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## Response of cereals to soil and fertilizer phosphorus

by

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# 1. ABSTRACT

Data from 1969 to 2008 on the response of 102 cereal crops to plant-available soil phosphorus (Olsen P) in three contrasting soils, each with a wide range of Olsen P, have been summarised. For each crop, the response curve, relating grain yield to Olsen P, was fitted statistically, and from the curve was determined i) the maximum yield and ii) the critical Olsen P associated with 98% of the maximum yield.

On a well structured silty clay loam at Rothamsted (Herts), maximum yield of 16 crops of winter wheat and 7 of spring barley was achieved on soil with:

- 6 to 15 mg/kg Olsen P (top P Index 0 to Index 1) in 20 of the 23 crop years.
- 16 to 25 mg/kg Olsen P (P Index 2) in 2 years and P Index 3 in only 1 year.

On a poorly structured sandy clay loam at Saxmundham (Suffolk), maximum yield of 44 winter wheat crops and 23 of spring barley was achieved on soil with:

- 8 to 15 mg/kg Olsen P (top P Index 0 to 1) in 29 (43%) of the 67 crop years.
- 16 to 25 mg/kg Olsen P (P Index 2) in 24 (36%) of the years.
- 26 to 36 mg/kg Olsen P (P Index 3) in 14 (21%) of the years.
- larger concentrations of Olsen P were needed where little nitrogen was given.

On a poorly structured, heavy silty clay loam at Rothamsted on which it was difficult to get a good seedbed for early drilling, maximum yield of 8 spring barley crops was achieved on soil with:

- 10 to 25 mg/kg Olsen P (P Index 1 to 2) in 6 of the 8 crop years.
- 26 to 35 mg/kg Olsen P (P Index 3) in 2 of the 8 crop years.
- on the same soil, but with less SOM and a very poorly structure, 40-52 mg/kg Olsen P were needed to achieve maximum yield.

Year to year variation in maximum yield was due to weather, mainly rainfall, and the length of the grain filling period. Year to year variation in critical Olsen P on each soil type reflected differences in soil and seedbed conditions and the way they interacted with weather factors. These results highlight:

- the importance of maintaining a good soil structure and using appropriate, timely, cultivations such that roots can readily find nutrients within the soil to achieve maximum yield.
- until more data are available, most fields should be maintained at P Index 2 for cereals (i) to ensure that maximum yield is achieved in most years, (ii) to allow for in-field variation in Olsen P.

Changes in Olsen P reflect changes in the P balance.

- Where large crops were grown and no phosphate was applied, Olsen P declined rapidly; from the mid-point of P Index 2 to the bottom of Index 1 in six years.
- Large amounts of phosphate were required to build up Olsen P. To increase Olsen P from the mid-point of P Index 1 to the mid-point of Index 2 required 300-330 kg/ha $P_2O_5$ (670-750 kg/ha triple superphosphate).

# 2. SUMMARY

## 2.1. Introduction

General guidelines on phosphate fertilisation in the new Fertiliser Manual (RB209) (Defra, 2010) are to raise Olsen P in soils growing arable crops and grass to P Index 2 and then maintain this level by replacing the phosphorus removed in harvested crops. For potatoes and vegetables the guideline is P Index 3. In response to queries about the relevance of these guidelines for cereals grown on all soil types, HGCA commissioned The Arable Group (TAG) and Rothamsted Research (Rothamsted) to assess current phosphate recommendations for cereals and, if possible, oilseed rape, on a wider range of soil types than had been done already. A major part of the Rothamsted contribution to this project was to review existing data on the response of cereals to phosphate in relation to current recommendations. This report summarises the results of the review, together with an Appendix with additional background information.

