Irish Journal of Agricultural and Food Research **44:** 281–296, 2005

The phosphorus requirements for silage production on high fertility soils

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The minimum phosphorus requirement for a mid-season ryegrass was investigated under cutting conditions over a 10-year period at each of three Teagasc sites (Clonroche, Johnstown Castle and Oak Park) in southeast Ireland. Treatments consisted of 0, 20, 30, 40, and 50 kg ha^{-1} year^{-1} P applied in autumn. Generally, there were three grass cuts each year and soil samples were taken after the third cut prior to the application of P. Nitrogen and potassium fertiliser was applied to ensure maximum grass yield. There was an emerging treatment effect over time as evidenced by the significance of the treatment × year interaction. The effect of site varied with year reflecting the variability in weather and number of cuts taken at the individual sites. A treatment effect on annual first-cut-silage yield was observed. The largest treatment difference for dry matter (DM) yield of first-cut silage was between the control and the P treated plots (0.32 t/ha). The results show that the draw down of soil-P reserves was adequate to maintain yield for a number of years without additional fertiliser P application. Initial soil tests indicated moderate to high soil test P levels (STP) as measured by the Morgan's test. Application of P at equivalent to removal rates did not maintain STP. The results suggest that application of a regular small maintenance dressing of P, replacing realistic removals, is the most appropriate fertiliser application strategy.

Keywords: Available P; phosphorus; P requirement; ryegrass

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Introduction

Work in Western Europe and the United States is increasingly focused on the establishment of soil phosphorus (P) availability limits above which no yield response to P can be expected (e.g., Withers, 1995; Vanoverstraeten and Hanotiaux, 1996; Jaakkola, Hartikainen and Lemola, 1997; Tunney *et al*., 1997). The P budgets for animal-based farming systems can show continued accumulation of soil P when inputs from manure, other waste products, and fertiliser exceed P removed by crops (Tunney, 1990; Lanyon, 2000; Bundy and Sturgul, 2001). Such work is undertaken in the context of environmental concerns with regard to the impact of excessive use of P fertilisers on water quality and seeks to re-evaluate traditional fertiliser use practices to ensure protection of the environment (Sharpley and Rekolainen, 1997). Environmental concerns have caused changes in P application advice to farmers in Ireland resulting in a decrease in fertiliser P use by over 30% from 1995 to 2001.

Examination of P requirements for grassland in Ireland has mainly been conducted on low to moderate fertility soils where a response to additional P application would be expected (Power, 1992). A number of field trials evaluating the impact of P on grass yield have been undertaken at this institute. The results of these trials are summarised in Table 1. Only trials where additional nitrogen was used have been included in this summary. These trials were generally characterised by a poor relationship between yield response and indices of soil P availability. While most of this work involved single harvests, response to additional P application was limited when soil test P (STP) levels, as measured by the Morgan's P test (Peech and English, 1944) exceeded 3 mg/l. A level of 3 mg/l would now be considered a low fertility status. In these experiments the availability indices were shown to be most useful in categorising trials into 'responsive' and 'non-responsive' sites. Coulter *et al.* (2004) further discuss the basis of current Teagasc recommendations for P usage in agriculture.

While previous work has concentrated on soils low in P, little work has been undertaken in Ireland on soils reflecting the high P status of modern agriculture. Phosphorus loss in runoff from agricultural land is an environmental concern because this P often promotes growth of weeds and algae in lakes, rivers and streams. Many natural fresh-water systems are sensitive to P additions because P is the nutrient that usually limits plant growth in these systems (Correll, 1998). Some studies have shown a relationship between STP levels and soluble P concentration in runoff (Pote *et al*., 1996; Sharpley *et al.,* 1996; Tunney, 2002) emphasising the importance of avoiding STP levels that are higher than needed for optimal crop performance. Reducing P loss to water to prevent pollution, including loss from agriculture, is now part of European Union and Irish policy and legislation.

The aim of this study was to measure the minimum fertiliser-P requirement for a mid-season ryegrass under cutting conditions. The experiment was conducted in the context of increased concern relating to the environmental impact of excessive fertiliser use. Trials were established at three sites with histories of intensive farming and regular P application in order to assess the influence of high STP on the P requirements for silage in an Irish context. The yield response to incremental rates of additional P fertiliser annually was assessed and compared with changes in STP.

