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END OF PROJECT REPORT

PROJECT 4231

AN ASSESSMENT OF THE LONG TERM EFFECTS OF THREE PHOSPHORUS FERTILISER REGIMES ON SOIL PHOSPHORUS AND SWARD COMPOSITION

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AN ASSESSMENT OF THE LONG TERM EFFECTS OF THREE PHOSPHORUS FERTILISER REGIMES ON SOIL PHOSPHORUS AND SWARD COMPOSITION

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SUMMARY

1. A grazing trial using beef animals (mean weight 260 kg) was used to determine optimum soil phosphorus levels for dry stock farming.

2. The trial commenced in 1968. There were three fertiliser P treatments, 0, 15 and 30 kg P/ha applied annually. There were two stocking rates, 3300 and 2400 kg liveweight at turn out, respectively. Animals were rotationally grazed around six paddocks per treatment and stocking rates were reduced in June and September to match feed supply. The trial continued until 1998.

3. Nitrogen was applied at a rate of 220 kg/ha per year to all treatments.

4. Liveweight gains/ha/year were monitored annually. Soil P levels were monitored by sampling to 10 cm depth.

5. The distribution of phosphorus in the soil was recorded by analysing P levels at various depths from 0-2 mm to 100 cm. Botanical composition was recorded at the commencement of the trial and again in 1997. Phosphorus levels in herbage were also recorded.

6. An analysis of the liveweight gain data showed that for optimum output a Soil Index of 3 (Morgans P between 6.1 and 10.0 mg/l) is the target Soil P Index.

7. Phosphorus recovery (as expressed by percentage of P fertiliser recovered in product) in the P30 treatments was low and was better in the P15 treatments.

8. The vast bulk of P accumulated near the surface of the soil, but there was some evidence of movement down the profile in the P30 treatment over a 30 year period.

9. The soil P status influenced both the botanical composition of the sward and the P content in the herbage. The perennial ryegrass content declined on the zero P treatment, while there were no significant differences between the P15 and P30 treatments. The P concentration in the herbage in the zero P treatments were not sufficient for healthy growth of plants or animals.

CONCLUSIONS

- This grazing trial demonstrated very clearly that for optimum production soil P levels should be in Index 3, i.e. Morgan's P levels between 6.1-10 mg/l.

- Phosphorus recovery in product at the low stocking rates was poor, but improved in the high stocking rates. It is deduced that when the new Teagasc recommendations are implemented, recovery of applied P in product should be very efficient.

- This trial showed that over a 30 year period, the applied P tended to accumulate at or near the surface of the soil. It is concluded that if there is a risk of run off, or erosion, it is probable that some P will also be carried in the run-off water and in the eroded soil. The amount of P loss to water after this occurs depends on proximity to water bodies.

- There is not a great deal of movement of P down the soil profile, although when 30 kg P/ha is applied for 30 years, there was limited evidence of some downward movement into 20-40cm depths of soil.

- With normal soil sampling the trial commenced in 1968 at a mean soil P level of 6 mg/l. Some 30 years later when 0, 15 and 30 kg P/ha was applied, mean soil P levels were 2, 7 and 17 mg P/l respectively.

- The soil P levels influenced the botanical composition of the sward. The P15 and P30 swards were still dominated by perennial ryegrass after 30 years of grazing. However the P0 swards which started out with predominantly perennial ryegrass swards were, after 30 years, dominated by unproductive grasses like *Agrostis* species.

- There was adequate P in the herbage to meet the nutritional requirements of plants in the P15 and P30 treatments. In the P0 treatments the mean P level was less than 2 mg/kg DM, and this appeared to be inadequate for healthy growth of perennial ryegrass. Grasses like *Agrostis*, that appear to be able to survive at impoverished soil P levels, thrived in these circumstances.

- There was adequate P in herbage in the P15 and P30 treatments to meet the nutritional requirements of the livestock. The mean P levels in the herbage in the P0 treatments were inadequate to meet the nutritional requirements of livestock.

INTRODUCTION

The use of phosphorus fertiliser in agriculture has been the subject of heated debate in recent years. While phosphorus is an essential element for plant and animal growth, its over-use in agricultural ecosystems can lead to leakages of P to water bodies. The presence of P in water bodies can lead to eutrophication and significant deterioration in water quality.

