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Characteristics of Phosphorous Components in Drainage Water

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Phosphorous (P) is an element for plant growth and its input has long been recognized as necessary to maintain profitable crop production. Phosphorous inputs can also increase the biological productivity of surface waters. Although nitrogen (N) and carbon (C) are essential to the growth of aquatic biota, most attention has focused on P inputs, because of the difficulty in controlling the exchange of N and C between the atmosphere and water and fixation of atmospheric N by some blue-green algae. Thus, P is often the limiting element and its control is of prime importance in reducing the accelerated eutrophication of fresh waters (Sharpley AN et al 1997). Since the late 1960s, point sources of water pollution have been reduced, due to their relative ease of identification and control. Even so, water-quality problems remain, and, as further point-source control becomes less cost-effective, attention is now being directed towards the contribution of agricultural P non-point sources to P in surface waters. Thus, a greater understanding of where P is coming from, how much P in soil and water is too much and how and where we can reduce these inputs and losses must be gained through research and extension programmes, in order to develop agricultural resource systems that sustain production and environmental quality, as well as farming communities. Phosphorus may be lost from agricultural land to water by several processes. These include erosion, surface runoff and subsurface flow (leaching) (Brookes PC et al. 1997). As most soils have a high absorption capacity for P, usually far exceeding the quantities of P added as manures or fertilizers (van Riemsdijk et al. 1987), it has long been considered that leaching losses of P from soil to water are negligible in most cases (Cooke 1976; Ryden et al. 1973; Lu Jialong et al. 1999).

Here I present data from drainage water of the Broadbalk Continuous Wheat Experiment at Rothamsted in UK (Johnston 1969), which question these findings.

MATERIALS AND METHODS

A detailed description of the Broadbalk experiment is given by Avery and Bullock (1969). The silt loam and silty clay loam of the Batcombe series (Chromic Luvisol) together make up >90% of topsoil, which overlies clay-with-flints at < 60 cm, in turn resting on chalk. The experiment consists of 20 plots, 18 of which run the full length of the field and are 0.24 ha each. They receive different fertilizer treatments without replication. The experiment is divided, at right angles to the plots, into 10 sections, which test different agronomic treatments. Five are in continuous wheat, and five are in a rotation of fallow, potato and three successive wheat crops. Tile drains were installed along the middle of each plot in 1849 (1884 on the FYM+N2 strip) at a depth of about 65 cm, which opened into a ditch at one end of the experiment. In 1993 the old drains were replaced by perforated plastic tube drains on one section of continuous wheat nearest the ditch (section 9). Unlike the old drains, where the overlying clay had settled to the same bulk density as the soil mass, the new drains had a permeable gravel backfill up to 30 cm soil depth. The old drains were intercepted by a cross drain to avoid water from the rest of the experiment interfering with the new drains. Fertilizer treatments are listed in table 1. Chalk is applied every 5 year to maintain the pH at around 7.5 (Table 1). Water flowing from drains, 65 cm under soil surface, between winter 2000 and early summer 2001 was collected and analyzed for total and dissolved P. My aim was to see if significant quantities of P were lost through drainage and what are the percents of different phosphorus forms.

Table 1. Details of the treatment and the soil from the Broadbalk experiment.

Plot no.	Treatment	Annotation
2.2	FYM	**FYM:** 35 t ha^{-1} farmyard manure **N0-N5:** supplying 0, 48, 96, 144, 192 and 240 kg N ha^{-1} both autumn and spring application. Supplying N to plots 17 and 18 in spring (April), to other plots in autumn (before ploughing) **P:** supplying 35 kg P ha^{-1} **K:** supplying 90 kg K ha^{-1} **Na:** supplying 35 kg Na ha^{-1} **Mg:** supplying 20 kg Mg ha^{-1} to plot 14, 35 kg Mg ha^{-1} every 3rd year to other plots since 1974
3	NIL	
5	P K Mg	
6	N1 P K Mg	
7	N2 P K Mg	
8	N3 P K Mg	
9	N4 P K Mg	
10	N2	
11	N2 P	
12	N2 P Na	
13	N2 P K	
14	N2 P K Mg	
15	N5 P K Mg	
17	N1+N3, 1/2 [P K Mg]	
18	N0+N3, 1/2 [P K Mg]	

Table 2. Average concentrations of phosphorus and particulate matter in drainage water.

