Soil Use and Management (2005) **21**, 370–376 DOI: 10.1079/SUM2005338

Response of organically managed grassland to available phosphorus and potassium in the soil and supplementary fertilization: field trials using grass–clover leys cut for silage

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Abstract. Effective use and recycling of manures together with occasional and judicious use of supplementary fertilizing materials forms the basis for management of phosphorus (P) and potassium (K) within organic farming systems. Replicated field trials were established at three sites across the UK to compare the supply of P and K to grass–clover swards cut for silage from a range of fertilizing materials, and to assess the usefulness of routine soil tests for P and K in organic farming systems. None of the fertilizing materials (farmyard manure, rock phosphate, Kali vinasse, volcanic tuff) significantly increased silage yields, nor was P offtake increased. However, farmyard manure and Kali vinasse proved effective sources of K to grass and clover in the short to medium term. Available P (measured as Olsen-P) showed no clear relationship with crop P offtake in these trials. In contrast, available K (measured by ammonium nitrate extraction) proved a useful measurement to predict K availability to crops and support K management decisions.

Keywords: Phosphorus, potassium, organic farming, grass, clover

INTRODUCTION

Recent years have seen a very rapid growth in organic farming. Certified organic production in 1995 accounted for less than 0.1% of the total utilizable agricultural area in the European Union; by the end of 2003 this had increased to 2.5% (Organic Centre Wales 2004). The latest figures for the UK suggest that the organic hectarage is now >690 000 ha, representing around 4% of agricultural land (Defra 2005). In general, a larger proportion of land-based livestock systems (i.e. sheep, beef and dairy systems often including some arable or horticultural cropping) have undergone conversion to organic production than other farm types; so the majority of organic land in the UK is under grass (Defra 2005).

Successful organic farming systems rely on efficient cycling and use of phosphorus (P) and potassium (K) within the farm. P and K management decisions are made for the rotation or system as a whole (Watson *et al.* 2002a). The effective use and recycling of manures is a key component of P and K management in mixed and livestock systems. Supplementary fertilizing materials are also permitted, where other fertility management practices have been optimized (CEC 1991), and these have a wide range of nutrient contents, solubility and other properties. It has been widely shown that there is no inherent reason why organic farming systems or crop rotations should be unsustainable with regard to P or K (Watson *et al.* 2002b; Berry *et al.* 2003). However, these studies have also highlighted the variability in nutrient use efficiency among organic farms and the scope they have to become more efficient.

There is insufficient detailed knowledge to provide guidance to organic farmers in several key areas of P and K management: availability of P and K, both from soils of different types and from permitted fertilizers; the rate of soil P and K depletion (if any) under organic management; and the potential for nutrient recycling from livestock manures and other composted materials to overcome any P or K deficit.

This study compared the supply of P and K from a range of organically acceptable supplementary fertilizers under field conditions applied to organically managed grass–clover swards cut for silage. We also considered the usefulness of routine soil tests for P and K as a tool for nutrient management in organic farming systems.

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MATERIALS AND METHODS

Sites and trial design

Field trials were conducted at three sites with established organically managed grass–clover swards of 1–2 years old. The sites offered a range of soil types and different baseline soil P and K concentrations and had been fully converted to organic production for longer than one complete rotation: Tulloch Farm, Aberdeen (SAC), Elm Farm, Newbury (EFRC) and Harnhill Farm, Cirencester (RAC) (Table 1). All the sites have a humid mesothermal climate with cool to warm summers and no dry season (Köppen classification), also known as a cool temperate climate. Rainfall and temperature were recorded routinely at each of the field sites. All sites had similar mean monthly maximum (c. 23 °C) and minimum (c. 0 °C) temperatures, but the growing season at SAC was about 30 days shorter than that at EFRC or RAC, the latter being 220 days on average. Growing season rainfall was 327 and 416 mm at SAC and 435 and 439 mm at EFRC in 1999 and 2000, respectively. Rainfall was significantly greater at RAC, with 562 mm in the growing season in 1999.

Six fertilizer treatments allowed under organic standards were used (Table 2). The application rates were based on standard farm practice (Lampkin & Measures 1999) to provide results that could be readily interpreted for farm practice. Three replicate plots per treatment (at least 3 × 5 m) were laid out in a randomized block design. Fertilizers were surface-applied by hand following the first cut of silage in 1999 (Table 3).