A recent review of trials that examined responses to P (Teagasc, 1996) has shown that there is little agronomic justification for having a soil P level of greater than 10 mg/l. A survey of the P levels of soils analysed for nutrient status at Johnstown Castle indicate that some 25% of soils analysed had P levels in excess of agronomic requirements, while a further 25% had P levels that were so low that optimum productivity could not be guaranteed (Culleton, 1998).

The sale of phosphatic fertilisers is summarised in Table 1 and shows that P usage reached a peak in the 1979 - 1985 period and has declined to 49000 tonnes in 1997-1998. Tunney (1990) showed that in the region of 31,250t is exported annually in animal and plant product. It is logical to assume, therefore, that the excess P is, for the most part, remaining in the soil and it is this excess P applied annually that is leading to the steady increase in soil P that is evident in the trends over time i.e. from the 1950 level of one mg P/l to the levels of 8-9 mg P/l that are the current mean soil P levels.

Table 1: N P K usage in Ireland ('000 tonnes nutrient)

Year	Phosphorus	Potassium	Nitrogen
1960/1961	35.7	55.5	25.0
1964/1965	49.6	76.3	29.6
1969/1970	73.8	117.8	71.3
1974/1975	50.5	93.1	133.0
1979/1980	68.0	157.0	247.5
1984/1985	66.0	163.8	327.7
1989/1990	64.6	158.4	379.3
1994/1995	61.9	150.5	428.8
1995/1996	61.9	152.1	416.9
1996/1997	53.8	132.1	379.5
1997/1998	49.9	124.3	432.0

The objective of the study was:

a) to determine the optimum soil P level for grazing animals,

b) to determine the effects of fertiliser P on efficiency of usage,

c) to examine the distribution of P in the soil profile,

d) to examine the effects of P on herbage and botanical composition

METHODS AND MATERIALS

In 1968, an experiment was established at Johnstown Castle (Cowlands experiment) to examine the P requirements for grazing animals. The soil had initially a P level of 6 mg/l and is a sandy loam in texture. Three levels of P were applied, 0, 15 and 30 kg P/ha, with high and low stocking rates for each fertiliser treatment, 3300 kg and 2400 kg/ha at turnout in Spring. Stocking rates were reduced in July and September of each year so that animal demand was met by grass supply. The cattle (mean wt = 260 kg) in each of the six treatments were rotationally grazed around 6 paddocks. Live weight gains were recorded. All plots received optimal rates of N and K annually i.e. 220 kg N was applied annually in five equal dressings throughout the year and 40 kg K/ha was applied every Spring.

In 1996, all soils were sampled at various depths at intervals of 4cm to a depth of 20cm. In 1998, all soils were sampled at depths of 0-20, 20-40, 40-60, 60-80 and 80-100cm. Soil P status (Morgans extract) was determined for each depth. In 1998, a botanical analysis of each plot was conducted by taking 10x10cm quadrats to examine the species present. Ten quadrats per plot were taken and six replications of each fertiliser treatment were analysed. Results are expressed in terms of tillers/m^2. Herbage samples immediately prior to and post grazing were taken throughout 1998 and phosphorus content analysed as outlined by Byrne (1979).

Soil P levels for optimum output

The analysis carried out by Herlihy et al (1996) of the Cowlands grazing trial used the relative liveweight gain data at the high stocking rate for the years 1979-1988 inclusive, when the Morgan-P categories had equilibrated at values of about 2, 6 and 14 mg/l for the different fertiliser P inputs. The equations used to relate % liveweight gain (% LWG) included squared-term quadratic and various exponential functions as follows:

1. $y = a + bx + cx^2$
2. $y = a + b(r)^x$
3. $y = a + b(r)^x + cx_2$
4. $y = a + (b + cx)\ r^2$

Where y = % LWG, x = Morgan P and a, b are estimated parameters. The quadratic (1) and direct exponential (2) accounted for 84.9% of the variance, whereas equations (3) and (4) accounted for 84.3%, maximum LWG occurred at Morgan P values of 10.3, 16.0, 10.3 and 10.0, respectively. The direct exponential estimated the maximum attainable relative LWG as 98.7%, whereas the other equations gave estimates of 105-108%. If the optimum %LWG was assumed to occur at 97.5% of the maximum attainable, the corresponding soil-test values were 6.1 for the direct exponential and within the range 7.9-8.4 for other equations. On balance, these results suggest desirable Morgan P levels lies within the range of values of 6.1-10.0 mg/l.