Table 1. Results from historical cutting trials describing the response of Irish grassland to P application presented chronologically

Experiment	Number of sites and soil types	Initial Morgan's P (mg/l)	Fertiliser rate	Number of cuts	P Application rate (kg/ha)	Response	Reference
1st Soil test calibration trials	49 including Grey Brown Podzolics, Acid Brown Earths, Gleys	Average approximately 3	80 kg/ha N sulphate of potash (0, 62, 124 kg/ha K)	Cut once for one year only	0, 20, 40	Soils with P<3 mg/l showed reduced herbage P concentrations. Poor response to P application and poor correlation between % response to P and soil P availability. This was considered to be due to the fertility of the soils due to past P usage.	Sweeny (1963) Sweeny (1964) Brereton (1970)
2nd Soil test calibration trials (year 1)[1]	35 in Leinster, East Munster	Responsive sites 2.5 (7 sites) Non-responsive sites 4.0 (28 sites)	Additional N rate unknown	Cut once for one year only	0, 10, 20, 30, 40	Yield for highest P rate on responsive sites was less than yield on control on non-responsive sites. On the responsive sites the controls gave 71% of the yield of the 40 kg/ha P treatment.	Brogan, Murphy, & Kelly (1976)
2nd Soil test calibration trials (year 2)[1]	40 in Leinster, East Munster	Responsive (22 sites) Non-responsive (18 sites)	Additional N rate unknown	Cut once for one year only	0, 10, 20, 30, 40	Sites were selected so that 50% would be responsive. Yield at highest P rate on responsive sites was less than control on non responsive sites. This was partially explained by poorer grass species on responsive sites. Olsen's P test categorised sites well into responsive and non responsive. 20 kg/ha P or less achieved maximum yield at most sites.	Brogan, Murphy, & Kelly (1977)

(continued over)

Table 1. (continued)

Experiment	Number of sites and soil types	Initial Morgan's P (mg/l)	Fertiliser rate	Number of cuts	P Application rate (kg/ha)	Response	Reference
Phosphorus for silage production	1 Brown Earth	4 to 5	190 kg/ha N	Cut three times annually for 11 years	10, 20, 40, 80 annually 20, 40, 80 biennially 80, 120 once off 20, 40 as split dressings	Yield response to P in year 5 (13% increase in yield at highest P rate). P application stopped in year 5, and residual effect examined. Residual effect in cuts 1, 2 in subsequent 6 years with responses varying 5–10% in year 11 (final year). Calculation of recovery of applied P (based on assumption of 0.3% P concentration for all harvests) would suggest that 8.6% of the applied P was recovered in residual years at highest P treatment compared with 41% at lowest P treatment (Power 1992).	Collins (1967) Collins (1978)
Grassland productivity experiment	26 including Brown Podzolics, Brown Earths, Grey Brown Podzolics, Gleys	1 to 17 (only 4 soils exceeded 3)	224 kg/ha N 124 kg/ha N	Cut 3 to 5 times for 4 years	0, 20, 40, 80 or 0, 23, 45, 90 in spring	Significant response in annual yield to lowest P application rate in all years for all sites combined. Higher P rates showed no significant increase in yield compared with initial P rate.	Ryan & Finn (1976)

[1] The rate of N usage was not specified in trial records. All trials were carried out in An Foras Taluntais (the predecessor of Teagasc).

Materials and Methods

Experimental design

Field trials were set up on three Teagasc farms; Johnstown Castle and Clonroche, Co. Wexford, and Oak Park, Co. Carlow. Information on soils the three sites is summarised in Table 2. Each of the sites was in tillage for a number of years prior to this experiment. The sites were selected to represent a range of soils and STP levels.

The sites were sown with a mid-season perennial ryegrass (cv. Talbot) in the spring of 1986 at Johnstown Castle and Clonroche, and in autumn 1986 at Oak Park. At each site five replicates of a complete randomised block design were established. Phosphorus, as superphosphate (16% P), was applied at 0, 20, 30, 40 and 50 kg/ha. Within block treatments consisted of P applied annually in late October/early November after the final silage cut. Each plot measured 4 m × 10 m. In general, silage harvests were taken three times each year (May/June, July and September). Harvests for each plot measured over a 10-year period are reported in this paper.

Plots received optimal N application at rates shown in Table 3. The rate of N application was increased at all sites in 1989 to compensate for evidence of N deficiency at Clonroche. To correct for an expected sulphur deficiency at Oak Park a dressing of sulphate of ammonia was applied at a rate of 250 kg/ha in June 1987. From 1988 onwards UreaS (urea with added sulphur) replaced Urea for the spring N application at the Oak Park site. Nitrogen with sulphur added was used at

Table 2. Details of soil type for each trial site (soil texture was confirmed by analysis)

	Site		
	Clonroche	Johnstown	Oak Park
Origin	Ordovician shale glacial drift with some granite influence and which is considered a high P 'fixing' soil	Derived from mixed drift material of predominantly shale-quartzite composition	Light textured gravely soil derived from fluvioglacial limestone gravels
Soil texture	Clay loam	Sandy loam over a clay loam	Gravely sandy loam
Great soil group	Brown Earth	Brown Earth	Brown Earth
Drainage	Extremely well drained	Moderately well to imperfectly drained	Low moisture holding capacity
Source	Finch and Gardiner (1970)	Gardiner and Ryan (1964), J.J.; Diamond pers. comm.	Conry and Ryan (1967); M.J. Conry pers. comm.