Plot	TP (mg/L)	TDP (mg/L)	MRP (mg/L)	DOP (mg/L)	PP (mg/L)	PM (g/L)
2.2	1.202	0.796±0.10	0.696±0.08	0.100±0.01	0.502	0.223
3	0.099±0.02	0.040±0.01	0.014±0.01	0.026±0.01	0.064±0.02	0.025±0.01
5	0.677±0.15	0.349±0.15	0.305±0.06	0.044±0.01	0.330±0.11	0.106±0.04
6	1.470±0.42	0.615±0.40	0.550±0.09	0.065±0.04	0.854±0.35	0.268±0.11
7	2.355±0.61	0.621±0.59	0.548±0.06	0.074±0.03	1.732±0.56	0.601±0.21
8	1.713±0.48	0.452±0.47	0.398±0.06	0.053±0.02	1.268±0.43	0.465±0.16
9	0.985±0.27	0.287±0.29	0.245±0.07	0.042±0.02	0.700±0.25	0.278±0.11
10	0.454±0.24	0.082±0.24	0.029±0.01	0.053±0.02	0.374±0.23	0.177±0.10
11	1.294±0.36	0.559±0.34	0.509±0.09	0.050±0.02	0.733±0.32	0.301±0.14
12	1.993	0.894	0.884	0.010	1.100	0.316
13	1.538±0.41	0.602±0.46	0.563±0.16	0.040±0.02	1.007±0.32	0.282±0.10
14	1.681±0.47	0.673±0.51	0.626±0.22	0.047±0.02	1.024±0.32	0.281±0.10
15	0.831±0.26	0.272±0.25	0.235±0.07	0.038±0.02	0.569±0.20	0.176±0.07
17	0.648±0.25	0.204±0.24	0.157±0.04	0.047±0.01	0.449±0.26	0.188±0.11
18	0.997±0.24	0.127±0.24	0.079±0.01	0.048±0.003	0.870±0.24	0.294±0.08

Drainage water samples were collected in Winchester bottles at the drain outlets on five occasions between December 2000 and April 2001. In each case, water was collected after the drains had been running freely for a few hours. The entire time of collection usually took about 1 hr. Drainage water was filtered through 0.45-μm Millipore membrane filters (mixed cellulose ester) with subsequent measurement of molybdate reactive phosphorus (MRP), i. e., mainly inorganic P, (Murphy and Riley, 1962) on the same day. The particulate matters under 0.45-μm Millipore membrane filters were collected and dried in oven at 105-110 ℃, then, weighted them on balance. The contents of particulate matter in drainage water were calculated. For further analysis, samples were stored in Winchester bottles at 5 ℃ in the dark.

Total P in drainage water (TP), i. e., before filtration, and total dissolved P (TDP), i. e., after filtration, were determined after a modified perchloric acid digestion. An aliquot containing between 5 and 20 μg P was digested with 3 ml of perchloric acid (60%) and 0:5 ml saturated $MgCl_2$ nearly to dryness, redissolved in 0.6 M HCl, neutralized with 5 M NaOH (Brookes and Powlson, 1981) and analyzed for P by the method of Murphy and Riley (1962). Total particulate P (PP) was calculated from the difference between TP and TDP and dissolved organic P (DOP) from the difference between TDP and MRP. All measurements are the

Table 3. Average proportions MRP, DOP, TDP and PP in TDP or TP of drainage waters from Broadbalk.

