Phosphorus availability from sewage sludge and animal manures to grass in a pot experiment

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Abstract

Approximately 30 million tonnes of animal manure requires land spreading annually in Ireland. Annual Irish sewage sludge production is 20,000 tonnes but will increase to 120,000 tonnes by 2013 as a consequence of changes in European and National water legislation. Application to agricultural land represents a management option for this organic material, as it results in the recycling of the nutrients for crop production. In this study, the use of these products as a phosphorus (P) source for grass growth was examined in a pot experiment.

This study was conducted in a glasshouse from May to December 2000. At the start of the experiment (total 320 pots) two-soil types, limestone and shale, were selected. Dried bio-solid (DB), lime bio-solid (LB), anaerobic bio-solid (AB), dairy cow slurry (CS), and chemicals (CH) were mixed with the soils in varying amounts to give the following P concentrations per kg of soil, 15 mg (P15), 30 mg (P30), 60 mg (P60) and control (P0). In addition to the P treatments, pots received basal treatments of macro and micronutrients. The pots were sown with perennial ryegrass (*Lolium perenne* L.) and cut to 10 mm at each of 5 harvests, with dry weight (DW), and P concentrations measured at each.

Total DW for each treatment was highest for the first and second harvests, but decreased gradually for each of the subsequent cuts. The mean DW pot^{-1} was 5.9, 6.8, 3.7, 3.0, and 2.4 g for the 1st, 2nd, 3rd, 4th, and 5th harvests, respectively. Declining P, radiation and temperature may account for the observed fall off in DW. The DW and nutrient uptake data for the first cut were statistically analysed using analysis of variance. The mean effect of the amendments on DW was significant ($P < 0.05$) with mean pot yields for AB, CH, CS, LB and DB of 7.1, 6.7, 6.4, 4.7 and 4.4 g, respectively. The low dry matter amendments (AB and CS) gave a better response than the high dry matter ones (LB and DB). The DW averages were 2.93, 5.31, 6.05 and 6.22 g pot^{-1} for P0, P15, P30 and P60, respectively for the first harvest. The DW response with varying P concentrations is typical of normal nutrient quadratic response curves. The differences are statistically significant ($P < 0.05$) except between P30 and P60. In both soils, the P concentration in the DW was low (< 0.2%), a not unusual occurrence in glasshouse pot experiments. The overall mean DW from shale (6.47 g) was significantly greater than that from limestone (5.26 g), probably due to higher P reserves in shale.

Keywords: cattle slurry, perennial ryegrass, phosphorus, pot experiment, sewage sludge

Introduction

In 1998 there was approximately 7.8 million head of cattle in The Republic of Ireland. The animal manure produced annually is 30 million tonnes all of which is land spread. The Irish population started to increase after 1961, and reached 3.6 million in 1996. It is likely that the population of Ireland will continue to increase. Currently annual Irish sewage sludge production is 20,000 tonnes of dry matter per year but will increase to 120,000 tonnes by 2013 as a consequence of changes in European and National water legislation (Anon., 1993).

Most stored animal manure is applied to agricultural land directly as slurry. Sewage sludge is available for land application after various treatment processes (Hucker and Catroux, 1980). The three main areas for spreading sludge are agricultural land application as a fertiliser, reclamation of wasteland, and use in forestry. Application to agricultural land represents a management option for sewage sludge and animal slurry as it results in the recycling of the nutrients they contain in crop production.

This study collects basic data for agricultural land application of three types of sewage sludge and cattle slurry. In addition the growth of grass after the application of sewage sludge, animal manure and chemical nutrients is compared. Specifically, the use of these products as a phosphorus (P) source for grass growth was examined in a pot experiment.

Materials and Methods

This study was carried out in a glasshouse at Teagasc Johnstown Castle Research Centre, County Wexford, Ireland from May to December 2000. The experimental procedure followed was based on that used previously in Teagasc (Power, 1992).

Two soil types, one derived from limestone, Baggotstown from County Offaly, and the other from shale, Clonroche from County Wexford, were selected. Two soil samples were taken from each location, limestone (BAA and BAB) and shale (CLA and CLB) (i.e. a total of four soil samples). Table 1 shows the chemical analysis of the experimental soils. The data suggests that they are within the normal range of Irish soils.

