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THE EFFECT OF REDUCING FERTILISER NITROGEN AND PHOSPHORUS APPLICATIONS ON THE SUPPLEMENTARY PHOSPHORUS REQUIREMENTS OF RUMINANTS

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Introduction

Annual UK Surveys of Fertiliser Practice indicate that for all grassland the mean N applications have significantly decreased from a peak of 130 kg/ha in the mid-1980s to 105 kg/ha in 1998; annual use of P (not $P_2 0_5$) declined rapidly from 15 kg/ha in the early 1970s to 11 kg/ha by 1975 and has since fallen to 10 kg P/ha. In marked contrast, mean fertiliser use on grassland on dairy farms currently amounts to 190 kg N and 16 kg P/ha and reflects the enhanced applications required for increased stocking rates and milk production. These are still low in comparison with current MAAF (1994) recommendations of 340 kg N and 18 kg P/ha for intensive grazing and 380 kg N with 40 kg P/ha for optimum silage production.

A survey of 26 trials (7 sources) where herbage was cut repeatedly at either the grazing or silage stages shows a negligible mean response from 2.5 to 2.7 g P/kg DM resulting from annual applications of between 20 and 60 kg P/ha in the presence of adequate N and K fertilisers. Similarly, where herbage was given no P (but normal N and K applications) and repeatedly cut and removed, the mean reduction in P concentration was about 0.1 g P/kg DM per annum over about 5 years.

Phosphorus concentrations in herbage depend essentially on the stage of growth and the amount of fertiliser N supplied. For single spring applications of 59 and 177 kg N/ha, the crude protein (CP) concentrations (g /kg DM) declined progressively from 260 and 340 after 10 days growth to 50 and 90 respectively after 8 weeks growth (Hunt, 1973). The respective simultaneous reductions in herbage P at the same growth stages were from 5.1 and 5.6 g P/kg DM falling to 1.5 and 2.1 g P/kg DM respectively. Prins *et al.* (1985) established that to obtain maximum herbage production containing 250, 200 or 150 g CP /kg DM requires 27.3, 31.1 and 34.9 g P/kg DM. Davies *et al.* (1967) recorded that for a range of pasture legumes both mean P and CP concentrations (g/kg DM) declined linearly from 3.3 and 280 respectively in early May to 1.7 and 170 by mid-July with red clovers and lucerne having lower contents than white clovers.

Five large collections of herbages, silages and hays have shown consistent and significant relationships between CP and P concentrations. These would broadly cover the points connecting 50 CP and 1.0 P and 200 CP and 3.5 P (g/kg DM). It is well appreciated that in many range grassland areas throughout the world (e.g. Howard *et al.* 1962, in East Africa) seasonal changes in both CP and P rise and fall in a regular pattern from season to season depending on recent rainfall.

For intensive pastures (250-400 kg N and 40-60 kg P/ha) with paddock or strip grazing on 21-day cycles there are significant correlations between CP and P concentrations in herbage (Thompson and Warren, 1979; Ritchie and Hemingway, 1998). In consequence, any change in fertiliser policy, stage of herbage growth, stocking rate etc. which results in a change in herbage CP from say 250 to 200 g CP/kg DM would result in a corresponding reduction from 3.5 to 3.0 g P /kg DM (and, of course, *vice versa*). For a high yielding cow with a 20 kg herbage DM intake, this represents a reduction of 10 g P intake/day.

Phosphorus requirements for dairy cows (historical)

Assume a 600 kg cow giving 35 kg milk with 20 kg DM intake /day.

ARC (1965) proposed 4.9g P/kg DM but indicated that *'There is no way at present of testing the general applicability other than by practical experience accruing from their use'.*

ARC (1980) drastically reduced the recommendation to 3.5g P /kg DM i.e. from 94 to 67g P/day. This was emphatically not accepted by UK Advisory Services, UK Feed Trade Association or by the British Veterinary Association.

A Joint Working Party of MAAF /DAFS /DANI /UKASTA /BVA (1983) concluded that '*ARC (1965) has been widely used without serious criticism for 25 years and until definitive work is carried out or long-term trials completed, no recommendation could safely be made for long-term use.*' It was proposed that the ARC (1965) recommendations should continue to be used as 'dietary allowances' rather than as minimum requirements.

In America, the recommendation of 3.4g P/kg DM (NRC, 1978) was increased to 4.0g P/kg DM (NRC, 1989) but to as high as 4.9g P/kg DM during the first three weeks of lactation.