Plot	TDP	PP	MRP	DOP	MRP	DOP
	Percentage of TP				Percentage of TDP	
2.2	58.24	41.76	48.50	9.73	86.99	13.01
3	45.04	59.53	13.22	31.82	52.34	47.66
5	58.89	41.42	47.92	10.96	83.79	16.21
6	51.42	48.42	48.05	3.37	90.91	9.09
7	32.74	67.15	29.42	3.32	88.60	11.40
8	34.49	65.66	31.40	3.09	89.11	10.89
9	39.63	60.56	32.86	6.77	80.28	19.72
10	41.09	60.70	11.31	29.79	49.62	50.38
11	56.98	42.89	52.07	4.91	90.65	9.35
12	44.86	55.19	44.36	0.50	98.88	1.12
13	48.91	53.91	43.28	5.63	89.22	10.78
14	48.74	51.77	43.37	5.37	85.20	14.80
15	46.05	57.29	38.93	7.12	82.42	17.58
17	57.94	44.67	42.67	15.28	72.50	27.50
18	18.87	81.13	12.34	6.54	61.56	38.44

means of three replicate determinations.

RESULTS AND DISCUSSION

Arithmetic means of total P (TP), molybdate reactive P (MRP), total dissolved P (TDP), dissolved organic P (DOP), total particulate P (PP) and particulate matter (PM) and the mean proportions of MRP, DOP, TDP and PP in TDP or TP of drainage waters from Broadbalk plots of 5 drainage events monitored between December 2000 and April 2001 were tabulated in table 2 and table 3 respectively.

There was substantial variation both in total P concentration and the relative contribution of the P fractions between the five events and between the different plots. The Broadbalk experiment does not have facilities for monitoring of the drainflows. Therefore results given have mainly represent snapshots. The Table 2 and Figure 2 had showed, On Broadbalk, the lowest total P concentration, 0.099 mg L^{-1}, for each event was generally measured on the plot which had never received fertilizer (the Nil plot) and ranged from 0.07 to 0.152 mg L^{-1}. The exception was the 6 April event in 2001 when lowest total P concentration in drainage water was measured on Plot 10. Despite receiving no P fertilizer inputs, drainage waters from Plot 10 (N2) had frequently higher total P concentrations,

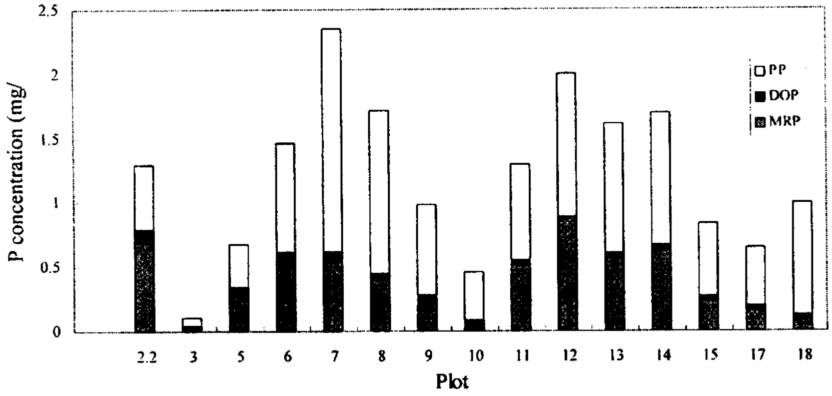

Figure 1. Phosphorus concentrations in drainage waters

reaching 0.454 mg L^{-1}. This was mainly attributable to larger concentration. Thus, drainage water MRP from Plot 10 only varied between 0 to 0.043 mg L^{-1}, with an average concentration, 0.454 mg L^{-1}, slightly lower than Plot 17 (0.468 mg L^{-1}). The lowest MRP concentrations were always measured on the NIL plot. The highest TP concentration in drainage water of 4.834 mg L^{-1} was measured on the N2PKMg plot. Dominated by PP, frequently, TP concentrations ranged 0.354 to 4.076 mg L^{-1}, especially on Plots 6,7,8,12,13 & 14 (Table 2 and Figure 1). Similarily, the highest MRP concentrations were usually found on plots 2.2 (exception), 7, 12, 13, & 14, ranging from 0.548 to 0.884 mg L^{-1} (Table 2 and Figure 1).