Table 2 shows the chemical composition of three types of sewage sludge and the cattle slurry. At the start of the trial, three types of sewage sludge, i.e. dried bio-solid (DB), lime bio-solid (LB), and anaerobic bio-solid (AB), a dairy cow slurry (CS) and chemicals (CH) were mixed with the soil. The solid sludges (DB and LB) were of high dry matter, 88.3% and 58.3% respectively and the liquid sludges (AB and CS) were of low dry matter, 0.9% and 7.7%, respectively. The trace element contents of the sewage sludges are within the safety levels of normal Irish sludges (O'Riordan *et al.*, 1986, 1994a, 1994b, 1994c). Photo 1 shows the nature of the sewage sludges, DB, LB, and AB as seen from the top. Anaerobic bio-solid is the liquid portion found after the dewatering of sewage sludge. Lime bio-solid is the solid portion found after lime processing, and dried bio-solid occurs after composting of the crumb structure. The nutrient composition of CH solution used was that described by Hoagland and Arnon (1950). There are various forms of this solution, the solution used contained nitrogen (N) and potassium (K) but did not contain P.

Table 1 Soil analysis data.

Soil type	Abreviation	pH	P*1	K*1	Mg*1	TON*2	NH4-N	Mn*3	Zn*3	Cu*3	Ni*3	Cr*3	Pb*3	Cd*3	Hg*3
Limestone	BAA	6.9	2.7	20.0	76.9	1.3	<1.0	88.5	76.7	9.0	26.2	15.9	21.5	1.03	0.06
	BAB	7.2	3.2	29.0	62.3	6.4	<1.0	987.0	68.2	8.9	26.2	18.9	17.0	0.86	0.08
Shale	CLA	6.6	1.6	120.0	186.0	9.2	<1.0	775.0	63.5	25.7	19.1	19.2	31.8	0.19	0.06
	CLB	6.1	2.2	39.0	67.2	2.7	<1.0	1124.0	86.3	23.7	30.4	20.6	47.1	0.23	0.09

*1 Available nutrients; Morgan's method (mg L-1) (Peech and English, 1944)
*2 Total oxidised nitrogen (mg L^{-1})
*3 Total nutrient contents (mg kg^{-1})

Table 2 Sewage sludge and animal manure analysis data.

Sludge type	Abreviation	pH	DM (%)	N	P	K	Mg	Ca	Mn	Zn	Cu	Ni	Cr	Pb	Cd	Hg
				(----------------mg kg^{-1}----------------)												
Dried bio-solid	DB	7.0	86.94	25500	61	950	551	7125	60.9	304.8	60.2	19.6	16.2	82.1	0.30	0.61
Lime bio-solid	LB	8.4	63.62	2762	1503	290	962	48182	60.4	120.2	50.5	18.8	9.0	51.7	0.14	0.25
Anaerobic bio-solid	AB	7.2	0.89	756	179	169	40	880	1.8	8.5	4.0	0.3	0.1	0.5	0.01	0.01
Cattle slurry	CS	7.5	8.90	2871	536	6213	644	7252	26.2	15.9	5.5	0.6	0.0	0.6	0.01	0.02

Photo 1 Nature of sewage sludge. (Dried bio-solid (DB), lime bio-solid (LB), and anaerobic bio-solid (AB); from the top).

Each material was applied to give the following rates of P addition per kg of soil: 15 mg (P15), 30 mg (P30), 60 mg (P60) and control (P0). The P addition of 30 mg per kg^{-1} soil was calculated based on the standard P application rate for two cuts of grass silage at 50 kg of phosphorus per hectare (Anon., 1998). Addition to a pot (1 kg of soil) was calculated based on one-hectare (10,000 m^2) containing 1,800 Mg (t) of soil. The P15 and P60 treatments were half and double of this basal value. N, K, magnesium (Mg), and micronutrients were added in adequate quantities to each pot so that P was the only limiting nutrient.

Figure 1 shows a cross-section of the experimental pot. Filter paper (Whatman No.2), nylon cloth, and glass filter paper (Whatman GF/A), were used to prevent soil loss. One kg of soil was put in each pot over 1 kg of coarse sand. The soil was sieved through 12.7 mm mesh to remove impurities, such as stones and insects. The appropriate quantity of sludge and fertiliser was mixed into 1 kg of soil, and added to the pot. Perennial ryegrass seeds (*Lolium perenne* L.) were sown at a rate of 0.5 g pot^{-1} and lightly covered with (4 mm mesh sieved) soil. There were a total of 320 pots in the experiment as follows: five treatments at three P levels with five replications in each of the two soils with two sub categories for each soil (300 pots), in addition to controls (P0), for four soils (20 pots). Table 3 shows the number and arrangement of the experimental pots.