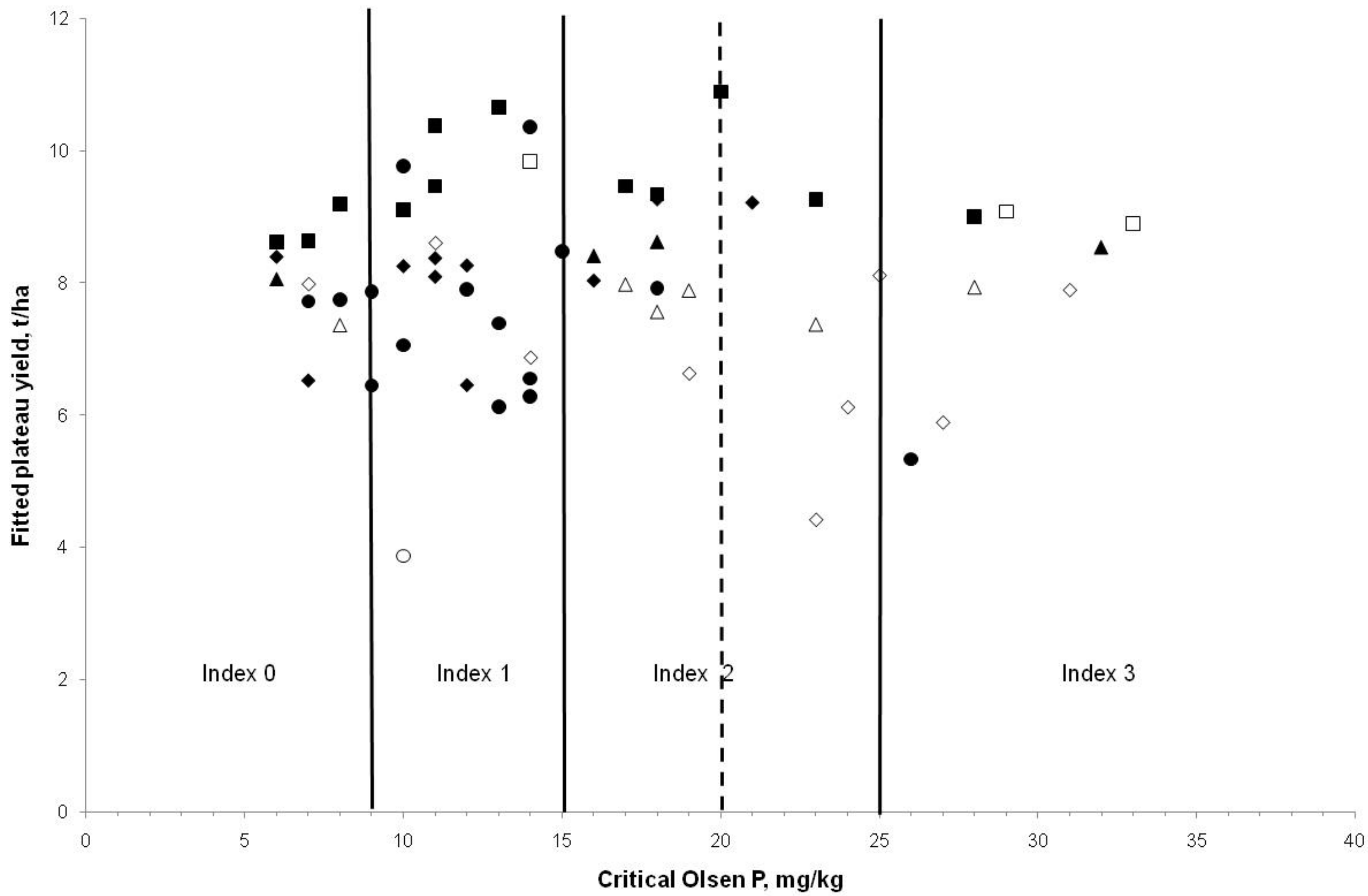
## 2.2. Methods

Data are available from three long-term field experiments each having plots with a range of established Olsen P which ensures that the various fractions of soil phosphorus, including Olsen P, were, as near as possible, in equilibrium when the experiments were made at different times between 1969 and 2008. The experiments were on the silty clay loam at Rothamsted (the Exhaustion Land and Agdell experiments) and the Rotation II experiment on the sandy clay loam at Saxmundham. For each crop, each year, a response curve relating yield and Olsen P was fitted statistically to determine maximum yield and the Olsen P level associated with 98% of the maximum yield. In this report we have divided the available data that fell within P Index 2 between two sub-groups, 15-20 and 21-25 mg/kg Olsen P.

## 2.3. Winter wheat – maximum yield and Olsen P

Data for 60 crop years of winter wheat are summarised in Summary Figure 1, which shows that i) the maximum grain yield, ranged from 4 to 11 t/ha, mean 8.03 t/ha, and ii) the Olsen P associated with 98% of the maximum yield ranged from 5 to 34 mg/kg, *i.e.* from the top of P Index 0 to the mid-point of P Index 3. Within this range:

- 55% of the maximum yields were on soils with 6 to 15 mg/kg Olsen P (P Index 0 and 1)
- about 30% of the maximum yields were on soils with 16 to 25 mg/kg Olsen P and mostly on soils with 16-20 mg P/kg (lower half of P Index 2)
- about 15% of the maximum yields were on soils with 26 to 35 mg/kg Olsen P (P Index 3) although most of these crops received only small amounts of nitrogen.
- there was no indication that a larger maximum yield necessarily needed a higher concentration of Olsen P




**Summary Figure 1.** Fitted plateau yields of winter wheat and the critical Olsen P associated with 98% of that yield. Saxmundham: 1st wheat, squares; 2nd wheat, triangles; 3rd/4th wheat, diamonds. Exhaustion Land: continuous wheat, circles. Filled symbols denote crops receiving sufficient N to achieve maximum yield; open symbols denote crops receiving insufficient N.

