014 |
| **Previous report:** | Annual report 2011<br>Annual report 2012<br>Annual report 2013 |
| **Key staff:** | Ron Stobart (Head of Agronomy KT and Training, NIAB TAG)<br>'Trials Team' (Field Trials Operations, NIAB TAG)<br>Paul Armitage (Senior Technical Officer, PGRO) |
| **Location of project:** | East Anglia |
| **Industry Representative:** | Richard Fitzpatrick, Holbeach Marsh Cooperative, Fleet Estate Office, Manor Farm, Holbeach Hurn, Spalding, Lincs. PE12 8LR |
| **Date project commenced:** | July 2010 |
| **Date project completed**<br>**(or expected completion date):** | May 2014 |

# DISCLAIMER

## *AUTHENTICATION*

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

[Name]

[Position]

[Organisation]

Signature ............................................................ Date ............................................

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**Report authorised by:**

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## *CONTENTS*

# *GROWER SUMMARY*

## Headline

Results from this project suggest that vining peas should be grown at phosphate (P) Index of 3. On average, across sites the mean yield response of vining peas grown on soils at a P Index 3 compared to an Index 2 was 0.8 t/ha.

## Background

The recent increasing costs of Phosphate (P) fertiliser and concerns from the risk of diffuse pollution have re-opened the debate on the need to apply P, and whether or not a target P Index of 2 (Olsen P 16-25 mg/l) is appropriate for all soil types and crop conditions. This project delivers improved guidance to growers on target soil P indices suitable, in terms of plant nutrition, for both yield and quality for vining pea crops on a range of soil types, and new information on crop response to fresh P fertiliser.

Guidance to growers following results from this project will allow the use of P fertiliser to improve the economic efficiency in vining pea production. Specific targeted doses of P fertiliser should reduce the risk of undesirable P losses to water courses resulting in eutrophication and potentially help to meet future requirements of the Water Framework Directive.

## Summary

Many vining pea growers are questioning whether or not a target soil Phosphate (P) Index of 2 (Olsen P range of 16-25 mg/l) is appropriate for all soil types and crop conditions. This target Index, based on critical soil P levels to achieve 95% of maximum crop yield, was established to achieve economic yields for all crops grown in any rotation and was based on the results of a limited number of field experiments.

Critical P values can vary between soils, depending upon soil physical conditions (e.g. soil structure, moisture, bulk density, stone content and soil porosity) and between crops, depending on root growth and architecture and P uptake rate needed to achieve maximum yield. To date, however, sufficient data for making a scientifically robust change to the recommendations have not been available.

This project aimed to identify the levels of Phosphate required in vining pea production to help growers maximise yield and quality.

Results over three cropping years from six sites on contrasting soils suggest that Olsen P should be maintained at P Index 3 for vining pea crops. Critical P values to achieve 98% of maximum yield were around 27 - 41 mg/l (or at P Index of 3) and this was economically justified. The mean yield response of vining peas grown on soils at a P Index 3 compared to an Index 2 was 0.8 t/ha. A small or large dose of fresh P fertiliser did raise vining pea yields to above that achieved at Index 2. Therefore, growers could maintain an Olsen P at Index 2 for combinable crops (across the wider farm rotation) and apply a fresh P fertiliser dose ahead of the vining pea crop. Applying either a small or large fresh P fertiliser dose ahead of vining peas resulted in a mean yield response of 0.2 t/ha or 0.5 t/ha respectively over and above Index 2 Maintaining higher soil Olsen P indices increased crop vigour and, in some instances, improved seed size and root nodulation.

## Financial Benefits

For all sites, to raise Olsen P from Index 2 to Index 3, before the additional crop value exceeds the cost of achieving and then maintaining an increase in P Index, would take 1 to 4 cropping cycles to see economic returns; which ranged from £125 to £580/ha. The number of cropping cycles would be dependent upon the length of farm rotation and the frequency of inclusion of vining pea crops within the rotation. However, maintaining an Olsen P at Index 2 for combinable crops (across the wider farm rotation) could potentially allow growers to apply a low fresh P dose and gain a net return of £44 to £393/ha above that at Index 2.

## Action Points

- Maintain soil Olsen P at Index 3 for optimum yield in vining peas.
- Ensure soil is regularly tested (every 3 to 4 years) for Olsen P to maintain Indices.
- Ensure soil structure is maintained to allow for improved crop rooting that will maximise P uptake and efficiency by the vining pea crop.

 

## *SCIENCE SECTION*

## Introduction

The British Survey of Fertiliser Practice shows that there has been an overall decline in phosphate (P) use on crops from 56 kg/ha $P_2O_5$ in 1983-87 to 34 kg/ha in 2004-08. Over recent seasons the long term price trend for P fertiliser has continued to rise. While there have been some recent fluctuations in P cost, price shifts for the 15 months running up to April 2008 saw world di-ammonium phosphate price rise by around 400%. Where P is not applied, crop off take (e.g. 8-10 kg/ha $P_2O_5$ for vining pea crops) is leading to a gradual decline in soil P reserves. The Fertiliser Manual (RB209) guidance on phosphate levels for vining pea crops suggests that P is required at more than maintenance where soil levels are less than Index 2. This can be expensive to the grower; for example at soil Index 1 or below, a dose of between 60 and 85 kg/ha of $P_2O_5$ is often suggested for vining pea crops, this dose could cost around £75/ha based on spring 2011 prices.

Many growers are questioning whether or not a target soil P Index of 2 (Olsen P range of 16-25 mg/l) is appropriate for all soil types and crop conditions. This target Index, based on critical soil P levels to achieve 95% of maximum crop yield, was established to achieve economic yields for all crops grown in any rotation and was based on the results of a limited number of field experiments. Although for a given Olsen P value the crop availability of P per unit volume of soil should be the same regardless of the crop and soil type (except perhaps on acid soils or for permanent grassland receiving water-insoluble P), critical P values can vary between soils, depending upon soil physical conditions (*e.g.* soil structure, moisture, bulk density, stone content and soil porosity) and between crops, depending on root growth and architecture and P uptake rate needed to achieve maximum yield. To date, however, sufficient data for making a scientifically robust change to the recommendations have not been available.

High soil P levels increase the risk of P transfer to surface waters leading to the undesirable effects of eutrophication; annual losses of P of as little as 2 kg/ha, whilst of no economic significance to the grower, can be associated with an increased eutrophication risk. In Ireland (Agri-Food and Biosciences Institute, 2002 and Environmental Protection Agency, 2011) phosphates have been found in high concentrations in surface waters; this has resulted in legislation being introduced under the Water Quality Standards for Phosphorus Regulations, 1998. Further monitoring of water quality under the Water Framework Directive (WFD) is likely to become of increasing importance within England and put further pressure on growers to validate P fertiliser use.

The P levels suggested for vining pea production are based on long-standing data and perceptions that have not been validated in the context of modern production techniques / varieties, environmental influences and current costs. The objective of this project is to provide agronomic validation of P requirements, help growers to maximise yield and quality and also potentially offer useful savings.

## Aim and Objectives

*Aim:* Identify critical soil P levels for vining pea crops on different soils.

*Objectives:*

1. Identify sites within vining pea cropping that have suitably low Olsen P levels.
2. Determine critical soil P levels for vining pea crops on soils where information is limited and examine the influence of soil type on critical soil P levels in vining pea crops and on crop responses to P fertiliser at different soil P levels.
3. To record, analyse and interpret data with a view to producing a final report.

Guidance to growers following results from this project should allow the use of P fertiliser to improve the economic efficiency in vining pea production.

## Materials and methods

### Overview

Field experiments were established on three different soils with a low soil P Index (ideally an Olsen P of 10 mg/l or less). These started in the autumn of 2010 and continued over a staggered four year trialling sequence for two cropping seasons (e.g. season one; cereal, season two; vining peas) in the same place. The aim was to create large blocks with a wide range of Olsen P levels on the same site, by applying various doses of triple superphosphate (TSP) fertiliser (some large) at the start of each cereal crop year (autumn 2010, 2011 and 2012) to create treatments with 'stabilised' Olsen P values ahead of the vining pea crop (giving 18 months for P to stabilise). Further treatments have had TSP fertiliser applied immediately prior to the vining pea crop (spring 2012, 2013 and 2014) to create treatments with 'fresh' Olsen P values. The target range of Olsen P levels, once the Olsen P levels had equilibrated, was from Index 0 or low Index 1 (12 mg/l or less) to Index 3 (26-45 mg/l). Information being made available through the HGCA RD-2008-3554 project (HGCA, 2014) facilitated the attainment of this range of soil P levels by applying appropriate amounts of triple superphosphate (TSP) fertiliser. The intention was that the cropping in the experiment would follow the farm rotation, such that sowing and routine inputs were completed by the host farmer. Ideally the first seasons crop was a winter cereal (season one), followed by vining peas (season two). Each large plot was soil sampled (for measurement of Olsen P) before the start of each cereal crop year, ideally in July (e.g. 2010, 2011 or 2012). They were then re-sampled during June-July in each vining pea crop year (e.g. 2012, 2013 and 2014).

These sites had a low inherent P index (with the majority at an Index 1 or lower) i.e. sites that would normally receive a substantial P dose ahead of a vining P crop. At each site a preceding crop (*e.g.* typically a cereal crop) was established and managed by the host farmer. A trial area was established within the cereal crop that was used as a canvas on which to create a range of Olsen P levels, on large plot areas, ranging from 0 mg/l to 24 mg/l above the lowest value at each site. At each site soil texture, stone content and soil organic matter was determined to aid interpretation. The soil was also analysed to ensure no other major nutrient deficiencies were present.

### Experimental design, layout and plot size

For each of the experimental locations, a series of sites destined for vining pea production (covering the desired set of soil types including a loamy sand, sandy loam and silty clay loam) were sought. Fourteen large plots measured 10 m wide and 18 m long and were perpendicular to the normal direction of sowing and application of other fertilisers and agrochemicals, with 3 m wide discard strips at the top and bottom of each plot (in which spray tramlines were located) and 2 m wide buffer areas between plots (see Appendix A for trial plan). The experiment area was then surrounded by a 24 m wide guard area to protect the plots from P fertiliser applied to the rest of the field. Relatively large plot areas were required so that plots remained in the same place and were easily locatable for the following vining pea crop. Phosphate treatments were not replicated because the aim was to measure yield response to the 14 individual Olsen P values at each site. The field experiments focused specifically on vining pea crops; approximately 3 experiments were carried out on each of 3 soil types across a staggered 4 year trialling sequence (giving around a total of 9 experiments) as detailed below.

 

**Table 1**. Proposed staggered experimental design

| | 2010/11 (Year 1) | 2011/12 (Year 2) | 2012/13 (Year 3) | 2013/14 (Year 4) |
|---|---|---|---|---|
| Experiment 1 | Cereal | Vining peas | - | - |
| Experiment 2 | - | Cereal | Vining peas | - |
| Experiment 3 | - | - | Cereal | Vining peas |

## P treatments and fertiliser application

The P treatments were not applied at random because, in each experiment, the aim was to increase the level of Olsen P on each individual plot to achieve a range of Olsen P levels from 12 mg/l or less to 25 mg/l or more to enable yield/Olsen P response curve to be plotted. Consequently, large plots received one of five different P fertiliser doses that were established prior to the preceding crop of the field experiments, in order to raise soil Olsen P levels by different amounts to create a range of 'stabilised' P values prior to sowing the vining pea crop. Further large plots received one of two different P fertiliser doses prior to the vining pea crop, in order to raise soil Olsen P levels by different amounts and create a range of 'fresh' P values. The number of plots receiving each treatment (Table 2) varied at each site depending on the range of Olsen P levels that already existed.

For each experiment, P was applied ahead of the preceding (cereal) crop that was allowed to 'stabilise' for around 18 months or was applied as a 'fresh' dose immediately ahead of the vining pea crop. To ensure that doses of P were sufficiently incorporated into the soil specific treatments for large doses were applied prior to primary cultivations. The application of TSP fertiliser was applied to the 12 m wide large plots using a 12 m wide pneumatic spreader, calibrated to deliver the required dose, or using a purpose built plot spreader. Specific application dates of fertiliser applications are detailed in Appendix B.

 

**Table 2:** Number of plots at each site receiving each P fertiliser treatment

| Target increase in Olsen P (mg/l) | 0 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 15 | 16 | 18 | 20 | Total plots |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | Number of plots receiving treatment to achieve above increase | | | | | | | | | | | | | | | | | |
| Brocklesby 2012 | 7 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 3 | 0 | 0 | 1 | 0 | 0 | 0 | 14 |
| Docking 2012 | 6 | 2 | 0 | 1 | 1 | 0 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 |
| Docking 2013 | 7 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 14 |
| Kirby Cane 2013 | 5 | 2 | 1 | 1 | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 14 |
| Hallington 2013 | 6 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 2 | 0 | 1 | 14 |
| Kirby Cane 2014 | 4 | 0 | 1 | 0 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 3 | 0 | 14 |
| Brocklesby 2014 | 6 | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 2 | 0 | 14 |

Estimated amounts of TSP fertiliser required per plot were calculated for specific treatments, to take account of soil type, stone content and cultivation depth (this took advantage of methods already being utilised in the analogous HGCA project; research at Rothamsted has shown how much fresh P fertiliser is needed to increase Olsen P by 1 mg/l) and assumed that 15 % of the P applied would remain plant-available as Olsen P after the added P had equilibrated with the existing soil P. The estimates of the amount of TSP needed to achieve a 1 mg/l increase in Olsen P are shown in Table 3.

 

**Table 3:** Estimated amounts of TSP needed to achieve each 1 mg/l increase in Olsen P

| Site | Cultivation depth (cm) | Bulk density adjusted for stone content ($g/cm^3$) | Soil weight (Mkg/ha) | Increase in Olsen P (kg/ha) | Amount of P required (kg/ha) | Amount of $P_2O_5$ required (kg/ha) | Amount of TSP required (kg/ha) |
|---|---|---|---|---|---|---|---|
| Brocklesby 2012 | 25 | 1.48 | 3.70 | 3.70 | 24.7 | 56.5 | 122.9 |
| Docking 2012 | 25 | 1.37 | 3.43 | 3.43 | 22.8 | 52.3 | 113.7 |
| Docking 2013 | 25 | 1.48 | 3.70 | 3.70 | 24.7 | 56.5 | 122.9 |
| Kirby Cane 2013 | 25 | 1.23 | 3.08 | 3.08 | 20.5 | 47.0 | 102.1 |
| Hallington 2013 | 22 | 1.33 | 2.93 | 2.93 | 19.5 | 44.7 | 97.2 |
| Kirby Cane 2014 | 25 | 1.33 | 3.33 | 3.33 | 22.2 | 50.8 | 110.4 |
| Brocklesby 2014 | 25 | 1.48 | 3.70 | 3.70 | 24.7 | 56.5 | 122.9 |

### Soil sampling and Olsen P analysis

Initial sampling, to obtain baseline Olsen P data, on which to base the amount of P to be applied took place between June and August in 2010, 2011 or 2012 as soon as the sites had been confirmed and the plots marked out. The target sampling for subsequent years was late June when the vining pea crop was reaching maturity.

Each of the 14 large plots were individually sampled, to the intended cultivation depth (22 cm or 25 cm), using a gouge auger or similar. Sixteen cores per large plot area were sampled at random. From each plot the soil cores were bulked and mixed thoroughly, cutting any lumps into small pieces and removing any vegetation, other extraneous material and as many stones as possible. Samples were partially air-dried prior to sending to the laboratory for preparation and analysis. A sub-sample of c. 1 kg from each plot was sealed in a plastic bag, labelled with the project title, site name, plot/rep number, and sampling date and sent to NRM Laboratories for analyses. After air-drying soil samples were ground to pass through a 2 mm screen and Olsen P (Olsen *et al.*, 1954) determined at NRM. Soils were weighed on a volume basis expressed as mg/l.

 

## Site details, cultivation method, cropping and agronomy

*Year 2 (2010-2012)*

Two experimental sites were found in 2011/12 (year 2) on a range of soil types as described in Table 4. In order to further understand the effects that soil P may have on relative crop maturity a sequential harvest over a period of days (once vining peas reached approximately TR 85) was completed at each site.

**Table 4**: Site details for vining peas in 2012

| Site | Soil type | Soil series | Cultivation and depth | Crop harvest 2011 |
|---|---|---|---|---|
| Brocklesby, Lincs | Sandy loam | Landbeach | Non-inversion (20 cm) | Winter wheat |
| Docking, Norfolk | Sandy loam | Barrow | Plough (25 cm) | Sugar beet |

The soil sampling was completed (as specified above) with each site attaining a range of Olsen P values as shown in Figure 1. The application of varying doses of TSP fertiliser created a range of Olsen P levels, on large plot areas, expected to range from 0 mg/l to 24 mg/l above the lowest value at each site as shown in Figure 2.

