# Temporal Trends in Soil-Test P and P Recovery in Grassland Soils

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## Introduction

During the period 1941 to 1946, phosphorus (P) inputs to agriculture were lower than removals, and Morgan soil-test P declined to mean levels of 1 mg $l^{-1}$ P (Hanley and Murphy, 1973). When soil testing began in the 1940's at Johnstown Castle, the objective was to improve soil fertility and crop production. Subsequently, the increasing trend in available P initially reflected increasing levels of fertiliser inputs, from 16,000 tonnes (t) in 1951 to a peak of 90,000 t in 1973, but the trend continued even after such inputs declined (Coulter and Tunney, 1996). Fertiliser P inputs had declined to 62,000 t in 1996, prior to the introduction of reduced guidelines by Teagasc at that time (Carton *et al*., 1996). They have declined further since then, and currently are less than 45,000 t. From 1951, the average soil Morgan-P rose from approximately 1 mg $l^{-1}$ P to a peak of 9.3 mg $l^{-1}$ P in 1991 (Coulter and Tunney, 1996). For the period 2001 and 2002, mean soil P levels were 8.1 mg $l^{-1}$ P, and this reflected samples from both REPS and non-REPS farms (Figure 1).

Current mean values in REPS and non-REPS farms are 7.4 and 9.3 mg $l^{-1}$ P, respectively (Anon., 2004). The breakdown by index indicates that 16 % of soils (17 % REPS, 16% non-REPS) contain $\leq$ 3 mg $l^{-1}$ P (index 1), while 23 % (20% REPS, 28% non-REPS) contain > 10 mg $l^{-1}$ P (index 4), i.e. in excess of agronomic requirements. Consequently, soil-test levels are sometimes perceived to be excessive, although for many years emphasis was placed on the progression of, and requirements for, build-up of soil P. There is currently a greater emphasis in high-P soils on moderation of levels that are deemed to be unacceptable in terms of environmental quality and sustainability (Tunney *et al.,* 1999). However, at low index levels with low associated environmental risk, depletion of P is undesirable if it impacts on production. In any case, more information is needed on the rate at which soil-test P declines or increases over time, in relation to P offtake and changes in P balance for different soil series and fertility categories.