Table 3. Nitrogen application on trial sites (kg/ha)

		Year				
Application time		1987		1988		1989–1996
Spring	Urea[1]	150	UreaS	150	UreaS	150
After Cut 1	ASN[1]	103	SuperNET	103	SuperNET	120
After Cut 2	CAN[1]	69	CAN	69	CAN	103
Total		322		322		373

[1]Composition of fertilisers used: Urea 46% N; UreaS 40% N, 5% S; SuperNET 27.5% N, 14% S; ASN 27.5% N, 14% S (ammonium sulphate nitrate); CAN 27.5% N (calcium ammonium nitrate).

all sites after the first silage cut. Potassium was spread in autumn at a rate of 250 kg ha^{-1} $year^{-1}$ as muriate of potash. No lime was applied during the course of the experiment. Plots were spot treated to control growth of docks (*Rumex obtusifolius*) with MCPP® (Bayer) or Asulox® (May and Baker), as required.

Only two cuts were harvested on the Oak Park plots in 1987 (due to the autumn sowing). During the course of the trial at Johnstown it became apparent that scutch (*Agropyron repens*) had extensively invaded a number of plots. All plots at this site were sprayed with glyphosate and replanted in August 1991 after the second silage cut. Establishment was good and three herbage cuts were obtained in 1992. In 1996 only two herbage cuts were obtained at Johnstown.

Herbage sampling and analysis

Each plot was harvested using a Haldrup 1500 plot harvester or an Agria mower. Differences in cutting height by the two harvesting techniques would not be expected to cause a significant difference in yield in a three-cut system (Sheldrick *et al.,* 1985).

The fresh weight of the cut herbage was measured and representative chopped sub-samples were taken for dry weight and mineral analysis. Samples were stored at 4 °C until dried for 24 h at 70 °C to determine dry matter (DM) concentration. Dried ground samples were analysed, following digestion with H_2SO_4/H_2O_2, for phosphate by the molybdenum blue method (Murphy and Riley, 1962; Byrne, 1979). Results are expressed in terms of DM yield.

Soil sampling and analysis

Soils were sampled after individual plots were marked out in autumn 1986 and in each autumn before fertiliser application. (It is practice in Ireland that soil tests are normally undertaken between autumn and early spring to predict the likely response to P in the subsequent season.) Additional soil samples were taken following the final harvest. Soils were sampled to a depth of 100 mm, dried at 40 °C for 16 h and sieved to pass a 2-mm mesh. Determination for pH was made in a 1:2 solution with distilled H_2O. Available P (STP) and K were determined by the modified Morgan's method (Peech and English, 1944). Olsen-extractable P was measured using the method of Olsen *et al*. (1954). Percent carbon was determined according to the Walkley Black procedure (Nelson and Sommers, 1982). Total N was determined using the Markam distillation method (Byrne, 1979).

Free iron was determined on composite samples for each site using buffered sodium dithionate extraction (Mehra and Jackson, 1960). Mechanical analysis was performed using the international pipette method with sodium hexameta phosphate as the dispersing agent (Kilmer and Alexander, 1949).

Statistical analysis

Response to the rate of fertiliser application (treatment) was investigated both in terms of herbage yield and soil P status. Herbage yield was assessed on the basis of total yield and the yield obtained from the first cut. Because of the variation in the number of cuts taken in individual years, total yield in a given year was calculated as the sum of two or three cuts as appropriate. First cuts are compared regardless of the date of cut.

The statistical analysis was carried out using PROC GLM of the Statistical Analysis Systems Institute (SAS, 1995).

The experiment was analysed as a spilt-plot design (split on time), with site as a fixed factor and block nested within site. Site was tested using the block(site) mean square; treatment (annual P application rate) was tested against the block × treatment(site) mean square. Linear and quadratic contrasts were used to evaluate the control versus P treated plots effect.

Results

Herbage DM yield

Mean annual total DM yields for the three sites are illustrated in Figure 1. Herbage DM yield averaged over 11 t/ha year^{-1}. These yields are above average for farming practice (*cf.* Roberts, Frame and Leaver, 1989). Overall annual mean yield was highest at Clonroche with lower yields at Johnstown and Oak Park (in that order). The Oak Park site suffered from drought in 1989, 1990 and 1995, which led to a reduction of the mean yield for the site over the 10 years of the trial. In 1989 and 1995 the second harvest at Oak Park was negligible, while all three harvests showed diminished yields at Oak Park in 1990, reflecting the dry summer conditions and poor moisture retentive properties of the site. Overall yields at the three sites were highest in cut 1 with reduced yields for cuts 2 and 3, reflecting the normal grass growth pattern.