Dissolved organic P (DOP) concentration, as determined by the difference between total and molybdate reactive P in the 0.45 μ m filtrate of drainage waters, was ranged from 0.01 to 0.1 mg DOP L^{-1}. Most of them were low-remaining frequently below 0.05 mg L^{-1} (Table 2). This is line with findings from other drainage experiment on similar soil types receiving inorganic P fertilizer (e.g. Culley 1983, Grant 1996, Ulén 1995) although they usually measured lower TP in general. A high mobility of DOP in soils is associated with large organic matter inputs (Table 2). Although DOP in drainage waters from the FYM plot tended to be higher than from plots receiving inorganic fertilizer (Table 2), the magnitude of DOP concentrations did not imply a significant contribution to leaching losses. The Broadbalk results are contrasted by findings on P fractions in the soil solution from an iron humus podzol. Ron Vaz (1993) found dissolved organic P to be

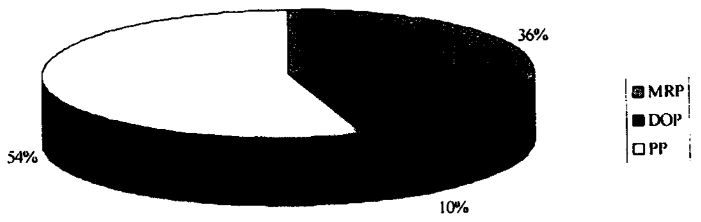

Figure 2. Mean proportions of MRP, DOP and PP in drains

the most significant fraction in soil solution below 10 cm soil depth on plots which had received up to 80 kg P $ha^{-1}yr^{-1}$ as superphosphate.

Table 2 and Table 3 illustrated the importance of P associated with Particulate matter (PP) in drainage waters and its treatment variation with the proportion of PP varying from 41.4% to 81.1% of the TP on plots. Particulate matter (PM) concentrations in drainage waters reached about 0.6 g L^{-1}which is comparatively high for subsurface drainage systems (Pilgrim and Huff 1983, Skaggs 1994). The variability of PP concentrations in drainage waters was matched by the broad distribution of particulate matter concentration (PM) from different plots and drainage events. Accordingly, highly significant linear relationships ($P<0.001$) were observed between PP and PM in drainage waters. Linear relationships between PP and PM in drainage waters were also reported from four agricultural drainage catchments on sandy loam in Denmark (Grant 1996). The proportion of DOP, 1-50%, was lower than that of MRP, 50-99%, in TDP, including FYM plot.

The proportions MRP, DOP and PP in total P (TP) and MRP and DOP in TDP were show on Table 3 and Figure 2. Particulate P comprised by far the highest P concentrations in drainage waters on individual plots reaching occasionally 81% of the TP. The average proportions of PP, 54%, was higher than that of MRP, 36%, in drainage waters—opposite result was obtained by Heckrath GJ and Brookes PC (1998). Their conclusion was the average proportions of PP and MRP of the TP in drainage waters across all plots and drainage events were relatively similar. With 55 and 40% for MRP and PP, respectively, the dissolved P fraction was on the whole more important. The findings from Broadbalk are broadly in accordance with those of Culley (1983) who found on average 62% to 68% molybdate reactive P, 17% to 25% particulate P and 11% to 17% soluble organic P in tile drainage of a moderately fertilized clay soil in arable cropping. Phosphorus concentrations tended to be larger in the drainage water after the installation of the new drains in September 1993 (Heckrath G et al. 1995). The inevitable disturbance of soil during the installation might have caused enhanced P losses and so these must be considered with caution, especially as particulate P was generally greater than in earlier samplings. This would be consistent with the movement of topsoil into drains following disturbance. Due to the gravel backfill used, it is also possible that some water passing through a smaller cross section of soil reached the new drains more quickly, thus decreasing the potential for P retention by the soil.

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