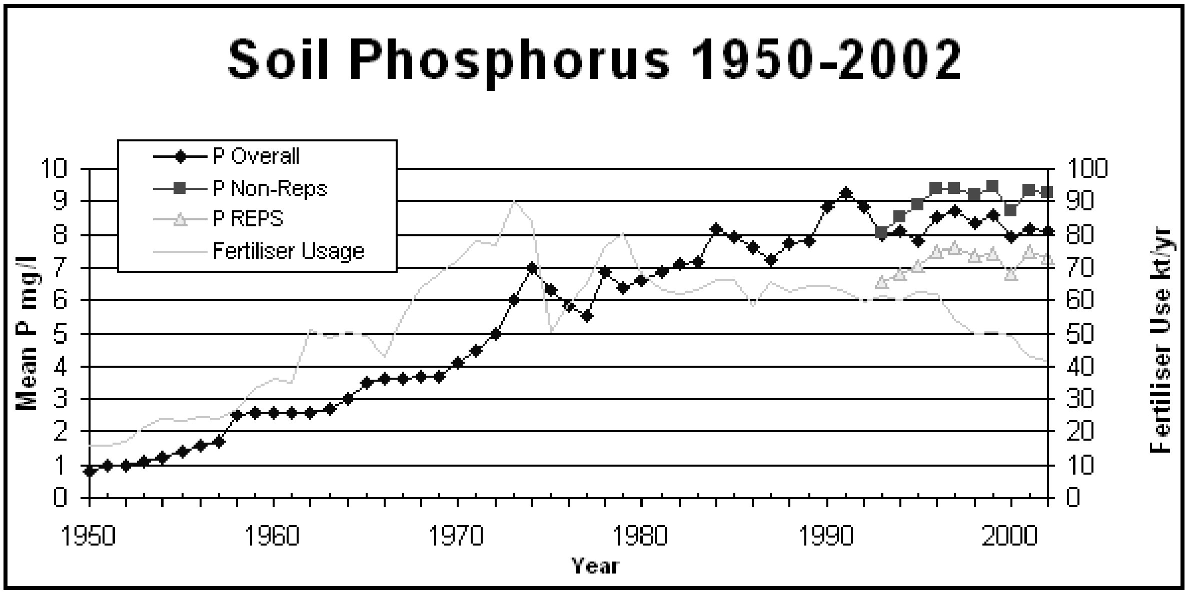

Figure 1. Mean fertiliser P usage and P levels in Irish soils, 1950 to 2002. From Johnstown Castle Research Centre website (Anon., 2004)

## Changes in P balance

Change in P balance, i.e. the difference between P input and P offtake in herbage or animal product, indicates the extent to which soil-P reserves may be enriched or depleted over time. Quantification of change in P balance, and the consequent effect on soil-test P, is essential for management of sustainable soil and fertiliser nutrient supply. The relevant time-span may be within a three to five year cycle, since soil tests are often monitored over that period in farming practice. The results of a recent study on cut swards on eight soil series over four years (1997 to 2000) showed that change in P balance was significantly affected by both P treatment and soil series (Herlihy *et al.*, 2004). This study included thirty two field sites, which consisted of four sites, with a range of soil-test P, on each of eight soil series or associations. Further evaluation of selected data for two of the soils, Clonroche (soil 14) and Baggotstown (soil 30), is discussed in this paper. Experimental inputs of P were applied in February each year at 20 ($P_{20}$) and 40 kg ha$^{-1}$ P ($P_{40}$). There was also a zero P control ($P_0$) and, in year one only, a once-off application of 60 kg ha$^{-1}$ ($P_{60}$). All soil samples were taken at the standard 10 cm depth, and available soil P was measured using Morgan's extractant on < 2 mm air-dried (40 °C) soil. To facilitate statistical analysis, index categories were combined into two groups, i.e. a low index-group and a high index-group representing the conventional index categories 1+2 (0–6.0 mg l$^{-1}$ P) and 3+4 (> 6.1 mg l$^{-1}$ P), respectively.

Table 1 shows the variation in P balance for the two contrasting soils (14 and 30). The changes in P balance are comparable to those observed elsewhere (Picone *et al.*, 2003), and, in the $P_0$ treatment, provide an estimate of the magnitude of soil-P availability for herbage production. For example, the cumulative P balance on the $P_0$ treatment in the low index group of soils 14 and 30, respectively, reflected P offtake, and hence soil-P availability, of 109.1 and 79.5 kg ha$^{-1}$ P. Corresponding values for the high index group were 159.7 and 107.1 kg ha$^{-1}$ P. P uptake on the $P_0$ plots declined between 1997 and 2000 and, by 2000, was 21.5 kg ha$^{-1}$ P and 34.4 kg ha$^{-1}$ P, i.e. 59.4 % and 77.6 % of the 1997 value in the low and high groups on soil 14. Corresponding values for soil 30 were 13.2 kg ha$^{-1}$ P and 17.0 kg ha$^{-1}$ P (i.e. 51.6 and 48.6 % of the 1997 value) in the low and high index groups, respectively. The marginal effects of the $P_{40}$ treatment on P balance in both index groups indicated that it more closely approximated the P requirements of herbage than the other treatments. Generally, there was a substantial positive P balance only at 60 kg ha$^{-1}$ in the year of application. After three years (1999), when similar amounts of P had been applied in the $P_{20}$ and the once-off $P_{60}$ treatments, the cumulative balances were comparable, which may indicate equally efficient availability over time for the two methods of application. The wide range in values is indicative of the widely-contrasting effects of inputs and offtakes between soils. The range in P offtake in the $P_0$ treatment of 79.5 to 159.7 kg ha$^{-1}$ P (Table 1) over four years in cut swards would equate with 10 to 20 years in grazed swards, when account is taken of differences in offtake observed under grazing at high stocking rates (Culleton *et al.,* 2002). In effect, studies on cut swards accelerate the process, and are more amenable to use where observations over a wide range of soils are required.