There was some evidence for an emerging treatment effect on total yield over time across the three sites as evidenced by the treatment × year interaction ($P < 0.11$). Variability between years, associated with weather and the number of cuts taken, is reflected in the significance of the interaction term site × year ($P < 0.001$). There was no evidence for site × treatment effect interaction.

The experimental design was capable of detecting a main effect difference in DM yield of 0.51 t/ha overall. The mean (non-significant) difference in total DM yield between the control and the highest P treatment across all sites and years was 0.4 t/ha. In the final year of the experiment reported, following 10 years without P application to the control plots, there was a difference in DM yield of 1 t/ha between the control and the highest P treatment. This would have economic significance in a farm situation.

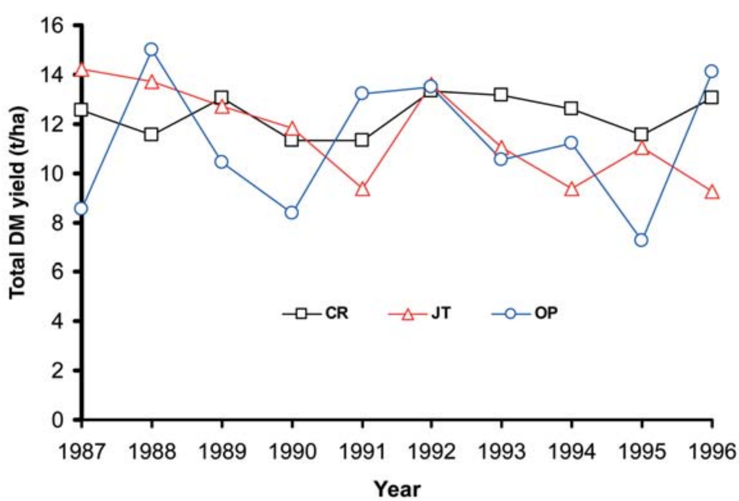

Figure 1: Mean total herbage dry matter (DM) yield for Clonroche (CR), Johnstown (JT) and Oak Park (OP) for each year of the trial.

