THIRTY YEARS OF PHOSPHORUS FERTILISER ON IRISH PASTURES: ANIMAL-SOIL-WATER RELATIONSHIPS

END OF PROJECT REPORT

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SUMMARY

Thirty years of research involving phosphorus (P) fertiliser rates (0, 15 and 30 kg/ha/yr) on pastures has been completed. Beef performance on pasture at relatively low and high stocking rates was determined by weighing beef animals (mean wt = 260kg) at the beginning and end of each grazing season for 18 years. Soil samples were taken at various times and at various depths. Live weight gain (LWG) was greatest at the high stocking rate (HSR) compared to the low stocking rate (LSR). LWG maximised at 15 kg P/ha. Maximum beef production took place with a soil test of 6 mg P/l using the Morgan's procedure. Most of the soil P and fertiliser P, as measured by both the Morgan's and Total P procedures, were in the top 10cm. However, a significant portion moved below that to the 10-20 cm layer, as determined by both Total and Morgan's P in both P treatments. Soil P and fertiliser P as determined by the Morgan's procedure moved into the 20-40 cm layer but no lower. Work done on the 30 kg/ha P treatment and on another site at Johnstown Castle showed that significant amounts of P moved off the plot with water in overland flow and the loss was related to the soil test (Morgan's) for P. The amount of P lost per unit of Morgan's was calculated to be 175g with a Morgan's soil test of 4 mg P/l and 281g with a soil test of 17 mg P/l.

A mass balance procedure was attempted for the 30 years' work to determine how much P was exported in beef, lost in overland flow or retained in the soil. This showed that fertilising beyond 15 kg/ha gave no increase in beef production and that the extra P was found in the soil, or lost in overland flow. When 15kg P/ha was applied annually for 30 years it was estimated that 20% and 4% of P applied was removed in beef or lost in overland flow, respectively. It was calculated that 76% of the P applied stayed in the soil.

CONCLUSIONS

(1) Thirty years of Research involving fertiliser P rates 0, 15 and 30 kg/ha/year on pastures at two stocking rates, 2,400 and 3,200kg liveweight of beef cattle/ha at turn-out, has been completed.

(2) Maximum beef production took place with a soil Morgan's P test of 6 mg/l.

(3) The zero P treatment had of 71% of the beef yield of the 15kg P treatment. There were no differences in output between the 15kg P and the 30 kg P treatments.

(4) When fertiliser P was applied in this trial it was assumed that it was
   - (a) exported in the beef
   - (b) lost via overland flow
   - (c) remained in the soil in various forms and at various depths

(5) Over the 30 years in the 15kg and 30 kg P treatments it was calculated that some 20% and 9%, respectively, were exported in beef produced per year.

(6) Over the 30 years in the 15kg and 30 kg P treatments it was calculated that some 4% and 14%, respectively, were lost via overland flow.

(7) Over the 30 years in the 15kg and 30 kg P treatments it was calculated that 76% and 77% respectively of P remained in the soil.

(8) In the 0, 15 and 30 kg treatments there were 181, 365 and 586 mg inorganic P/kg soil in the top 10 cm. In the 0, 15 and 30 kg treatments there were 371, 474 and 417 mg of organic P/kg soil in the top 10 cm. While there were 552, 838 and 1002 mg total P/kg soil in the top 10 cm, respectively.

(9) The P fertiliser at various depths (0-10, 10-20 cm) using Morgan's P were calculated (values greater than 0 P). In the 15 and 30 kg P/ha treatments some 80% and 73%

were found in the top 10cm, and 20% and 27% were found at the 10-20cm depth.

(10) There was some evidence that some P did move down to depths of 20-40 cm in the 30 kg P treatment. There was no evidence of increased P levels in any treatment below this depth.

(11) Vast quantities of P remain very close to the surface. In the zero P treatment, there were 5.3 and 3.8 mg P/l of soil in the top 0-5mm and 5-100 mm of soil. In the 30kg P/ha treatment there were 51.8 and 18.7 mg P/l soil in the top 0-5mm and 5-100 mm of soil.