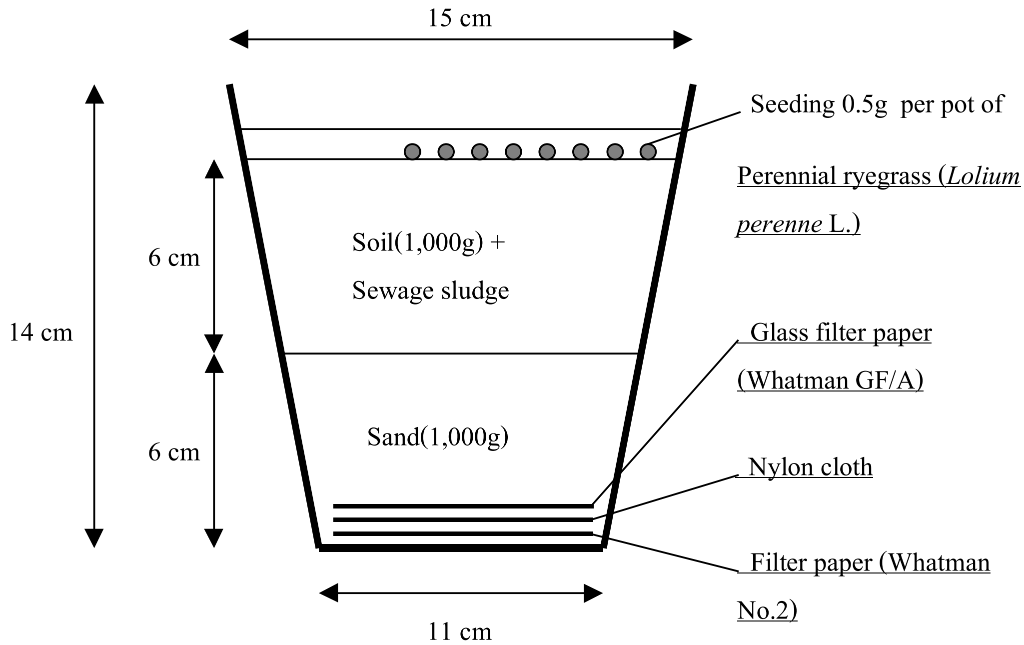


Figure 1 Cross-section of experimental pot.

Table 3 Number and arrangement of the experimental pots.

Soil types	Limestone soil (from Baggotstown) BAA, BAB
	Shale soil (from Clonroche) CLA, CLB
Treatments	Dried bio-solid (DB)
	Lime bio-solid (LB)
	Anaerobic bio-solid (AB)
	Cattle slurry (CS)
	Chemicals (CH)
P levels	15 (P15), 30 (P30), and 60 (P60) mg kg^{-1} soil (without CH)
	0 (P0), 15 (P15), 30 (P30), and 60 (P60) mg kg^{-1} soil (CH)
Replications	5 replications
Total pots	240 (without CH) + 80 (CH) = 320 pots

Supplementary applications of major plant nutrients without P, in addition to micronutrients, were applied following the first four harvests between June and October. These were also applied to the pots at rates determined to meet crop requirements. The grass was clipped to a stubble height of about 10 mm at each harvest; the last (5th) was in December. Measurements included, grass height and yield, green weight (GW), dry weight (DW), and chemical analysis for P, N, K and Mg. The dried grass, after DW analysis was ground finely for chemical analysis. The DW and nutrient uptake data for the first cut were analysed using analysis of variance and applying a 95% confidence interval.

Results and Discussion

The effect of soil texture on grass harvests

Figure 2 shows the differences in the total DW (1st - 5th harvests) by soil and P level for the five treatments. For each sewage sludge application an increase in P application gave an increase in DW. The overall mean DW from the shale (CLA and CLB) soil, 6.47 g was significantly ($P < 0.05$) greater than that from the limestone (BAA and BAB) soil, 5.26 g for the 1st harvest. The difference in the total amount (5 harvests) of average DW yields by soil shows that the shale soil exceeded the limestone soil, 23.74 g compared to 19.67 g pot^{-1}, respectively. In detail results were 25.63, 21.85, 20.27, and 19.08 g pot^{-1} for CLB, CLA, BAA, and BAB, respectively. The response of DW yield to added P was almost the same on both soils. The CLA shale soil was slightly higher than the limestone soil and CLB gave the highest yield, probably due to higher P reserves. The general soil texture of limestone soil (BAA and BAB) is clay 14%, silt 13 %, fine sand 21%, and coarse sand 52%, and the shale soil (CLA and CLB) clay 25%, silt 37%, fine sand 12%, and coarse sand 26% (Gardiner and Radford, 1980). The higher yield may be due to the higher clay content and nutrient reserves in the shale soil.