Crop sampling and analysis

Before fertilizer application, baseline measurements were made along the centre of each plot with a 1 m motorized cutting blade (Allen scythe) allowing variations in yield and vegetational composition between plots to be assessed. Subsequent silage cuts used the same procedure and were timed to coincide with silage cuts made on adjacent fields managed by the host farm. Only two silage cuts were taken per year at SAC, compared to three at the other sites (Table 3). The trial ran for 2 years at SAC and EFRC but unfortunately the trial at RAC had to be abandoned after the first year, owing to accidental removal of the trial markers over winter. Cut length, cut width and total cut fresh weight were recorded at each sampling. Subsamples were separated into grass, clover and weeds, dried at 80 °C weighed and milled using a rotary mill (1 mm screen). Samples were then analysed for total P and K (nitric and perchloric acid digest; Zhao *et al.* 1994) and total N (LECO CNS-2000 Combustion Analyser).

Soil sampling and analysis

Six soil cores (0–25 cm) were taken using an auger (2.5 cm internal diameter) at the start of the trials in spring 1999 and in autumn 1999 and 2000. The cores were bulked to give one sample per plot, then air-dried and ground (<2 mm) before analysis for pH (1: 2.5 w/v in H_2O), available P (Olsen; Anon. 1986) and available K (extraction with NH_4NO_3 at 1: 5 w/v; Anon. 1986).

Statistical analysis

Analysis of variance was performed on all the data sets to determine the significance of the treatment effects and the interactions between factors, after checks to ensure homogeneity of variance. All of the analyses used the baseline measurements (yield, nutrient concentration of plant material) as a covariate to allow for any variation resulting from differences in the baseline properties. GENSTAT version 5 was used for statistical analysis. Correlation/regressions were also carried out on some of the data sets using Microsoft Excel.

RESULTS AND DISCUSSION

Silage yields and sward composition

The grass and clover contents of individual plots were highly variable in the baseline cut, independent of the fertilizer treatments, and there was no significant effect of the applied fertilizer treatments on sward composition (data not shown). There were also no significant effects of treatment on dry matter (DM) yield, whether considered as individual yield components (grass or clover), by cut, or cumulatively over the season at either SAC or EFRC. However, in the third silage cut at RAC in 1999 there was a small yield response to the treatments: Kali vinasse, farmyard manure (FYM) and FYM plus redzlaag increased silage yields above those of the control plots ($P = 0.06$).

The yields of grass and clover from the silage cuts showed significant differences between sites and cuts (e.g. data for 1999, Table 4). However, there were no significant differences ($P = 0.122$) between sites in the cumulative total yield of silage in each growing season, despite their contrasting soils and climatic conditions. The first cut of silage taken in each year had a very significantly greater DM yield than either the second or third cuts, typical of

Table 1. Field trial site and soil characteristics.

Site[a]	Latitude and longitude	Topsoil texture[b]	Soil group[c]	pH	Available K ($mg\,kg^{-1}$)	Available P (Olsen) ($mg\,kg^{-1}$)
SAC	N 57.177 W − 2.247	Sandy loam	Ferric podzol	6.5	59	73
EFRC	N 51.385 W − 1.407	Clay loam	Hapli-endostagnic luvisol	6.3	74	13
RAC	N 57.177 W − 1.893	Clay loam (calcareous)	Lepti-calcaric cambisol	7.3	206	10

[a]For site key, see Materials and Methods. [b]Estimated in the field using hand-texturing keys. [c]Source: FAO-ISRIC-ISSS 1998.

Table 2. Fertilizer treatments used in the field trials.

Treatment	P applied (kg ha^{-1})	K applied (kg ha^{-1})	N applied in the treatment
Control	0	0	No
Rock phosphate[a] (redzlaag[b] at RAC)	78.5	3.9	No
Farmyard manure[c] (FYM) at 25 t FW ha^{-1}	31.3	237.5	Yes
FYM and rock phosphate (redzlaag at RAC)	31.3 + 78.5	241.4	Yes
Kali vinasse[d]	0.5	41.5	Yes
MsL-K[e]	1.6	41.5	No