(12) This work indicates that there is some scope for further changes in the Teagasc Recommendations. It suggests that some modifications of the break points in the various indices are possible. However, the data in this report are based on some speculation and calculations, and therefore warrant further verification. The problem with further modifications of the index system is that we may be attributing more accuracy to a soil index system than is warranted. If further modifications are made considerably more attention will need to be paid to the whole area of soil testing and analysis, and the P requirements of high yielding ruminants.

LITERATURE REVIEW

During the last 40 to 50 years grasslands in Ireland have been fertilised with phosphorus (P) and this has led to increases in the levels of production and the concentration of phosphorus in the soil. Imports of P fertiliser exceeded exports as produce in all years 1900-1953 except for the second world war years. Annual fertiliser use over this period varied from 17,000 to 30,000 tonnes of P. From the 1950's onwards fertiliser P use rose (Walsh, Ryan and Kilroy 1957) until a peak of over 80,000 t was reached in 1970 with an annual average of over 60,000 tonnes in recent years (source, Department of Agriculture and Food). In the years 1997, 1998 and 1999, P usage has dropped to approximately 50,000 tonnes.

National P budgets for Ireland show that the surplus (input-output) of P for Ireland in tonnes in 1953, 1968 and 1988 respectively were 8093, 60672 and 46041. On an area basis (kg/ha) those figures translate to 1.4, 10.6 and 8.0 for the same years indicating substantially more P applied than is used to produce crops and animals, (Walsh *et al.* 1957, Hanley & Murphy 1973 and Tunney 1990). As a result of the use of fertiliser P and grain concentrates containing P the Morgan's soil test values for Irish soils has risen from less than l mg/l of soil to 9 mg/l of soil from 1950 to 1995 (Power, 1992).

There have been numerous experiments in Ireland looking at the response of P on grassland. Walsh, Mannion & Ryan (1950) reported that 90% of the Irish soils at that time were moderately or very deficient in P. Neenan, Murphy and Conway (1961) reported the results of 44 grazing trials during the years 1957-1959 carried out on commercial farms. Yields were determined by clippings from enclosure cages. Application of P tended to cause a 20% yield increase. Sweeney (1963) looked at 0, 20 and 40 kg/ha over three years on 49 pasture sites including Grey Brown Podzolics, acid Brown Earths and Gleys for a silage harvest in the spring. Soils which tested less than 3 mg/ l by the Morgan's method showed reduced herbage P concentrations.

Some 20% of the soils analysed for nutrient status at Johnstown Castle Laboratories in 1997/1998 had P levels in excess of 10 mg/l (Morgan's), and these levels are unnecessary for optimum production (Culleton *et al.* 1996, Herlihy *et al.* 1996)

It seems that if this trend continues, soil P will remain high and the threat to the country's water quality will continue which will put agriculture in conflict with the country's environmental agenda. The Cowland's experiment at Johnstown Castle is the only-long term grazing trial conducted in Ireland and is valuable as a source of information on P requirements for grazed pasture and on the partitioning of soil P forms.

METHODOLOGY

The experiment known as Cowlands was initiated at Johnstown Castle in 1968. Phosphorus fertiliser was applied annually at 0, 15 and 30 kg/ha. The annual application was made in the spring and was spread on the top of the soil. Each treatment had a low stocking rate (LSR) and a high stocking rate (HSR) (2200 and 3300 kg stock/ha). The animals in each treatment were rotationally grazed around six paddocks, with 18-24 day rest intervals. Stocking rates were progressively reduced as grass growth declined as the year progressed. Plot size was 0.45 ha. Animal performance was determined by weighing the steers each month. Yearly live weight gain (LWG) was determined from 1970 to 1987. Murphy (1970-1987) provides a more detailed description of the methods used in this experiment. The yearly LWG was averaged over the 18-year period and this average was used to determine the LWG over the 30-year period. In 1968, all plots were dominated by *L. perenne*. In 1998, the P0 plots were dominated by *Agrostis tenuis*. The P15 and P30 plots remained dominated by *L. perenne*.