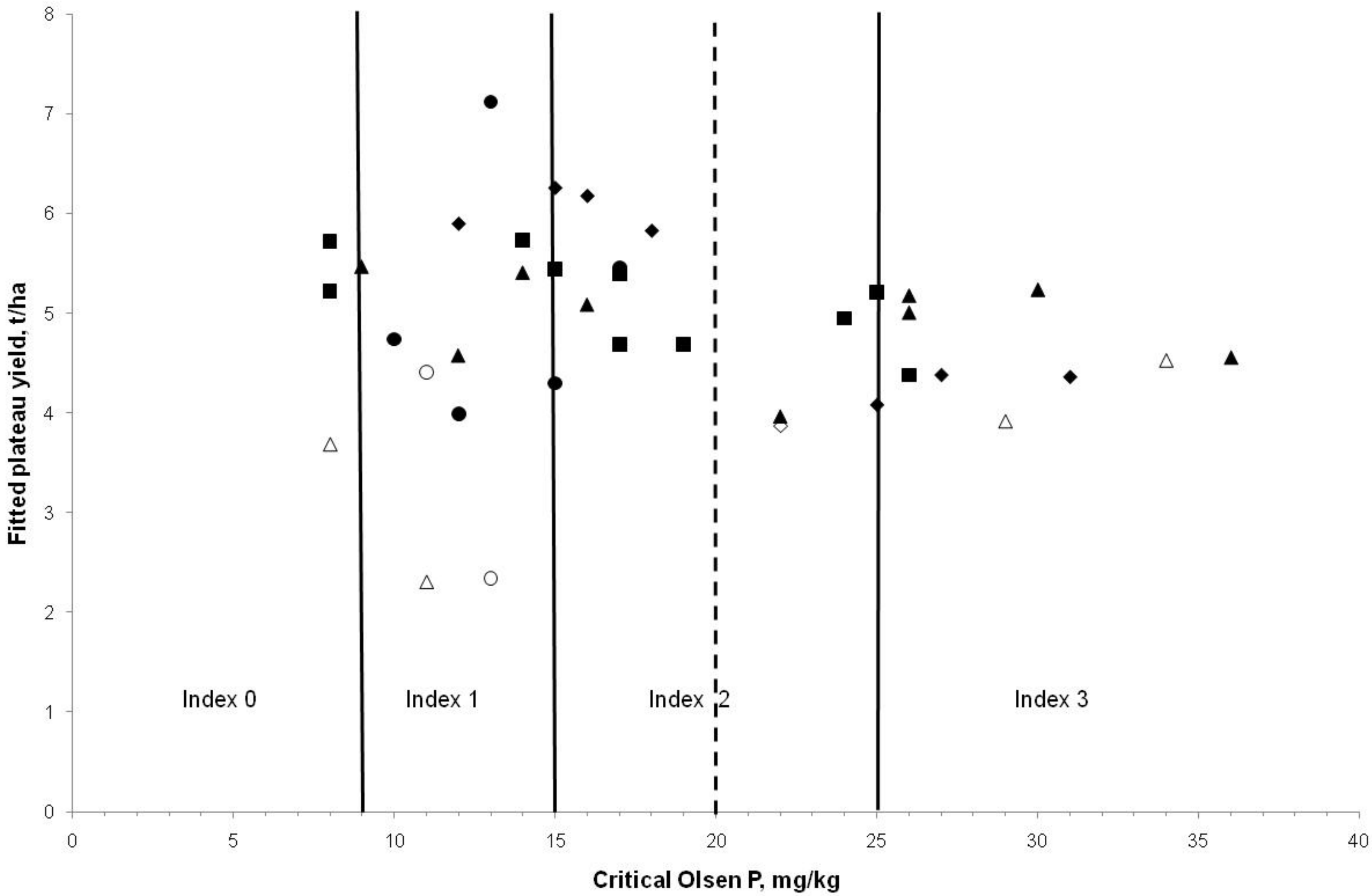
For wheat to have yielded well in some years with only 6 to 15 mg/kg Olsen P (top P Index 0 and P Index 1) suggests that seedbeds and soil conditions, especially for root growth and nutrient acquisition, were particularly favourable in those years. Conversely, however, about the same proportion of maximum yields were on soils with more than 16 mg/kg Olsen P (P Index 2 and above) suggests that seedbed and soil conditions were less favourable in those years.