[a]Highly carbonate-substituted apatite, ground then prilled; [b]Calcined double calcium/aluminium orthophosphate, finely ground; [c]On-farm composted manure, coarsely chopped, from straw-housed dairy cattle; [d]Waste product from sugar beet industry, dried, coarsely ground; [e]Waste from stone-cutting industry (volcanic tuff), finely ground. RAC = site at Harnhill Farm (Royal Agricultural College), Cirencester.

silage in the UK (Newton 1999). Ryegrass (*Lolium perenne*) formed the major component of the first silage cut at all sites. However, the sward composition differed between cuts because of the contrasting growth patterns of grass and clover (Frame & Newbould 1986). White clover (*Trifolium repens)* made up 5 and 15% of the DM yield in the first silage cut at EFRC and SAC, respectively; this increased approximately three-fold by the second cut in both years. Red clover (*Trifolium pratense*) made up 30% of the DM yield in the first silage cut at RAC; this increased to 70% by the second cut in 1999.

Cumulative yields of silage at the sites were large, even from the control plots (SAC 14.3 t ha^{-1}, EFRC 11.2 t ha^{-1} and RAC 12.3 t ha^{-1} in 1999). These are larger than the yield range typically given for organic grassland, that is, 1.2–8.5 t ha^{-1} measured in cages on grazed fields (Newton 1999). Coupled to the lack of yield response to fertilizer treatment, these data indicate that silage yields at these sites were not limited by P or K. Keatinge (1997) also found no significant yield response to a range of supplementary P and K sources (including Kali vinasse, rock potash, rock phosphate and redzlaag) on organically managed pastures in upland systems and attributed this to nutrient sufficiency at the sites.

Nutrient concentrations of grass and clover

The full data for P and K concentrations in grass and clover at each cut are not shown, lest the reader be overwhelmed by data showing few differences on a plot-by-plot basis; key means are given in the text where relevant.

Effect of cut. P and K concentrations of grass and clover were very highly significantly different between cuts in both years at all sites. In grass samples, P and K concentrations were greater in the later cuts (0.37% P and 2.6% K on average across all sites) than the first cut (0.27% P and 2.2% K on average). The higher grass yields and more mature grass in the first cut probably led to this dilution effect (Jarrell & Beverly 1981). In contrast, P and K concentrations of clover were smaller in the second silage cuts (0.25 and 1.9% on average across all sites compared with 0.28 and 2.2% on average in the first cut). The dilution effect for clover is seen in the second cut of silage due to its later active period of growth (Jarrell & Beverly 1981).

Factors affecting P concentration. There was no significant effect of treatment on the P concentration of either grass or clover in the trials. P concentrations of grass from the trials were within the range of critical values given for adequate grass production (0.2–0.3% P in DM; Mayland & Wilkinson 1996). However, clover P concentrations, which ranged from 0.19 to 0.47%, were often below the critical values (0.3–0.4% P in DM) for clover grown in association with rye grass (Dunlop & Hart 1987).

The site effect on grass and clover P concentrations was very highly significant; RAC had significantly lower P concentrations in both grass and clover. There was no significant difference between grass P concentration at SAC and EFRC, despite the very different available soil P concentrations at the two sites (Table 1). However, in 2000 the P concentration of clover at EFRC was highly significantly greater than that at SAC ($P < 0.001$ and $P = 0.009$ for the

Table 3. Dates of silage cuts in 1999 and 2000 at the three trial sites.[a]

	SAC	EFRC	RAC
1999			
First cut (baseline)	2 July	20 May	17 June
Second cut	7 September	22 July	23 July
Third cut	–	8 October	11 October
2000			
First cut	9 June	31 May	No trial
Second cut	21 August	1 August	No trial
Third cut	–	21 September	No trial

[a]For site key, see Materials and Methods.

Table 4. Mean yields of grass and clover (t DM ha^{-1})[a], with the standard error of the means given in parentheses, for the silage cuts taken in 1999[b] from the three field trial sites.