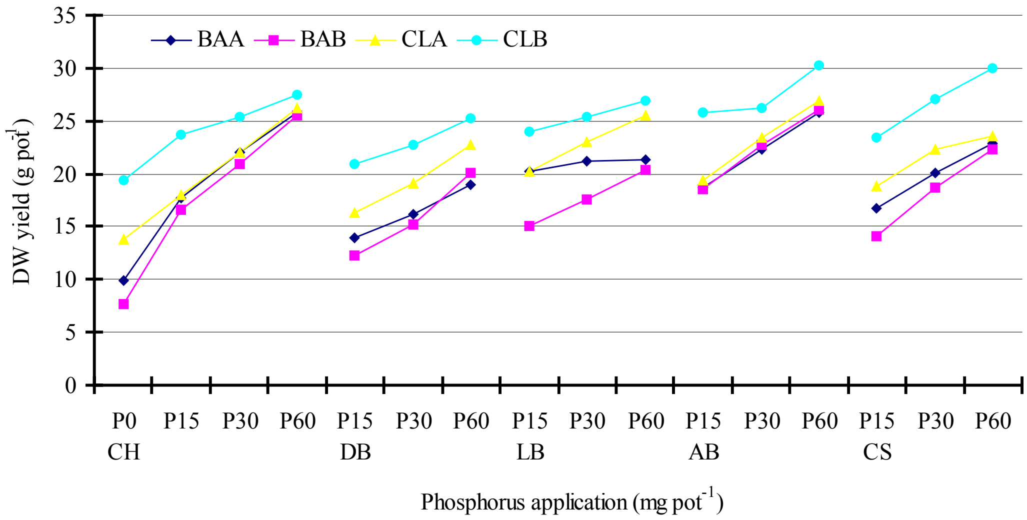


Figure 2 Difference in total DW and P levels for the five treatments.

Influence of sewage sludge P on grass yield

Figure 3 shows the dry weight for each treatment (DB, LB, AB, CS, CH, and control) in all soils. Total DW for each treatment was highest for the 1st and 2nd harvests. It decreased gradually for each of the subsequent cuts. This is as a consequence of DW levels in winter months being restricted due to the low levels of light which are half that during the summer months (Culleton *et al.*, 1992). This fall off in DW was probably due to declining available phosphorus, and shorter and colder days. The low temperature, low solar radiation, and high rainfall outside the glasshouse, was atypical between September and December 2000. The mean effect of the amendments on DW yield was significant ($P < 0.05$) with mean pot yields for the AB, CH, CS, LB and DB treatments of 7.1, 6.7, 6.4, 4.7 and 4.4 g pot^{-1}, respectively. The liquid sludge (AB and CS) gave a higher response than that of the solid sludge (DB and LB). This may be because organic phosphorus in organic matter is less readily mineralised in solid sludge, or solid sludge has some negative effect on grass growth.

Figure 4 shows the response of each treatment (DB, LB, AB, CS, CH and control) for grass growth expressed as a percentage relative to a standard, when the DW of CH is 100%. The details of each sludge application response to the annual total yields compared with CH for the DB, LB, AB, and CS treatments were 82.45, 96.04, 105.46, and 95.76%, respectively. These results show the P efficiency of the sludges compared with that of chemical P. For example, activitated sludges have been shown to have efficiency figures of 83% and 81%, and anaerobic digested sludges values of 72% and 68% (O'Riordan *et al.*, 1987). In the annual change of grass growth from the 1st to 5th harvests, the liquid sludge gave a similar response to chemicals, and gave a higher response than the solid sludge in the 1st and 2nd harvests. The solid sludge showed an increased response for the 3rd and subsequent cuts. This indicates that they have less readily mineralised phosphorus in organic materials as found by Robinson *et al.* (1995).