Yields with open symbols are for crops given small amounts of nitrogen in experiments testing both nitrogen and Olsen P. For these crops, about 68% of maximum yields were on soils with more than 16 mg/kg Olsen P. Probably more Olsen P was required to encourage the production of sufficient roots to take up the small amount of nitrogen that was available. In practice however, it would be better to be more precise in the amount of nitrogen applied than to increase soil to, and then maintain it, above P Index 2 just to encourage root growth.

## 2.4. Spring barley – maximum yield and Olsen P

Data for 42 crop years of spring barley was assessed; 38 crop years are summarised in Summary Figure 2 which excludes data from four crops grown on soil with little SOM. The data show that i) the average maximum grain yield was only 4.76 t/ha, range 2.2 to 7.2 t/ha; however, most of the experiments were in the earlier years of the period 1969-2008 when the yield potential of the spring barley varieties then available was smaller than those of today, and ii) the Olsen P associated with 98% of the maximum yield ranged from 8 to 36 mg/kg. Within this range:

- one third of the maximum yields were on soils with 16 to 25 mg/kg Olsen P (top P Index 2) and another third on soils with 8 to 15 mg/kg Olsen P (top of P Index 0 and P Index 1)
- 26% of the maximum yields were on soils with 26 to 36 mg/kg Olsen P (P Index 3)
- for four crops grown on soils with little SOM and a very poor structure the range in Olsen P required was 40 to 55 mg/kg (data not shown in Summary Figure 2)
- there was no indication that larger maximum yields of spring barley necessarily needed a larger concentration of Olsen P, as with winter wheat




**Summary Figure 2.** Fitted plateau yields of spring barley and the critical Olsen P associated with 98% of that yield. Saxmundham: 1st barley, squares; 2nd/3rd/continuous cereal, triangles. Agdell, 1st barley on high SOM soil, diamonds. Exhaustion Land: continuous barley, circles. Filled symbols denote crops receiving sufficient N to achieve maximum yield; open symbols denote crops receiving insufficient N.

## 2.5. Effect of soil type on maximum yield and Olsen P

The effect of soil type on maximum yield and the Olsen P required to achieve 98% of the maximum yield can be assessed by combining the data for winter wheat and spring barley.

On a well structured silty clay loam at Rothamsted (Herts), maximum yield of 16 crops of winter wheat and 7 of spring barley was achieved on soil with:

- 6 to 15 mg/kg Olsen P (top P Index 0 to Index 1) in 20 of the 23 crop years
- 16 to 25 mg/kg Olsen P (P Index 2) in 2 years and P Index 3 in only 1 year

On a poorly structured sandy clay loam at Saxmundham (Suffolk), maximum yield of 44 winter wheat crops and 23 of spring barley was achieved on soil with:

- 8 to 15 mg/kg Olsen P (top P Index 0 to 1) in 29 (43%) of the 67 crop years
- 16 to 25 mg/kg Olsen P (P Index 2) in 24 (36%) of the 67 crop years
- 26 to 36 mg/kg Olsen P (P Index 3) in 14 (21%) of the 67 crop years
- larger concentrations of Olsen P were needed where little nitrogen was given

On a poorly structured, heavy silty clay loam at Rothamsted on which it was difficult to get a good seedbed for early drilling, maximum yield of 8 spring barley crops was achieved on soil with:

- 10 to 25 mg/kg Olsen P (P Index 1 to 2) in 6 of the 8 crop years
- 26 to 35 mg/kg Olsen P (P Index 3) in 2 of the 8 crop years
- on the same soil, but with less SOM and a very poor structure, 40-52mg/kg Olsen P were needed to achieve maximum yield

Year to year variation in maximum yield was due to weather, mainly rainfall, and the length of the grain filling period. Year to year variation in critical Olsen P on each soil type reflected differences in soil and seedbed conditions and the way they interacted with weather factors. These results highlight:

- the importance of maintaining a good soil structure and using appropriate, timely, cultivations such that roots can readily find nutrients within the soil to achieve maximum yield
- until more data are available, most fields should be maintained at P Index 2 for cereals (i) to ensure that maximum yield is achieved in most years, (ii) to allow for in-field variation in Olsen P

## 2.6. Conclusions

### 2.6.1. Cereal yields and Olsen P

Results presented here show that the maximum yield of both winter wheat (Summary Figure 1) and spring barley (Summary Figure 2) was achieved on soils with a wide range of Olsen P - from the top of P Index 0 to P Index 4.The variability in the maximum yield from year to year is mainly due to weather factors, especially rainfall, and the length of the grain filling period. For crops well supplied with nitrogen, the variability in critical Olsen P required to achieve 98% of the maximum yield probably reflects variation in soil conditions from year to year. Variability in soil structure and seedbed conditions will be related to timeliness of soil cultivations and weather. The wide range in Olsen P required to achieve 98% of the maximum yield within each of these three different soils suggests that it would be difficult to offer more specific advice about Olsen P for a particular soil type than is currently available.