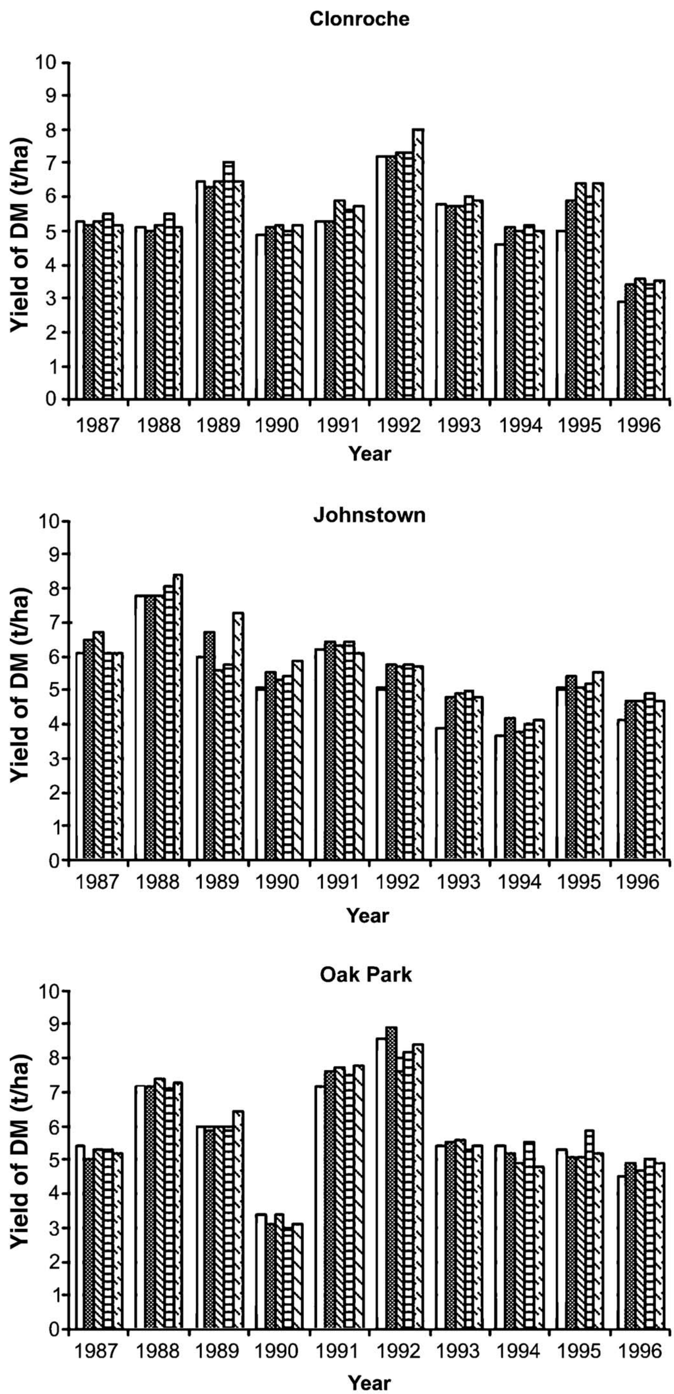

Figure 2: Mean dry matter (DM) yield for first cut for individual P treatments (□0, ▩20, ▧30, ▤40, ▨50) at three sites, legend indicates annual P application rate (kg/ha).

For the first-cut yield, a treatment effect was apparent ($P < 0.05$), as shown in Figure 2. The treatment × year interaction term was not significant ($P > 0.5$) suggesting that treatments behaved similarly in each year of the experiment. As for total yield the difference between sites varied with year ($P < 0.001$). The interaction term site × treatment was not significant suggesting that first-cut yield responded to treatment in a similar manner at each site. Comparison of mean first-cut yield for all treatments showed that the largest difference was between the control and P-treated plots ($P < 0.01$). The magnitude of the difference between the control and the highest P treatment for first-cut DM yield at all sites combined was 0.32 t/ha.

Herbage P concentration

The respective order of mean herbage P concentration was generally cut 3 > cut 2 > cut 1. The range in P concentration for herbage harvests is outlined in Table 4. No attempt has been made to statistically analyse these results as they are strongly influenced by cutting date, reflecting a dilution of P concentration with herbage growth.

Herbage P concentration reflects the level of P fertiliser application. Lower herbage P concentrations tended to occur at the Clonroche site, with higher concentrations at Oak Park (particularly noticeable in the early years of the experiment). The minimum herbage P concentrations tended to occur in the final years of the experiment.

Herbage P uptake

Mean values for total P uptake (i.e. DM yield multiplied by herbage P concentration expressed on an area basis) for all three silage cuts are shown in Figure 3.

Table 4. Range of P concentration in herbage dry matter (mg/kg)

	Clonroche	Johnstown	Oak Park
Cut 1	1.6 – 4.6	1.6 – 5.0	2.2 – 5.6
Cut 2	1.8 – 4.5	1.7 – 6.0	1.7 – 5.4
Cut 3	1.8 – 4.8	1.7 – 5.2	2.2 – 7.0

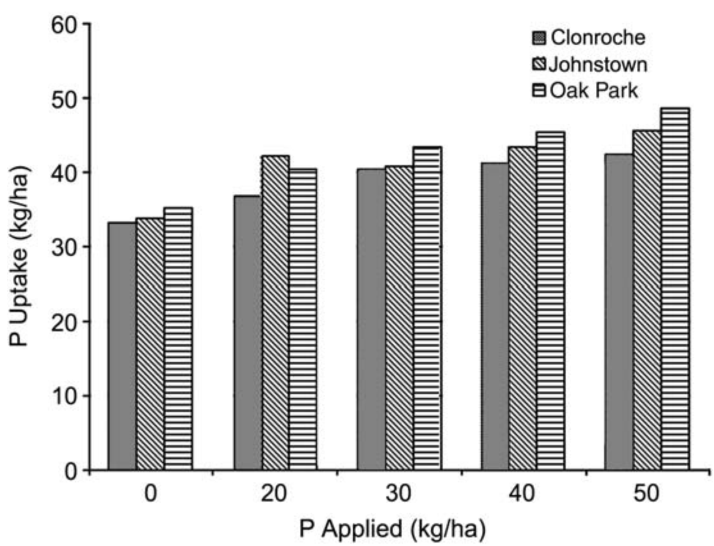

Figure 3: Mean annual P uptake at each of the three sites for individual P treatments.

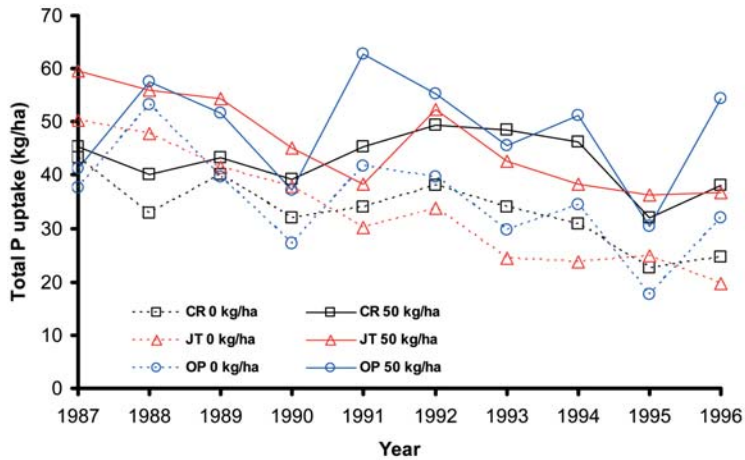

Figure 4: Change in total P uptake with time for the control (0 kg/ha) and high P (50 kg/ha) application rate at Clonroche (CR), Johnstown (JT) and Oak Park (OP).