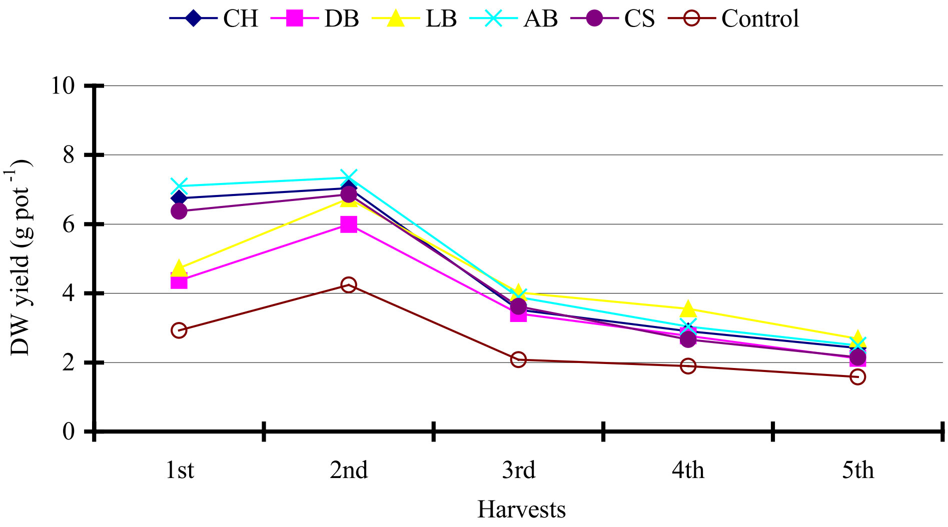


Figure 3 Dry weight for each treatments and control in all four soils.

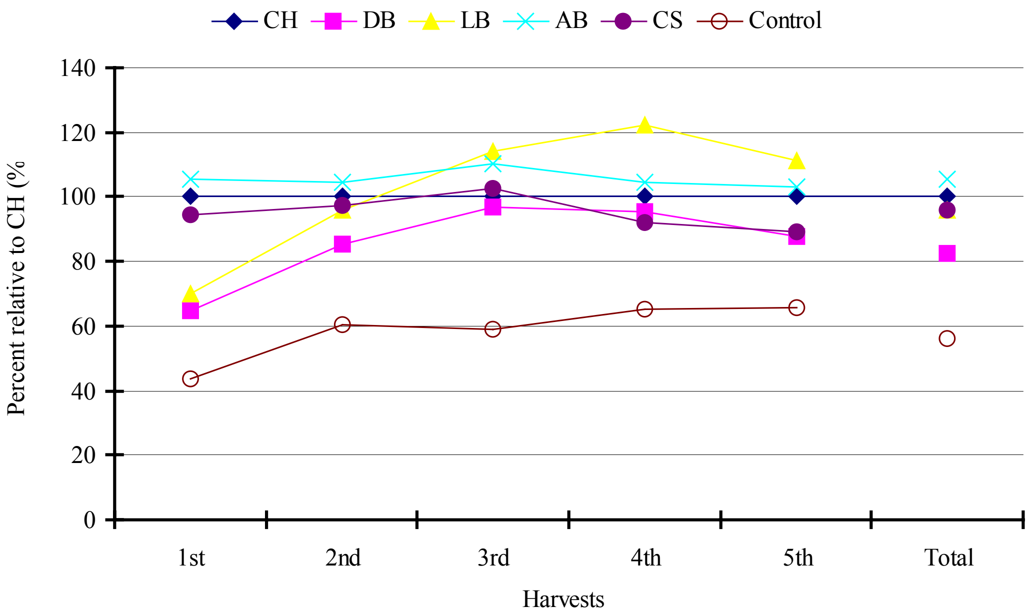


Figure 4 Response of grass yield to each treatments and control when DW of CH = 100%.

Herbage response to P application

Figure 5 shows the relationship between DW yield and P application for the 1st and 2nd harvests compared with the sum of the results of the 3rd to 5th harvests. In the 1st harvest, DW for chemical P application had a typical quadratic response curve. The yield curve for chemical application showed a steep slope up to 30 mg pot^{-1}. The sludges (except DB and LB) also showed similar slopes to that of chemical P. The yield curve of the AB and CS produced curves similar to CH, while DB and LB treatments didn't produce such a distinct curve and reached a plateau at lower levels (about two thirds that of chemical P). The DW yields averaged over all the treatments and soils were 2.93, 5.31, 6.05 and 6.22 g pot^{-1} for the P0, P15, P30 and P60 treatments respectively for the 1st harvest. The differences are statistically significant ($P < 0.05$) except between P30 and P60. After the 2nd harvest, the yield curve of CH approximated a linear increase. The yield curve of AB, CS, and DB showed a similar trend to chemical P, although LB showed a quadratic response curve. These results indicate that LB has less readily mineralised P in the organic materials, and also CH, AB, and CS has more readily available P.