Farmers have to decide at what level to maintain the Olsen P in their soils in relation to the financial viability of the farm. Data presented here in Summary Figure 1 for winter wheat and in Summary Figure 2 for spring barley grown on a sandy clay loam soil and two silty clay loams, on one of which there are more problems with soil structure, can be used to indicate the risk of not maintaining soils at P Index 2 and thus the opportunity to optimise the yield of cereals in most years. For example, for winter wheat, only 55% of the maximum grain yields were on soils at top P Index 0 and P Index 1, i.e. in about half of the years when winter wheat was grown on such soils optimum economic yields would not be achieved. For spring barley, only a third of the maximum yields were on soils at top P Index 0 and P Index 1, indicating an even greater risk than with winter wheat, of not achieving optimum economic yields if soils are not maintained at P Index 2.

### 2.6.2. Use of Olsen P for measuring readily plant-available soil phosphorus

For each fitted response curve relating yield to Olsen P the percent variance accounted was also calculated. This is a measure of how well Olsen P explained (accounted for) the variability in yield. A percent variance larger than 50% indicates that Olsen P was the major factor controlling yield, and thus Olsen P is a good indicator of the level of readily plant-available soil phosphorus. Summary Table 1 shows the number of response curves where the variance accounted for fell into one of three groups.

**Summary Table 1.** The number of response curves where the variance accounted for fell into one of three groups.

| | Number of fitted response curves | | | | | |
|---|---|---|---|---|---|---|
| | Winter wheat | | | Spring barley | | |
| | Variance accounted for, % | | | Variance accounted for, % | | |
| | <50 | 50-79 | ≥80 | <50 | 50-79 | ≥80 |
| Exhaustion Land | - | 1 | 16 | - | 1 | 5 |
| Saxmundham | 7 | 22 | 14 | 4 | 7 | 12 |
| Agdell | | | | | | |
| High SOM | nd[a] | nd | nd | 3 | 5 | - |
| Low SOM | nd | nd | nd | 4 | - | - |

[a] not possible to fit a response curve

On the well structured, silty clay loam on the Exhaustion Land Olsen P accounted for more than 80% of the variance in the great majority of cases for both wheat and barley. On the less easy to cultivate sandy clay loam at Saxmundham more than 50% of the variance was accounted for by Olsen P in most cases. Where less than 50% was accounted for we believe that seedbed conditions and soil structure were less than ideal and root development and growth were impeded. Such soil conditions would also explain why, for spring barley grown on the poorly structured silty clay loam on Agdell, the variance accounted for was often less than 50%.

### 2.6.3. Effect of phosphorus balance on changes in Olsen P

Two frequently asked questions are: i) how much phosphate must be added to increase Olsen P, and ii) how quickly will Olsen P decline if no phosphate fertilizer is applied. A change in Olsen P depends on the phosphorus balance, which is the difference between the amount of phosphate applied and the amount removed in the harvested crops. Usually, Olsen P increases when the phosphorus balance is positive and declines when the balance is negative. The effect of a positive phosphorus balance on an increase in Olsen P has been determined in these experiments. It is quite small. A phosphorus balance of 23 kg $P_2O_5$/ha increased Olsen P by only 0.56 and 0.60 mg/kg on the silty clay loam (Rothamsted) and the sandy clay loam (Saxmundham) respectively. Thus, to increase Olsen P from the mid-point of P Index 1 (12 mg/kg) to the mid-point of P Index 2 (20 mg/kg) would require 327 and 304 kg $P_2O_5$/ha for the silty clay loam and sandy clay loam respectively (see Section 3.5.1). A decline in Olsen P will depend on the size of the negative phosphorus balance (see Section 3.5.2). On the silty clay loam (Rothamsted), soil at the mid-point of P Index 2 declined to the mid-point of P Index 1 over a six year period when no P was applied and with a total offtake of 120 kg P/ha. On the sandy clay loam (Saxmundham) soil at the mid-point of P Index 2 declined to the upper half of P Index 1 over a six year period with a total P offtake of 100 kg/ha.