Soil samples were taken in November 1997 at 0-2, 2-4, 4-6, 6-10, 10-14, 14-20 and 0-10 cm depths in all plots. Four soil samples were taken in August 5th, 1998 in the HSR plots (one plot per treatment) at 0-20, 20-40, 40-60, 60-80 and 80-100cm. Soil samples were taken on August 27th, 1998 at 0-5mm and 5-100mm from one plot in the HSR area. Soil samples taken at various depths and times in 1997 and 1998 were extracted to determine Morgan's P. In addition, total P, inorganic P and organic P were determined by the ignition method of Saunders and Williams (1955), as modified by Walker and Adams (1958) on the samples taken in November, 1997 in the HSR plots.

RESULTS AND DISCUSSION

The animal production data are presented in Table 1. There is a response to both stocking rate and fertiliser P with respect to beef production. Across all P rates, the higher stocking rate produced more beef compared to the low stocking rate. Maximum beef production in the HSR was in the 15kg P treatment. Additional P did not increase production and the 0 P treatment had a relative yield of 71% of the 15kg P treatment. The P exported or removed from these various grazing systems in the beef over the 30-year period was lower where no P was used. In both stocking rates P increased the amount of P in the beef exported, as would be expected. The amount of P fertiliser that was exported in the beef ranged from about 6% to 20 % suggesting that most of the fertiliser P is still in the soil. The highest fertiliser use efficiency was at the 15kg P rate which met the needs of the plants whereas at the 30 kg P rate the extra 15 kg/ha of P was not needed for grass or beef production. The export of P per year in beef from the 15 and 30 kg P treatments was 1.6 to 3 kg/ha greater than the 0 P treatment.

Table 1: Effect of P and stocking rate on live weight gain (LWG) and some other factors, Cowlands experiments, 1968-1998

	P (kg/ha/yr)			P (kg/ha/yr)		
	LSR			HSR		
	0	15	30	0	15	30
LWG kg*	21,273.00	26,790.00	27,800.00	26,285.00	36,318.00	35,393.00
LWG kg/ha/yr	709.00	893.00	927.00	876.00	1,211.00	1,180.00
LWG % of 15 P	79.00	100.00	104.00	72.00	100.00	97.00
P in Beef kg/ha/yr+	6.40	8.00	8.30	7.90	10.90	10.60
P in Beef, kg/ha&	192.00	240.00	249.00	237.00	327.00	318.00
P appl. in 30 years	0	450.00	900.00	0	450.00	900.00
% P fert in beef^		11.50	6.30		20.00	9.00

* LWG for 1970-1987

\+ Based on 1970-1987 data and that there is 0.9kg of P/100kg beef.

& Calculation for 30 years using average for 1970-1987

^ Uses the 0 kg/ha of P as a base

Soil samples were taken in 1997 which is 30 cropping seasons after the experiment was initiated and the soil P were extracted with Morgan's extractant. In Table 2 the Morgan's P in the 0-10 cm sample in the OP plots was 2.4 mg P/l, and in the 15 P plots was 6 mg P/l.

Table 2: Effect of P fertiliser and sampling depth on Morgan's P (mg P/l soil), Cowlands 1997

Soil Depth (cm)	P applied (kg/ha)		
	0	15	30
0 - 2	5	12	23
2 - 4	3	8	17
4 - 6	2	6	15
6 - 10	2	5	11
10 - 14	2	3	9
14 - 20	1	2	4
0 - 10	2.4	6.0	14
10 - 20*	1.4	2.4	6

* Weighted average using above data

Phosphorus application level, soil stratum and soil stratum x stocking rate were statistically significant at the 0.0001 level.