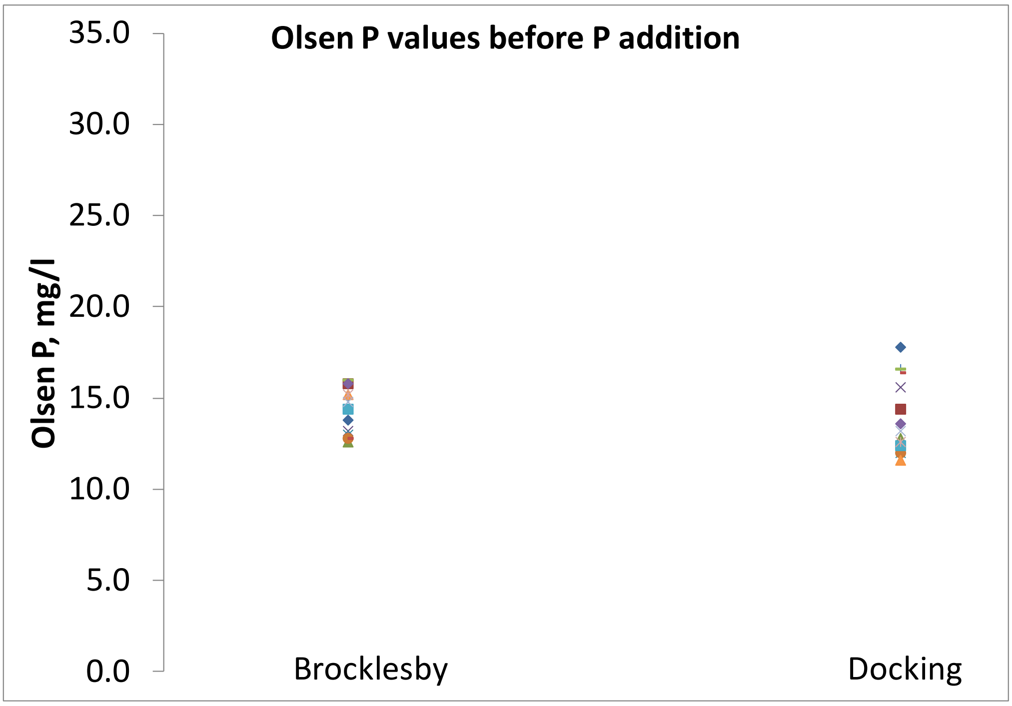


**Figure 1**: Olsen P values attained at each site in Year 1 (2010-12) prior to P fertiliser addition

Note: Individual coloured points represented separate plots

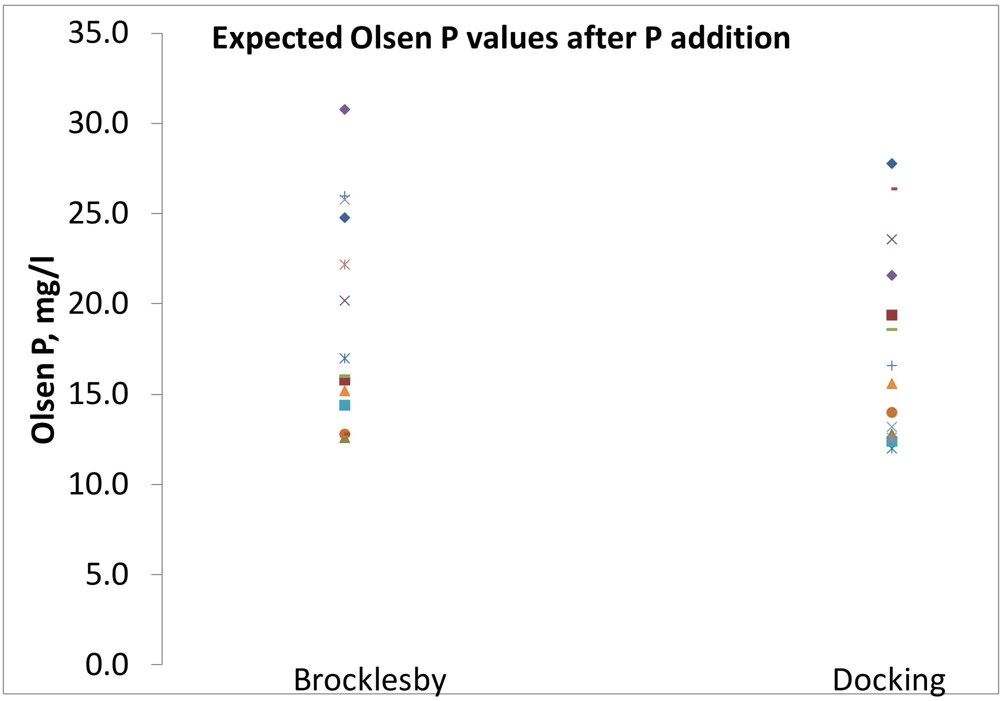


**Figure 2**: Expected Olsen P values attained at each site in Year 1 (2010-12) following P fertiliser addition

Note: Individual coloured points represented separate plots

 

*Year 3 (2011-2013)*

Three experimental sites were found in 2012/13 (year 3) on a range of soil types as described in Table 5. In order to further understand the effects that soil P may have on relative crop maturity a sequential harvest over a period of days (once vining peas reached approximately TR 85) was completed at each site.

**Table 5**: Site details for vining peas in 2013

| Site | Soil type | Soil series | Cultivation and depth | Crop harvest 2012 |
|---|---|---|---|---|
| Docking, Norfolk | Sandy loam | Barrow | Plough (25 cm) | Sugar beet |
| Kirby Cane, Suffolk | Clay loam | Beccles | Plough (25 cm) | Winter wheat |
| Hallington, Lincs | Silty clay loam | Andover 1 | Non-inversion (22 cm) | Winter barley |

The soil sampling was completed (as specified above) with each site attaining a range of Olsen P values as shown in Figure 3. The application of varying doses of TSP fertiliser created a range of Olsen P levels, on large plot areas, expected to range from 0 mg/l to 24 mg/l above the lowest value at each site as shown in Figure 4.

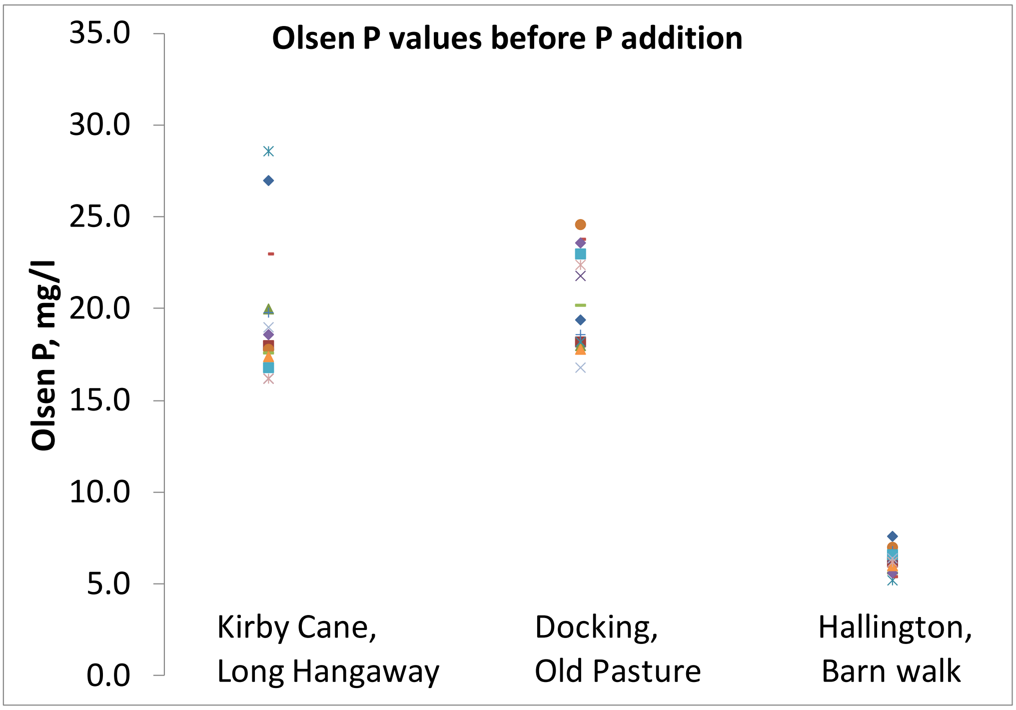


**Figure 3**: Olsen P values attained at each site in Year 3 (2011-13) prior to P fertiliser addition

Note: Individual coloured points represented separate plots

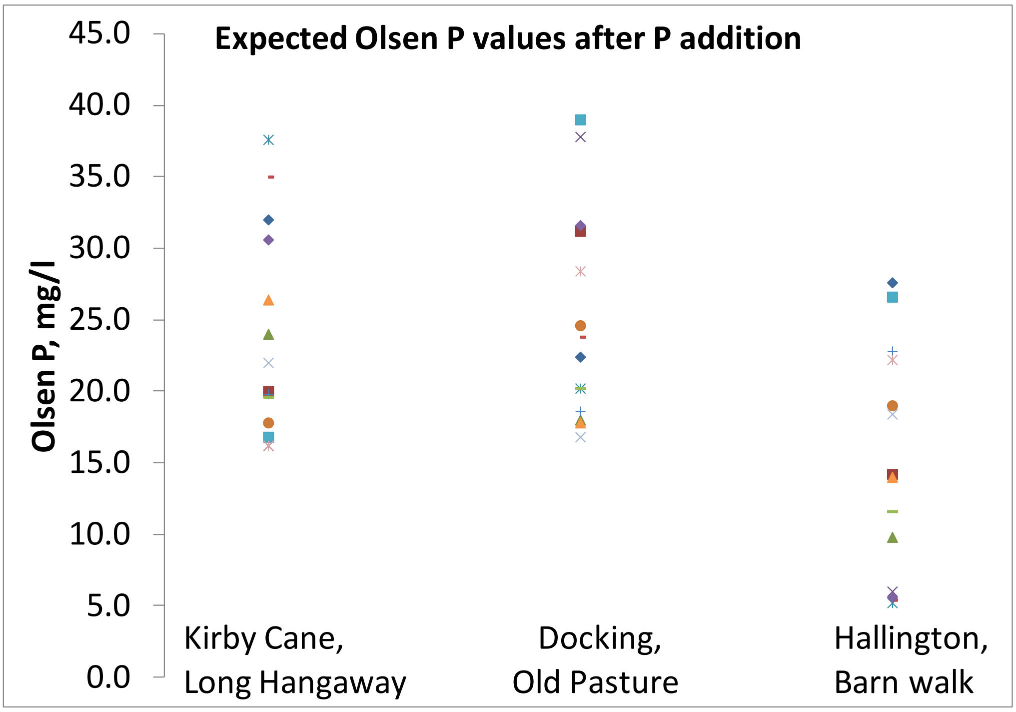


**Figure 4**: Expected Olsen P values attained at each site in Year 3 (2011-13) following P fertiliser addition.

Note: Individual coloured points represented separate plots

*Year 4 (2012-2014)*

A further two experimental locations for vining peas in 2013/14 (Year 4) were completed as shown in Table 6. In order to further understand the effects that soil P may have on relative crop maturity a sequential harvest over a period of days (once vining peas reached approximately TR 85) was completed at each site.

**Table 6**: Site details for vining peas in 2014

| Site | Soil type | Soil series | Cultivation and depth | Crop harvest 2013 |
|---|---|---|---|---|
| Brocklesby, Lincs. | Sandy loam | Andover 1 | Plough (25 cm) | Winter wheat |
| Kirby Cane, Suffolk | Clay loam | Beccles | Plough (25 cm) | Winter wheat |

The soil sampling was completed (as specified above) with each site attaining a range of Olsen P values as shown in Figure 5. The application of varying doses of TSP fertiliser created a range of Olsen P levels, on large plot areas, expected to range from 0 mg/l to 24 mg/l above the lowest value at each site as shown in Figure 6.

 

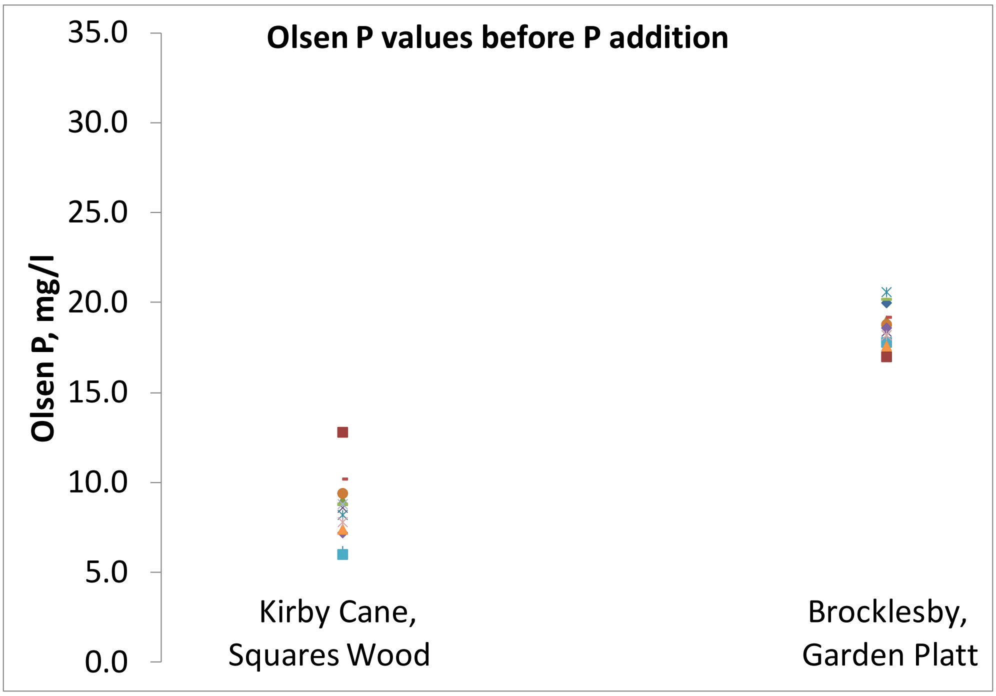


**Figure 5**: Olsen P values attained at each site in Year 4 (2012-14) prior to P fertiliser addition

Note: Individual coloured points represented separate plots

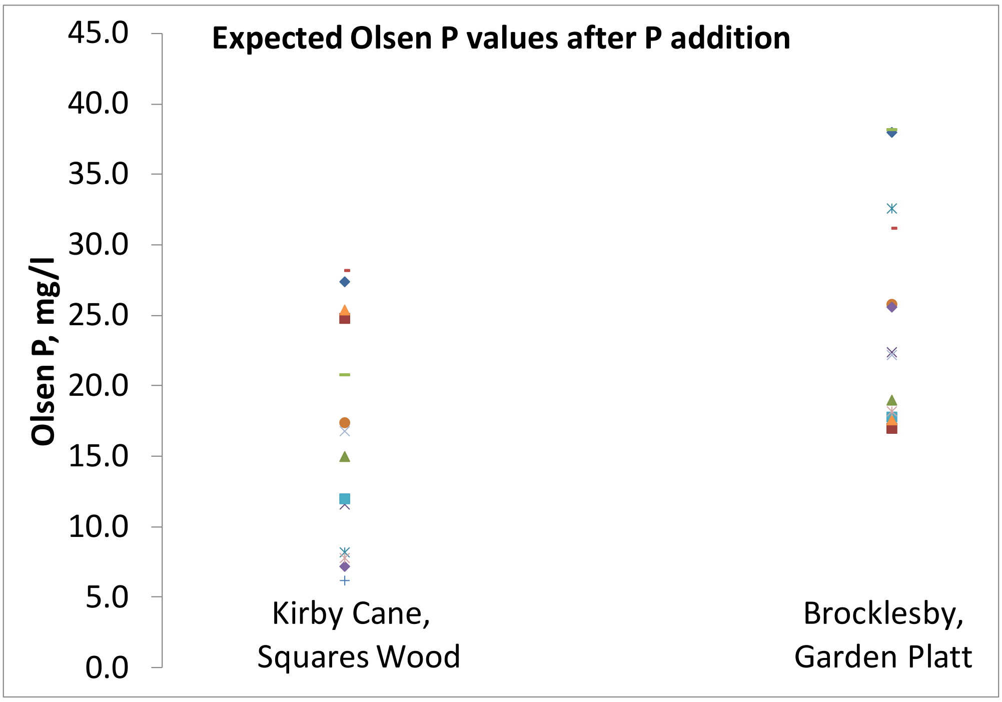


**Figure 6**: Expected Olsen P values attained at each site in Year 4 (2012-14) following P fertiliser addition

Note: Individual coloured points represented separate plots

 

## Crop vigour, root nodulation and crop quality

A note of crop vigour was made in each plot, at each site, every year at mid-late flowering. Where differences were apparent further notes on crop growth, colour and vigour were made that could be related to treatment or soil P status and photographs were taken of affected and unaffected plots. At the time of assessing crop vigour 10 plants were dug up and the roots of the best five were scored for root nodulation and colour. The response to fresh P is based on the average root nodulation score from two plots at each site receiving either a low or high fresh P dose.

A refractometer (Atago Pal-1) was used to measure the refractive index of the pea juice, which was obtained by crushing peas between 2 glass petri dishes. The Brix scale is based on a sucrose (sugar) and water solution. Since the juice contains substances other than sugar – such as minerals and proteins – the Brix percentage effectively represents the total concentration of all the soluble solids in the sample. At each site the Brix percentage scores were averaged for each P Index for Olsen P. The response to fresh P was based on the average Brix percentage scores from two plots at each site receiving either a low or high fresh P dose. The specific Olsen P values for fresh P were not reported due to the difficulties of stating Olsen P values that had not reached equilibrium.

## Harvesting and yield determination

A sequential harvest was completed at each site in each year to assess for relative crop maturity. Sub-plot boundaries within each main plot were marked at full crop emergence by hoeing out all plants along a line to create five sub-plots each measuring 6 $m^2$ (1.5m x 4m). The maturity of the vining peas was tested by taking samples adjacent to the harvest plot area and tested for maturity using the PGRO Martin Pea Tenderometer. Harvesting commenced when Tenderometer values (TR) reached 80 and continued on a sequential basis (every $2^{nd}$ or $3^{rd}$ days after the previous harvest) until TR reached approximately 120.

Yield analysis was completed for each site between one to five harvest timings (depending on TR values at each individual site). Vining pea yields were adjusted to a standardised TR value of 100 using an adjustment factor derived from Pumprey *et al*. (1975) – see adjustment table in Appendix D.

To determine the proportion of each seed size class (very small, small, medium and large) each seed sample from each harvested plot was individually weighed and calculated as the proportion, by weight, for each size class of the total weight. Data was calculated for seed size based on an average of harvest timings using a 5 point rolling mean.

### Yield data analysis and curve plotting

For each site, pea yields were calculated at each Olsen P level, using the values, at each harvest timing at the particular site. In plots that received fresh P fertiliser treatments, Olsen P levels had not fully equilibrated when measured in the vining pea crop and therefore could not be used to determine critical levels. The number of individual values comprising the mean yield at each P Index varied for each experiment. A standard deviation was calculated for yield means comprising two or more individual values. Response curves were fitted to the yield and Olsen P data from each site in 2012, 2013 and 2014. The form of the asymptotic curve fitted was:

$$\text{Yield} = a - b * r^{p}$$

Where *a* is the asymptotic yield in t/ha, and *b* and *r* are range and rate parameters, respectively, which were estimated by maximum likelihood.

Three values were determined from each curve:

- The fitted asymptotic (maximum) yield and its standard error (s.e.).
- The percentage variance (variability) in yield accounted for by Olsen P. A percentage variance over 50% indicates that Olsen P was the single most important soil factor affecting yield.
- The concentration of Olsen P and its standard error (s.e.), at which 98% of the fitted maximum yield was reached. This ‘critical level’, at 98% of the fitted maximum yield, was calculated by solving the equation:

$$P = (\ln(0.02) + \ln(a) - \ln(b))/\ln(r)$$

 

Standard errors for the fitted maximum yield and critical Olsen P level reflect how well the curve 'fits' the data. Where the standard errors of the yield or critical P level are unacceptably large (i.e. the relationship between yield and Olsen P was very poor), the critical level has been discounted. Due to the shape of the response curve, the higher the percentage of maximum yield targeted, the larger the standard error on the critical P level. For each curve, critical Olsen P levels have been determined for both 95% and 98% of maximum yield.