The treatment effect on total P uptake varied between years (P < 0.001). The total P uptake at individual sites also varied with year (P < 0.001). The site × treatment interaction was not significant, suggesting that P uptake responded to P application in a similar manner at each site.

There was a general decline in P uptake on the control plots during the course of the experiment (see Figure 4). In excess of 330 kg P was removed per hectare in harvests from the control plots at each site over the 10 years. The higher cumulative P uptake on the P-treated plots suggests luxury consumption of P (424 to 485 kg P was removed per hectare from the highest P treatments at the three sites).

General soil characteristics

At the start of the experiment pH values for the control plots were 6.6, 6.6 and 7.2 for the Clonroche, Johnstown and Oak Park sites, respectively. Following the final harvest corresponding values were 5.2, 5.6 and 5.3. The biggest change was at the Oak Park site. No significant treatment effect or site × treatment effect was observed in pH during the course of the experiment.

The means for available soil K were 131, 111 and 138 mg/l for the Clonroche, Johnstown and Oak Park sites, respectively (for all years and treatments). Values of soil K between 100 and 150 mg/l are considered optimum for grass production. No treatment effect (P < 0.17) or site × treatment effect (P < 0.39) was observable in K levels.

Results of analysis for C and N concentrations in soil are summarised in Table 5. These results for soils sampled at the onset of the experiment reflect the tillage histories of the site. Results for free iron content and bulk density values are also included in Table 5. Comparison of values for the bulk density of the total soil column with that of the <2 mm sieved fraction, indicates the high gravel proportion at the Oak Park site.

Soil P level

At the start of the experiment all soils demonstrated a moderate to high STP (as measured by the Morgan's P method). Control values at the start of the experiment were 5.4, 8.8 and 44.6 mg/l for Clonroche, Johnstown and Oak Park,

Table 5. Soil characteristics at each site based on soil sampled to a depth of 10 cm

	Clonroche	Johnstown	Oak Park
Carbon	2.5	1.8	2.1
Nitrogen	0.29	0.23	0.23
Free Fe	3.5	1.5	1.6
Bulk density (Total)	1008	1123	1151
Bulk density (<2 mm)	798	881	760

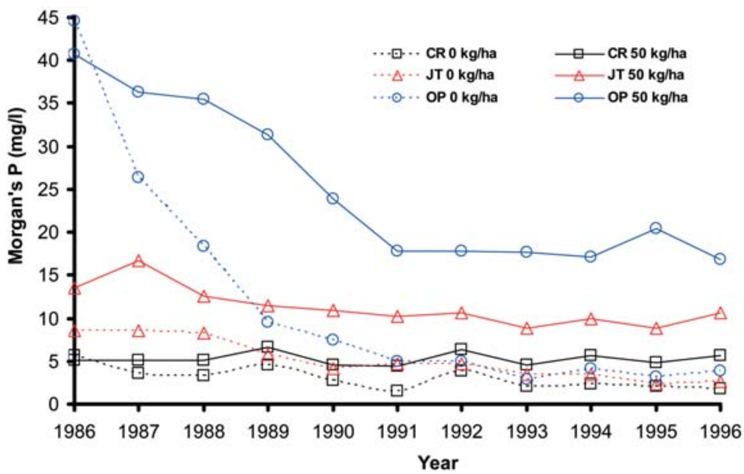

Figure 5: Change in Morgan's P levels with time for the control (0 kg/ha) and high P (50 kg/ha) application rates at Clonroche (CR), Johnstown (JT) and Oak Park (OP).

respectively (Figure 5). Corresponding values following the final harvest were 1.4, 2.4, and 4.0 mg/l. Initial Olsen P values for the control plots were 44, 47, and 49 mg/l for the Clonroche, Johnstown and Oak Park sites, respectively.

The most rapid decline in soil P levels occurred at the Oak Park site (Figure 5). A more gradual drop in P level was observable at the Clonroche and Johnstown sites. Morgan's P levels initially declined even at the highest rate of annual application (which equated with or exceeded crop removals). In the latter years of the experiment a balance appears to have been established at each site between application rate and removals in terms of Morgan's P levels for the highest P treatment.