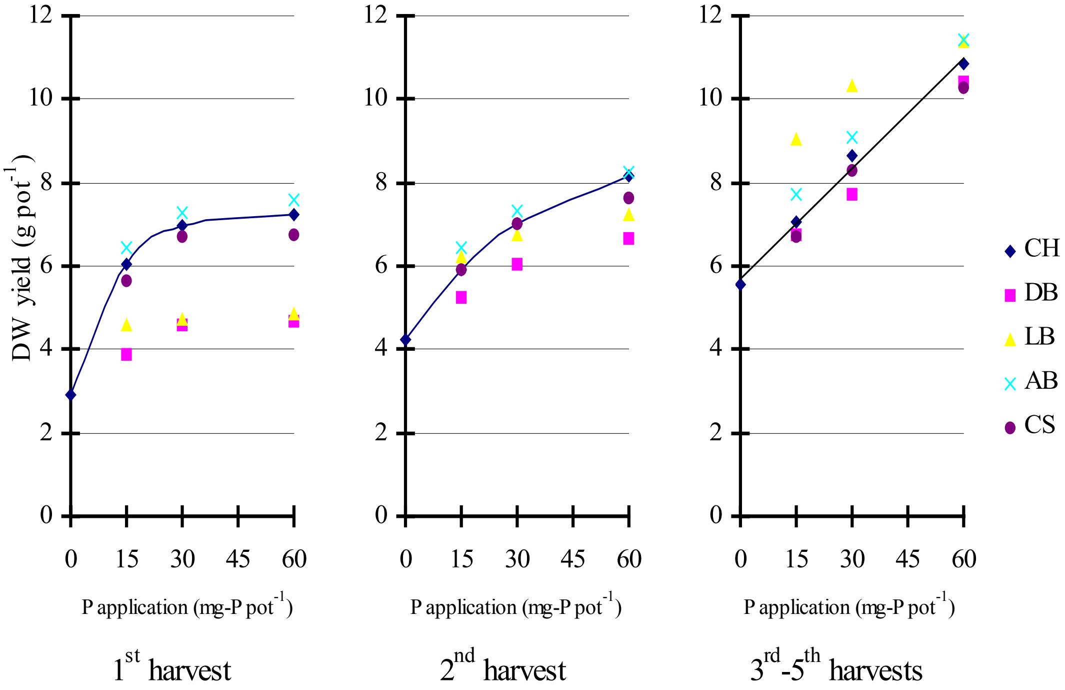


Figure 5 Relationship between DW and P application.
The line shows the P response curve for chemical P (CH).

Figure 6 shows the relationship between the annual DW yield of grass and P application. In the CH treatment, 30 mg pot^{-1} of P application gave 23 g pot^{-1} of grass DW for the annual yield (5 cuts), and gave 14 g DW pot^{-1} for the total of 1st and 2nd harvest. These results approximated to the results of Tunney and Pommel (1987). When this data is extrapolated into corresponding field values, about 50 kg ha^{-1} P applied (Anon., 1998) should produce about 40 t ha^{-1} of grass DW for a year (5 cuts), and about 25 t ha^{-1} of DW for the 1st and 2nd harvest. In practice under field conditions 3 cuts give a maximum of about 15 t DW ha^{-1} y^{-1}.

These results exceeded by about 18 t DW ha^{-1} the yields shown in the Irish Department of Agriculture report (Anon., 1999), but the total of 1st and 2nd harvests approximated to this published value. In the present study, the reason that DW exceeded the field yields is due to pot cultivation in the glasshouse. In a separate field experiment over 4 years at these sites, yields plateaued at 10 t DW ha^{-1} (Ryan and Finn, 1976). This was probably due to the continuing experiment for four years (1967 – 1970) in the field, and to low soil P. Therefore, for P application to the field for AB and

CS a rate of 40 kg ha^{-1} a year is desirable or the same amount as for the chemical P. The DB application may require over 1.2 times the rate for chemical P. The results suggest, that to have adequate P, more LB needs to be applied in order to achieve yields comparable to CH particularly in the first 3 harvests. The poor response with LB is probably due to less readily mineralised phosphorus. In this study, P application was less than that of O'Riordan *et al.* (1987). However with higher rates of application one may risk damage to the grass due to excess N, K, and other chemicals, if sewage sludge was increased for higher P application.