### Economic analysis

The cost of raising the initial P level by one Index (Table 7) was calculated for each site, assuming elemental P cost £1.45 per kg (equivalent to a TSP fertiliser price of about £290 per tonne). For each site the calculations were based on the weight of the treated soil per hectare and assuming 15% of the actual P fertiliser remained available (once equilibrated).

**Table 7**: Increase in Olsen P required to raise P Index by one level.

| Target change in P Index | Olsen P level (mg/l) | | |
|---|---|---|---|
| | Start (mid-point) | End (mid point) | Increase |
| 1 to 2 | 12.5 | 20.5 | 8.0 |
| 2 to 3 | 20.5 | 35.5 | 15.0 |

The yield increase or decrease obtained by raising the P Index from 1 to 2 or 2 to 3 was converted to a financial value for each site based on an average vining pea price of £340 per tonne. The vining pea price is based on the frozen pea price excluding the cost of harvest and transport, as such growers should consider a 5% adjustment, where necessary, to reflect the RM price in the field. At each site, the net cost or benefit of having initially raised the soil from an Index 1 to 2 or 2 to 3, and then maintaining it at that level was calculated as follows:

| | |
|---|---|
| | Initial cost of P fertiliser to raise Index by one level |
| LESS | Value of increase or decrease in crop yield |
| PLUS | Cost of replacing <u>additional</u> P offtake (due to higher yield) to maintain Index |
| EQUALS | Remaining cost of raising P Index |

 

The number of cropping cycles required for the additional crop value to exceed the cost of achieving and maintaining and increase in P Index of one level was then calculated for each site. This was based on the value of the additional yield less cost of achieving and maintaining an increase in P Index less replacing the additional offtake.

## Results

### Olsen P

### Measured Olsen P levels from 2012 to 2014

A complete record of Olsen P levels within each plot (2012, 2013 and 2014) at each site is in Appendix C, Tables C1 to C7. The number of plots falling within each P Index at each P site is shown in Appendix C, Table C8.

Initial and final Olsen P levels in the normal cultivated layer are summarised in Table 8, excluding plots that received fresh P prior to the vining pea crop. At most sites, initial Olsen P started from a mid Index 1 or lower Index 2. At one site initial Olsen P was at P Index 0. At three sites there was substantial plot-to-plot variation in the initial Olsen P levels. This existing variation was exploited to help create the range of Olsen P levels required within each experimental site to create a range of Olsen P levels, from Index 0 to >Index 3.

**Table 8**: Summary of initial and final levels of Olsen P at each site (excluding fresh P plots).

| Site | Depth of cultivated layer (cm) | Olsen P (mg/l) | | | |
|---|---|---|---|---|---|
| | | Initial | | Final | |
| | | Mean | Range | Mean | Range |
| Brocklesby 2012 | 25 | 14.4 | 12.6 - 16.0 | 16.4 | 11.2 - 32.6 |
| Docking 2012 | 25 | 14.0 | 12.0 - 17.8 | 22.6 | 13.0 - 68.6 |
| Docking 2013 | 25 | 19.8 | 16.8 - 24.6 | 29.8 | 16.2 - 69.8 |
| Kirby Cane 2013 | 25 | 19.2 | 16.2 - 27.0 | 30.7 | 20.8 - 55.8 |
| Hallington 2013 | 22 | 6.2 | 5.2 - 7.6 | 19.9 | 11.0 - 32.6 |
| Brocklesby 2014 | 25 | 18.6 | 17.0 - 20.6 | 31.3 | 22.8 - 59.6 |
| Kirby Cane 2014 | 25 | 8.5 | 6.0 - 12.8 | 21.0 | 9.2 - 52.0 |

 

Initial and final Olsen P levels in the normal cultivated layer are summarised in Table 9 that received fresh P prior to the vining pea crop. At most sites, final Olsen P started from a mid Index 1 or Index 2. However, final Olsen P peaked across some sites at Index 4 or above. This substantial increase in Olsen P relates to the apparent availability of the applied P fertiliser once the increase in Olsen P has equilibrated, this will be discussed later. The changes in average Olsen P levels were measured 4-6 months after P fertiliser was applied and this may not have allowed the fresh P to become equilibrated within the soil.

**Table 9**: Summary of initial and final levels of Olsen P at each site for fresh P plots.

| Site | Depth of cultivated layer (cm) | Olsen P (mg/l) | | | |
|---|---|---|---|---|---|
| | | Initial | | Final | |
| | | Mean | Range | Mean | Range |
| Brocklesby 2012 | 25 | 14.2 | 13.0 - 15.2 | 33.4 | 14.0 - 49.0 |
| Docking 2012 | 25 | 14.4 | 11.6 - 16.6 | 54.7 | 16.2 - 86.6 |
| Docking 2013 | 25 | 22.2 | 19.4 - 23.8 | 20.6 | 19.0 - 21.6 |
| Kirby Cane 2013 | 25 | 21.1 | 18.0 - 28.6 | 56.2 | 25.2 - 94.4 |
| Hallington 2013 | 22 | 6.3 | 6.0 - 6.8 | 42.9 | 29.4 - 66.6 |
| Brocklesby 2014 | 25 | 19.0 | 18.2 - 20.0 | 61.5 | 35.2 - 61.5 |
| Kirby Cane 2014 | 25 | 8.8 | 7.4 - 9.4 | 25.5 | 11.4 - 58.4 |

## Yield response to Olsen P

Seven vining pea crops were grown in total over the four sites. At Brocklesby in 2014 the full range of Olsen P Indices was not represented so this crop has been excluded from Tables 10 and 11. Mean yields at each P Index, and the standard deviation for each mean, are shown in Table 10.

Largest vining pea yields were obtained in 2013 at Hallington where mean yield at Index 3 was 11.01 t/ha, across all sites, yields at Index 3 ranged from 5.94 t/ha to 11.01 t/ha. The mean yield at Index 1 was 6.56 t/ha ranging from 5.80 t/ha to 7.91 t/ha. At Index 2 the mean yield was 6.47 t/ha, although this ranged from 5.13 t/ha to 9.30 t/ha across the sites. Over the four sites and six vining pea crops, when compared to an Olsen P Index 2, the mean yield difference at Index 1 was negligible. The mean yield advantage at Index 3 was 0.79 t/ha, when compared to an Olsen P Index 2.

**Table 10**: Effect of P Index on mean vining pea yield with Olsen P.

| Site | Year | Mean yield (t/ha) | | | Standard deviation on mean | | |
|---|---|---|---|---|---|---|---|
| | | Index 1 | Index 2 | Index 3+ | Index 1 | Index 2 | Index 3+ |
| Docking | 2012 | 5.80 | 5.30 | 5.78 | 0.39 | 0.39 | 0.46 |
| | 2013 | - | 5.66 | 6.08 | - | 0.51 | 0.77 |
| Brocklesby | 2012 | 5.87 | 5.64 | (6.59) | 0.54 | 0.47 | - |
| Kirby Cane | 2013 | - | 5.13 | 5.94 | - | 0.50 | 0.51 |
| | 2014 | 7.91 | (7.78) | 8.15 | 0.57 | - | 0.62 |
| Hallington | 2013 | 6.64 | 9.30 | 11.01 | 0.72 | 1.78 | 0.23 |
| **Mean 6 site years** | | **6.56** | **6.47** | **7.26** | | | |

( ) Value based on only 1 plot

The decrease or increase in yield relative to that at P Index 2 for all sites (except Brocklesby in 2014) are shown in Table 11. At Index 1 the mean yield penalty was 0.48 t/ha compared to Index 2, although this ranged from +0.50 t/ha to -2.66 t/ha. The greatest yield penalty at Index 1 was at the Hallington site in 2013. Across site years, the mean yield increase at Index 3 was 0.79 t/ha, although this ranged from +0.37 t/ha at Kirby Cane in 2014 to +1.71 t/ha at Hallington in 2013.

**Table 11**: Increase or decrease in vining pea yield compared to a P Index of 2

| Site | Year | Yield increase (+) or decrease (-) vs Index 2 (t/ha) | |
|---|---|---|---|
| | | Index 1 | Index 3+ |
| Docking | 2012 | +0.50 | +0.48 |
| | 2013 | - | +0.42 |
| Brocklesby | 2012 | +0.23 | +0.95 |
| Kirby Cane | 2013 | - | +0.81 |
| | 2014 | +0.12 | +0.37 |
| Hallington | 2013 | -2.66 | +1.71 |
| **Mean 6 site years** | | **-0.45** | **+0.79** |

 

### Yield response to fresh P

Data on yield response to fresh P fertiliser were obtained from 6 vining pea crops. For each site yields with fresh P are shown for low and high fresh P doses, based on the average Olsen P of the two plots that received either a low or high fresh P dose (Table 12). The yield increase or decrease with fresh P was then calculated relative to the yield for Olsen P, at Index 2. Yield responses at Hallington in 2013 were abnormally large and were likely due to the high yield potential of the site. Excluding Hallington, yield increases with fresh P ranged from -0.2 to +0.2 t/ha with a low fresh P dose. For a high fresh P dose yield increases ranged from -0.9 to +0.77 t/ha. On average, across all sites yields were on average 6.63 and 6.98 t/ha where a low or high fresh P dose had been applied. This compares to an average yield of 6.47 t/ha at an Olsen P Index 2 equating to a 0.24t/ha response from a low fresh P dose and 0.51 t/ha from a high fresh P dose.

**Table 12**: Effect of P Index on mean vining pea yield with fresh P and the yield increase or decrease vs Olsen P Index 2.

| **Site** | **Year** | **Mean yield (t/ha)** | | **Yield increase (+) or decrease (-) vs Olsen P Index 2 (t/ha)** | |
|---|---|---|---|---|---|
| | | Low fresh P dose | High fresh P dose | Low fresh P dose | High fresh P dose |
| Docking | 2012 | 5.21 | 5.56 | -0.09 | +0.26 |
| | 2013 | 5.43 | 5.56 | -0.23 | -0.10 |
| Brocklesby | 2012 | 5.41 | 4.73 | +0.23 | -0.91 |
| Kirby Cane | 2013 | 5.26 | 5.90 | +0.13 | +0.77 |
| | 2014 | 8.01 | 8.05 | +0.23 | +0.27 |
| Hallington | 2013 | 10.46 | 12.06 | +1.16 | +2.76 |
| **Mean 6 site years** | | **6.63** | **6.98** | **0.24** | **0.51** |

## Critical P levels

For each site response curves were fitted to the yield / Olsen P data in 2012, 2013 and 2014, as described in section Materials and Methods. Seven vining pea crops were grown in total over the 3 seasons. At Brocklesby in 2012 and 2014, Docking 2012 and 2013 and Kirby Cane 2014 it was not possible to obtain meaningful estimates of the critical P level associated with 95% and 98% of maximum yield for the vining pea crops at these sites.

Response curves for vining pea crops at Hallington in 2013, over three sequential harvest timings are shown in Figures 7 (harvest timing one), 8 (harvest timing two) and 9 (harvest timing three). The yield response plateaued at a lower level of Olsen P at the earlier lift timings. Response curves for Kirby Cane in 2013, over two harvest timings are shown for comparison in Figures 10 (harvest timing one) and 11 (harvest timing two).

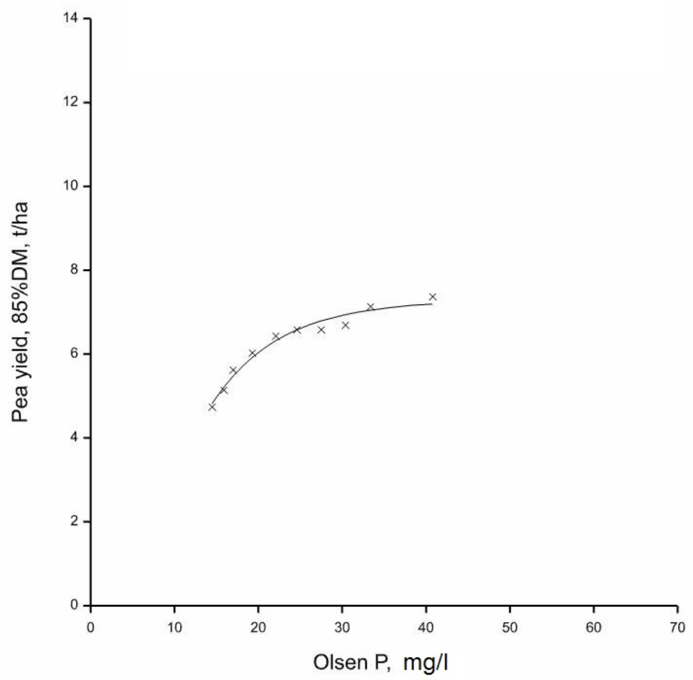


**Figure 7**: Fitted yield response curve for the 2013 vining pea crop at Hallington at the first harvest timing.

At Hallington, at the later harvest timings, the yield response was much steeper and plateaued at a lower level of Olsen P compared to Kirby Cane, suggesting the higher yield potential of the site.

 

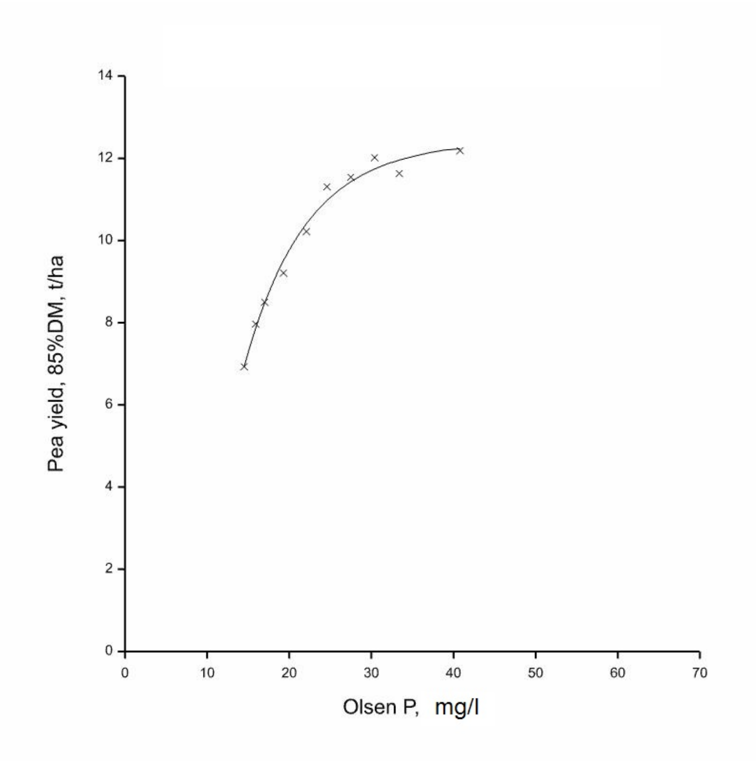


**Figure 8**: Fitted yield response curve for the 2013 vining pea crop at Hallington at the second harvest timing.

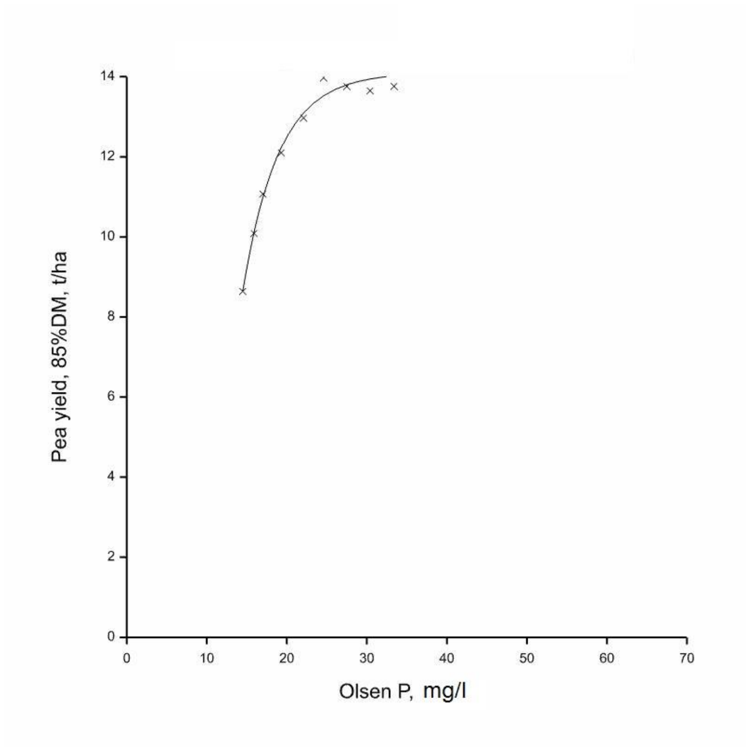


**Figure 9**: Fitted yield response curve for the 2013 vining pea crop at Hallington at the third harvest timing.

 

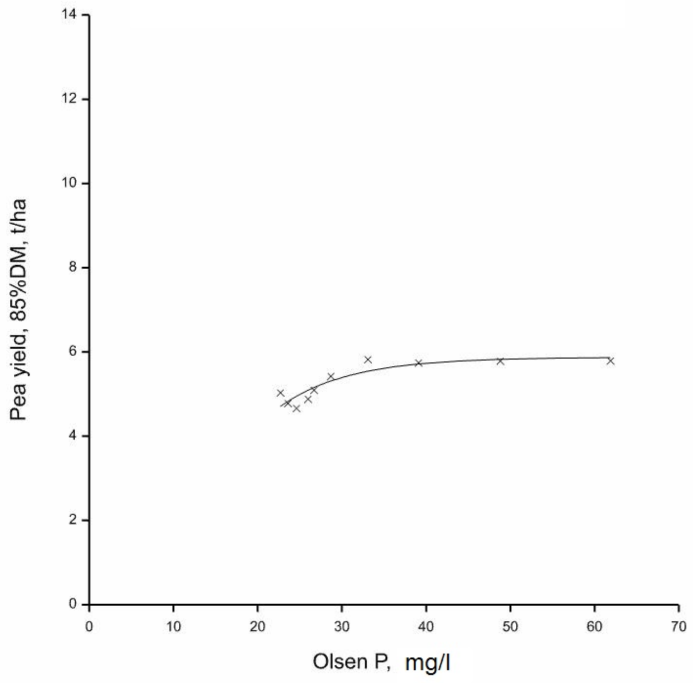


**Figure 10**: Fitted yield response curve for the 2013 vining pea crop at Kirby Cane at the first harvest timing.

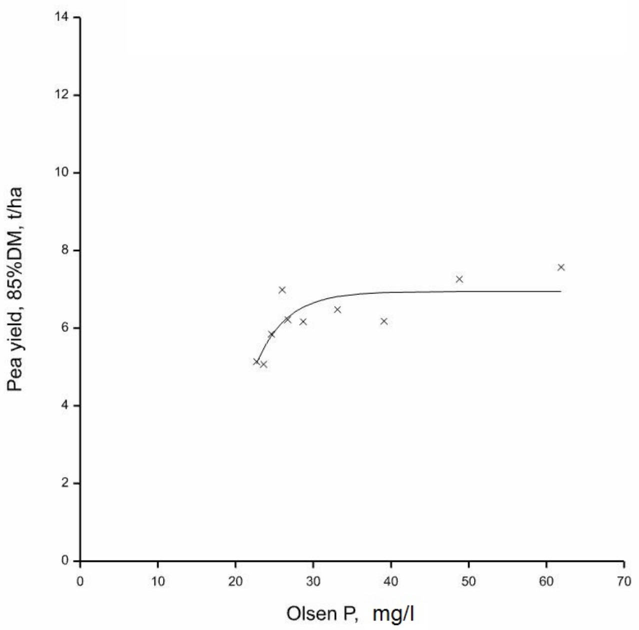


**Figure 11**: Fitted yield response curve for the 2013 vining pea crop at Kirby Cane at the first harvest timing.

Meaningful estimates of the fitted maximum (plateau) yield and critical Olsen P levels associated with 95% and 98% of the maximum yield were obtained for two of the seven vining pea sites from 2013 that had an adequate range of Olsen P (Table 13).