Site[c]	Cut	Yield (t DM ha^{-1})			
		Grass		Clover	
SAC	1	8.1	(0.23)	1.4	(0.13)
	2	2.7	(0.12)	1.4	(0.08)
EFRC	1	5.0	(0.13)	0.2	(0.02)
	2	2.2	(0.06)	0.5	(0.06)
	3[d]	2.9(0.07)			
RAC	1	5.1	(0.19)	2.3	(0.16)
	2	0.8	(0.05)	1.6	(0.09)
	3[d]	2.4(0.08)			

[a]Other species never contributed more than 0.05 t DM ha^{-1} at any site. [b]In 2000, yields were not significantly different from those obtained in 1999. [c]For site key, see Materials and Methods. [d]Subsample was not separated into grass and clover for the third silage cut.

first and second cuts, respectively). It is usually assumed that in situations where P availability from soil is low, such as at EFRC (Table 1), grass will out-compete clover (Dunlop & Hart 1987). However, in this case competition between grass and clover for available P may have been complicated by the interactions of environmental and soil factors at each site.

Factors affecting K concentration. The site ($P < 0.001$; RAC < EFRC = SAC) and treatment ($P < 0.001$) had a significant effect on grass K concentration at the second cut in 1999. At all sites the FYM treatment increased grass K concentration, and at EFRC and RAC the FYM + rock P treatment also increased it significantly. In 2000, the application of FYM and Kali vinasse significantly increased grass K concentration at SAC and EFRC ($P < 0.001$), with the exception of the FYM + rock P treatment at EFRC (second cut). By the third cut in 2000, the grass from the FYM plot at EFRC still had significantly greater K concentration than the grass from the other plots.

At RAC, clover K concentration was significantly increased in the FYM treatments (+ and − rock P) at the second cut in 1999. The K concentration in the clover at SAC (first and second cuts in 2000) was significantly increased by the application of FYM and FYM + rock P ($P = 0.01$). At EFRC, increases in clover K concentration were found where Kali vinasse, rock P, FYM and FYM + rock P had been applied. However, at the second cut in 2000, significant increases were found only where FYM had been applied. Keatinge (1997) also found that additions of Kali vinasse increased plant K concentration.

Grass and clover at SAC and RAC had K concentrations below the given critical ranges (2.5 % for grass and 1.8–2.3% for clover; Dunlop & Hart 1987); in contrast, very few samples from EFRC fell outside the sufficiency range. The ratio of nutrients to nitrogen (N) in plant tissue has been suggested as a better guide to nutrient sufficiency; the use of the ratio compensates for differences due to stage of plant maturity (Dunlop & Hart 1987). At all the sites the N:K ratio in the grass and clover samples (>1.1) did not indicate that K was limiting crop growth (PDA 2000).

Available P in soil

Available P (Olsen-P) concentrations varied significantly between sites at the samplings in 1999 and 2000 (Table 5, $P < 0.001$) as expected from the initial site means. Comparing these results against the broad classes (soil indices) developed to highlight soils that have increased potential for crop deficiency (Anon. 2000), EFRC and RAC might have been expected to show a crop response to fresh P application, particularly in clover (Index 1), whereas SAC had very high available P (Index 5). There was a significant decline in available-P concentrations between 1999 and 2000 at EFRC and SAC ($P < 0.001$); a more rapid decline occurred at SAC than EFRC ($P < 0.001$). There were no significant effects of treatment on soil available-P concentrations at any of the sites for either year (Table 5). Similar results have been found elsewhere (Benbi *et al.* 1988; Bolland 1993) where relatively small applications of P in slowly available forms have been made, for example, at field rates of rock phosphate application.

Available K in soil

Available K concentrations in soil varied significantly between sites at the samplings in 1999 and 2000 ($P < 0.001$; Table 6) as would have been expected from the initial means at the sites. Where the results are compared against the soil index classes (Anon. 2000), EFRC (Index 0) and SAC (Index 1) might have been expected to show a crop response to fresh K application, whereas RAC had

Table 5. Available P in soil (Olsen-P extraction, $\mathrm{kg\,ha^{-1}}$) and P offtake by silage ($\mathrm{kg\,ha^{-1}}$) at the three trial sites.[a] Means with standard error in parentheses.