There is clearly a downward movement of P fertiliser in the soil profile as all the P fertiliser was applied to the surface. Most of the P is in the very top part of the soil, as determined by Morgan's method. There is evidence that the P fertiliser has moved to the 14-20 cm depth after 30 years. There is also an increase in the soil P when comparing the 15 and 30 kg P treatments, indicating that the second increment of P increased the soil test for P. Further analysis on the samples taken in November 1997 shows the effect of P fertilisation on soils at various depths with respect to total, inorganic and organic P (Table 3).

Table 3 shows that the addition of P fertiliser over 30 years and the data for total, inorganic and organic P supports that found with the Morgan's extractant. Inorganic, organic and total P were significantly different at the 0.05 level across P rates and soil depths. Inorganic and total P were significantly different at the 0.05 level for the P rate x soil depth but organic P was not. There was increasing P in both inorganic and organic fractions as a result of P additions, although the largest increase was in the inorganic fraction. In the 0 P treatment at 0-2 cm, 32 % of the total P was inorganic whereas in the 15 and 30 kg P treatments it was 44 and 47 % respectively. Inorganic P was higher with increasing rates of P at all depths sampled. However, at the 14-20 cm depth the difference between the 15 and 30 kg P rate was quite small. These values were much closer to the 0 P rate than in the soil above this zone. This indicates that there was movement from the surface of the soil where the P was applied to at least 20 cm. The same general trend is also evident in the total soil P values. The organic P is higher in the top 10 cm but after that there appears to be only slight differences.

Table 3: Effect of P rate over 30 years and sampling depth on inorganic, total and organic P (mg P/kg soil)

	P fertiliser (kg/ha/yr)								
Soil Depth (cm)	Inorganic P			Total P			Organic P		
	0	15	30	0	15	30	0	15	30
0 - 2	223	456	589	693	1027	1237	471	571	635
2 - 4	187	452	706	582	954	1192	395	501	486
4 - 6	175	399	689	550	893	1154	374	493	465
6 - 10	169	334	551	513	822	910	343	488	359
10 - 14	181	319	458	512	689	820	331	370	362
14 - 20	149	240	268	427	618	563	258	378	295
Mean									
0 - 10	181	365	586	552	838	1002	371	474	417

Standard Error (S.E.) for P rates, soil depth and P rate x soil depth for inorganic, organic and total P.

	Inorganic	Organic	Total
P Rate	6.28	7.77	10.14
Soil depth	9.59	11.88	15.49
P rate x soil depth	16.61	20.57	26.83

A further set of soil samples was taken in 20 cm increments to a depth of 100 cm to ascertain whether P was moving down the soil profile below 20 cm (Table 4). Morgan's P increases with P fertiliser rate and decreases with depth in the soil profile, as would be expected. There is evidence that P has moved into the 20-40 cm depth to some extent in both the 15 and 30 kg P treatments but not beyond that. Beyond that depth there is some slight variation in the soil P level but it appears to be random.

Table 4: Effect of P rate and sampling depth on Morgan's P (mg/l) in the HSR of the Cowlands (Sampled August 1998)			
Soil Depth (cm)	P applied (kg/ha)		
	0	15	30
0 - 20	1.4	6.2	13.2
20 - 40	0.9	1.6	2.7
40 - 60	0.9	1.0	0.8
60 - 80	0.5	0.8	0.6
80 - 100	0.5	0.7	0.6

All figures are averages of four samples

Additional soil samples were taken from the top soil layers in the HSR 0 and 30 kg P/ha treatments. One plot in each treatment was sampled at 0-5mm and 5-100mm (Table 5). These samples were taken to determine the P status at the very top portion of the soil. If there is overland flow, it is most likely that it is in this portion that interacts with the water as it moves across the soil surface.