Table 1. Variation in cumulative P balance (kg ha$^{-1}$ P) for soils 14 (Clonroche series) and 30 (Baggotstown series).

| Index | Soil no. | P input | 1997 | 1998 | 1999 | 2000 |
|---|---|---|---|---|---|---|
| 1+2 | 14 | $P_0$ | -36.2 | -62.4 | -87.7 | -109.1 |
| | 14 | $P_{20}$ | -17.9 | -27.3 | -38.4 | -45.6 |
| | 14 | $P_{40}$ | -0.8 | 6.3 | 10.1 | 19.0 |
| | 14 | $P_{60}^{\dagger}$ | 19.3 | -9.6 | -36.8 | -59.8 |
| | 30 | $P_0$ | -25.6 | -45.8 | -66.3 | -79.5 |
| | 30 | $P_{20}$ | -14.3 | -22.8 | -36.2 | -41.0 |
| | 30 | $P_{40}$ | 2.3 | 9.2 | 7.4 | 17.7 |
| | 30 | $P_{60}^{\dagger}$ | 20.3 | -7.8 | -34.4 | -50.4 |
| 3+4 | 14 | $P_0$ | -44.4 | -83.0 | -125.2 | -159.7 |
| | 14 | $P_{20}$ | -25.4 | -45.2 | -71.2 | -87.3 |
| | 14 | $P_{40}$ | -7.8 | -11.8 | -19.8 | -20.3 |
| | 14 | $P_{60}^{\dagger}$ | 11.7 | -29.3 | -76.1 | -112.0 |
| | 30 | $P_0$ | -34.9 | -60.9 | -90.2 | -107.1 |
| | 30 | $P_{20}$ | -20.3 | -35.3 | -54.6 | -57.8 |
| | 30 | $P_{40}$ | -3.3 | 0.8 | -3.2 | 9.5 |
| | 30 | $P_{60}^{\dagger}$ | 14.2 | -18.6 | -49.9 | -67.0 |

$^{\dagger}$ Once-off application in 1997.

## Temporal trends in soil-test P

Soil-test P can be expected to decline in the absence of fertiliser P input, and the extent of decline is likely to reflect the initial P status. Other work has shown that the magnitude of change was greatest where Morgan P was high, with reductions from 5.0

to 2.0 mg $l^{-1}$ P *vs*. 20 to 7.3 mg $l^{-1}$ P after four years offtake with no fertiliser P on cut swards (Herlihy *et al*., 2004). Figure 2 shows the trend in soil-test P over time for soils and P treatments in the low and high index groups. There was no significant decline on the $P_{40}$ treatments on either soil in the low index group, whereas the decline was significant for $P_0$. Initially there was no significant difference between soil P levels, but after four years, the values on the $P_0$ plots on soil 30 were significantly lower than the $P_0$ plots on soil 14. However the annual trends were erratic, because the $P_{40}$ treatment was more closely matched to offtake, so that marginal differences (positive and negative) affected the annual changes in soil-test P. This contrasted with more consistent effects where P input was limited. The tendency for the $P_{40}$ treatment to sustain soil-test P levels reflected the corresponding minimal change in P balance (Table 1) consistent with other reports (Schmidt *et al*., 1997; Zhang *et al*., 1995). In 1999, when cumulative P inputs on the $P_{20}$ and $P_{60}$ plots were the same, Morgan P values were comparable.