It is largely these conclusions, that led to the new Teagasc recommendations for grazing i.e. for intensive farming Index 3, (6.1-10 mg/l) is the target Soil P Index. Once this is achieved the entire P fertiliser strategy is based on a) replacing what is removed by the farming system and b) regular soil testing to monitor the sustainability of the system.

Soil P levels and P Resources

At the start of the trial in 1968, all soils were at a mean soil P level of 6 mg/l. Table 2 outlines the soil P levels after 30 years.

Table 2: Soil P levels (Morgans extract) 1968 and 1998

		High Stocking Rate			**Low Stocking Rate**		
	kg P/ha	**0**	**15**	**30**	**0**	**15**	**30**
Soil P Levels (mg/1)	1968	6	6	6	6	6	6
	1998	2	7	14	2	**6**	

Soil P levels decreased in the zero P treatments and increased as the rate of P fertiliser increased. The issue of efficiency of P recovery is covered in Table 3. The liveweight gain/ha/data are typical of outputs from similar systems. The P exported from these various grazing systems in the beef over the thirty year period was lower when 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 that was exported in the beef ranged from about 11% to 33%, suggesting that most of the fertiliser P is still in the soil. The higher fertiliser use efficiency was at the 15 P rate which meet the needs of the plants whereas at the 30 P rate the extra 15 kg/ha was not needed for grass or animal production.

Table 3: LWG as affected by stocking rate and phosphorus fertiliser in the cowlands experiment 1968-1998

	LSR P (kg/ha)			**HSP P (kg/ha)**		
Fertiliser Treatment	**0**	**15**	**30**	**0**	**15**	**30**
LWG kg*	21,273	26,790	27,800	26,285	36,318	35,393
LWG kg/ha+	709	893	927	876	1,211	1,180
P in Beef kg/ha+	10.6	13.4	13.9	13.2	18.2	17.7
P in Beef kg/ha&	318	402	417	395	545	532
P Applied in 30 years	0	450	900	0	450	900
% P Fert. In Beef^	0	18.6	11.0	0	33.0	15.2

* LWG for 1970 -1987
+ Based on 1970 - 1987 data and that there is 0.9 kg of p/100kg beef
& Calculation for 30 years using average for 1970 - 1987
^ Uses the 0 kg/ha of P as a base (for example 402 -318/450=18.6)

There are two distinct parts to the new recommendations, the first part is deciding the target soil P level. This trial determined that Index 3 is the target index. The second part is to replace what is removed. The maintenance dressings are summarised in Table 4.

Table 4: P maintenance required for dry stock (kg/ha)

	Stocking Rate Lu/ha			
	1.0 - 1.5	**1.6- 2.0**	**2.1 - 2.5**	**>2.5**
Dry stock	3	5	7	9

This trial showed 33% recovery when 15 kg P/ha was applied. When the recommended P rate is applied at the correct soil P levels, we now assume 100% recovery in the long term. This does not take P losses by run-off or leaching into account. Hence, there is a need to soil test regularly to monitor soil nutrient levels.

Distribution of P in Soil

Phosphorus forms compounds in most soils that have extremely low solubility in water are generally (although not always) held in the soil against leaching by drainage water (Cooke, 1967). It is mobile only in some peat soils and sands. When phosphorus is applied to normal soils it is dependant on tillage operations and the actions of soil organisms including plant roots for distribution in the rooting zone of the soil profile. In the case of grassland, tillage operations are absent, and soil phosphorus distribution is dependent on processes within the soil. This can lead to stratification of available P with the higher concentrations near the surface. Grasslands, therefore, represent a large reservoir of P which is vulnerable to export via surface and subsurface path ways (Harris, Heathwaite and Haygarth, 1995).