Table 5: Influence of P fertiliser and sampling depth on the Morgan's soil test value in the Cowlands experiment		
P applied(kg/ha)	Morgan's P mg/l soil	
	0-5mm	5-100mm
0	5.3	3.8
30	51.8	18.7

As expected, the top 5mm has more P than the 5 to 100 mm, as all the fertiliser and manure is put on the surface. As the rate of fertiliser P increases the P in the top 5mm increases much more proportionately than in the 5 to 100mm sample. The Morgan's P in the 30kg P treatment in the top 5mm is almost 10 times higher than in the 0 P treatment. This may partially explain why the loss of P from soils testing higher in P have a proportionately greater loss of P than the soils testing lower in P. Power (1992) and Daly (1999) would support this. Their research in the Cowlands showed that as the Morgan's P increased water soluble P increased. This agrees with the review by Sibbesen and Sharpley (1997).

During rainfall, water will move downhill and across the surface of the soil. As it does, some of the P in solution will move with the water and the equilibrium dynamics at that time will attempt to restore the balance and therefore solid-phase P will move into the solution phase. The higher the P in the whole system the more P will move off into the overland flow, which is borne out in the work of Kurz (1999).

In a separate trial at Johnstown Castle, the soil P and the loss of P via overland flow were monitored in an area called the Warren. In the Warren, the soil P was 4 mg/l, while in the plot where the run-off was measured in the Cowlands the soil P was 17 mg/l. It was found that the loss of P from soils testing 17 and 4 respectively was 4,774 and 698 g/ha/yr (Kurz 1999). This yearly loss was calculated from a monitoring period of 493 days. These data indicate that soil P test is a very important indication of the total export of P from an area via overland flow. It also shows that loss of P from soil increases more than proportionately as the soil test increases. If the loss of P where the soil test was a Morgan's 4 which is 698 g/ha is divided by 4 we get 175 which indicates that there were 175 g of P lost per unit of Morgan's soil test P. Where the soil tested 17 it is 4774/17, which is 281 g of P lost per unit of Morgan's soil test P.

The loss of P fertiliser from the plots with a Morgan's test of 6 (15kg P) and 17 (30kg P) over a 30-year period would be 19 and 130 kg/ha (Table 6). The loss of P fertiliser (30kg P-0 P) from the 30kg P treatment over the 30 year period was 14.5% of the fertiliser P applied over the thirty years. The Warren has a slightly higher soil test P than the 0 P treatment (4.0 compared to 2.4) so the loss of P from the 0 P treatment would most likely be less. If the average soil test is 2.4 and if we use the value of 175 g per unit of Morgan's P the loss would be 420 g/ ha (175x2.4) The loss over a 30-year period would be 12.6 kg/ha.

Table 6: Loss of P from Cowlands Experiment via overland flow			
	P applied (kg/ha/yr)		
	0 *	15 &	30 #
kg/ha/yr	0.420	1.050	4.774
kg/ha/30 years	13	32	143
Loss greater than 0 P for 30 years (kg/ha)		19	130

* Using soil test of 2.4 Morgan's P and a loss of 175 g/ unit Morgan's P

& Using soil test of 6.0 Morgan's P and a loss of 175 g/unit Morgan's P

Measured value by Kurz (1999)

MASS BALANCE STUDIES

The amount of P fertiliser exported in beef and lost via overland flow has been determined. Movement of P has also been detected into the 20-40 cm zone. The mass balance of P or the accounting for where the fertiliser P has gone has not yet been fully determined.

The mean balance of P could be determined by knowing the sum of the various pathways of P fertiliser. It would be very helpful to have soil P analysis at time zero and at the end of 30 years in all plots but we have only the data at the end of 30 years. It would also be helpful to have the amount of P lost via overland flow in each of the plots each year. This was not done but we do have the amount lost in one year in the 30kg P treatment and in the Warren experimental site at Johnstown Castle. Phosphorus lost via overland flow was not the original objective of this work. We have animal performance over 18 of the 30 years so we are able to estimate P exported in beef quite well. We do not know the amount of P tied up in grass or manure at the beginning or the end of the experiment but the amount that would be in that form would be very small. If we had 1000 kg/ha of grass at 0.3% P that would be 3 kg/ha. If there were double that in manure we would have less than 10 kg/ha over a 30- year period that could not be accounted for. These sources are being eliminated in this process as not being sufficiently important to affect what we are really trying to do. Another possibility would for P to be lost due to erosion. However, under the conditions of this experiment that would be very small and it is also eliminated as a pathway. Therefore, the P pathway from fertiliser will be as follows:

Fertiliser P in the soil = total P fertiliser applied - (fertiliser P in beef + fertiliser P lost via overland flow)

Fertiliser P in a 15kg P or 30kg P treatment = (15kg P or 30kg P - 0 P)

The Mass Balance that is carried out is an exercise that is based on calculations and assumptions as mentioned above and probably some speculation. It is important to attempt to address this issue because it will help to present a holistic view of what the pathways are for P fertiliser over the long period of this experiment. Tables 7, 8, 9 and 10 present data for total and Morgan's P for the top 20 cm.

Table 7: Effect of P application rate for 30 years in the Cowlands on total P (kg/ha) at various depths

Soil Depth (cm)	P applied (kg/ha)		
	0	15	30
0 - 2	125	185	223
2 - 4	105	173	215
4 - 6	99	161	208
6 - 10	185	296	328
10 - 14	184	248	295
14 - 20	154	222	304
Total	852	1285	1573

Calculations based on a soil weight of 900,000 kg/ha for 10 cm of depth.

Table 8: P feriliser detected at various depths using total P (values greater than 0 P)

Soil Depth (cm)	P applied (kg/ha)			
	15		30	
	kg/ha	% of total	kg/ha	% of total
0 - 2 2 - 4 4 - 6 6 - 10	60 68 62 111	14 16 14 25	98 110 109 143	14 15 15 20
Sub Total	301	69	460	74
10 - 14 14 - 20	64 68	15 16	111 115	15 21
Sub Total	132	31	226	36
Total	433	100	686	110

Table 9: Morgan's P (kg/ha) detected at various soil depths as affected by P fertiliser after 30 years

Soil Depth (cm)	P applied (kg/ha)		
	0	15	30
0 - 2 2 - 4 4 - 6 6 - 10	0.9 0.5 0.4 0.7	2.2 1.4 1.1 1.8	4.1 3.1 2.7 4.0
Sub Total	2.5	6.5	13.9
10 - 14 14 - 20	0.7 0.5	1.1 1.1	3.2 2.2
Sub Total	1.2	2.2	5.4
Total	3.7	8.7	19.3

Calculations based on a soil weight of 900,000 kg for 10 cm of

Table 10: P ferliser detected at various depths using Morgan's P (values greater than 0 P) after 30 years of fertiliser

Soil Depth (cm)	P applied (kg/ha)			
	15		30	
	kg/ha	%	kg/ha	%
0 - 2	1.3	26	3.2	20
2 - 4	0.9	18	2.6	17
4 - 6	0.7	14	2.3	15
6 - 10	1.1	22	3.3	21
Sub Total	4.0	80	11.4	73
10 - 14	0.4	8	2.5	16
14 - 20	0.6	12	1.7	11
Sub Total	1.0	20	4.2	27
Total	5.0	100	15.6	100

Total P is increased by P fertiliser application and the fertiliser P in the top 10 cm is 70% or more of the total detected in the top 20 cm (Tables 7 and 8). The Morgan's P data (Tables 9 and 10) show a similar trend and the fertiliser P detected in the top 10 cm varies from 74 to 80%. Both total P and Morgan's P suggest that the P from fertiliser moved at least to the 14-20 cm depth and it also suggests that it has probably moved below that.

Table 11 is an attempt to use the data from Tables 1, 3 and 6 to get some sense of where the P fertiliser went in the treatments receiving P.