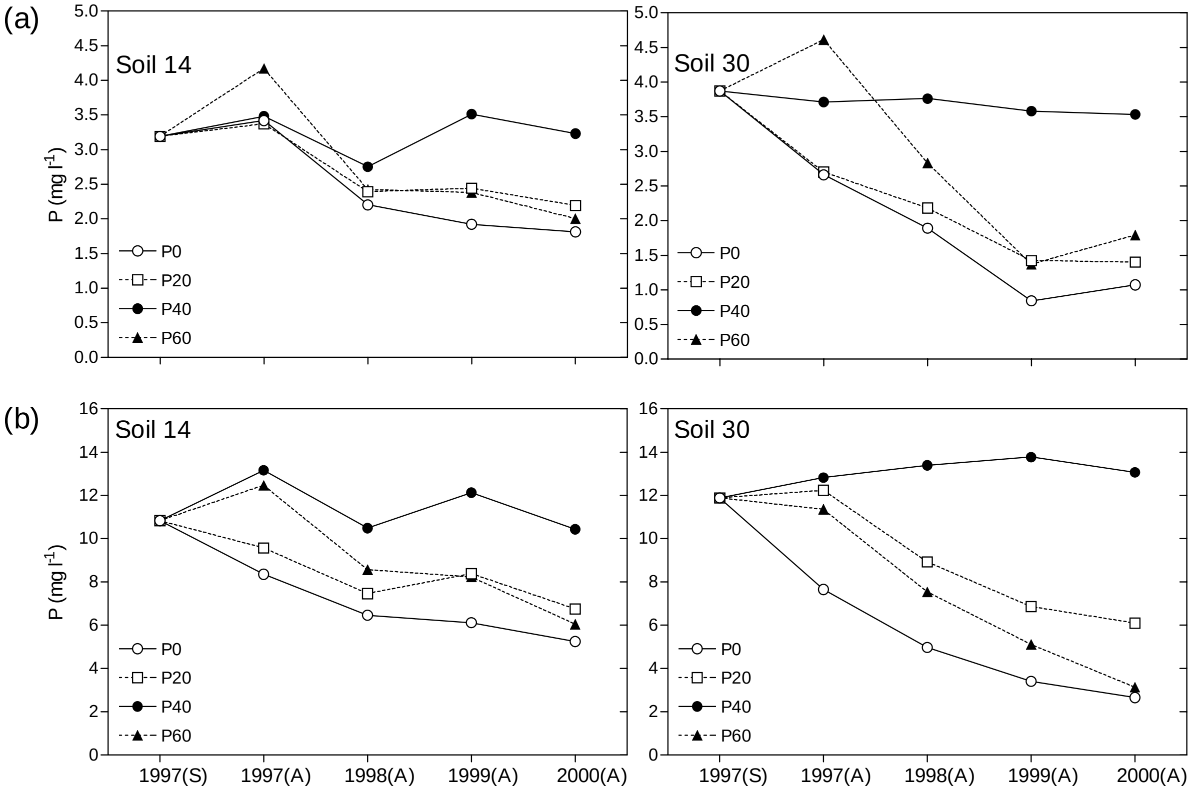

Figure 2. Morgan P for soils 14 and 30 in the (a) low index group, and (b) high index group. S = Spring, A = Autumn.

The changes between soils in the high index group broadly paralleled those for the low index group. Differences across index groups were smaller than differences between soils when expressed as percentage change over time, although in absolute terms, the decline was greater in the higher index group. Generally, soil-test P declined more rapidly in the high index group, i.e. high initial soil P, in agreement with the findings of Barber (1979). Decreases in soil P were in the order $P_0 > P_{20} > P_{40}$. Where no fertiliser P was applied, the decline in soil-test P over four years was -43.4 % and -51.6% for soil 14 in the low and high index groups, respectively. These declines were less than those of. -72.5 % and -77.6 % in soil 30. With no fertiliser P input in the high index group, the Morgan index-category decreased from 4 to 2 for soil 14 (10.8 to 5.2 – a reduction of 5.6 mg $l^{-1}$ P) and from 4 to 1 for soil 30 (11.9 to 2.7 – a reduction of 9.2 mg $l^{-1}$ P).