Levels of Olsen P associated with 95% of maximum yield ranged from 23.7 mg/l (Index 2) to 34.0 mg/l (Index 3), and for 98% of maximum yield the range was 27.8 mg/l (Index 3) to 41.6 mg/l (Index 3). Over all five vining pea harvest timings, average critical P levels were around 30 mg/l for 95% of maximum yield and 35 mg/l for 98% of maximum yield, which are within the lower half of P Index 3.

Meaningful estimates of the fitted maximum yield and critical Olsen P levels for fresh P were not possible due to the difficulties of stating Olsen P values for fresh P that had not reached equilibrium.

**Table 13**: Fitted maximum vining pea yield and Olsen P to achieve 95% and 98% of maximum yield in 2013.

| Site | Harvest timing | Fitted maximum yield | | Olsen P for 95% max yield | | Olsen P for 98% max yield | | Variance accounted for (%) |
|---|---|---|---|---|---|---|---|---|
| | | t/ha | s.e. | mg/l | s.e. | mg/l | s.e. | |
| Hallington | One | 7.29 | 0.02 | 30.0 | 3.62 | 37.4 | 5.28 | 96 |
| | Two | 12.39 | 0.02 | 30.8 | 2.35 | 37.7 | 3.33 | 98 |
| | Three | 14.10 | 0.02 | 23.7 | 1.09 | 27.8 | 1.61 | 98 |
| Kirby Cane | One | - | - | - | - | - | - | - |
| | Two | 6.95 | 0.13 | 29.3 | 1.49 | 32.9 | 3.44 | 55 |
| | Three | 5.87 | 0.05 | 34.0 | 4.91 | 41.6 | 8.70 | 78 |

## Effect of Olsen P and fresh P on crop vigour and root nodulation

 

Seven vining pea crops were grown in total over the four sites. At Brocklesby in 2014 the full range of Olsen P Indices was not represented so this crop has been excluded from Table 14. The effect of P Index on crop vigour at mid to late flowering with Olsen P are shown in Table 14. Mean crop vigour at Index 1 was 2.3 (range 1.8 - 2.8), at Index 2 was 3.1 (range 2.7 - 5.0) and Index 3 was 4.4 (3.5 - 5.0). In most (3 out of 4 sites) situations where Olsen P was recorded at Index 1, crop vigour was notably improved at Olsen P Index 2 and further improved at most sites (5 out of 6 sites) where Olsen P was at Index 3 compared to an Index 2.

**Table 14**: Effect of P Index on mean crop vigour at mid to late flowering with Olsen P.

| **Site** | **Year** | **Mean crop vigour (1-5 score)** | | |
|---|---|---|---|---|
| | | Index 1 | Index 2 | Index 3+ |
| Docking | 2012 | 2.8 | 2.8 | 3.5 |
| | 2013 | - | 2.0 | 5.0 |
| Brocklesby | 2012 | 2.0 | 5.0 | 5.0 |
| Kirby Cane | 2013 | - | 2.0 | 4.0 |
| | 2014 | 2.5 | 4.0 | 4.3 |
| Hallington | 2013 | 1.8 | 2.7 | 4.3 |
| **Mean 6 site years** | | **2.3** | **3.1** | **4.4** |

1 = weakest, 5 = most vigorous

Data on the effect of fresh P on crop vigour at mid to late flowering was obtained for six crops across four sites (Table 15). For each site average crop vigour are shown for a low fresh P dose and a high fresh P dose. In general, where a low fresh P application was made crop vigour was only marginally improved to that where Olsen P was at an Index 1 with a mean vigour score of 2.7 compared to 2.3 respectively. However, crop vigour indicated a large response to a large fresh P application resulting in a mean crop vigour score of 4.0, this was comparable to where Olsen P was at Index 3 (Table 14). The differences in crop vigour scores across the six sites with low doses of fresh P ranged from 2.0 - 4.5 and high doses of fresh P ranged from 2.5 - 5.0.

 

**Table 15**: Effect of P Index on mean crop vigour at mid to late flowering with fresh P.

| Site | Year | Mean crop vigour (1-5 score) | | |
|---|---|---|---|---|
| | | Index 1 (Olsen P | Low fresh P dose | High fresh P dose |
| Docking | 2012 | 2.8 | 3.5 | 4.5 |
| | 2013 | - | 2.0 | 5.0 |
| Brocklesby | 2012 | 2.0 | 4.5 | 5.0 |
| Kirby Cane | 2013 | - | 1.5 | 3.5 |
| | 2014 | 2.5 | 2.0 | 2.5 |
| Hallington | 2013 | 1.8 | 2.5 | 3.5 |
| **Mean 6 site years** | | **2.3** | **2.7** | **4.0** |

1 = weakest, 5 = most vigorous

Across most sites, both at stem elongation (GS 105) and flowering (GS 203), clear visual differences in crop vigour were noted between P fertiliser treatments as shown in Figure 12. Crops that had a soil P Index 1 (10-15 mg/l) were notably stunted with thinner, paler coloured leaves compared to a crop where an Index 3 (26-45 mg/l) was maintained. At Brocklesby 2012 these differences were noted to occur through crop growth stages from stem elongation to flowering of the vining peas.

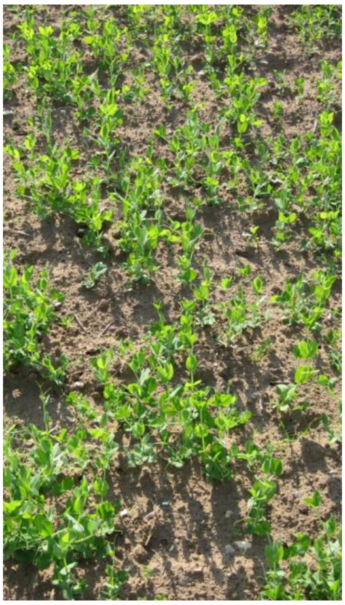

Figure 12a

Figure 12b

**Figure 12**: Crop vigour during stem elongation between low (Figure 10a) and high (Figure 10b) soil Olsen P treatments. Photographs taken on 20/06/2012.

 

The effect of P Index on root nodulation at mid to late flowering with Olsen P are shown in Table 16. Mean root nodulation at Index 1 was 7 (range 6 - 8), at Index 2 was 7 (range 4 - 9) and Index 3 was 8 (6 - 9). In general there was little apparent affect of Olsen P on root nodulation from Index 1 through index 3. However, there is some suggestion that at Olsen P Index 3 root nodulation is less variable across sites.

At Brocklesby 2014, where the site suffered from Fusarium foot rot (*Fusarium solani*), it was noted that where Olsen P was at Index 2 or greater crop vigour was 2.5 compared to 1.0 at an Index 1 (Figure 13). Where fresh P had been applied crop vigour was notably improved and was 4.0 compared to an Olsen P Index 1.

Figure 13a

Figure 13b

**Figure 13**: Crop vigour during flowering between low (Figure 13a) and high (Figure 13b) soil Olsen P treatments. Photographs taken on 01/07/2014.

**Table 16**: Effect of P Index on mean root nodulation at mid to late flowering with Olsen P.

| **Site** | **Year** | **Mean root nodulation (1-10 score)** | | | |
|---|---|---|---|---|---|
| | | Index 0 | Index 1 | Index 2 | Index 3+ |
| Docking | 2013 | - | - | 7 | 9 |
| Brocklesby | 2012 | - | 6 | 8 | 7 |
| Kirby Cane | 2013 | - | - | 8 | 6 |
| | 2014 | - | 6 | 4 | 9 |
| Hallington | 2013 | - | 8 | 9 | 9 |
| **Mean 5 site years** | | **-** | **7** | **7** | **8** |

1 = low, 10 = high

 

Data on the effect of fresh P on root nodulation at mid to late flowering was obtained for five crops across four sites (Table 17). For each site, average root nodulation scores are shown for a low fresh P dose and a high fresh P dose. In general, where a low or high fresh P application was made root nodulation was only marginally improved to that where Olsen P was at an Index 1 with a mean vigour score of 8 and 8 compared to 7 respectively. Fresh P fertiliser also made little difference to that where soil Olsen P was maintained at Index 2 or 3.

**Table 17**: Effect of P Index on mean root nodulation at mid to late flowering with fresh P.

| **Site** | **Year** | **Mean root nodulation (1-10 score)** | | |
|---|---|---|---|---|
| | | Index 1 (Olsen P) | Low fresh P dose | High fresh P dose |
| Docking | 2013 | - | 8 | 8 |
| Brocklesby | 2012 | 6 | 6 | 9 |
| Kirby Cane | 2013 | - | 8 | 8 |
| | 2014 | 6 | 8 | 4 |
| Hallington | 2013 | 8 | 9 | 10 |
| **Mean 5 site years** | | **7** | **8** | **8** |

1 = low, 10 = high

## Effect of Olsen P and fresh P on seed size and BRIX test

Seven vining pea crops were grown in total over the four sites. At Brocklesby in 2014 the full range of Olsen P Indices was not represented so this crop has been excluded from Table 18. The effect of P Index on average seed size across harvest timings (based on % of total weight) with Olsen P are shown in Table 18.

 

**Table 18**: Effect of P Index on average seed size across harvest timings (based on % of total weight) with Olsen P.

| | | Seed size % of total weight | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Site** | **Year** | **Index 1** | | | | **Index 2** | | | | **Index 3+** | | | |
| | | VS | S | M | L | VS | S | M | L | VS | S | M | L |
| Docking | 2012 | 6 | 20 | 44 | 31 | 5 | 18 | 44 | 32 | 5 | 18 | 43 | 33 |
| | 2013 | - | - | - | - | 3 | 21 | 57 | 18 | 2 | 22 | 57 | 19 |
| Brocklesby | 2012 | 1 | 7 | 44 | 47 | 1 | 11 | 44 | 44 | 2 | 13 | 42 | 43 |
| Kirby Cane | 2013 | - | - | - | - | 1 | 5 | 38 | 56 | 0 | 4 | 35 | 60 |
| | 2014 | 1 | 6 | 34 | 46 | 1 | 6 | 35 | 45 | 1 | 6 | 34 | 46 |
| Hallington | 2013 | 2 | 13 | 41 | 44 | 1 | 10 | 40 | 48 | 1 | 7 | 37 | 55 |
| **Mean 6 site years** | | **3** | **11** | **41** | **42** | **2** | **11** | **43** | **41** | **2** | **12** | **41** | **43** |

VS = very small, S = small, M = medium, L = Large

At two (Hallington and Kirbby Cane, 2013) out of the seven crops a positive increase was seen in percentage seed size by weight in the large seed class. The highest percentage increase in large seed size was obtained in 2013 at Hallington (Figure 14) where the average large seed size by weight at Olsen P Index 3 was 55% compared to 44% at an Olsen P Index 1. The mean percentage large seed size by weight, across all sites, at Index 3 was 43% ranging from 19% to 60%. At Index 1 the average large seed size by weight was 42% although this ranged from 31% to 47% across the sites. At Docking 2012, Docking 2013, Kirby Cane 2014 sites showed little Olsen P response to seed size. At Brocklesby 2012 showed a slight decline in larger seed sizes with increasing Olsen P. At these sites factors such as rainfall during seed development may have limited seed weight increase over and above changes in Olsen P indices.

 

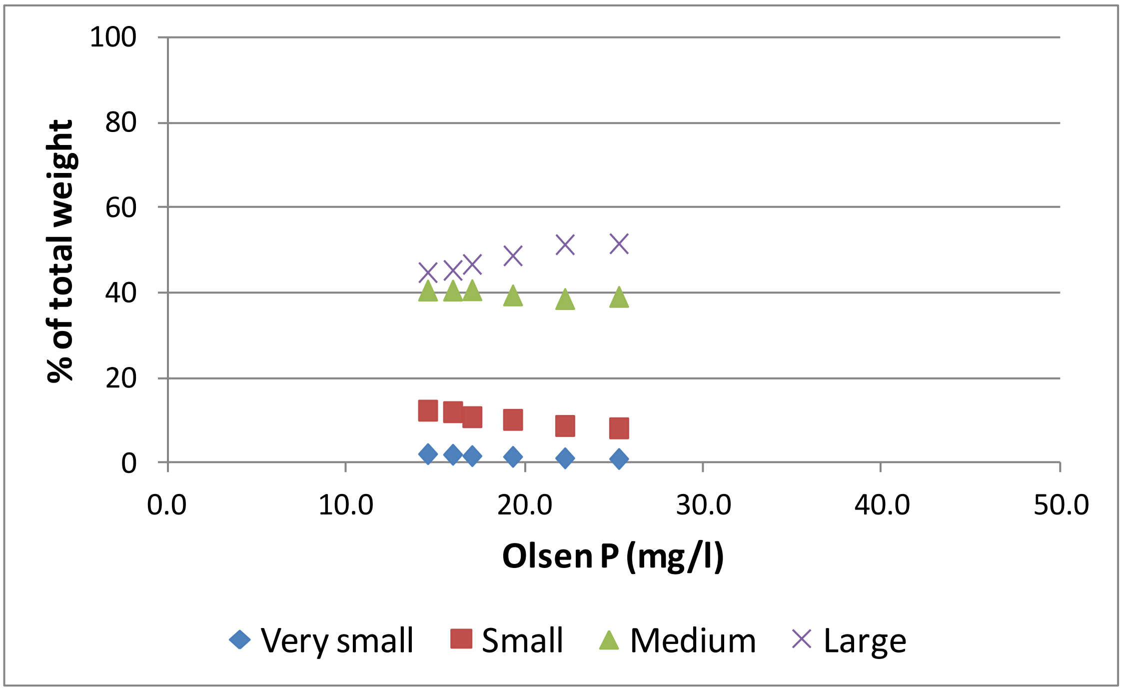


**Figure 14**: The effect of Olsen P on the average seed size across harvest timings (based on % of total weight) at the Hallington site (2013).

Data on the effect of fresh P on average seed size across harvest timings (based on % of total weight) was obtained for five crops (Table 19). For each site, average seed size across harvest timings (based on % of total weight) are shown for a low fresh P dose and a high fresh P dose. The response to fresh P is based on the average seed size from two plots at each site receiving either a low or high fresh P dose. The average seed size from fresh P is then compared relative to plots untreated with P fertiliser for P Index 1. In general there was little change in average seed size relative to Index 1 from applying a low fresh P dose. In general, where a high fresh P dose was applied there was little difference in average seed size from fresh P when compared relative to plots untreated with P fertiliser. However, at two sites, Hallington 2013 and Kirby Cane 2013 there was a suggestion that where plots received a large dose of fresh P fertiliser there was a greater proportion of large seeds by total weight relative to plots untreated with P fertiliser for P Index 1. At Hallington 2013 a high dose of fresh P increased the percentage large seeds from 44% to 60% respectively. This increase in the percentage of large seeds to fresh P was slightly greater than that seen at Index 3 with Olsen P (Table 19).

 

**Table 19**: Effect of P Index on average seed size across harvest timings (based on % of total weight) with fresh P.

| | | Seed size % of total weight | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Site** | **Year** | **Index 1 (Olsen P)** | | | | **Low fresh P dose** | | | | **High fresh P dose** | | | |
| | | VS | S | M | L | VS | S | M | L | VS | S | M | L |
| Docking | 2012 | 6 | 20 | 44 | 31 | 6 | 19 | 43 | 31 | 7 | 23 | 43 | 27 |
| | 2013 | - | - | - | - | 4 | 26 | 53 | 16 | 3 | 24 | 55 | 18 |
| Brocklesby | 2012 | 1 | 7 | 44 | 47 | 2 | 11 | 48 | 40 | 2 | 14 | 43 | 40 |
| Kirby Cane | 2013 | - | - | - | - | 1 | 5 | 38 | 56 | 0 | 4 | 35 | 61 |
| | 2014 | 1 | 6 | 34 | 46 | 1 | 6 | 35 | 45 | 0 | 5 | 31 | 50 |
| Hallington | 2013 | 2 | 13 | 41 | 44 | 1 | 6 | 37 | 56 | 1 | 5 | 35 | 60 |
| **Mean 6 site years** | | **3** | **11** | **41** | **42** | **3** | **12** | **42** | **41** | **2** | **13** | **40** | **43** |

VS = very small, S = small, M = medium, L = Large

Seven vining pea crops were grown in total over the four sites. At Brocklesby in 2014 the full range of Olsen P Indices was not represented so this crop has been excluded from Table 20. The effect of P Index on Brix % according to Olsen P are shown in Table 20 for five sites. Little difference in mean BRIX test scores was seen at any site regardless of Olsen P Index.

**Table 20**: Effect of P Index on Brix % with Olsen P.

| **Site** | **Year** | **Brix % to Olsen P** | | |
|---|---|---|---|---|
| | | Index 1 | Index 2 | Index 3+ |
| Docking | 2013 | - | 10.3 | 10.2 |
| Brocklesby | 2012 | 8.7 | 9.8 | 8.7 |
| Kirby Cane | 2013 | - | 8.1 | 8.7 |
| | 2014 | 8.4 | 8.3 | 8.6 |
| Hallington | 2013 | 9.9 | 10.0 | 9.8 |
| **Mean 5 site years** | | **9.0** | **9.3** | **9.2** |

Data on Brix % response to fresh P was obtained from for six crops across four sites (Table 21). For each site Brix % with fresh P are shown for a low fresh P dose and a high fresh P dose due to the difficulty of fresh P fertiliser applied at each site not reaching equilibrium. The response to fresh P is based on the average Brix % from two plots at each site receiving either a low or high fresh P dose. The Brix % from fresh P is then compared relative to plots untreated with P fertiliser for P Index 1. In general, there was little change in Brix % relative to Index 1 either from applying either a low or high fresh P. The fresh P fertiliser applications also showed little further benefit to Brix % compared to values obtained from Olsen P Indices of either 2 or 3. Mean Brix scores were in the range of 9.0 to 9.4% when either looking at Olsen P or fresh P.