Table 11: P in soil, lost via overland flow or exported in beef as affected by P fertiliser over a 30-year period

	P (kg/ha)		
	0	15	30
Total P in top 20cm	852	1285	1573
P fertiliser applied	0	450	900
Total soil P over 0 P	0	433	721
P fertiliser in beef over 0 P	0	90	81
P fertiliser lost via overland flow over 0 P	0	19	130
Total P detect in soil, water and beef above 0P	0	542	932
P detected excess <*> Compared to 0 P soil plus 0 P beef	0	*92	*32

*Total P in top 20 cm (sum of 0-2, 2-4, 4-6, 6-10, 10-14 and 14-20 cm)

The 15kg P treatment has 92 kg P/ha over and above that in P 0 detected in the beef, in the top 20 cm of soil and lost via overland flow as coming from the fertiliser than was actually applied (Table 11). The extra P could be coming from below the 20 cm depth, which is probable, or the extra P detected could be from original soil differences which are unknown. The 30kg P treatment has 32 kg P/ha which cannot be detected as being in the beef or the soil to a depth of 20 cm. Some has moved below the 20 cm depth so these figures would actually be larger. The data from Table 4 from beyond the 20 cm depth could help clarify where the fertiliser P finally ended up and this is presented in Table 12.

Table 12: Fertiliser P exported in beef, lost via overland flow and remaining in the soil after 30 years of applying 15 and 30 kg/ha of P fertiliser in the Cowlands experiment

	P (kg/ha/yr)	
	15	30
Fertiliser P applied, kg/ha	450.00	900.00
Fertiliser P in beef	90.00	81.00
Fertiliser P lost via overland flow	19.00	130.00
Fertiliser P in the soil	341.00	689.00
kg/ha Morgan's P, 0-10cm	4.00	11.40
kg/ha Morgan's P, 10-20cm	1.00	4.20
kg/ha Morgan's P, 20-40cm	1.30	3.20
Total Morgan's P, 0-40cm	6.30	18.80
% of Morgan's P, 0-10cm	63.00	61.00
% of Morgan's P, 10-20cm	16.00	22.00
% of Morgan's P, 20-40cm	21.00	17.00
kg P/ha needed to increase Morgan's P one unit	54.00	37.00
Based on above ratio and Morgan's P value		
Fertiliser P in 0-10cm, kg/ha	215.00	420.00
Fertiliser P in 10-20cm, kg/ha	55.00	152.00
Fertiliser P in 20-40cm, kg/ha	72.00	117.00

Figures in the above table for kg/ha of P in the soil were determined by subtracting the 0 P treatment from the 15 or 30kg P treatment.

Using 0.9 mg P/l as the base level of P in the 0 P treatment at the 20-40 cm depth there is an additional 0.7 mg P/l of soil at this depth in the 15kg P treatment. This amounts to an additional 1.3 kg of P in the 20-40 cm layer compared to the 0 P treatment. For the 30kg P treatment assuming that the base level of Morgan's P in the 20-40 cm depth is 0.9 mg P/l of soil (the amount in the 0 P treatment) then the amount of increase in soil P at the 20-40 cm depth is 1.8 mg soil P/l. That amounts to 3.2

kg of Morgan's P that has moved into the 20-40 cm depth. This allows us to calculate new values of P in the profile as a result of fertiliser additions of 15 and 30 kg of P/ha for a 30-year period based on Morgan's P.

Table 12 shows that more than 60% of the Morgan's P detected in the 15 and 30kg P treatments is in the top 10 cm with the remainder in the 10-40 cm zone. This means that a very significant amount of available P is beyond the zone of soil testing and yet could be contributing to grass and beef production. There may be a small amount of P fertiliser P that moved below 40 cm via macro-pores that is not detectable using the Morgan's P but this is assumed not to affect the central point of this exercise which is that most or almost all the fertiliser P went to beef, was lost to overland flow or stayed in the soil.

There are limitations in our ability to take accurate samples and account for all the P without error. It does account for where most of the P is presumed to go, in that it is assumed that all the P is in the beef, soil and overland flow. The 15 kg P treatment had five times more P exported in the beef compared to that lost via overland flow. However, in the 30kg P treatment more P was lost via overland flow than was exported in the beef. This indicates that when the soil is high in P that this P is susceptible to being moved off-site via overland flow, when conditions exist such as those in some Johnstown Castle soils. The P not exported in the beef or lost via overland flow is assumed to be in the top 40 cm of soil which seems to be reasonably based on the biology, chemistry and physics of P and the data that have been developed in this investigation. Most of the P applied is still in the soil and most of that is in the top 10 cm.