It is evident from the foregoing that large changes in index category are possible within a short time interval, which is relevant in the context of abatement of soil P levels following increase due to loadings of high-P wastes or other products. Currently, the EPA prohibits manure applications from intensive agricultural enterprises (IAE) on spreadlands where the existing Morgan P exceeds 10 mg $l^{-1}$. Teagasc advises that for IAE, manure applications should be allowed up to 15 mg $l^{-1}$ Morgan P provided the land is classified as being low risk in terms of P loss (Carton and Magette, 1999). This is to accommodate the significant difficulties IAE operators encounter in securing spreadlands within the acceptable limit. Teagasc clearly state that the subsequent draw-down of soil P by the crop to acceptable levels (< 10 mg $l^{-1}$) is of critical importance to this strategy. Guidance on the time-frame for draw-down and the quantification of the ensuing soil-test P levels for different soils and P offtakes, or P balance values, can be inferred from this and similar studies (Herlihy *et al.*, 2004). However, it should be noted that soil-test P is not the only criterion in decisions on P inputs, and that the Department of the Environment and Local Government, the EPA and the Geological Survey of Ireland have also issued guidelines for the protection of groundwater based on a vulnerability rating (DoELG/EPA/GSI, 1999).

Generally, the relationship between P balance or P offtake and decline in soil P reflects what might be expected in terms of reduction of elevated soil P levels that resulted from long-term high fertiliser use or from high loadings of manures. On the $P_0$ plots, the ratios of P offtake to change in soil-test P for soils 14 and 30 were 79:1 and 28:1 in the low index group and 29:1 and 12:1 in the high index group, respectively. These compare favourably with the mean ratios over a wider range of soils (Herlihy *et al.*, 2004). Generally, differences between soils can be expected to reflect effects of variation in soil texture and soil chemistry. Not surprisingly, the well-buffered soil 14 sustained its P levels better than the light limestone soil 30. Others (Tunney *et al.*, 1999) showed that annual inputs of 40 to 50 kg $ha^{-1}$ maintained Morgan P over ten years in loams with 5 to 11 mg $l^{-1}$ P, but Morgan P values were halved in a sandy loam with an initial 40 mg $l^{-1}$ P.

Depletion was the operative effect in our study, since P inputs generally did not exceed offtakes. However, in a separate, more simple, laboratory study of build-up of P in the absence of concurrent offtake, large differences between soils were also evident in the input needed to increase soil-test P, irrespective of P status. Thus, a range from 104 mg $l^{-1}$ P in light limestone soils to 496 mg $l^{-1}$ P in loams and heavy-textured soils was required to build up soil-test P from 4 to 10 mg $l^{-l}$ (Table 2). The corresponding range was 97 to 307 mg $l^{-l}$ P where build-up was from 10 to 20 mg $l^{-l}$ P.

Table 2. P input (mg $l^{-1}$) required to raise Morgan P levels over two soil-test P ranges (adapted from Power, 1992).

| Soil type | Soil-P 4-10 mg $l^{-l}$ | Soil-P 10-20 mg $l^{-l}$ |
|---|---|---|
| Loams / Heavy soils | 496 | 307 |
| Limestones | 104 | 97 |
| Sandstones | 367 | 264 |
| Shales | 281 | 259 |

## Fertiliser P recovery

Recovery of fertiliser P by herbage over four years was calculated as the difference between cumulative P uptake in the $P_0$ control and the once-off $P_{60}$ treatment in 1997, which enabled measurement of its continuing residual effect and recovery over the four years (Figure 3). P recovery increased over time, but there were wide differences between the two soils and between index groups. Recovery in the season of application was low, particularly for soil 14. After four years, values were in a higher range of 17.8% and 51.5 % for soils 14 and 30, respectively, in the low index group. Corresponding values for the high index group were 20.6 % and 33.2 %. Others have noted crop recovery of 25% or less of fertiliser P in the year of application (Read *et al.*, 1973), with increases over time to 40 to 50% (Halvorson and Black, 1985). Consequently, P recovery for soil 14 appears to be inefficient, although our four-year values may underestimate those attainable over a longer time-span, i.e. by determination of possible longer-term residual effects. Soil 30 is a light-textured limestone soil, less prone to fixation of fertiliser P, and with lower buffering capacity than soil 14 (McGrath, D. and Herlihy, M., unpublished), and therefore likely to be more susceptible to high recovery of fertiliser P.