AFRC (1991) changed their 1980 proposals to 3.9g P/kg DM (q=0.7) or 4.6g P/kg DM (q=0.6). They did, however, make several important qualifications. viz.
'*Few aspects of P metabolism are fully understood.*' '*Relevant data for cattle are so limited that P requirements are dependent on sheep data'. 'Conceptional differences between average requirements and safe dietary allowances were identified'. 'Conclude from dearth of information that realistic safety margins could not be calculated'. 'Instead, the skeleton should be relied upon to provide the necessary elasticity between supply and demand'. There is a need to test fully the dietary recommendations in long-term feeding trials especially using forage-based diets'.*

Recent comparisons of phosphorus intake by dairy cows

De Boer *et al.* (1981) evaluated diets providing 3.4, 5.1 and 6.9g P/kg DM by addition of mono-ammonium phosphate. Mean plasma P concentrations were respectively 2.0*, 2.2 and 2.3 mmol /litre and there were linear responses in milk protein percentage. There were no differences in reproduction parameters.

Kincaid *et al.* (1981) used sodium tripolyphosphate to increase total P intakes from 3.1 to 5.4g P/kg DM (70 *v* 120g P /day). The lower P intake resulted in significantly reduced DM intake (21.9* *v* 22.4kg), lower mean milk yield (28.1* *v* 30.1 kg), lower feed efficiency and lower plasma P concentration (1.7* *v* 2.1 mmol /litre).

Call *et al.* (1987) compared diets containing 2.4, 3.2 and 4.2g P/kg DM by addition of monosodium phosphate. Cows given only 2.4g P/kg DM showed distinct clinical signs of P deficiency including reduced appetite, lower milk yields which contained less protein and significantly reduced plasma P content. The diet containing 3.2g P/kg DM although apparently equivalent to that containing 4.2g P/kg DM was considered to be *'marginal'* as there was greater individual cow variability.

Brodison *et al.* (1989) compared ARC (1980) with ARC (1965) P intakes over three lactations by adjusting the P content of two compound feeds (4.0-4.5 and 6.0-6.5g P/kg DM) such as to give 3.5 or 4.4g P/kg DM during the winter months (when housed). The differences in total P intake were 13, 13 and 19g P in each succeeding year. Both groups grazed together on the same pasture (3.5g P/kg DM) during the summer months. Overall, there were no significant differences in milk yield or composition. Most of the cows were mated when at grass and so reproductive aspects could not be ascribed accurately to diets. Overall mean plasma P concentrations were 1.57* *v* 1.75 (winter) and 1.77 *v* 1.79 (summer) mmol P/litre for ARC (1980) and ARC (1965) intakes respectively. It was concluded that *'these reductions, although small, must be looked on with some concern and that longer studies would be required for complete confidence in the lower allowances'.*

Brintrup *et al.* (1993) supplemented the maize silage component of the diet given to one group of cows with 6g P/day using an unspecified source of mineral P. These cows were also given a mono-calcium phosphate supplemented concentrate. The two final diets contained 3.3 and 3.9g P/kg DM respectively and supplied 60g and 69g P/day respectively. There were no significant differences in roughage DM intake or in diet digestibility, milk yield (about 25 kg /day) or in milk phosphorus or protein concentrations or in reproductive performance. The median plasma P concentrations were 1.4 and 1.5 mmol /litre both with ranges from 1.0-2.0 mmol/litre (mean and sem values were not given).

Valk and Sebek (1999) used sodium phosphate to supplement a diet providing 2.4g P/kg DM to either 2.8 or 3.3g P/kg DM for two consecutive lactations. In the second lactation the cows given the unsupplemented diet had markedly reduced DM intakes, gave less milk and lost more liveweight than for the other two groups. For lactation yields of about 9000 kg there were no differences between the 2.8 and 3.3g P/kg DM in milk yields and composition or in reproductive performance. Neither plasma nor milk P concentrations were measured.

Discussion

It is noteworthy that five of the six above references used either mono-Ca, mono-NH_4, or Na phosphates as major components of the total phosphorus given to supplemented groups. (Brodison *et al* (1989) did not define the P supplement used). All are fully soluble in the rumen and are presumably equivalent to salivary P. Witt and Owens (1983) found mono-Ca, mono-di-Ca, di-Ca and defluorinated phosphates to be progressively less soluble in both ruminal and abomasal fluids. Parkins and Hemingway (1998) found loss of P from 23 µm mesh nylon bags in the rumen to be 85% for mono-Ca, 14% for di-Ca and 3% for defluorinated phosphates.