Values for Morgan's P exhibited increasing variance for increasing means (Figure 6). This was particularly apparent for the Oak Park site which demonstrated high soil test values and variance. A similar trend of increasing variance with sample mean for Morgan's P values has been discussed by Foy *et al.* (1997). Statistical analysis was therefore carried out on log-transformed data. The year and the treatment × year interaction were both significant ($P < 0.001$), but the site × treatment interaction was not significant.

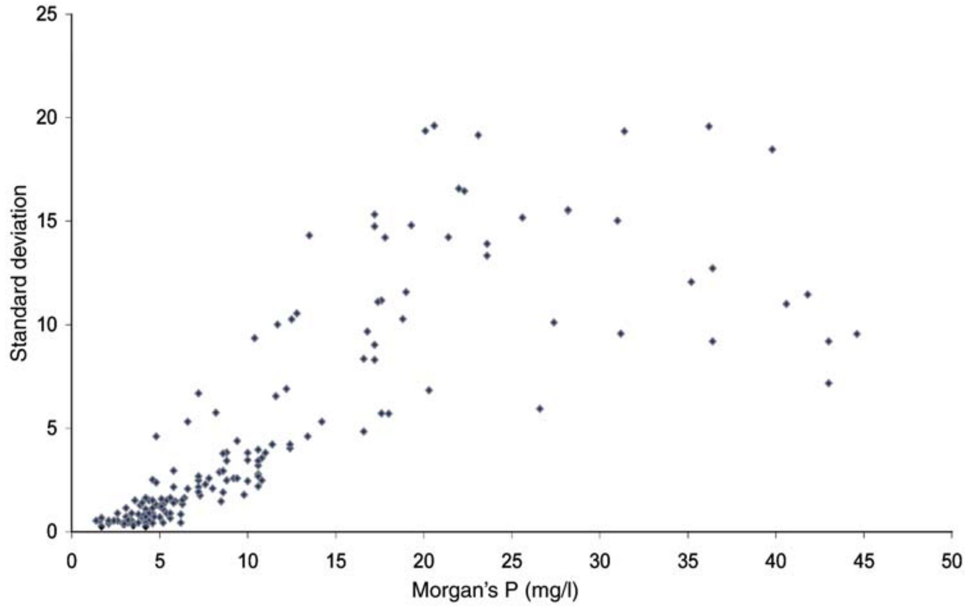

Figure 6: Standard deviation plotted against mean Morgan's P values for all sites and treatments.

The decrease in STP over the course of the experiment shows that it is possible in farming practice to reduce high levels in the medium term without an impact on yield. Such a drop in STP may reduce the potential for P loss to water.

Discussion

The trials at the three sites demonstrated a limited yield response to P application for first-cut silage compared to control plots which received no P application for 10 years. The nature of the response to P application suggests that a minimal P application is sufficient to maintain yield at these sites. Similar limited yield responses were observed by Paynter and Dampney (1991), in a study of 21 sites cut for silage in England and Wales with moderate to high soil P availability. The treatment effect in the current study was not initially reflected in overall yield but a treatment effect on total yield emerged in the final years of the trial. The magnitude of the first-cut yield response to P application was similar to the magnitude of the non-significant difference between the control and high P treatment in terms of overall yield. It was also similar to the magnitude of the DM yield response (0.32 t/ha) recorded by Paynter and Dampney (1991). Swift *et al.* (1998) in a study of 12 upland pasture sites in Scotland recorded no significant response in first-cut silage yield to spring application on soils with moderate P levels. However, this may be due to the fact that only a single cut was harvested.

While no yield response to P addition may preclude fertiliser application, it is necessary that the herbage fed to animals has sufficient P concentration to satisfy the dietary requirements of livestock. Herbage P levels are influenced by cutting date (Fleming, 1963; Fleming and Murphy, 1968). Ensiling tends to have little effect on P concentration as P loss is in proportion to DM loss in silage effluent. Low P concentrations have been found in herbage from perennial ryegrass dominated swards in other studies on soils with high P status (Adams, 1973; Swift *et al.,* 1988; Paynter and Dampney, 1991). Silage samples submitted in 1976 to the Department of Agriculture, Northern Ireland had average P concentrations in DM of 2.9, 3.2 and 3.1 mg/kg for 1st, 2nd and 3rd cuts, respectively. Mean concentration was 3.0 mg/kg (Stevenson and Unsworth, 1978). As the nutrient concentration in herbage rises later in the season, later silage cuts, while low in yield, may be important in raising the overall P concentration of the diet.

Silage P concentrations in DM of 3.0 to 3.1 mg/kg were considered adequate for lactating Friesian cows (ARC, 1988) but these estimates have now been revised upwards (AFRC, 1991). Haygarth *et al.* (1998) have recently produced a P budget for a typical dairy farm and have established that silage requires a P concentration of 3.5 mg/kg. It can thus be assumed that herbage P concentrations from the current trials would be inadequate to solely satisfy dietary requirements of lactating dairy cows for P.