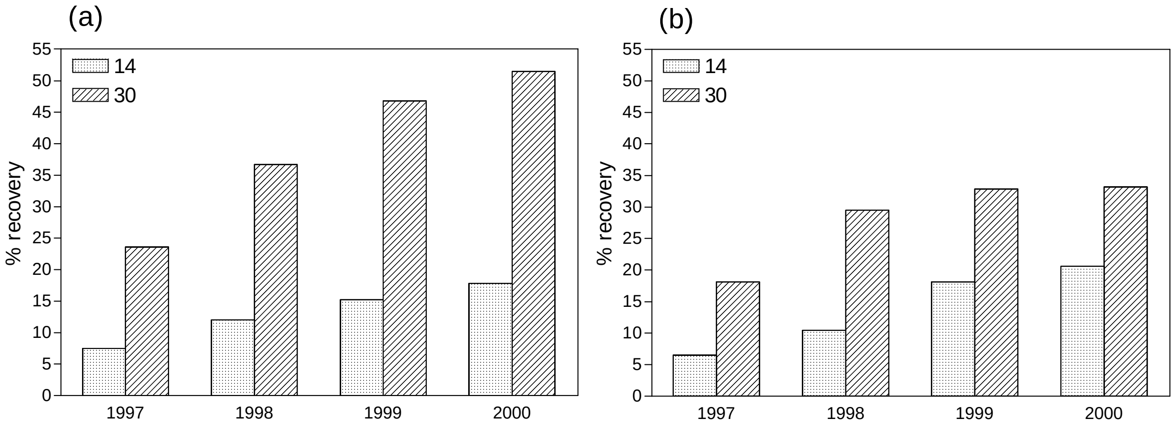

Figure 3. Variation in cumulative recovery of the $P_{60}$ application for (a) low index group, and (b) high index group.

## Conclusions

Teagasc fertiliser-P recommendations were modified in 1996, because inputs for the then prevailing range of soil-test levels were perceived to be excessive, especially in the environmental context. However, the current mean value of 9.3 mg $l^{-1}$ P in non-REPS farms is similar to the overall mean peak value recorded in 1991. The mean of 7.4 mg $l^{-1}$ P in REPS farms may reflect the implementation of EU environmental policies, and possibly the fact that many such farms were always less intensively farmed. More generally, the breakdown according to index shows that 23 % of soil samples analysed at Johnstown Castle (2001 to 2002) contained > 10 mg $l^{-1}$ P, which is in excess of agronomic requirements. There is an interest in establishing the rate of soil-test P decline over time in relation to change in P balance, i.e. the difference between P inputs and offtakes, both in the context of fertiliser needs of soils of low P status, and of reduction of high levels of soil-test P following loadings of high-P wastes.

The wide range observed in P balance is indicative of the widely-contrasting effects of inputs and offtakes between soils. High levels of P offtake, and consequently P balance, in cut swards accelerated the observed changes in soil-test P compared with grazed swards. However, effects on soil-test P were similar for cut and grazed swards if account was taken of differences in duration required for similar levels of P offtake. Decline in soil-test P varied widely in contrasting soils, and with differences in index categories. The results demonstrated that in cut swards, large reductions in soil-test P were attainable in a limited period of four years, where fertiliser-P application was withheld.

For a given level of fertiliser-P input or P offtake, both recovery of P and depletion of soil-test P varied widely between contrasting soils. Both high recovery of fertiliser P and rapid depletion of soil-test P was evident in the light-limestone Baggotstown soil, which contrasted with changes observed in the loam (Clonroche). These results generally confirm the inherent limitation in assuming an exact (1:1) relationship between inputs and offtakes in different soils, as noted previously (Herlihy *et al*., 2004).

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