Agriculture Group Symposium
Magnesium and Calcium in Plant and Animal Nutrition

The following are summaries of papers presented at a joint meeting of the Agriculture Group and the Fertiliser Society held on 17 February 1981 at the Society of Chemical Industry, 14 Belgrave Square, London SW1X 8PS. The papers so published are entirely the responsibility of the authors and in no way reflect the views of the Editorial Board of the Journal of the Science of Food and Agriculture.

Hormonal Control of Calcium Uptake

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The content of elements in plants is controlled to a large extent by the rate of growth, which in turn is a reflection of the ratio of growth-promoting and growth-inhibiting hormones. Duckweed (Lemna gibba L.) grows readily in axenic culture and its rate of growth can be controlled by the addition of the growth promoter, benzyladenine (BA), or the growth inhibitor, abscisic acid (ABA), in varying proportions. The mineral composition of the fronds reflects the rate of growth, the content of calcium being depressed by BA and increased by ABA; the potassium:calcium ratio also relates to the rate of growth.1

Many calcium deficiency diseases are induced by high growth rates. Thus, tip-burn of lettuce is known to occur during rapid growth following a period of growth inhibition. Excision of young fruit trusses or portions of trusses from tomatoes result in blossom-end rot (BER).2 Also parthenocarpic fruit induced by hormonal sprays are prone to BER. Heavy fruit set in both tomatoes3 and apples, prevent BER and bitter pit.

Incidence of internal browning (IB) of Brussels sprouts can also be related to growth rate as it is the larger sprouts at the base of the stem, formed when the plants are growing most rapidly, that exhibit IB. Varietal differences in IB susceptibility can be related to growth rate, the earlier varieties being more susceptible, whereas late varieties seldom show IB. It is, therefore, unlikely that IB is related to the water regime, although water stress will induce higher ABA concentrations and so more calcium in the sprout. Transport of calcium is not involved.

References

Requirements of Magnesium Fertiliser by Sugar Beet

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In the UK sugar beet is grown predominantly on sandy soils which contain little natural magnesium. Compared with other arable crops, it has a large requirement of magnesium and a shortage results in characteristic deficiency symptoms on the leaves. When the cause of the symptoms had been
established, the advice given was to spray deficient crops with a solution of Epsom salts. Experiments later showed that whilst this went some way to curing symptoms it improved sugar yield little. There is now ample evidence from over 100 experiments in all the main sugar beet growing areas that the approach which should be taken is to apply a suitable magnesium compound to the soil as a fertiliser. This increases yield of deficient sugar beet and soil reserves of magnesium, which may improve the performance of other crops in the rotation.

The paper examines yields in experiments made with soil-applied magnesium during the 1960s and compares them with those in recent experiments, in relation to the amount of soil magnesium extracted by ammonium nitrate. It is shown that this test provides a useful guide to which fields are likely to produce magnesium-deficient sugar beet crops. Initially, crops on many fields which had never been treated with magnesium fertiliser responded greatly and (at present prices) 100 kg Mg ha⁻¹ as the sulphate, costing £50 ha⁻¹, increased sugar production on some fields by over 10% or 1 t sugar ha⁻¹, worth £160. The smaller responses in the recent experiments contrast sharply with these and call into question the profitability of magnesium fertiliser on many fields.

The paper examines the effect of the fertiliser in each of the ranges: 0–25, 25–50 and 0–100 mg Mg litre⁻¹ soil in both the early and the recent group of experiments. It is likely that most of the deficient fields where sugar beet is grown have now had one or more applications of magnesium fertiliser. Long-term experiments showed that magnesium has a large residual value, some being still present from one sugar beet crop to the next, even in a 5 year rotation on coarse sandy soils.

Results of experiments investigating magnesium oxide as a fertiliser for sugar beet are also described. This material, produced by calcining magnesite, is about half the price of the equivalent as sulphate. Initial problems over poor availability of magnesium to the plant have been overcome by improved monitoring of the calcining conditions. The paper concludes with proposals for future use of magnesium fertilisers for arable cropping sequences.

References

Variation in the Magnesium Content of Grasses and its Improvement by Selection

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It is recognised that the incidence of hypomagnesaemia in grazing ruminants is only partly related to herbage magnesium content because various factors influence the availability of magnesium. There is evidence, however, that hypomagnesaemia is less likely to occur where herbage magnesium levels exceed 0.2% in the spring and 0.25% in the autumn, levels which are rarely found in the varieties of Italian ryegrass currently available. An initial survey of 11 Italian ryegrass varieties of varying origin showed that although there were only small differences in magnesium content between varieties considerable variation existed between genotypes within varieties.

Since high heretabilities have been shown for magnesium content in tall fescue the variation within these 11 varieties was used to form the basis of a selection programme for magnesium content in Italian ryegrass.