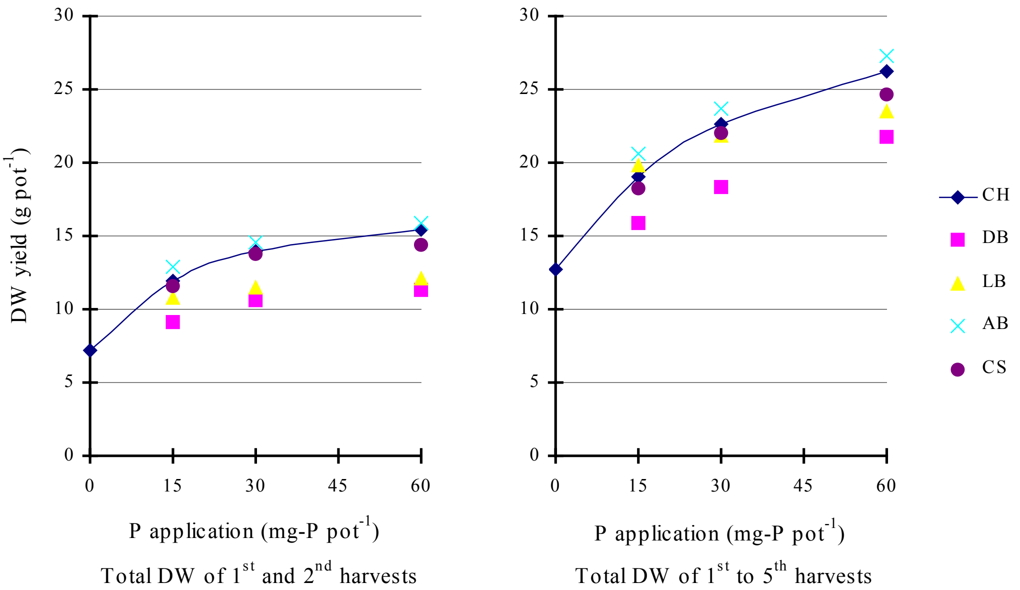


Figure 6 Relationship between DW and P application for grass harvests. The line shows the P response curve for chemical P (CH).

Phosphorus concentration in the grass

Figure 7 shows relationship between DW and the rate of phosphorus concentration for each harvest. In the 1st harvest, overall P concentration in the grass was low (< 2.0 mg g^{-1}), which is not an unusual occurrence in pot experiments in a glasshouse. The 2nd harvest was also generally less with < 1.0 mg g^{-1}. Normally one would be expect to find > 3.0 mg g^{-1} P in grass (Power, 1992). This is probably as a result of conducting the experiment in a glasshouse.

Figure 8 shows the relationship between DW and grass P removed (uptake) for all harvests. These results show that total P uptake increases with increasing dry weight. Maximum DW yields were of the order of 4.0 to 8.0 g pot^{-1} while maximum P removal was about 10 mg pot^{-1}. This data indicates that 7.0 to 14.5 t ha^{-1} of the grass DW in the field would remove a maximum of 18 kg P ha^{-1}. The phosphorus removed for timothy was 13.0 kg P ha^{-1} at 6.0 t DW ha^{-1} (Mengel and Kirkby, 1978). In the 1st and 2nd harvests of this report, P removal agrees with the values for timothy grass in the above study, although the DW is nearly two times higher.