Available P at baseline	Treatment[b]	P added	P offtake, year 1	Available P, end year 1	P offtake, year 2	Available P, end year 2
SAC	Control	0	17 (2.2)	208 (6.5)	37 (0.9)	177 (4.7)
	Kali vinasse	0.5	15 (2.0)	210 (16.4)	38 (2.8)	182 (5.7)
218 (5.6)	Msl-K	1.6	16 (2.1)	224 (12.5)	36 (3.1)	185 (13.1)
	Rock P	78.5	15 (2.3)	207 (5.1)	39 (1.4)	176 (4.2)
	FYM + Rock P	109.8	14 (2.3)	215 (5.6)	38 (0.1)	185 (6.5)
	FYM	31.3	15 (2.6)	225 (3.9)	39 (1.3)	176 (5.0)
EFRC	Control	0	21 (1.4)	41 (3.5)	36 (1.8)	36 (1.9)
	Kali vinasse	0.5	21 (1.0)	33 (3.5)	38 (6.3)	29 (1.3)
39 (3.2)	Msl-K	1.6	20 (2.0)	41 (2.7)	39 (8.4)	30 (2.6)
	Rock P	78.5	21 (1.3)	47 (0.7)	36 (1.3)	35 (4.1)
	FYM + Rock P	109.8	23 (0.7)	41 (2.7)	39 (3.6)	36 (0.6)
	FYM	31.3	23 (2.0)	52 (5.8)	41 (1.7)	32 (4.4)
RAC	Control	0	18 (1.4)	26 (1.8)		
	Kali vinasse	0.5	17 (0.7)	26 (2.9)		
29 (1.8)	Msl-K	1.6	16 (1.5)	28 (3.4)		
	Redzlaag	78.5	18 (1.3)	29 (2.6)		
	FYM + redzlaag	109.8	18 (1.3)	35 (7.0)		
	FYM	31.3	18 (2.0)	33 (2.5)		

[a] For site key, see Materials and Methods; [b] for treatments, see Table 2.

Table 6. Available K in soil (ammonium nitrate extraction, kg ha^{-1}) and K offtake by silage (kg ha^{-1}) at the three sites.[a] Means with standard error in parentheses.

Available K at baseline	Treatment[b]	K added	K offtake, year 1	Available K, end year 1	K offtake, year 2	Available K, end year 2
SAC	Control	0	109 (21.5)	190 (6.1)	211 (33.2)	138 (8.3)
	Kali vinasse	41.5	115 (22.1)	365 (65.1)	266 (31.8)	200 (30.0)
178 (2.7)	Msl-K	41.5	105 (15.5)	196 (5.7)	207 (11.2)	156 (8.4)
	Rock P	3.9	94 (22.7)	214 (8.0)	224 (13.1)	139 (3.6)
	FYM + Rock P	241.4	102 (10.1)	497 (17.3)	282 (3.5)	225 (23.3)
	FYM	237.5	112 (30.9)	383 (38.6)	291 (16.6)	225 (33.1)
EFRC	Control	0	160 (14.4)	343 (5.0)	264 (8.1)	323 (13.5)
	Kali vinasse	41.5	174 (6.7)	457 (42.2)	294 (46.8)	373 (20.5)
223 (2.4)	Msl-K	41.5	155 (8.3)	414 (31.9)	288 (37.2)	296 (17.5)
	Rock P	3.9	166 (9.3)	470 (56.7)	274 (19.7)	330 (34.5)
	FYM + Rock P	241.4	196 (25.4)	509 (82.3)	311 (19.3)	311 (25.7)
	FYM	237.5	200 (22.8)	853 (46.1)	354 (13.5)	419 (29.2)
RAC	Control	0	127 (9.9)	718 (12.1)		
	Kali vinasse	41.5	140 (2.6)	902 (81.9)		
617 (9.6)	Msl-K	41.5	119 (18.7)	755 (56.5)		
	Redzlaag	0.8	134 (6.6)	735 (38.1)		
	FYM + redzlaag	238.3	156 (3.7)	957 (96.8)		
	FYM	237.5	156 (22.7)	1023 (105.9)		

[a]For site key, see Materials and Methods; [b]for treatments, see Table 2.

sufficient available K (Index 2). There was a significant decline in available soil K between the samplings in 1999 and 2000 in all plots at SAC and EFRC. Additions of FYM significantly ($P < 0.001$) increased available soil K in 1999 (Table 6) and soil K concentrations were also increased where Kali vinasse was applied, but this increase was not significant at all sites. At SAC and EFRC, the significant increases in available soil K did not persist until measurement in 2000. However, there was still some indication of larger available K levels in plots treated with FYM and Kali vinasse (Table 6). At SAC and EFRC, there was a significant decline in available K of soil between the samplings in 1999 and 2000 in all plots.