The data concerning the available P distribution as measured by Morgan's extract in the top 20cm of soil in the various fertiliser treatments are summarised in Table 5. The available P accumulated at or near the surface. The differences between treatments when measured in terms of available P did not appear to be significant at

Table 5: Extractable P(Morgans) at different depths and different P application rates on soil receiving 0,15 and 30 kg P/ha

	P Application rate (kg/ha)			
Depth (mm)	mean	1.4	3.7	7.6
0-20	**0**	2.9	1.4	4.0
20-40	4.6	**15**	6.7	14.3
40-80	3.5	13.1	**30**	**mean**
80-120	3.1	8.2	27.8	15.2
120-160	2.8	6.8	18.4	10.0
160-200	2.2	5.6	15.1	8.3
			12.6	

Phosphorus rate LSD=1.96
Depth LSD=0.86

depths below 160mm.
The normal depth of soil testing in grassland soils in Ireland is from 0-100mm. Culleton and Murphy (1998) reported that some 75% of Irish soils that were tested at Johnstown Castle had P levels in Index 3 (soil P > 6 mg/l). The results from this trial suggest that in such soils P levels at or near the surface are liable to be considerably higher than 10 mg/l. Therefore the concentration of P in soil exposed to water flowing over the soil surface is highly likely to be higher than would be indicated by the routine soil testing of grassland soils in this country.

There is some evidence that there is loss of P to waterways from grassland in this country via overland flow and sub surface flow (Ekholm 1994, Sharpley et al. 1994, Tunney et al. 1997). In the light of the high P concentration at or near the soil surface, there is a case to be made to reduce soil P to those levels that are agronomically necessary. This is especially important where overland flow is liable to occur, and where that overland flow has access to waterbodies.

The soil test as we know it is designed to determine the soil fertility levels for the successful growth of crops. It is debatable whether it is a suitable test for environmental risk assessment. A sampling procedure that examines the P concentration in the top 0-50 mm in grassland might be more suitable for environmental purposes. It is entirely possible also that Morgan's P may not be the best method of determining P levels that are liable to run-off. More work is needed on P testing for environmental purposes.

Further testing of the soil profiles in the various P fertiliser treatments were carried out in 1998. The soils were sampled to a depth of 100cm. The results are summarised in Table 6.

Table 6: Morgan's P (mg/l) as affected by P rate and soil depth in the high stocking rate of the Cowlands, samples taken August 1998.			
Depth (cm)	**kg P/ha**		
	0	**15**	**30**
0-20	1.4	2.6	13.2
20-40	0.9	1.0	2.7
40-60	0.9	0.8	0.8
60-80	0.5	0.8	0.6
80-100	0.5	1.1	0.6

Morgan's P increased with P fertiliser rate and decreased with depth in the soil profile. There is evidence that P has moved into the 20-40 cm depth in the 30 kg P/ha treatment but not beyond that. There is some slight variation in the soil P level below 40cm but it would appear to be random. It could be possible for some P to have moved into the lower levels but the Morgan's test is not really sufficiently sensitive to detect that. The evidence from this work suggests by far the greatest proportion of P stays at the surface, but there is slight evidence of downward movement, especially at the high soil P levels. This concurs with Rothamsted results which showed that when Olsen's P passed 60 mg/l, there was some evidence of downward movement of P.

Effects of phosphorus on botanical composition

When soils P levels are in Index 1 (0-3 mg/l) there is little scope for improvements in productivity. In the absence of applied P the productive grasses like perennial ryegrass do not thrive, while grasses like *Agrostis* thrive in these impoverished situations. If high stocking rates are required, it is imperative that soil P levels be moved out of

Index 1.

Conway, McLoughlin and Murphy (1972) demonstrated this very clearly using old permanent pasture for sheep and cattle production systems in Ballintubber, Co. Roscommon. It was shown that when P was applied to an impoverished soil over a four year period and improved management strategies implemented that the stocking rate of cattle and sheep could be increased, resulting in a four fold increase in liveweight gain between the first and the fourth years. There was a major change in botanical composition in the sward over the four years.