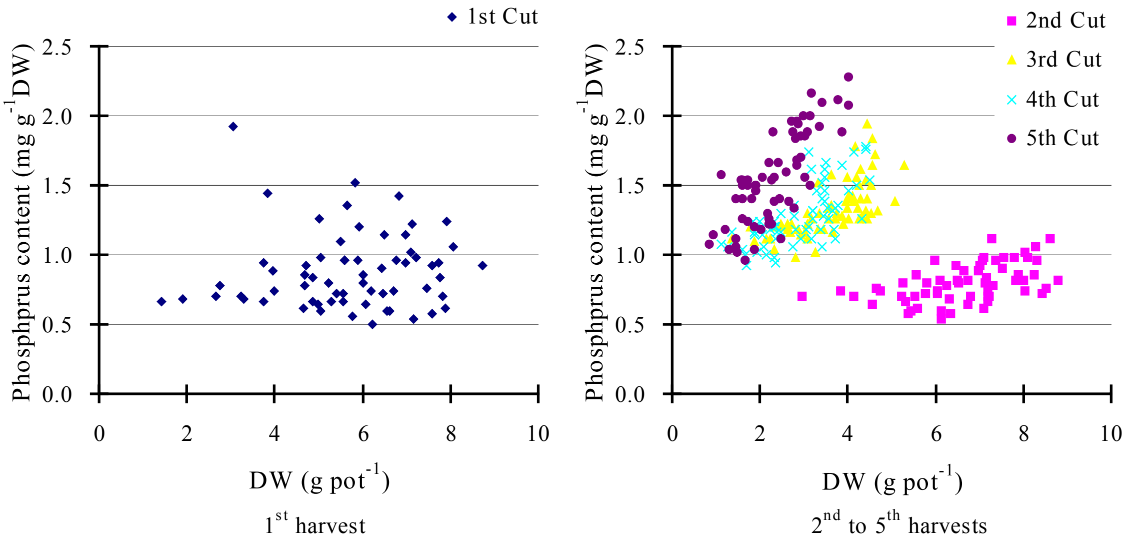
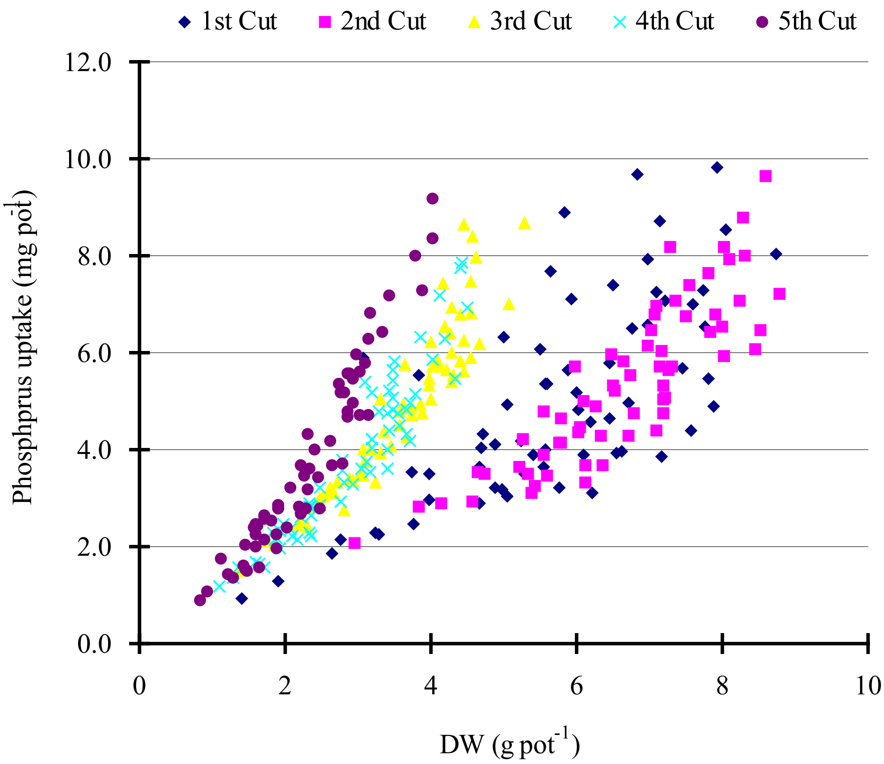


Figure 7 Relationship between DW and P concentration in grass for each harvest.



1 to 5 harvests

Figure 8 Relationship between DW and P uptake for all harvests.

The P concentration in grass in the first two harvests and the subsequent three harvests were compared. The P content of the DW (Figure 7) was low at 0.5 - 1.5 mg P g^{-1} DW in the 1st and 2nd harvests and relatively high by comparison at 1.0 - 2.5 mg P g^{-1} DW in the 3rd to 5th harvests. The P uptake (Figure 8) showed the same maximum and decreased with subsequent harvests and the differences between harvests 1st to 2nd and 3rd to 5th are evident. The decline in grass DW in the last three harvests was possibly due to the influence of environmental factors, that is the decrease in daylight hours and temperature. These environmental factors had a greater influence on the decrease in grass DW than the decrease in P accumulation in the grass. These reactions are probably due to irregular growth or rosette growth under winter conditions (Sailsbury and Ross, 1969).

Conclusions

The increased additions of P in sewage sludge, animal manures and chemicals increased grass DW yields. The influence of sewage sludge application on grass yield was highest for the 1st and 2nd harvests. In the 1st harvest, the rate of DW response declined with P application rate, which is typical of normal nutrient response curves. A yield curve was seen with all applications and showed a sharp increase up to 30 mg P pot^{-1}. After the 3rd harvest, the inclination of the yield curve approximated to a linear increase, which was probably due to the continued shorter and colder days. These results approximated to field results of about 50 kg ha^{-1} P application giving 25 t DW ha^{-1} for a total of five harvests.

The effects between each of the sludges, on the grass yield of CH, AB, and CS treatments were higher in the 1st and 2nd harvests, and LB and DB were higher in the 3rd and 4th harvests. The liquid sludge (AB and CS) includes more readily available P and gave a better response in the early period of grass growth. On the other hand, the solid sludge (LB and DB) may provide soil improvement and more long term P availability. The relative grass yield of DB, LB, AB, and CS treatments expressed as a percentage of CH at 100% DW were 82.5, 96.0, 105.5, and 95.8%, respectively. Therefore, P application, in the field, for AB and CS should be of the same order as that for chemical P, and the DB application may require over 1.2 times that of chemical P. Lime bio-solid application needs to be higher than CH to achieve higher yields up to the 3rd harvest, due to the effect of the less readily mineralised phosphorus.

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