Table 13 presents a general summary of where the P fertiliser went. About 75% remains in the soil in both treatments but there is a major difference where the other P went and that seems to be very related to the relative soil test. If it is in the range where the soil P is sufficient to take care of the plant needs a small portion will be lost via overland flow. However, if the soil P test is considerably higher than that needed for plant production then the amount lost via overland flow is considerable.

Table 13: Percent of P Fertiliser found in beef, soil and lost via overland flow in the 15 and 30kg P treatments in the Cowlands experiment over a 30-year period		
	P applied (kg/ha/yr)	
	15	30
Beef	20%	9%
Soil	76%	77%
Overland Flow	4%	14%

During the last 40 years Irish agriculture has benefited greatly from the use of fertilisers. Soil P levels that were quite low resulted in low production. During this 40 year period as the soil P levels have increased and production has benefited the issue of P runoff into Irish rivers and lakes has appeared.

The response curve to P fertiliser appears to be quite steep between a Morgan's 0 and 2, 3 or 4. The Cowlands research, and research in Ireland and other places, suggests that once the yield maximum is reached the response curve is quite flat. This means there is little or no probability of additional response to P fertiliser beyond some point around 4, 5 or 6, based on the literature and the Cowlands data. Fertiliser should be applied where the probability of the response is high and it should be omitted where the probability is very low or nil.

There is a very significant body of research in the United States about the economics of production, and environmental quality, as affected by soil testing methods and philosophies of making fertiliser recommendations (Eckert and McLean 1981, Liebhardt 1981, Olsen *et al.* 1982). This work has convincingly shown that the concept of the sufficiency level is superior to both the maintenance and cation balance philosophies for both farmers and the environment. The sufficiency level approach states that you test for an element and when the level is sufficient in the soil no further additions of fertiliser are made. The USA experience with both the maintenance and cation balance method appears to make sense but they are not based on research and field calibration data in general. Both recommend fertiliser additions when the sufficiency level would not, driving up the cost for farmers and damaging the environment. The maintenance approach can justify applying the amount of fertiliser that was removed in the crop, even at soil test levels beyond the sufficiency level approach. The Irish system of soil testing is a combination of the sufficiency method and the maintenance method. The Teagasc advice of no fertiliser P at all is recommended for grassland above 10 mg/l. Below this the maintenance method is used between 6 and 10 mg/l.

Based on the data from this work and from the literature with respect to production agriculture, the upper limit for Morgan's P soil test could be somewhat lower than is currently the case for Irish soils where grass and/or legumes are grown for animal production. This would improve the economics for farmers and reduce the loss of P from agriculture, enhancing environmental quality.

There are some difficulties with further modifications to the current P advice. The P advice is based on the four principles, the first is to maintain soils at satisfactory P levels and the second is, once satisfactory soil P levels are attained, they are maintained by using organic or inorganic P to replace the P that is removed in milk, meat or losses via overland flow. The third principle is to constantly monitor soil P levels, and the fourth is to follow a code of practice for spreading fertilisers. Replacing P that is removed is surely a sustainable practice that is difficult to criticise. Changing the target soil P status (*i.e.* the soil index) is therefore where attention must be focused.

At the moment Index 3 is recommended for intensive agriculture and the range is this Index is 6.1 – 10 mg/litre soil. Changing this index is fraught with difficulties and if Index 3 were to be reduced, considerably more attention will need to be paid to soil sampling and soil types assuming productive agriculture is to be protected. Issues like soil type variations, soil sampling intervals, uniformity of areas to be sampled, sampling depth, sampling errors, methodology of sampling and analytical variations all warrant very close attention. Finally, if the target soil P levels are to be reduced, more attention will also need to be paid to the P nutritional requirements of productive ruminents.

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