**Table 21**: Effect of P Index on Brix % with fresh P.

| Site | Year | Brix % to fresh P | | |
|---|---|---|---|---|
| | | Index 1 (Olsen P) | Low fresh P dose | High fresh P dose |
| Docking | 2013 | - | 10.1 | 10.5 |
| Brocklesby | 2012 | 8.7 | 9.2 | 9.4 |
| Kirby Cane | 2013 | - | 8.5 | 8.2 |
| | 2014 | 8.4 | 8.7 | 8.7 |
| Hallington | 2013 | 9.9 | 9.8 | 10.1 |
| **Mean 5 site years** | | **9.0** | **9.3** | **9.4** |

## Economic analysis

For each site, the value of the yield obtained less the cost of replacing the amount of P removed (required to maintain the Olsen P level) was calculated, for an increase in P Index from 1 to 2, or 2 to 3). Results are shown in full in Appendix F, Table F1 and F2. Using the value of the extra yield less the cost of replacing the P offtake, the number of cropping cycles required at each site for the additional crop value to exceed the cost of first achieving and then maintaining an increase in P Index from 1 to 2 and 2 to 3 was calculated for Olsen P and fresh P (Tables 22 and 23).

With a limited range of sites at an Index 1 Olsen P there is little economic analysis for the majority of sites for raising Olsen P from Index 1 to 2, except for Hallington 2013, where the average value of the extra yield less the cost of replacing the P offtake returned £902 and was achieved within a single cropping cycle. Raising Olsen P from Index 2 to 3 across all site ranged from 1 to 4 cropping cycles before the benefit exceeded cost. Economic returns ranged from £125 to £580/ha.

 

**Table 22**: Number of cropping cycles required for the additional crop value to exceed the cost of achieving and maintaining an increase in P Index (based on average P availability) for Olsen P.

| Site | Year | Time required for benefit to exceed cost when raising P level for Olsen P | |
|---|---|---|---|
| | | From Index 1 to 2 | From Index 2 to 3 |
| Brocklesby | 2012 | - | 2 cropping cycles |
| Docking | 2012 | - | 3 cropping cycles |
| Docking | 2013 | - | 4 cropping cycles |
| Kirby Cane | 2013 | - | 2 cropping cycles |
| Kirby Cane | 2013 | - | 4 cropping cycles |
| Hallington | 2013 | 1 cropping cycle | 1 cropping cycle |

The economic analyses for fresh P compares the number of cropping cycles required where the average value of the extra yield from fresh P fertiliser exceeds the cost of achieving and maintaining an Olsen P Index 2. Where a low fresh P dose had been applied the average value of the extra yield less the cost of raising P level was in the range of £44 to £393/ha and required between 1 and 5 cropping cycles to achieve this. Where a high fresh P dose had been applied the average value of the extra yield less the cost of raising P level was in the range of £88 to £934/ha and required between 1 and 6 cropping cycles to achieve this.

 

**Table 23**: Number of cropping cycles required for the additional crop value to exceed the cost of achieving and maintaining an increase in P Index (based on average P availability) for fresh P.

| Site | Year | Time required for benefit to exceed cost when raising P level for Olsen P | |
|---|---|---|---|
| | | Low fresh P dose | High fresh P dose |
| Brocklesby | 2012 | 4 cropping cycles | - |
| Docking | 2012 | - | 6 cropping cycles |
| Docking | 2013 | - | - |
| Kirby Cane | 2013 | 5 cropping cycles | 2 cropping cycles |
| Kirby Cane | 2013 | 3 cropping cycles | 5 cropping cycles |
| Hallington | 2013 | 1 cropping cycle | 1 cropping cycle |

## Discussion

The field experiments reported here have generated a significant amount of new data, but it is important that the limitations of the dataset are recognised. Current advice is based on the findings of previous research on a limited number of field experiments. The duration of this project was limited to six vining pea crops over a staggered four year trialling sequence to study critical P levels for vining pea crops. The experiments required a range of Olsen P levels to be established in large plots, on soil types that were typical of vining pea production. It was necessary to achieve this by building-up sites that started with low Olsen P levels, rather than running down sites with high levels, which would not have been possible within the duration of the project.

With a similar study recently completed looking at critical P for cereal and oilseed rape crops (Knight et al., 2014) a greater understanding about the time required for the increase in Olsen P to stabilise following the application of TSP for achieving the desired increase in Olsen P. When calculating how much TSP to apply to each plot to create the desired range of Olsen P levels, an assumption had to be made as to what proportion of the P applied remained as Olsen P after equilibration. Based on previous long-term research at Rothamsted a value of 15% was assumed and this proved to be remarkably close to the average value of 17% that was found for the experiments reported in the HGCA funded project (Knight et al., 2014). The equilibration of fresh P fertiliser applications made in this study to answer grower queries relating to whether fresh P applications could deliver similar yield and quality benefits to those found from maintaining Olsen P Index 2 proved challenging. This was due to the time gap between applying fresh P fertiliser (just prior to the vining pea crops) and taking soil samples for Olsen P analysis to determine plant available soil P being too short and not allowing the P fertiliser to equilibrate within the soil. Findings from the HGCA project suggest that a time period of at least 18 months is required, particularly for large P doses, to be equilibrated within the soil (Knight et al., 2014).

Vining pea crop yields are greatly influenced by weather. Of the three cropping seasons included within the project the spring of 2012 was unseasonably wet, especially for the east, whilst 2013 and 2014 remained nearer to long-term average, 1981 – 2010 rainfall anomaly. Mean temperature for the spring period for 2012, 2013 and 2014 seasons were also characterised by extremes, particularly in 2013 where the average temperature was approximately 2.0ºC below the long-term average, 1981 – 2010 temperature anomaly. These cooler temperatures during crop stem elongation and flowering may partly explain why the Halllington site was not short of water, leading to very high yields. To acquire nutrients and water the roots of annual arable crops have to explore the largest possible volume of soil in the shortest possible time, especially spring sown crops. When the volume of soil that can be explored by roots is restricted because of poor structure, especially when the soil is compacted, the opportunity for roots to take up nutrients and water is limited. Experiments at Rothamsted have indicated that soils that have a poor structure must contain more Olsen P to achieve satisfactory yields (Johnston and Poulton, 2011).

The variation in response to Olsen P across sites and seasons highlight both the extent and spatial variation in Olsen P that can occur. This underlines that Olsen P should be considered as an indication of the amount of plant-available P, not an exact measurement, and that monitoring over a period of years for each field gives a better indication of plant-available soil P status than a single result in any one year.

Excluding Brocklesby 2014 because of the limited range of Olsen P levels obtained from a single vining pea variety, yield from all sites were analysed and means calculated at each P index. Although the comparisons are based on an unequal number of values such that differences should be treated with caution, there was a consistent yield benefit in the mean yield of vining peas grown on soils at a P Index 3 compared to an Index 2 with a mean yield response of 0.8 t/ha. Mean yield penalties at Index 1 compared to an Index 2 were more variable with a mean yield penalty of 0.5 t/ha although at the Hallington site, where yield response to Olsen P was highest the yield penalty at Index 1 was 2.7 t/ha. The application of a low or high fresh P dose generally gave variable results across the trial sites. This may partly relate to the fact that Olsen P was yet to reach equilibrium in this situation and partly to soil and weather conditions across the sites and the resulting variable response to Olsen P. However, at Hallington, where the crop showed a high level of response to Olsen P, the application of a low fresh P fertiliser dose indicated around a 1 t/ha yield response over and above a soil Olsen P Index 2 and over 2.5 t/ha for a high fresh P fertiliser dose.

Current advice in the Fertiliser Manual RB209 (Defra, 2010) states that "…where crops are grown on soils below the target Index applying large amounts of phosphate (and potash) rarely produces yields equal to those where the crop is grown on soil at the target Index". The responses to fresh P fertiliser in this project suggests that, in general, a small, or large amount of fresh P fertiliser (larger than that recommended in RB209) applied to crops at Index 1 or low Index 2 was, in general, effective at raising yields to that above levels achieved at Olsen P Index 2. This suggests that fresh P fertiliser applications could be used to increase crop yields. However, it should be noted that irrespective of whether soils are maintained at an Olsen P Index 1 or 2, it would still be necessary to replace the amount of P removed in the harvested crop.

At Hallington and Kirby Cane 2013, where critical Olsen P levels to achieve 98% of the maximum yield for individual harvest timings were obtained, all values fall within the range of 27.8 to 41.6 mg/l (Index 3). However, due to limitations on the fitted model for other sites, further critical Olsen P levels were not attainable and the reason for this remains unclear. However, it is likely that the variation in response to Olsen P over a range of Indices at the other sites may have been confounded by the weather or soil structure interactions. It would therefore seem prudent that to further validate this model in vining peas, further field validation across a range of soil Olsen P levels, including Index 0, is necessary.

Crop vigour was notably reduced where soil Olsen P was below 15 mg/l (Index 1) and results indicated that crop vigour was less variable at Index 3. This would suggest that phosphate is affecting crop rooting and to some extent root nodulation. Therefore, where soil Olsen P is below the recommendation, yields may be below the site potential. It was also particularly interesting to note that at one site where Fusarium foot rot (*Fusarium solani*) was present, the increase in soil Olsen P to an Index 2 or in particular, where a fresh P fertiliser dose was applied, crop vigour was notably increased and it suggested that higher soil Olsen P improved the resilience of the crop through improved rooting in the presence of Fusarium foot rot. Where soil Olsen P was at an Index 1, infected plants showed classical symptoms of infection, premature maturity or failing to reach maturity. Further research in this area to look at the interaction between soil Olsen P levels and fungal development would be of interest to the industry.

At the two sites where yield responses were the greatest e.g. Hallington and Kirby Cane 2013 it was noted that soil Olsen P had a substantial effect on the average seed size (based on the percentage of total weight) particularly at Hallington where the mean large seed size increased from 44% at Index 1 to 55% at Index 3. At Hallington and Kirby Cane sites the application of a large fresh P dose substantially increased the mean large seed size to 60 and 61%, respectively. This increase in seed size may be associated with improved root function that is essential for better uptake of other major nutrients e.g. nitrogen. Johnston and Poulton (2011) reported that phosphate interacted with nitrogen availability and efficiency and the ability of the crop to take up sufficient nutrients in adequate proportions was reduced where Olsen P was sub-optimal.

Economic analysis shows that the payback from raising the P Index from 1 to 2 can be very rapid (less than 1 cropping cycle) although caution to this should be made given the limited number of sites where Olsen P was measured at Index 1. However, the payback from raising the P Index from 2 to 3 was also fairly rapid (within 4 cropping cycles) although it is worth mentioning that the length of time would be dependent upon the length of farm rotation and the frequency of inclusion of vining pea crops within the rotation. However, from the HGCA study (Knight et al., 2014) reporting on the economic analysis in combinable crops the payback period would potentially be less if growers followed the advice of maintaining soil Olsen P at an Index 2 for combinable crops.

As a more general discussion point, if arable soils in general were maintained at, or around, an Index 2 then where vining peas are grown on rented arable land there would be less of a risk to a yield penalty and the economics of applying only a small P fertiliser dose, required for maintenance purposes would become more common. Whilst growers continue to rent land for vining pea production on arable soils with a sub-optimal Olsen P status then there are increased risks of yield reductions in vining pea crops associated with low soil Olsen P or to the economics of applying larger P doses to raise soil Olsen P that may not result in payback over such a short duration (possibly a single season).

## Conclusions

Results over three cropping years from six sites on contrasting soils suggest that Olsen P should be maintained at P Index of 3 for vining pea crops. The critical Olsen P varied from site to site in experiments, probably due to variations in soil physical conditions and seasonal affects e.g. rainfall. Critical P values to achieve 98% of maximum yield were around 27 - 41 mg/l (or at P Index of 3) and this was economically justified. There were differences between sites and crops or years in the responsiveness of yield to Olsen P. These were not obviously related to soil conditions or other crop or site factors. However, the extremes of weather experienced during the project mean that further field experiments would be required to enable a more robust interpretation. On average there was a yield penalty of around 0.5 t/ha where vining pea crops were grown at an Index 1. The mean yield response of vining peas grown on soils at a P Index 3 compared to an Index 2 was 0.8 t/ha. A small or large dose of fresh P fertiliser did raise vining pea yields to at least the level achieved at Olsen P Index 2.

Economic analysis suggests that the payback from raising the P Index from 2 to 3 was fairly rapid (within 4 cropping cycles). The length of time would be dependent upon the length of farm rotation and the frequency of inclusion of vining pea crops within the rotation although maintaining an Olsen P Index 2 for combinable crops would potentially reduce this payback period further. Maintaining higher soil Olsen P indices increased crop vigour and, in some instances, improved seed size and root nodulation.

## Knowledge and Technology Transfer

Knowledge transfer activities have included a series of articles in the following publications highlighting the results from this project:

- NIAB Landmark, Issue 8, May 2011
- AHDB Horticulture Field Vegetable Review 2012

- PGRO Vegetable Magazine (Winter 2011)
- AHDB Horticulture Field Vegetable Review 2013
- PGRO Vegetable Magazine (Winter 2012)

A short presentation on the interim results from this project were presented at:

- Vegetable Agronomists Association meeting at PGRO, Thornhaugh, Peterborough on 15th January 2013.
- Birds Eye growers meetings on 9th December 2013.
- AICC Technical Conference, Towcester on 14th January 2015.
- Vegetable Agronomists Association meeting at PGRO, Thornhaugh, Peterborough on 28th January 2014.

Grower events to present results to the industry were attended including:

- PGRO Vining Pea Trials Day, Thornhaugh, Peterborough on 11th June 2013
- PGRO Demonstration Day, STC, 1st July 2014.

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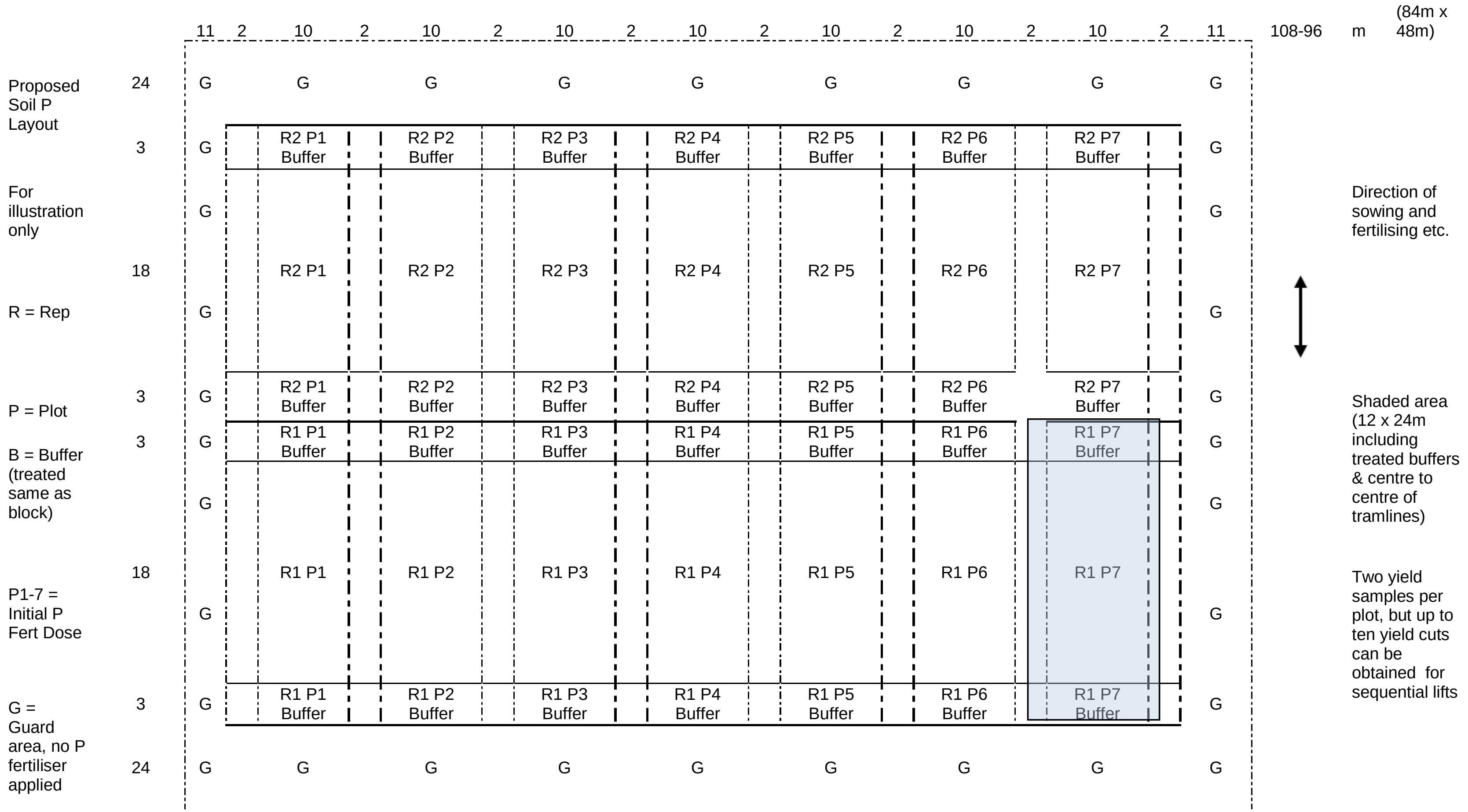
# Appendices

## Appendix A – Trial plan



## Appendix B – Site details

Year 2 – 2010-2012

| Site | County | Soil series | Soil description | Primary cultivation Type | Primary cultivation depth (cm) | TSP application 'Stabilised' TSP application date | TSP application 'Fresh' TSP application date | Vining peas Date drilled | Variety |
|---|---|---|---|---|---|---|---|---|---|
| Brocklesby | Lincs | Landbeach | Sandy loam | Plough | 25 | 13/09/2010 | 13/03/2012 | 30/03/2012 | Swallow |
| Docking | Norfolk | Barrow | Sandy loam | Plough | 25 | 14/12/2010 | 02/12/2011 | 05/03/2012 | Anubis |