Table 7: Output parameters in Ballintubber trial (Conway et al, 1972)

	Year 1	**Year 4**
P levels	1-2 mg/1	?
Fertiliser inputs	40 kg/ha	40 kg/ha
Agrostis spp.	49.8	11.8
Rough Stalked Meadow Grass	2.2	53.3
Liveweight gain kg/ha	213	810

The Cowlands trial examined the reverse situation, i.e. soil P levels were 6 mg/l at the commencement of the trial and the sward was dominated by perennial ryegrass. In the zero P treatment the botanical composition deteriorated as the soil P levels dropped. Table 8 summarises this data. In 1998, the P levels in the zero P plots were 2.0 mg/l and the plots were dominated by *Agrostis* species. Swards in the higher P treatments were still dominated by perennial ryegrass. There were no differences in ryegrass content between the P15 and P30 treatments.

Table 8: Botanical composition in 1968 and 1998

	1968			**1998**		
Soil P (mg/l)	PO	P15	P30	PO	P15	P30
	6	6	6	1.8	7	17
Perennial Ryegrass	90	90	90	30	70	75
Agrostis	5	6	4	41	10	10
Other species	5	4	6	29	20	15

Phosphorus Concentrations in Herbage

Phosphorus is an essential nutrient for plant and animal growth. Phosphorus has many functions in the plant. It is a constituent of nucleoproteins and is thus involved in the portion of protoplasm concerned with cell division and the transfer of hereditary characteristics by chromosomes (Gauch, 1972). Plants suffering from P deficiency are small with a limited root system and thin stems. It is well documented in the literature that nutrient deficiency may cause some redistribution of growth within the plant, root growth often occurring more rapidly in relation to shoot growth (Clarkson et al, 1978, Taylor and Goubran, 1976). The symptoms of P deficiency in grass are blueish-grey leaves and purple colours in young leaves (Murphy, 1977). Normally, perennial ryegrass plants require at least 2.5 g/kg DM for satisfactory growth.

Table 9, summarises the P status of herbage pre grazing at various stages of the 1998 grazing season. In the P15 and P30 treatments there was more than adequate P present to ensure good grass growth.

Table 9: Phosphorus status in pre-grazed herbage from a range of fertiliser treatments in the Cowlands trial

Treatment P	Stocking Rate	Soil P level	Herbage P (g/kg)					
Fertiliser kg/ha	kg/ha at turn-out	(mg/l)	April	May	June	July	Aug	Sept
0	1900	2.7	1.7	0.8	2.1	2.0	2.3	1.9
15	3300	5.8	2.6	3.8	3.1	2.5	2.9	2.9
30	3300	17.6	2.6	4.4	4.4	3.4	3.1	4.5
LSD (P=0.05)			0.5	0.6	0.6	0.7	0.6	0.8
0	1600	2.9	1.6	0.9	1.8	1.3	2.0	1.8
15	2400	5.9	2.9	3.9	4.3	3.9	3.7	4.1
30	2400	17.8	3.8	6.0	4.7	4.7	4.1	4.2
LSD (P=0.05)			0.7	0.7	0.6	0.7	0.6	0.5

However, in the P0 treatments the P levels in herbage were low and were too low for good growth of perennial ryegrass. This explains very well the decline in percentage ryegrass in the sward (Table 8). This data also suggests that species like *Agrostis* perform better in impoverished P soils, than in soils that are high in phosphorus.

From an animal point of view, the recommended dietary allowance of phosphorus (g/kg DM) for cattle depends on animal liveweight and expected liveweight gain. At 700 g daily gain the recommended P levels for 200-400 kg animals is 3.2-3.8 g/kg DM. At 1400 g daily gain the recommended P level is 4.5-5.0 g/kg DM. It is clear from Table 9, that in the P15 and P30 treatments there was adequate P present in the herbage to meet the animals dietary requirements, and it is also clear that there is no significant differences between the P15 and the P30 treatments. However, the P concentrations in the P0 treatments were very low and were inadequate for the needs of animals expected to gain 1 kg liveweight per day. Thus, in Index 1 soils, there is not enough P for healthy plant or animal growth.

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