Relationships between available pools of P and K and silage offtake

Phosphorus. The significantly larger ($P < 0.001$) available P concentrations in soil at SAC compared with EFRC or RAC were not reflected in increased P offtakes at SAC (Table 5). The significantly smaller P offtake at RAC reflects both the lower available P concentrations measured and the reduced quantity in the soil profile of the 'available' nutrients determined in sieved soil, due to a high stone content of the soil at RAC and limited rooting depth, which may also have led to drought restrictions on growth. Given that much of the P applied in rock-P is only slowly available (Robinson & Syers 1990), it is not surprising that no clear responses to fertilizer addition were seen in these relatively short-term trials. The decline in available P on the control plots represented only 9.5% and 25% of the P removed in plant material at EFRC and RAC, respectively. Pools of P in the soil not measured by Olsen-P, such as undissolved rock-P and organic forms of P, may also have played an important role in P supply in these soils. However, where the available P pool was larger in the control soil at SAC, the decline in available P represented 83% of P offtake. Similar results have been shown for a sandy clay loam soil at Saxmundham (Johnston 2000) on soils with little Olsen-P (e.g. 3–7 mg P kg^{-1}), where only a small amount of the P offtake (8%) was accounted for by a decrease in Olsen-P, while on soils well supplied with P (e.g. 67 mg P kg^{-1}), 46% of P offtake was accounted for by the decline in available P. Overall, there was no clear relationship between the available P pool, extracted by Olsen's reagent, and the P offtakes in herbage. The increased importance of reserves of P held in organic forms and as undissolved rock phosphate in the soil for crop P supply in organic farming systems (Stockdale *et al.* 2002) may mean that the pool of available P measured by routine soil tests (Anon. 1986) may be less useful for assessing plant response. Newton (1995) also found that the typical exponential relationship between yield and available P (e.g. Johnston 2001) as applied in management of conventional grass could not be easily transferred to support decision-making in organic grassland.

Potassium. As for P, reductions in available K in the soil were much less than the K removed by harvested plant material; similar results were found by Johnston (2001). The decline in soil available K in year 2 was greatest where treatments had raised soil available K by the most, but those treatments still maintained soil K concentrations above or equal to the control plots in 1999.

At EFRC and SAC, crop offtake in 2000 increased with increasing soil available K measured in autumn 1999 (Figure. 1). Plant and soil interactions at each site result in gradients of the fitted regression lines that are slightly different. Soil clay content, the shorter growing season at SAC, conditions for rooting, and sward composition will affect the relationship between soil available K and K offtake (Syers 1998). Askegaard *et al.* (2003) suggest that measurement of exchangeable K is a useful tool to guide K

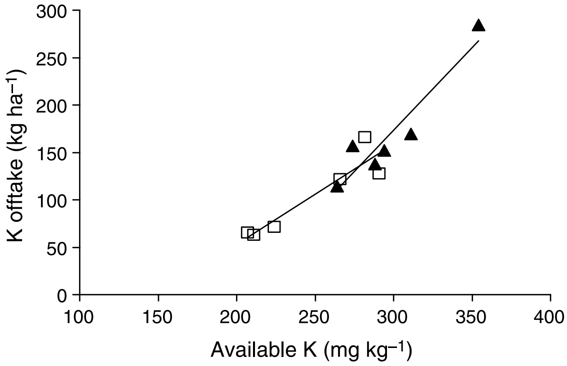

Figure 1. Relationship between the available K (ammonium nitrate extractable) measured in the soil in autumn 1999 and plant K offtake the following year (2000) at SAC (□, $r^2 = 0.86$) and EFRC (▲, $r^2 = 0.89$). For site key, see Materials and Methods.

management in organic systems when applied on a crop rotation basis. The data collected in this study suggest that available soil K does give a guide to likely plant response to additional K in organic, as well as in conventional, farming systems.