Year 3 – 2011-2013

| Site | County | Soil series | Soil description | Primary cultivation Type | Primary cultivation depth (cm) | TSP application 'Stabilised' TSP application date | TSP application 'Fresh' TSP application date | Vining peas Date drilled | Variety |
|---|---|---|---|---|---|---|---|---|---|
| Docking | Norfolk | Barrow | Sandy loam | Plough | 25 | 24/10/2011 | 14/12/2012 | 28/03/2013 | Hesbana |
| Kirby Cane | Suffolk | Beccles | Clay loam | Plough | 25 | 15/09/2011 | 11/02/2013 | 03/05/2013 | Boogie |
| Hallington | Lincs | Andover 1 | Silty clay loam | Plough | 25 | 07/09/2011 | 01/03/2013 | 18/05/2013 | Oasis |

Year 4 – 2012-2014

| Site | County | Soil series | Soil description | Primary cultivation | Primary cultivation depth (cm) | TSP application 'Stabilised' TSP application date | TSP application 'Fresh' TSP application date | Vining peas Date drilled | Variety |
|---|---|---|---|---|---|---|---|---|---|
| Kirby Cane | Suffolk | Beccles | Clay loam | Plough | 25 | 04/10/2012 | 26/09/2013 | 01/05/2014 | Boogie |
| Brocklesby | Lincs | Landbeach | Sandy loam | Plough | 25 | 26/09/2012 | 28/03/2014 | 27/04/2014 | Balance |

## Appendix C – Full Olsen P data, mg/l

### Appendix Table C1 - Docking (2012) – Olsen P, mg/l

| Plot | Initial Olsen P | Expected Olsen P | Actual Olsen P | |
|---|---|---|---|---|
| | | | No fresh P | Fresh P |
| 1 | 17.8 | 27.8 | 15.6 | |
| 2 | 14.4 | 19.4 | 15.6 | |
| 3 | 12.8 | 12.8 | 68.6 | |
| 4 | 15.6 | 23.5 | | 61.2 |
| 5 | 12.0 | 12.0 | 20.2 | |
| 6 | 12.0 | 14.0 | 13.4 | |
| 7 | 16.6 | 16.6 | 16.2 | |
| 8 | 16.4 | 25.4 | 17.6 | |
| 9 | 16.6 | 18.6 | | 16.2 |
| 10 | 13.6 | 21.6 | | 86.6 |
| 11 | 12.4 | 12.4 | 26.4 | |
| 12 | 11.6 | 15.6 | | 54.6 |
| 13 | 13.2 | 13.2 | 19.8 | |
| 14 | 12.6 | 12.6 | 13.0 | |

**Appendix Table C2 - Brocklesby (2012) – Olsen P, mg/l**

| Plot | Initial Olsen P | Expected Olsen P | Actual Olsen P | |
|---|---|---|---|---|
| | | | No fresh P | Fresh P |
| 1 | 13.8 | 24.8 | | 49.0 |
| 2 | 15.8 | 15.8 | 11.6 | |
| 3 | 12.6 | 12.6 | 11.4 | |
| 4 | 13.2 | 20.2 | 16.6 | |
| 5 | 13.0 | 17.0 | | 21.8 |
| 6 | 12.8 | 12.8 | 12.4 | |
| 7 | 15.0 | 26.0 | 25.0 | |
| 8 | 12.8 | 12.8 | 11.2 | |
| 9 | 16.0 | 16.0 | 11.4 | |
| 10 | 15.8 | 30.8 | 32.6 | |
| 11 | 14.4 | 14.4 | 13.0 | |
| 12 | 15.2 | 15.2 | | 14.0 |
| 13 | 14.8 | 25.8 | | 48.6 |
| 14 | 16.2 | 22.2 | 19.0 | |

**Appendix Table C3 – Docking (2013) – Olsen P, mg/l**

| Plot | Initial Olsen P | Expected Olsen P | Actual Olsen P | |
|---|---|---|---|---|
| | | | No fresh P | Fresh P |
| 1 | 19.4 | 22.4 | | 21.4 |
| 2 | 18.2 | 31.2 | 69.8 | |
| 3 | 18.0 | 18.0 | 23.4 | |
| 4 | 21.8 | 37.8 | | 21.6 |
| 5 | 18.2 | 20.2 | 21.0 | |
| 6 | 24.6 | 24.6 | 20.2 | |
| 7 | 18.6 | 18.6 | 18.4 | |
| 8 | 23.8 | 23.8 | | 20.4 |
| 9 | 20.2 | 20.2 | 19.8 | |
| 10 | 23.6 | 31.6 | | 19.0 |
| 11 | 23.0 | 39.0 | 63.0 | |
| 12 | 17.8 | 17.8 | 16.5 | |
| 13 | 16.8 | 16.8 | 16.2 | |
| 14 | 22.4 | 28.4 | 29.2 | |

**Appendix Table C4 – Kirby Cane (2013) – Olsen P, mg/l**

| Plot | Initial Olsen P | Expected Olsen P | Actual Olsen P | |
|---|---|---|---|---|
| | | | No fresh P | Fresh P |
| 1 | 27.0 | 32.0 | 55.8 | |
| 2 | 18.0 | 20.0 | | 28.2 |
| 3 | 20.0 | 24.0 | 29.0 | |
| 4 | 16.2 | 16.2 | 20.8 | |
| 5 | 28.6 | 37.6 | | 94.4 |
| 6 | 17.8 | 17.8 | 35.0 | |
| 7 | 19.8 | 19.8 | 25.2 | |
| 8 | 23.0 | 35.0 | 47.4 | |
| 9 | 17.6 | 19.6 | 26.0 | |
| 10 | 18.6 | 30.8 | | 76.8 |
| 11 | 16.8 | 16.8 | 21.4 | |
| 12 | 17.4 | 26.4 | 25.2 | |
| 13 | 19.0 | 22.0 | | 25.2 |
| 14 | 16.2 | 16.2 | 21.0 | |

**Appendix Table C5 – Hallington (2013) – Olsen P, mg/l**

| Plot | Initial Olsen P | Expected Olsen P | Actual Olsen P | |
|---|---|---|---|---|
| | | | No fresh P | Fresh P |
| 1 | 7.6 | 27.6 | 32.6 | |
| 2 | 6.2 | 14.2 | | 29.4 |
| 3 | 6.8 | 9.8 | 17.5 | |
| 4 | 6.0 | 6.0 | 14.4 | |
| 5 | 5.2 | 5.2 | 11.0 | |
| 6 | 7.0 | 19.0 | 29.6 | |
| 7 | 6.8 | 22.8 | | 66.6 |
| 8 | 5.4 | 5.4 | 15.0 | |
| 9 | 5.6 | 11.6 | 18.0 | |
| 10 | 5.6 | 5.6 | 14.6 | |
| 11 | 6.6 | 26.6 | 26.0 | |
| 12 | 6.0 | 14.0 | | 34.4 |
| 13 | 6.4 | 18.4 | 19.8 | |
| 14 | 6.2 | 22.2 | | 41.0 |

**Appendix Table C6 – Kirby Cane (2014) – Olsen P, mg/l**

| Plot | Initial Olsen P | Expected Olsen P | Actual Olsen P | |
|---|---|---|---|---|
| | | | No fresh P | Fresh P |
| 1 | 9.4 | 27.4 | | 14.4 |
| 2 | 12.8 | 24.8 | 52.0 | |
| 3 | 9.0 | 15.0 | 14.8 | |
| 4 | 8.6 | 11.6 | 28.0 | |
| 5 | 8.2 | 5.2 | 15.4 | |
| 6 | 9.4 | 17.4 | | 11.4 |
| 7 | 6.2 | 6.2 | 9.6 | |
| 8 | 10.2 | 28.2 | 34.0 | |
| 9 | 8.8 | 20.8 | 14.6 | |
| 10 | 7.2 | 7.2 | 9.2 | |
| 11 | 6.0 | 12.0 | 20.2 | |
| 12 | 7.4 | 25.4 | | 17.8 |
| 13 | 8.8 | 16.8 | | 58.4 |
| 14 | 7.8 | 7.8 | 12.2 | |

**Appendix Table C7 – Brocklesby (2014) – Olsen P, mg/l**

| Plot | Initial Olsen P | Expected Olsen P | Actual Olsen P | |
|---|---|---|---|---|
| | | | No fresh P | Fresh P |
| 1 | 20.0 | 38.0 | | 79.6 |
| 2 | 17.0 | 17.0 | 29.6 | |
| 3 | 19.0 | 19.0 | 26.8 | |
| 4 | 18.4 | 22.4 | | 45.2 |
| 5 | 20.6 | 32.6 | 32.8 | |
| 6 | 18.8 | 25.8 | 31.2 | |
| 7 | 17.8 | 17.8 | 24.2 | |
| 10 | 18.6 | 25.6 | 34.6 | |
| 11 | 17.8 | 17.8 | 26.4 | |
| 12 | 17.6 | 17.6 | 25.4 | |

N.B. Incomplete data set shown due to different varieties of vining peas sown at site. Data set shown for single vining pea variety only.

**Appendix Table C8 – Number of plots in each P index for each site (No fresh P)**

| Site | P Index | Olsen P (mg/l) | Number of plots |
|---|---|---|---|
| Docking (2012) | 0 | 0-9 | 0 |
| | 1 | 10-15 | 2 |
| | 2 | 16-25 | 6 |
| | 3 | 26-45 | 1 |
| | 4+ | 46+ | 1 |
| Brocklesby (2012) | 0 | 0-9 | 0 |
| | 1 | 10-15 | 6 |
| | 2 | 16-25 | 3 |
| | 3 | 26-45 | 1 |
| | 4+ | 46+ | 0 |
| Docking (2013) | 0 | 0-9 | 0 |
| | 1 | 10-15 | 0 |
| | 2 | 16-25 | 7 |
| | 3 | 26-45 | 1 |
| | 4+ | 46+ | 2 |
| Kirby Cane (2013) | 0 | 0-9 | 0 |
| | 1 | 10-15 | 0 |
| | 2 | 16-25 | 5 |
| | 3 | 26-45 | 3 |
| | 4+ | 46+ | 2 |
| Hallington (2013) | 0 | 0-9 | 0 |
| | 1 | 10-15 | 4 |
| | 2 | 16-25 | 3 |
| | 3 | 26-45 | 3 |
| | 4+ | 46+ | 0 |
| Kirby Cane (2014) | 0 | 0-9 | 1 |
| | 1 | 10-15 | 5 |
| | 2 | 16-25 | 1 |
| | 3 | 26-45 | 2 |
| | 4+ | 46+ | 1 |
| Brocklesby (2014) | 0 | 0-9 | 0 |
| | 1 | 10-15 | 0 |
| | 2 | 16-25 | 2 |
| | 3 | 26-45 | 6 |
| | 4+ | 46+ | 0 |

## Appendix D – Harvest data

Yield data has been calculated by:

- Assimilating all the harvest data from each harvest timing between TR 95-TR 170.
- Adjusting all yields to a TR (tenderometer reading) of 100 derived from data published by Pumphrey *et al*. (1975).
- Results have been sorted in descending order for measured Olsen P values
- The measured Olsen P and yield data has then been averaged using a 5 point moving average.

TR 100 adjustment factor

| **TR Reading** | **Adjustment factor (%age)** | | **TR Reading** | **Adjustment factor (%age)** | | **TR Reading** | **Adjustment factor (%age)** | | **TR Reading** | **Adjustment factor (%age)** | | **TR Reading** | **Adjustment factor (%age)** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 130 | 128.6 | | 122 | 124.6 | | 114 | 118.2 | | 106 | 109.1 | | 98 | 97.1 |
| 129 | 128.3 | | 121 | 123.9 | | 113 | 117.2 | | 105 | 107.8 | | 97 | 95.4 |
| 128 | 127.4 | | 120 | 123.2 | | 112 | 116.2 | | 104 | 106.4 | | 96 | 93.6 |
| 127 | 127.5 | | 119 | 122.5 | | 111 | 115.1 | | 103 | 105 | | 95 | 91.8 |
| 126 | 126.9 | | 118 | 121.7 | | 110 | 113.9 | | 102 | 103.5 | | 94 | 89.9 |
| 125 | 126.5 | | 117 | 120.9 | | 109 | 112.8 | | 101 | 102 | | 93 | 88 |
| 124 | 125.8 | | 116 | 120 | | 108 | 111.7 | | 100 | 100 | | 92 | 86 |
| 123 | 125.2 | | 115 | 119.1 | | 107 | 110.4 | | 99 | 98.8 | | 91 | 83.9 |

## Appendix Table D1 - Docking (2012) - Adjusted yield (corrected TR 100) for each harvest timing

| **Descending Olsen P (mg/l)** | **Plot** | **Harvest 1 (02/07/2012)** | | **Harvest 2 (04/07/2012)** | | **Harvest 3 (05/07/2012)** | | **Harvest 4 (06/07/2012)** | | **Average** | **Olsen P (mg/kg) 5 point moving average** | **Yield (t/ha) 5 point moving average** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Adj. yield t/ha | TR | Adj. yield t/ha | TR | Adj. yield t/ha | TR | Adj. yield t/ha | TR | Adj. yield t/ha | | |
| 86.6 | 10 | 3.89 | 97 | 6.07 | 103 | 7.50 | 112 | 10.14 | 122 | 6.90 | | |
| 68.6 | 3 | 3.90 | 102 | 5.02 | 108 | 7.46 | 119 | 8.04 | 127 | 6.11 | | |
| 61.2 | 4 | 4.06 | 94 | 5.49 | 99 | 6.07 | 107 | 9.90 | 115 | 6.38 | 59.5 | 6.32 |
| 54.6 | 12 | 4.51 | 92 | 5.74 | 98 | 7.65 | 107 | 9.20 | 111 | 6.77 | 46.2 | 6.09 |
| 26.4 | 11 | 3.90 | 94 | 5.25 | 105 | 5.51 | 115 | 7.17 | 119 | 5.46 | 36.4 | 5.91 |
| 20.2 | 5 | 3.88 | 94 | 4.54 | 105 | 7.23 | 115 | 7.33 | 120 | 5.75 | 27.7 | 5.78 |
| 19.8 | 13 | 3.66 | 98 | 4.87 | 109 | 5.44 | 117 | 6.80 | 124 | 5.19 | 20.0 | 5.49 |
| 17.6 | 8 | 3.74 | 98 | 5.18 | 107 | 6.89 | 116 | 7.23 | 121 | 5.76 | 18.0 | 5.39 |
| 16.2 | 7 | 3.44 | 100 | 5.02 | 111 | 5.58 | 119 | 7.18 | 127 | 5.30 | 17.1 | 5.31 |
| 16.2 | 9 | 3.58 | 90 | 4.87 | 99 | 5.28 | 107 | 6.15 | 115 | 4.97 | 16.2 | 5.23 |
| 15.6 | 1 | 4.25 | 100 | 4.76 | 109 | 5.64 | 120 | 6.59 | 121 | 5.31 | 15.4 | 5.19 |
| 15.6 | 2 | 3.68 | 93 | 4.74 | 102 | 4.99 | 110 | 5.87 | 118 | 4.82 | 14.8 | 5.34 |
| 13.4 | 6 | 3.07 | 95 | 5.00 | 103 | 6.70 | 113 | 7.32 | 124 | 5.52 | | |
| 13.0 | 14 | 3.82 | 94 | 5.73 | 105 | 6.62 | 111 | 8.14 | 118 | 6.08 | | |

**Appendix Table D2 - Brocklesby (2012) - Adjusted yield (corrected TR 100) for each harvest timing**

| **Descending Olsen P (mg/l)** | **Plot** | **Harvest 1 (03/08/2012)** | | **Harvest 2 (07/08/2012)** | | **Average** | **Olsen P (mg/kg) 5 point moving average** | **Yield (t/ha) 5 point moving average** |
|---|---|---|---|---|---|---|---|---|
| | | Adj. yield t/ha | TR | Adj. yield t/ha | TR | Adj. yield t/ha | | |
| 49.0 | 1 | 4.54 | 96.5 | 6.01 | 118.0 | 5.28 | | |
| 48.6 | 13 | 3.98 | 115.5 | 4.39 | 157.5 | 4.18 | | |
| 32.6 | 10 | 5.21 | 118.0 | 7.97 | 158.5 | 6.59 | 35.4 | 5.50 |
| 25.0 | 7 | 5.05 | 98.0 | 7.28 | 133.5 | 6.16 | 29.4 | 5.55 |
| 21.8 | 5 | 4.43 | 96.5 | 6.15 | 126.0 | 5.29 | 23.0 | 5.76 |
| 19.0 | 14 | 5.08 | 115.0 | 5.99 | 170.5 | 5.53 | 19.3 | 5.55 |
| 16.6 | 4 | 5.18 | 100.0 | 5.29 | 134.0 | 5.24 | 16.9 | 5.36 |
| 14.0 | 12 | 5.20 | 103.5 | 5.88 | 142.5 | 5.54 | 15.0 | 5.30 |
| 13.0 | 11 | 6.06 | 98.5 | 4.35 | 143.5 | 5.20 | 13.5 | 5.48 |
| 12.4 | 6 | 6.45 | 96.5 | 3.49 | 125.0 | 4.97 | 12.5 | 5.71 |
| 11.6 | 2 | 6.37 | 102.5 | 6.54 | 137.0 | 6.46 | 12.0 | 5.75 |
| 11.4 | 3 | 6.31 | 103.5 | 6.43 | 141.5 | 6.37 | 11.6 | 6.01 |
| 11.4 | 9 | 4.81 | 96.0 | 6.65 | 123.5 | 5.73 | | |
| 11.2 | 8 | 5.60 | 100.0 | 7.40 | 137.0 | 6.50 | | |