It should be recognised that silage comprises only a portion of the dietary intake of dairy cows. Usage should be considered both in terms of the overall input concentration and the stage of lactation of the cow. As cutting date influences herbage P concentration, mineral supplementation of animal feed may be more appropriate for animals fed predominantly on a grass-based diet. The environmental risks of excessive P application to land may further dictate such a choice.

The rapid fall in STP on the control plots at Oak Park compared to the Clonroche soil demonstrates that soil type has a significant impact on the interpretation of Morgan's soil test values. A P application of 50 kg/ha failed to maintain Morgan's P values at initial levels in the early years of the experiment at Johnstown or Oak Park even though more P was applied than removed in the crop. At all sites in the final five years of the experiment, the high P application rate appears to have halted the decline in soil test values. This demonstrates that the P application rate required to maintain a given soil P status will vary with the level of soil available P.

Sharpley and Rekolainen (1997) noted that the rate of decline in soil P status in high P soils varied with soil type and management when fertiliser application ceased. Citing White (1980) they suggested that with regular P application, the importance of soil fixation processes is diminished as soil P sorption capacity becomes slowly saturated and a higher concentration of P is maintained in soil solution. The rate of decrease in available soil P with cropping when no P is applied relates to the P buffering capacity of the soil or P sorption saturation. An example would be the rapid decline in soil P levels at the Oak Park site and the comparative maintenance of soil P status at the Clonroche site on the control plots.

It can be assumed that all three sites had homogeneous available P concentrations in the plough layer (due to the tillage histories of the sites). These sites may therefore have higher P reserves than soils in long-term grassland with similar soil tests levels due to the fact that in an unploughed grassland situation P tends to accumulate in surface layers.

Adams (1973) has indicated that where gross deficiencies have been eliminated, best P fertiliser policy was one where neither run-down nor build up of P occurred in the system. He estimated that, on swards cut three times annually and receiving 180 to 360 kg/ha N, between 37 and 40 kg/ha N were required to leave soils reserves unchanged. Withers (1995) present a similar argument for cereals on calcareous soils. This approach can be validated by soil testing to indicate changes in soil P status. However in implementing such an approach on calcareous soils there is need for caution in that an acid extractant such as the Morgan's P test may overestimate soil P reserves (Jaakkola, Hartikainen and Lemola, 1997).

Results from the current study also suggest that replacement of the P removed in the crop rather than soil test maintenance is the best fertiliser policy. This will result in a decline in soil test values but prevent accumulation of soil P in less available P forms. Such an approach is substantiated by difficulties in measuring changes in soil P status over short time periods due to the high variance of soil test values. This lack of sensitivity of a range of soil tests to P application and accumulation in tillage trials in five European countries is evident in results reported by Vanoverstraeten and Hanotiaux (1996).

Thus, the maintenance P requirement may be set simply to balance crop removals of about 40 kg/ha P for a 3-cut system (in the exceptional situation where slurry is not recycled). This level is designed to maintain productivity of the sward and is based on the P removals from 20 and 30 kg/ha P treatments (see Tunney *et al*., 1996). The results of the present study further suggest that there can be a response to additional P as evidenced by the significance of the response in the first-cut yield. In this situation regular application of P of an order reflecting that removed in the crop will ensure maximum crop yields and reduce excess accumulation of P in the soil. In practice, the P recycled in animal manure needs to be taken into account when calculating the quantity of chemical fertiliser required.

The modest decrease in STP over the course of the experiment shows that it is possible in farming practice to reduce high levels in the medium term and thus lead to reduced P loss to water. The net P removal recorded here (average 334 kg/ha P for a 10 year period) would be much less in actual farming practice because it would be the norm to recycle P in animal manures to silage ground. This was not done in this experiment. In some situations, the recycling of manures produced from grass harvested from fields with high STP to fields with low STP may offer a possibility to reduce high P levels.

Conclusion

Regular small maintenance dressings of P, replacing realistic removal levels, are considered the most appropriate fertiliser application strategy. Such applications should be combined with soil testing to ensure moderate soil test P levels are not excessively depleted and to enable assessment of depletion or accumulation of P in individual farm situations. Concern with regard to low herbage P concentrations can be most appropriately addressed by mineral supplementation to meet animal requirements and optimisation of silage cutting times to maximise herbage P concentration.

Acknowledgements

The authors acknowledge the contributions of the following: Lance R. Broad for statistical advice, McDonagh/Albatros Fertilisers for funding the senior author's Fellowship, Liam Quirke, Sean Ormond and Tom O'Donnell for field assistance, the staff of

Analytical Services at Teagasc for soil and plant analysis and the late Dr. Thomas F. Gately for his encouragement and advice throughout the study.

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Received 23 July 2004