Treatment effects seen in the soil analysis in 1999 ($P < 0.001$, Table 6) were also reflected in the K offtakes in 2000. The Kali vinasse and FYM treatments both significantly increased soil K levels and produced the largest K offtakes. MsL-K does not contain a large pool of soluble K and, not surprisingly, did not have the same short-term effect. K offtakes from the Kali vinasse treated plots were similar to the FYM treatments, despite the fact that Kali vinasse supplied only 17% of the K added in FYM. The satisfactory soil supply of K, as indicated by the grass N:K ratios (see earlier), may have prevented any yield response to the additional K supplied in the FYM. In addition, rapid exchange can occur between the exchangeable and non-exchangeable pools when K is applied, making the K unavailable in the short term (Syers 1998). The amount of K added in FYM at standard farm application rates is very large ($>150\,\mathrm{kg\,K\,ha^{-1}}$); this is not widely appreciated by farmers and K response may be improved by using smaller applications of FYM more frequently. Alfaro *et al.* (2003) also highlighted the difficulties of attaining a balanced application of N and K where FYM is applied to grassland and showed that the timing of application, as well as the amount of K applied, is important for K efficiency to be improved. More work is needed to consider the best management approaches for manure on organic farms, where management is required not only to optimize N supplied, but also the significant amounts of P, K and micronutrients applied.

Despite the significantly larger soil available K concentrations measured at RAC compared with EFRC and SAC, the K offtakes were much lower than might have been expected and similar to those measured at SAC and EFRC (Table 6). In shallow chalk and limestone soils, such as at RAC, the restricted root depth and the high proportion of 'stone' in the topsoil can reduce the volume of soil available for both nutrient retention and provision, so that the quantity of plant nutrients available to the plant at the same level of soil available K is less than in a deeper and/or non-stony soil, thus explaining the low K offtakes seen (Johnston 2001).

However, at RAC the increased soil K levels following additions of Kali vinasse and FYM produced significantly larger yields at the third cut of silage in 1999. From the soil analysis results, RAC would have been expected to show no yield response to K additions. It may be that the cation exchange capacity in strongly calcareous soils is highly buffered so that not all the measured available K is readily available to crops, thus K availability may be below optimum, even at a K Index >2 (Arnold & Shepherd 1990). Unfortunately, the loss of the trial at RAC after 1 year meant that comparisons between available soil K in 1999 and K offtake in 2000 could not be made. However, this study does suggest that the results of soil tests must be carefully interpreted alongside knowledge of soil and site factors; a single K index system may not be suitable for predicting K offtakes from all soils or managing K fertilizer application, particularly for chalk and limestone soils.

CONCLUSIONS

It has been postulated that available P and K indices of 1 are acceptable for maintaining production in organically managed grassland (Keatinge 1997). These trials have shown that available K, as measured routinely using ammonium nitrate extraction (Anon. 1986), can support management of K in organic farming systems, as long as care is taken to prevent levels declining. These data also support the conclusion that maintenance of a K index of 1 on non-calcareous soils would be sufficient to maintain crop production. However, routine measurement of available P (Olsen-P) does not seem to provide sufficient information alone to guide P management decisions at rotation or farm level. It must be noted that there is no simple relationship between either P or K removed through crop offtake and the decline in available P and K levels in soil. An increased understanding of the supply of P and K from the 'less available' pools that are not measured by standard extraction procedures would be useful. However, the long-term use of soil reserves without replacement can be considered to be soil mining, and it is important that as far as possible P and K management in organic farming systems leads to balanced P and K budgets.

These trials have confirmed that many of the materials available to organic farmers as supplementary sources of K (e.g. FYM, Kali vinasse) are largely interchangeable with conventional K fertilizers (Johnston & Goulding 1990). However, to match the K applications provided by small amounts of concentrated K fertilizers, large volumes of organic waste materials may be needed (Fortune *et al.* 2004). The storage and handling of large volumes of organic materials may limit the adoption of these materials. However, the additional nutrients (N, P, micronutrients) provided by such materials, together with their contribution to maintenance of soil organic matter levels make them more attractive. More work needs to be done to develop management practices and provide practical advice, which enable the complex mixtures of major and minor nutrients in such materials to be used efficiently and effectively within organic farming systems.

ACKNOWLEDGEMENTS

We gratefully acknowledge the assistance of the farm managers at the field sites in maintaining the trials, particularly Tony Norris and Mike Limb at RAC; David Younie and Michael Coutts at SAC. Christian Peake and Di Moss helped with the sampling. We also thank the Analytical Section at Rothamsted, particularly Adrian Crosland; Wendy Wilmer and Maureen Birdsey also provided substantial advice and assistance. The work was supported by funding from the Department for Food and Rural Affairs (defra). Rothamsted Research also acknowledges the grant-aided support of the Biotechnology and Biological Sciences Research Council.

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Received November 2004, accepted after revision July 2005.