**Appendix Table D3 - Docking (2013) - Adjusted yield (corrected TR 100) for each harvest timing**

| Descending Olsen P (mg/l) | Plot | Harvest 1 (08/07/2013) | | Harvest 2 (09/07/2013) | | Harvest 3 (10/07/2013) | | Harvest 4 (12/07/2013) | | Average | Olsen P (mg/kg) 5 point moving average | Yield (t/ha) 5 point moving average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Adj. yield t/ha | TR | Adj. yield t/ha | TR | Adj. yield t/ha | TR | Adj. yield t/ha | TR | Adj. yield t/ha | | |
| 69.8 | 2 | 5.61 | 98.0 | 6.31 | 100.0 | 6.86 | 104.0 | 7.46 | 115.5 | 6.56 | | |
| 63.0 | 11 | 6.80 | 95.0 | 4.93 | 101.0 | 6.52 | 105.5 | 7.65 | 118.0 | 6.48 | | |
| 29.2 | 14 | 4.17 | 95.5 | 3.44 | 103.0 | 6.44 | 106.5 | 6.70 | 124.0 | 5.19 | 41.4 | 6.01 |
| 23.4 | 3 | 3.49 | 97.0 | 6.25 | 102.0 | 6.28 | 104.0 | 9.85 | 118.0 | 6.46 | 31.7 | 5.85 |
| 21.6 | 4 | 5.39 | 95.0 | 3.91 | 101.0 | 3.13 | 102.5 | 8.94 | 117.0 | 5.34 | 23.3 | 5.58 |
| 21.4 | 1 | 4.94 | 96.5 | 4.16 | 99.0 | 6.42 | 103.0 | 7.59 | 118.0 | 5.78 | 21.6 | 5.57 |
| 21.0 | 5 | 5.04 | 98.0 | 3.00 | 104.0 | 3.57 | 106.0 | 8.87 | 121.5 | 5.12 | 20.9 | 5.47 |
| 20.4 | 8 | 5.09 | 95.0 | 3.96 | 102.0 | 2.93 | 104.0 | 8.50 | 119.5 | 5.12 | 20.6 | 5.56 |
| 20.2 | 6 | 4.87 | 97.0 | 4.96 | 103.0 | 5.68 | 105.5 | 8.50 | 126.0 | 6.00 | 20.1 | 5.55 |
| 19.8 | 9 | 5.73 | 95.0 | 3.36 | 99.5 | 6.77 | 104.0 | 7.15 | 116.5 | 5.75 | 19.6 | 5.65 |
| 19.0 | 10 | 4.54 | 94.5 | 3.79 | 100.0 | 5.89 | 102.0 | 8.76 | 114.5 | 5.74 | 18.8 | 5.76 |
| 18.4 | 7 | 5.41 | 97.0 | 4.14 | 103.0 | 5.97 | 103.0 | 6.96 | 120.5 | 5.62 | 18.0 | 5.55 |
| 16.5 | 12 | 4.62 | 96.0 | 5.70 | 100.0 | 2.32 | 105.0 | 10.08 | 119.0 | 5.68 | | |
| 16.2 | 13 | 5.00 | 96.5 | 2.96 | 104.5 | 6.29 | 106.0 | 5.63 | 124.5 | 4.97 | | |

**Appendix Table D4 - Kirby Cane (2013) - Adjusted yield (corrected TR 100) for each harvest timing**

| **Descending Olsen P (mg/l)** | **Plot** | **Harvest 1 (25/07/2013)** | | **Harvest 2 (26/07/2013)** | | **Harvest 3 (27/07/2013)** | | **Average** | **Olsen P (mg/kg) 5 point moving average** | **Yield (t/ha) 5 point moving average** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Adj. yield t/ha | TR | Adj. yield t/ha | TR | Adj. yield t/ha | TR | Adj. yield t/ha | | |
| 94.4 | 5 | 3.75 | 107.0 | 6.92 | 116.0 | 5.85 | 126 | 5.51 | | |
| 76.8 | 10 | 5.23 | 96.0 | 7.86 | 109.5 | 5.81 | 119.5 | 6.30 | | |
| 55.8 | 1 | 6.79 | 98.5 | . | . | 5.19 | 129.5 | 5.99 | 61.9 | 6.03 |
| 47.4 | 8 | 5.97 | 97.0 | 7.91 | 109.5 | 6.32 | 123.5 | 6.73 | 48.8 | 6.01 |
| 35.0 | 6 | 5.04 | 96.0 | 6.00 | 108.5 | 5.80 | 122.0 | 5.61 | 39.1 | 5.99 |
| 29.0 | 3 | 5.94 | 95.0 | 4.62 | 113.5 | 5.66 | 123.0 | 5.41 | 33.1 | 5.98 |
| 28.2 | 2 | 5.70 | 95.5 | 7.38 | 106.5 | 5.52 | 115.0 | 6.20 | 28.7 | 5.54 |
| 26.0 | 9 | 6.42 | 95.5 | 6.67 | 107.0 | 4.69 | 122.0 | 5.93 | 26.7 | 5.56 |
| 25.2 | 7 | 4.65 | 95.0 | . | . | 4.50 | 119.0 | 4.58 | 26.0 | 5.34 |
| 25.2 | 12 | 5.29 | 95.0 | 6.91 | 106.0 | 4.82 | 119.0 | 5.67 | 24.6 | 5.06 |
| 25.2 | 13 | 4.36 | 91.0 | 3.95 | 108.0 | 4.63 | 119.0 | 4.31 | 23.6 | 5.00 |
| 21.4 | 11 | 4.90 | 91.5 | 4.34 | 107.5 | 5.19 | 114.5 | 4.81 | 22.7 | 5.08 |
| 21.0 | 14 | 4.54 | 93.0 | 6.58 | 106.5 | 5.77 | 125.5 | 5.63 | | |
| 20.8 | 4 | 6.21 | 101.0 | 3.90 | 104.5 | 4.76 | 120.0 | 4.96 | | |

**Appendix Table D5 - Hallington (2013) - Adjusted yield (corrected TR 100) for each harvest timing**

| Descending Olsen P (mg/l) | Plot | Harvest 1 (09/08/2013) | | Harvest 2 (12/08/2013) | | Harvest 3 (13/08/2013) | | Average | Olsen P (mg/kg) 5 point moving average | Yield (t/ha) 5 point moving average |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Adj. yield t/ha | TR | Adj. yield t/ha | TR | Adj. yield t/ha | TR | Adj. yield t/ha | | |
| 66.6 | 7 | 8.27 | 95.5 | 14.19 | 124.0 | 15.53 | 135.5 | 12.66 | | |
| 41.0 | 14 | 8.95 | 94.5 | 10.14 | 120.5 | 15.30 | 132.0 | 11.47 | | |
| 34.4 | 12 | 7.46 | 95.5 | 11.93 | 115.0 | 12.64 | 124.5 | 10.68 | 40.8 | 11.32 |
| 32.6 | 1 | 6.45 | 89.5 | 12.10 | 107.0 | 13.73 | 113.0 | 10.76 | 33.4 | 10.84 |
| 29.6 | 6 | 5.72 | 91.5 | 12.58 | 117.0 | 14.83 | 111.5 | 11.04 | 30.4 | 10.79 |
| 29.4 | 2 | 7.05 | 97.5 | 11.39 | 124.0 | 12.27 | 123.5 | 10.24 | 27.5 | 10.63 |
| 26.0 | 11 | 6.78 | 86.5 | 12.12 | 111.0 | 14.76 | 127.0 | 11.22 | 24.6 | 10.62 |
| 19.8 | 13 | 6.89 | 91.5 | 9.51 | 115.0 | 13.22 | 122.0 | 9.87 | 22.1 | 9.87 |
| 18.0 | 9 | 6.47 | 88.5 | 10.94 | 109.0 | 14.77 | 123.0 | 10.73 | 19.3 | 9.11 |
| 17.5 | 3 | 4.94 | 86.0 | 7.15 | 103.0 | 9.81 | 110.0 | 7.30 | 17.0 | 8.40 |
| 15.0 | 8 | 5.07 | 88.5 | 6.35 | 97.5 | 7.92 | 108.0 | 6.45 | 15.9 | 7.73 |
| 14.6 | 10 | 4.75 | 90.0 | 8.54 | 108.0 | 9.64 | 115.0 | 7.64 | 14.5 | 6.77 |
| 14.4 | 4 | 4.48 | 87.0 | 6.87 | 99.0 | 8.32 | 109.0 | 6.56 | | |
| 11.0 | 5 | 4.48 | 89.5 | 5.76 | 103.5 | 7.51 | 107.5 | 5.92 | | |

**Appendix Table D6 - Kirby Cane (2014) - Adjusted yield (corrected TR 100) for each harvest timing**

| **Descending Olsen P (mg/l)** | **Plot** | **Harvest 1 (18/07/2014)** | | **Harvest 2 (19/07/2014)** | | **Harvest 3 (21/07/2014)** | | **Average** | **Olsen P (mg/kg) 5 point moving average** | **Yield (t/ha) 5 point moving average** |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Adj. yield t/ha | TR | Adj. yield t/ha | TR | Adj. yield t/ha | TR | Adj. yield t/ha | | |
| 58.4 | 13 | 6.13 | 96.5 | 6.11 | 103.0 | 12.20 | 126.0 | 8.15 | | |
| 52.0 | 2 | 6.36 | 91.0 | 6.73 | 102.0 | 12.79 | 119.0 | 8.63 | | |
| 34.0 | 8 | 5.91 | 90.5 | 7.18 | 103.0 | 12.03 | 120.0 | 8.37 | 38.5 | 8.08 |
| 28.0 | 4 | 5.57 | 92.0 | 4.17 | 95.0 | 12.63 | 121.5 | 7.46 | 30.4 | 8.04 |
| 20.2 | 11 | 6.11 | 92.0 | 6.21 | 99.0 | 11.04 | 119.0 | 7.78 | 23.1 | 7.95 |
| 17.8 | 12 | 6.27 | 91.0 | 6.22 | 103.0 | 11.39 | 131.0 | 7.96 | 19.2 | 7.92 |
| 15.4 | 5 | 6.49 | 90.5 | 6.65 | 99.0 | 11.39 | 116.0 | 8.18 | 16.6 | 8.14 |
| 14.8 | 3 | 5.87 | 88.5 | 6.25 | 99.0 | 12.61 | 128.0 | 8.24 | 15.4 | 8.24 |
| 14.6 | 9 | 6.46 | 89.5 | 6.23 | 99.0 | 12.87 | 119.0 | 8.52 | 14.3 | 8.12 |
| 14.4 | 1 | 6.12 | 90.0 | 6.02 | 98.0 | 12.73 | 121.0 | 8.29 | 13.5 | 8.03 |
| 12.2 | 14 | 5.79 | 92.0 | 5.08 | 97.0 | 11.23 | 121.5 | 7.37 | 12.4 | 7.83 |
| 11.4 | 6 | 5.75 | 92.0 | 5.62 | 97.0 | 11.82 | 119.0 | 7.73 | 11.4 | 7.63 |
| 9.6 | 7 | 5.00 | 86.5 | 5.92 | 94.0 | 10.76 | 115.0 | 7.23 | | |
| 9.2 | 10 | 5.45 | 91.0 | 6.51 | 96.0 | 10.68 | 121.0 | 7.54 | | |

**Appendix Table D7 - Brocklesby (2014) - Adjusted yield (corrected TR 100) for each harvest timing – Results showing single variety only**

| Descending Olsen P (mg/l) | Plot | Harvest 1 (22/07/2014) | | Average | Olsen P (mg/kg) 5 point moving average | Yield (t/ha) 5 point moving average |
|---|---|---|---|---|---|---|
| | | Adj. yield t/ha | TR | Adj. yield t/ha | | |
| 79.6 | 1 | 2.81 | 90.0 | 2.81 | | |
| 45.2 | 4 | 1.83 | 92.0 | 1.83 | 44.7 | 1.47 |
| 34.6 | 10 | 0.84 | 91.0 | 0.84 | 34.7 | 1.29 |
| 32.8 | 5 | 1.08 | 90.5 | 1.08 | 31.0 | 1.04 |
| 31.2 | 6 | 0.79 | 92.0 | 0.79 | 29.4 | 0.95 |
| 29.6 | 2 | 1.89 | 91.0 | 1.89 | 27.9 | 0.82 |
| 26.8 | 3 | 0.60 | 88.5 | 0.60 | 26.4 | 0.70 |
| 26.4 | 11 | 0.38 | 92.0 | 0.38 | | |
| 25.4 | 12 | 0.46 | 91.0 | 0.46 | | |

N.B. Incomplete data set shown due to different varieties of vining peas sown at site. Data set shown for single vining pea variety only.

## Appendix E – Crop and quality data

### Appendix Table E1 – Crop vigour scores

| Plot | Docking 2012 | Brocklesby 2012 | Docking 2013 | Kirby Cane 2013 | Hallington 2013 | Kirby Cane 2014 | Brocklesby [*1] 2014 |
|---|---|---|---|---|---|---|---|
| Date assessed | 01/06/2012 | 11/07/2012 | 13/06/2013 | 17/07/2013 | 18/07/2013 | 02/07/2014 | 08/07/2014 |
| 1 | 3.0 | 5.0 | 5.0 | 5.0 | 4.0 | 3.0 | 5.0 |
| 2 | 1.0 | 3.0 | 5.0 | 1.0 | 2.0 | 4.0 | 3.0 |
| 3 | 4.0 | 1.0 | 2.0 | 2.0 | 1.0 | 2.0 | 2.5 |
| 4 | 5.0 | 5.0 | 5.0 | 3.0 | 1.0 | 4.0 | 3.0 |
| 5 | 3.0 | 5.0 | 3.0 | 4.0 | 2.0 | 2.0 | 2.5 |
| 6 | 2.0 | 1.0 | 1.0 | 3.0 | 4.0 | 1.0 | 2.0 |
| 7 | 2.0 | 5.0 | 2.0 | 2.0 | 3.0 | 3.0 | 1.0 |
| 8 | 3.0 | 3.0 | 3.0 | 5.0 | 1.0 | 5.0 | - |
| 9 | 3.0 | 3.0 | 5.0 | 3.0 | 3.0 | 4.0 | - |
| 10 | 4.0 | 5.0 | 1.0 | 3.0 | 3.0 | 3.0 | 2.5 |
| 11 | 3.0 | 3.0 | 5.0 | 2.0 | 5.0 | 4.0 | 2.0 |
| 12 | 5.0 | 4.0 | 3.0 | 1.0 | 3.0 | 3.0 | 1.0 |
| 13 | 3.5 | 5.0 | 1.0 | 2.0 | 4.0 | 2.0 | - |
| 14 | 3.5 | 5.0 | 5.0 | 3.0 | 4.0 | 2.0 | - |

1 = weakest 5 = most vigorous

[*1] Scores recorded for one variety only

**Appendix Table E2 – Root nodulation scores**

| Plot | Docking 2012 | Brocklesby 2012 | Docking 2013 | Kirby Cane 2013 | Hallington 2013 | Kirby Cane 2014 | Brocklesby 2014 |
|---|---|---|---|---|---|---|---|
| Date assessed | 01/06/2012 | 12/07/2012 | 13/06/2013 | 18/07/2013 | 19/07/2013 | 02/07/2014 | 08/07/2014 |
| 1 | - | 9.2 | 7.2 | 6.6 | 9.2 | 8.0 | 8.0 |
| 2 | - | 3.8 | 8.0 | 8.6 | 8.4 | 8.0 | 4.0 |
| 3 | - | 4.2 | 7.0 | 8.0 | 8.4 | 6.0 | 2.0 |
| 4 | - | 6.4 | 9.4 | 8.4 | 6.8 | 8.0 | 6.0 |
| 5 | - | 3.4 | 7.8 | 6.4 | 8.0 | 7.0 | 6.0 |
| 6 | - | 5.8 | 7.0 | 5.0 | 9.0 | 7.0 | 3.0 |
| 7 | - | 6.2 | 6.2 | 8.2 | 9.8 | 5.0 | 3.0 |
| 8 | - | 6.4 | 8.4 | 5.0 | 7.4 | 9.0 | - |
| 9 | - | 7.4 | 9.4 | 4.2 | 8.8 | 4.0 | - |
| 10 | - | 8.0 | 7.8 | 9.4 | 8.0 | 5.0 | 4.0 |
| 11 | - | 5.4 | - | 8.6 | 10.0 | 4.0 | 2.0 |
| 12 | - | 8.2 | 7.2 | 8.4 | 9.6 | 4.0 | 1.0 |
| 13 | - | 9.2 | 7.2 | 7.6 | 9.6 | 3.0 | - |
| 14 | - | 9.6 | 8.6 | 5.6 | 9.6 | 6.0 | - |

1 = low 10 = high

[*1] Scores recorded for one variety only

**Appendix Table E3 – BRIX scores**

| Plot | Docking 2012 | Brocklesby 2012 | Docking 2013 | Kirby Cane 2013 | Hallington 2013 | Kirby Cane 2014 | Brocklesby 2014 |
|---|---|---|---|---|---|---|---|
| Date assessed | - | 07/08/2012 | 08/07/2013 | 26/07/2013 | 09/08/2013 | 18/07/2014 | - |
| 1 | - | 8.3 | 10.6 | - | 10.1 | 9.0 | - |
| 2 | - | 7.7 | 9.3 | 8.7 | 9.4 | 8.6 | - |
| 3 | - | 8.2 | 10.6 | 8.7 | 9.9 | 8.7 | - |
| 4 | - | 9.4 | 10.35 | 8.7 | 9.6 | 8.8 | - |
| 5 | - | 8.7 | 10.8 | 7.9 | 10.3 | 8.7 | - |
| 6 | - | 8.8 | 10.2 | 8.5 | 9.5 | 8.4 | - |
| 7 | - | 9.2 | 9.55 | - | 10.1 | 7.7 | - |
| 8 | - | 9.3 | 10.3 | 8.9 | 9.8 | 8.1 | - |
| 9 | - | 9.2 | 10.6 | 8.6 | 9.9 | 7.9 | - |
| 10 | - | 8.1 | 9.85 | 8.4 | 9.8 | 7.8 | - |
| 11 | - | 8.9 | 10.2 | 8.4 | 9.9 | 8.3 | - |
| 12 | - | 9.7 | 9.7 | 7.7 | 10.1 | 8.4 | - |
| 13 | - | 10.4 | 10.65 | 8.4 | 10.3 | 8.9 | - |
| 14 | - | 10.2 | 10.65 | 7.7 | 10.1 | 8.1 | - |