The AFRC (1991) review indicates that salivary P production is influenced by the q-value of the diet, the flow rate and the dietary P intake and is reduced depending on the severity and duration of dietary insufficiency. Phosphorus return to the rumen via saliva considerably exceeds phosphorus of direct dietary origin. When dietary P intake was severely reduced for beef cows from mid-pregnancy (Fishwick *et al.* 1977; Bass *et al.* 1981) voluntary straw intake was only significantly reduced when mean plasma P concentrations fell below about 1.5 mmol P/litre at 2-3 weeks after calving. By 5-6 weeks after calving voluntary straw intake markedly reduced as plasma P concentrations fell below the critical level of 1.0 mmol P/litre. Individual intakes (18 cows) ranged widely from 6.0 kg straw DM at 1.0 mmol P/litre to 2.1 kg DM with 0.2 mmol P/litre. At that time radiographic density of tail bones was observed. Long-term studies are clearly required to cover individual variability in all aspects of phosphorus metabolism. Studies should also include periods when the cows are at grazing; only Brodison *et al.* (1989) included this aspect in the above references.

Reduced reproductive efficiency has frequently been associated with inadequate or marginal phosphorus intake. Many results of observations are anecdotal and any specific confirmed effects are difficult to disentangle from simultaneous inadequate dietary energy and protein intakes, other possible dietary deficiencies and management practices such as body condition, gross individual variation in feed intake in group-feeding systems, lameness, failure to date-record all signs of oestrus activity etc. Where allocation of experimental cows to different phosphorus intakes occurs at calving, it cannot be expected that there could be differences in reproductive performance after less than two months.

However, in longer term experiments and where different P intakes were also given in the dry period, significant differences in reproductive efficiency may be observed. Steevens *et al.* (1971) in a two-year experiment gave cows either 4.1 or 6.0g P/kg DM during the first year and recorded a non-significant difference in the number of inseminations per conception (2.6 *v.* 2.1 respectively). During the following dry period the contrasting P intakes were 3.2 and 4.8g/kg DM. For the second year with dietary intakes of 4.0 and 5.3g P/kg DM, a significant difference ($P < 0.05$) was recorded for the number of services/conception; 4.4 for the lower P content diet and 1.9 for those cows with the higher P intake.

Other adverse consequences may be observed in experiments conducted over more than one lactation. Valk and Sebek (1999) gave diets with 2.4, 2.8 or 3.3g P/kg DM over two successive lactations coupled with 1.6, 1.9 or 2.6g P/kg DM respectively in the intervening dry period. For those cows given the lowest P intake throughout, voluntary straw intake was reduced significantly in the dry period and the following lactation when milk yields were also significantly reduced (‘dramatically’ for almost half the cows). It is noteworthy that in this second year that clinical signs of acetoneamia were observed for three of the six cows given the 2.4g P/kg DM diet, for two of the 8 cows given the 2.8g P/kg DM and in one of the six cows receiving the 3.3g P/kg DM diet. Five of the total of 18 cows in the experiments were lame during the second lactation. No comments were made on conception rates during the second lactation. These findings confirm that individual cows show varied responses to inadequate or marginal dietary P concentrations as salivary P production and bone mineral depletion occurs.

Inadequate or marginally adequate dietary P intake will eventually lead to bone depletion. The perhaps somewhat careless statement by AFRC (1991) that '*skeletal depletion should be relied upon.....*' must not be taken by investigators as an excuse to deprive high yielding cows of the appropriate supply of an essential nutrient as a means of partial alleviation of a potential environmental preblem. This could become a matter of animal welfare. It certainly raises a question of the ethics of animal experimentation if undertaken knowingly in advance. The use of 'should' and not 'could' by AFRC (1991) is most unfortunate. Full professional responsibility for any adverse consequences must be accepted by those who advise farmers to reduce phosphorus inputs to dairy cows.

Safety margins

The late Sir Kenneth Blaxter (1958), in advance of the decisions of the ARC to produce a series of recommendations for nutrient requirements for all farm animal species from the 1960s, argued strongly that these be established on a statistical basis: i.e. mean, plus or minus. He stressed that under- or over-feeding could be recognized fairly promptly in growing or fattening cattle and adjustment could readily be made. But with dairy cows liveweight changes and milk production made this more difficult. He concluded that '*the reason for including safety margins for the cow is to avoid under-feeding and is based on the fact that over-feeding is less detrimental to the cow than under-feeding*'. ARC requirements have always been regarded as minimum recommended nutrient intakes.
If serious consideration were to be given to reduce current, established levels of recommended phosphorus intake, it would seem to be essential for all feeds to be analysed in advance. This is not feasible. Phosphorus originating from grass and maize silage and from grazing amounts to about half the total P intake of a high-yielding cow and any serious under-provision could be damaging. Sensible safety margins (agreeable to all interests) should always be included (MAFF et al., 1983). Where it is apparently essential to reduce inputs of N and P in limited and specific geographical areas it should be recognized that the problem arises largely because of exceptionally high stocking rates and milk production. This is a major problem of agricultural political economy and there are obvious (but very unpalatable) political solutions. To deliberately feed cows too close to their nutritional margin of adequacy may be far from either a safe or sensible remedy. There are other well-appreciated sources of N and P pollution of ground and river water.

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