**Appendix Table E4 – Docking 2012 - Percentage of seed size by total weight**

| | Harvest 1 | | | | Harvest 2 | | | | Harvest 3 | | | | Harvest 4 | | | | Average of harvests | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Plot | VS | S | M | L | VS | S | M | L | VS | S | M | L | VS | S | M | L | VS | S | M | L |
| 1 | 8 | 30 | 43 | 19 | 5 | 20 | 41 | 31 | 5 | 18 | 43 | 34 | 4 | 15 | 44 | 37 | 5 | 21 | 43 | 30 |
| 2 | 6 | 22 | 44 | 28 | 4 | 17 | 40 | 34 | 4 | 11 | 45 | 40 | 3 | 11 | 45 | 40 | 4 | 16 | 43 | 36 |
| 3 | 7 | 27 | 41 | 24 | 5 | 18 | 44 | 33 | 4 | 15 | 46 | 35 | 3 | 13 | 42 | 41 | 5 | 18 | 43 | 33 |
| 4 | 12 | 34 | 40 | 15 | 6 | 24 | 46 | 26 | 5 | 19 | 44 | 33 | 3 | 16 | 46 | 35 | 6 | 23 | 44 | 27 |
| 5 | 8 | 25 | 45 | 22 | 5 | 18 | 47 | 29 | 5 | 16 | 46 | 33 | 4 | 13 | 44 | 40 | 6 | 18 | 45 | 31 |
| 6 | 10 | 27 | 43 | 20 | 6 | 19 | 44 | 31 | 4 | 17 | 46 | 32 | 4 | 15 | 46 | 35 | 6 | 20 | 45 | 30 |
| 7 | 8 | 26 | 46 | 20 | 6 | 19 | 41 | 30 | 5 | 17 | 46 | 33 | 4 | 14 | 44 | 38 | 6 | 19 | 44 | 30 |
| 8 | 9 | 25 | 44 | 23 | 6 | 18 | 42 | 31 | 3 | 15 | 46 | 36 | 4 | 15 | 43 | 38 | 5 | 18 | 43 | 32 |
| 9 | 7 | 24 | 44 | 25 | 5 | 16 | 41 | 32 | 4 | 17 | 46 | 33 | 4 | 14 | 44 | 37 | 5 | 18 | 44 | 32 |
| 10 | 12 | 30 | 40 | 19 | 6 | 24 | 44 | 26 | 6 | 23 | 44 | 27 | 4 | 18 | 44 | 34 | 7 | 24 | 43 | 26 |
| 11 | 8 | 25 | 44 | 23 | 5 | 18 | 38 | 34 | 5 | 15 | 45 | 34 | 4 | 10 | 42 | 44 | 6 | 17 | 42 | 34 |
| 12 | 9 | 28 | 42 | 20 | 6 | 21 | 41 | 31 | 5 | 18 | 44 | 34 | 4 | 13 | 42 | 42 | 6 | 20 | 42 | 32 |
| 13 | 10 | 26 | 44 | 20 | 6 | 19 | 41 | 32 | 6 | 18 | 43 | 33 | 4 | 14 | 44 | 37 | 6 | 19 | 43 | 31 |
| 14 | 9 | 27 | 44 | 20 | 5 | 20 | 40 | 33 | 4 | 16 | 44 | 35 | 3 | 15 | 43 | 39 | 5 | 20 | 43 | 32 |

VS = very small, S = small, M = medium, L = Large

**Appendix Table E5 – Brocklesby 2012 - Percentage of seed size by total weight**

| | Harvest 1 | | | | Harvest 2 | | | | Average of harvests | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Plot | VS | S | M | L | VS | S | M | L | VS | S | M | L |
| 1 | 4 | 22 | 41 | 33 | 2 | 11 | 44 | 44 | 3 | 16 | 42 | 38 |
| 2 | 1 | 7 | 44 | 48 | 0 | 2 | 35 | 62 | 1 | 5 | 40 | 55 |
| 3 | 1 | 6 | 45 | 48 | 1 | 3 | 37 | 59 | 1 | 4 | 41 | 54 |
| 4 | 3 | 19 | 43 | 36 | 0 | 4 | 39 | 57 | 2 | 11 | 41 | 46 |
| 5 | 3 | 20 | 46 | 31 | 1 | 6 | 46 | 47 | 2 | 13 | 46 | 39 |
| 6 | 1 | 8 | 52 | 39 | 0 | 2 | 37 | 61 | 1 | 5 | 45 | 50 |
| 7 | 2 | 18 | 49 | 32 | 0 | 4 | 42 | 54 | 1 | 11 | 46 | 43 |
| 8 | 2 | 16 | 51 | 31 | 1 | 5 | 48 | 47 | 1 | 10 | 49 | 39 |
| 9 | 4 | 19 | 44 | 33 | 1 | 4 | 47 | 48 | 2 | 12 | 46 | 41 |
| 10 | 3 | 20 | 42 | 35 | 1 | 6 | 42 | 51 | 2 | 13 | 42 | 43 |
| 11 | 2 | 14 | 48 | 37 | 1 | 4 | 39 | 56 | 1 | 9 | 44 | 46 |
| 12 | 2 | 13 | 51 | 34 | 0 | 4 | 48 | 48 | 1 | 8 | 50 | 41 |
| 13 | 3 | 19 | 46 | 32 | 0 | 6 | 42 | 52 | 2 | 12 | 44 | 42 |
| 14 | 3 | 17 | 45 | 35 | 0 | 3 | 45 | 52 | 1 | 10 | 45 | 43 |

VS = very small, S = small, M = medium, L = Large

**Appendix Table E6 – Docking 2013 - Percentage of seed size by total weight**

| | Harvest 1 | | | | Harvest 2 | | | | Harvest 3 | | | | Harvest 4 | | | | Average of harvests | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Plot | VS | S | M | L | VS | S | M | L | VS | S | M | L | VS | S | M | L | VS | S | M | L |
| 1 | 7 | 43 | 41 | 9 | 3 | 29 | 52 | 16 | 2 | 24 | 58 | 15 | 1 | 9 | 65 | 26 | 3 | 26 | 54 | 16 |
| 2 | 4 | 35 | 49 | 12 | 2 | 23 | 59 | 16 | 2 | 18 | 61 | 20 | 1 | 9 | 65 | 26 | 2 | 21 | 58 | 18 |
| 3 | 4 | 32 | 53 | 10 | 2 | 21 | 61 | 15 | 1 | 16 | 62 | 21 | 1 | 7 | 62 | 30 | 2 | 19 | 60 | 19 |
| 4 | 4 | 35 | 49 | 12 | 3 | 26 | 54 | 17 | 2 | 17 | 59 | 23 | 1 | 6 | 64 | 30 | 2 | 21 | 57 | 20 |
| 5 | 5 | 37 | 48 | 10 | 1 | 15 | 62 | 22 | 1 | 12 | 63 | 24 | 1 | 6 | 63 | 30 | 2 | 17 | 59 | 22 |
| 6 | 4 | 35 | 50 | 10 | 2 | 24 | 57 | 16 | 1 | 14 | 64 | 21 | 1 | 6 | 64 | 30 | 2 | 20 | 59 | 19 |
| 7 | 6 | 44 | 42 | 8 | 4 | 29 | 54 | 13 | 2 | 17 | 61 | 20 | 1 | 5 | 64 | 30 | 3 | 24 | 55 | 18 |
| 8 | 9 | 46 | 38 | 7 | 4 | 28 | 55 | 14 | 2 | 17 | 61 | 20 | 1 | 7 | 64 | 28 | 4 | 24 | 55 | 17 |
| 9 | 5 | 42 | 44 | 9 | 4 | 28 | 52 | 16 | 2 | 18 | 64 | 16 | 1 | 7 | 68 | 23 | 3 | 24 | 57 | 16 |
| 10 | 9 | 48 | 38 | 5 | 6 | 35 | 47 | 12 | 4 | 23 | 58 | 16 | 1 | 6 | 63 | 30 | 5 | 28 | 51 | 16 |
| 11 | 6 | 40 | 45 | 10 | 2 | 24 | 55 | 19 | 1 | 14 | 62 | 23 | 1 | 12 | 62 | 24 | 3 | 23 | 56 | 19 |
| 12 | 6 | 42 | 45 | 8 | 4 | 31 | 53 | 11 | 2 | 15 | 60 | 23 | 1 | 7 | 66 | 26 | 3 | 24 | 56 | 17 |
| 13 | 5 | 42 | 44 | 9 | 4 | 22 | 58 | 16 | 2 | 16 | 62 | 20 | 1 | 9 | 61 | 28 | 3 | 22 | 57 | 18 |
| 14 | 4 | 35 | 51 | 10 | 3 | 23 | 55 | 19 | 1 | 12 | 65 | 23 | 1 | 7 | 65 | 28 | 2 | 19 | 59 | 20 |

VS = very small, S = small, M = medium, L = Large

**Appendix Table E7 – Kirby Cane 2013 - Percentage of seed size by total weight**

| | Harvest 1 | | | | Harvest 2 | | | | Harvest 3 | | | | Average of harvests | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Plot | VS | S | M | L | VS | S | M | L | VS | S | M | L | VS | S | M | L |
| 1 | 1 | 7 | 44 | 48 | - | - | - | - | 0 | 1 | 21 | 77 | 0 | 4 | 33 | 63 |
| 2 | 1 | 7 | 49 | 43 | 0 | 4 | 41 | 54 | 0 | 2 | 29 | 68 | 0 | 5 | 40 | 55 |
| 3 | 1 | 7 | 46 | 46 | 0 | 4 | 35 | 61 | 0 | 2 | 25 | 73 | 0 | 4 | 35 | 60 |
| 4 | 1 | 9 | 50 | 41 | 1 | 5 | 35 | 59 | 0 | 2 | 26 | 71 | 1 | 5 | 37 | 57 |
| 5 | 0 | 4 | 36 | 60 | 0 | 3 | 34 | 62 | 0 | 2 | 24 | 74 | 0 | 3 | 31 | 66 |
| 6 | 1 | 8 | 50 | 42 | 0 | 5 | 41 | 54 | 0 | 3 | 30 | 67 | 0 | 5 | 40 | 55 |
| 7 | 1 | 7 | 45 | 48 | - | - | - | - | 0 | 2 | 26 | 71 | 0 | 4 | 36 | 60 |
| 8 | 0 | 5 | 41 | 54 | 0 | 3 | 35 | 62 | 0 | 1 | 23 | 76 | 0 | 3 | 33 | 64 |
| 9 | 1 | 6 | 45 | 48 | 0 | 4 | 34 | 61 | 0 | 2 | 27 | 70 | 0 | 4 | 36 | 60 |
| 10 | 1 | 8 | 46 | 45 | 0 | 3 | 40 | 56 | 0 | 3 | 27 | 70 | 0 | 5 | 38 | 57 |
| 11 | 1 | 9 | 50 | 40 | 1 | 5 | 40 | 55 | 0 | 3 | 33 | 63 | 1 | 6 | 41 | 53 |
| 12 | 1 | 8 | 50 | 41 | 1 | 5 | 41 | 53 | 0 | 3 | 26 | 71 | 1 | 5 | 39 | 55 |
| 13 | 1 | 10 | 48 | 41 | 1 | 4 | 35 | 61 | 0 | 3 | 27 | 70 | 1 | 6 | 37 | 57 |
| 14 | 1 | 8 | 47 | 45 | 0 | 5 | 41 | 54 | 0 | 2 | 25 | 73 | 0 | 5 | 38 | 57 |

VS = very small, S = small, M = medium, L = Large

**Appendix Table E8 – Hallington 2013 - Percentage of seed size by total weight**

| | Harvest 1 | | | | Harvest 2 | | | | Harvest 3 | | | | Average of harvests | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Plot | VS | S | M | L | VS | S | M | L | VS | S | M | L | VS | S | M | L |
| 1 | 2 | 13 | 46 | 40 | 1 | 8 | 40 | 52 | 1 | 6 | 35 | 59 | 1 | 9 | 40 | 50 |
| 2 | 1 | 9 | 43 | 46 | 0 | 3 | 28 | 69 | 0 | 3 | 32 | 64 | 1 | 5 | 34 | 60 |
| 3 | 4 | 19 | 43 | 34 | 1 | 9 | 35 | 55 | 0 | 7 | 35 | 58 | 2 | 11 | 38 | 49 |
| 4 | 5 | 22 | 47 | 26 | 1 | 12 | 42 | 44 | 1 | 10 | 40 | 49 | 3 | 15 | 43 | 40 |
| 5 | 4 | 19 | 46 | 31 | 1 | 10 | 39 | 50 | 1 | 9 | 35 | 55 | 2 | 12 | 40 | 45 |
| 6 | 1 | 11 | 42 | 46 | 0 | 4 | 33 | 63 | 0 | 3 | 31 | 65 | 1 | 6 | 36 | 58 |
| 7 | 1 | 9 | 39 | 51 | 0 | 3 | 27 | 70 | 0 | 3 | 28 | 69 | 1 | 5 | 31 | 63 |
| 8 | 4 | 19 | 47 | 30 | 2 | 11 | 37 | 50 | 1 | 8 | 36 | 54 | 2 | 13 | 40 | 45 |
| 9 | 3 | 17 | 47 | 32 | 1 | 9 | 39 | 51 | 1 | 5 | 34 | 61 | 2 | 11 | 40 | 48 |
| 10 | 4 | 17 | 49 | 31 | 1 | 8 | 40 | 51 | 1 | 6 | 38 | 55 | 2 | 10 | 42 | 46 |
| 11 | 2 | 13 | 45 | 41 | 0 | 6 | 37 | 57 | 0 | 3 | 27 | 70 | 1 | 7 | 36 | 56 |
| 12 | 1 | 11 | 47 | 41 | 0 | 5 | 37 | 58 | 0 | 5 | 36 | 59 | 1 | 7 | 40 | 52 |
| 13 | 2 | 14 | 46 | 39 | 1 | 7 | 40 | 52 | 1 | 6 | 44 | 49 | 1 | 9 | 44 | 47 |
| 14 | 1 | 10 | 47 | 41 | 0 | 4 | 34 | 62 | 0 | 3 | 32 | 64 | 1 | 6 | 38 | 56 |

VS = very small, S = small, M = medium, L = Large

**Appendix Table E9 – Kirby Cane 2014 - Percentage of seed size by total weight**

| | Harvest 1 | | | | Harvest 2 | | | | Harvest 3 | | | | Average of harvests | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Plot | VS | S | M | L | VS | S | M | L | VS | S | M | L | VS | S | M | L |
| 1 | 1 | 8 | 29 | 22 | 1 | 7 | 47 | 46 | 0 | 1 | 26 | 72 | 1 | 5 | 34 | 47 |
| 2 | 1 | 9 | 29 | 21 | 1 | 9 | 46 | 45 | 0 | 2 | 26 | 72 | 1 | 7 | 34 | 46 |
| 3 | 1 | 10 | 30 | 19 | 1 | 7 | 45 | 47 | 0 | 1 | 22 | 76 | 1 | 6 | 32 | 47 |
| 4 | 1 | 10 | 31 | 18 | 1 | 9 | 46 | 44 | 0 | 1 | 26 | 72 | 1 | 7 | 34 | 45 |
| 5 | 1 | 9 | 30 | 20 | 1 | 9 | 47 | 44 | 0 | 1 | 29 | 69 | 1 | 6 | 36 | 44 |
| 6 | 1 | 11 | 31 | 17 | 1 | 10 | 48 | 41 | 0 | 2 | 27 | 71 | 1 | 7 | 35 | 43 |
| 7 | 1 | 12 | 30 | 17 | 1 | 10 | 50 | 39 | 0 | 2 | 27 | 71 | 1 | 8 | 36 | 42 |
| 8 | 1 | 8 | 30 | 21 | 0 | 8 | 47 | 44 | 0 | 2 | 24 | 74 | 1 | 6 | 34 | 46 |
| 9 | 1 | 8 | 31 | 20 | 1 | 7 | 49 | 44 | 0 | 1 | 24 | 74 | 1 | 6 | 35 | 46 |
| 10 | 1 | 8 | 32 | 19 | 1 | 9 | 48 | 42 | 0 | 2 | 27 | 71 | 1 | 6 | 36 | 44 |
| 11 | 1 | 7 | 30 | 22 | 1 | 8 | 46 | 45 | 0 | 2 | 30 | 68 | 1 | 6 | 35 | 45 |
| 12 | 1 | 7 | 30 | 22 | 0 | 6 | 44 | 50 | 0 | 1 | 20 | 79 | 0 | 5 | 31 | 50 |
| 13 | 0 | 6 | 28 | 26 | 1 | 6 | 43 | 50 | 0 | 1 | 24 | 75 | 0 | 5 | 31 | 50 |
| 14 | 1 | 9 | 31 | 19 | 1 | 8 | 47 | 44 | 0 | 1 | 26 | 73 | 1 | 6 | 35 | 45 |

VS = very small, S = small, M = medium, L = Large

**Appendix Table E10 – Brocklesby 2014 - Percentage of seed size by total weight**

| | Harvest 1 | | | | Average of harvests | | | |
|---|---|---|---|---|---|---|---|---|
| Plot | VS | S | M | L | VS | S | M | L |
| 1 | 24 | 51 | 23 | 2 | 24 | 51 | 23 | 2 |
| 2 | 19 | 55 | 24 | 3 | 19 | 55 | 24 | 3 |
| 3 | 25 | 53 | 21 | 2 | 25 | 53 | 21 | 2 |
| 4 | 20 | 53 | 25 | 2 | 20 | 53 | 25 | 2 |
| 5 | 21 | 56 | 21 | 2 | 21 | 56 | 21 | 2 |
| 6 | 20 | 55 | 23 | 2 | 20 | 55 | 23 | 2 |
| 7 | 23 | 54 | 19 | 3 | 23 | 54 | 19 | 3 |
| 8 | 25 | 54 | 20 | 1 | 25 | 54 | 20 | 1 |
| 9 | 23 | 56 | 18 | 3 | 23 | 56 | 18 | 3 |
| 10 | 23 | 57 | 18 | 1 | 23 | 57 | 18 | 1 |
| 11 | 24 | 51 | 23 | 2 | 24 | 51 | 23 | 2 |
| 12 | 19 | 55 | 24 | 3 | 19 | 55 | 24 | 3 |
| 13 | 25 | 53 | 21 | 2 | 25 | 53 | 21 | 2 |
| 14 | 20 | 53 | 25 | 2 | 20 | 53 | 25 | 2 |

VS = very small, S = small, M = medium, L = Large

**Appendix F – Cost or benefit from raising P Index**

**Appendix Table F1 – Net cost or benefit from raising P level by one Index with Olsen P**

| Site | Value of extra yield less cost of replacing higher P offtake (£/ha) | |
|---|---|---|
| | Index 1 to 2 | Index 2 to 3 |
| Brocklesby 2012 | -78 | 322 |
| Docking 2012 | -169 | 163 |
| Docking 2013 | - | 143 |
| Kirby Cane 2013 | - | 275 |
| Hallington 2013 | 902 | 580 |
| Brocklesby 2014 | -44 | 125 |

**Appendix Table F2 – Net cost or benefit from raising P level by one Index with fresh P**

| Site | Value of extra yield less cost of replacing higher P offtake (£/ha) | |
|---|---|---|
| | Low fresh P dose | Low fresh P dose |
| Brocklesby 2012 | 78 | -308 |
| Docking 2012 | -30 | 88 |
| Docking 2013 | -78 | -34 |
| Kirby Cane 2013 | 44 | 260 |
| Hallington 2013 | 393 | 934 |
| Brocklesby 2014 | 78 | 91 |