Beginning in 1973, three generations of selection were carried out for high and low magnesium content and agronomic performance in terms of yield, persistency, winter hardiness and disease resistance. During all three selection cycles widely spaced plants (50 x 50 cm) were established in the field in the autumn and were assessed for magnesium content in the first spring and autumn.
The agronomic performance was assessed over two harvest years. The magnesium content of the herbage was determined by atomic absorption spectrophotometry after dry ashing. From this initial breeding material of 100–140 genotypes each of the 11 varieties of Italian ryegrass two groups of plants containing high magnesium and one group containing low magnesium were selected. These groups were isolated separately to produce seed for the second cycle of selection. Sixty progeny from each maternal parent were then assessed for magnesium content and agronomic performance and high and low groups again selected and isolated for seed production. In the third and final cycle of selection 30 progeny from each maternal parent were assessed and final selections of the high and low magnesium genotypes made in March 1980. In September 1980, seed from the final selections was sown in plots to measure the response to selection for magnesium content and agronomic performance under sward conditions.

Magnesium levels in the 11 varieties in this study compare favourably with those reported by other workers. Concentrations were higher in the autumn than the spring and within varieties these were significantly correlated. All three cycles of selection for high and low magnesium content gave a response to selection. Results from the first harvest 7 weeks after sowing in swards of the final selections showed an increase of 35% in magnesium content in the high lines and a decrease in the low line of 24% when compared with the control variety cv. RVP. Although there was no relationship between plant productivity and magnesium content in the unselected material, following the second cycle of selection fresh weight yields were significantly lower on the high magnesium lines than the control variety. The low selection line showed no such decline in yield. However, dry matter yields from the first harvest in the sward assessment trial showed no decline in yield for either the high or low selection lines.

These results show that the magnesium content of Italian ryegrass varieties can be changed by selection. The levels achieved in the direction of high magnesium are within the range where they might be expected to reduce the incidence of hypomagnesaemia. However, the significant decline in the yielding capacity of these lines after two cycles of selection needs further investigation. The sward assessment trial will determine the overall agricultural value of these selections while further tests are needed to assess the availability of these high magnesium levels to the grazing animal and to assess any changes in other plant mineral levels.

References
1. Todd, J. R. Method of increasing the magnesium contents of herbage with particular reference to the prevention of hypomagnesaemia testing in ruminants. 10th Int. Grassld Conf. 1966, 88–90.

Agricultural Use of Lime

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Many advisers believe that an increasing number of plant growth problems are associated with soil acidity. These include not only the effect of acidity on the availability of some macro- and micronutrients but also effects on some soil-inhabiting plant pathogens and the efficiency of some biologically-active chemicals. This summary of a recent, more detailed review discusses what is known about current lime use and methods of predicting calcium losses from soil.

Only very modest dressings of calcareous materials are required to replenish calcium removed in agricultural crops. Very much larger quantities of lime are needed to maintain non-calcareous soils at acceptable pH levels because much calcium is lost from soil in drainage. ADAS current recommendations are to maintain arable soils at pH 6.5 and grassland at pH 6.0.

On many soils calcium is the principal cation lost maintaining the electrical neutrality of drainage which contains nitrate, chloride and bicarbonate anions. Two methods for calculating lime losses
from soil have been discussed in detail;\textsuperscript{1} in both calcium losses depend on soil pH, one method allows for fertiliser use directly, the other makes an indirect allowance.

Soil pH can be determined so easily and a liming recommendation made so quickly on the basis of a laboratory determination, that no farmer should suffer loss of yield because of soil acidity. However, the ability to predict calcium losses from soil reasonably accurately has at least two uses. On a field basis it should indicate how long a dressing of lime is likely to remain in the soil and hence indicate when the next sampling to check soil pH should be made.

On a national scale predicted calcium losses can be related to the amounts of liming material spread on agricultural land; the application of much too little lime serving as an early warning of possible future problems with soil acidity. Since the withdrawal in 1976 of the subsidy towards the cost of lime dressings there have been problems of collecting reliable information on lime use. Currently attempts are being made to estimate lime use and its effect of soil pH from various survey data.

Since 1974 the Survey of Fertiliser Practice\textsuperscript{3} has included both the estimated percentage of crop area limed and the amount of the dressing. The information on lime use is not so precise as that for fertiliser, but over a number of years trends in lime use will become apparent. Current data suggest that only about half the area that should be limed does get lime each year.

ADAS soil science specialists are also monitoring changes in soil reaction by resampling the same fields every 5 years. Preliminary data for two groups of fields first sampled in 1969 and 1970\textsuperscript{4} showed that the average pH of arable and ley-arable soils increased slightly or remained the same and there was no evidence of any increase in the proportion of soils with pH less than 6. This is perhaps not surprising because the total amounts of liming material applied each year until about 1973 supplied more calcium than the probable minimum losses. The average pH of grassland soil however decreased slightly and the proportion of grassland soils with pH less than 6 increased. This probably reflects the declining use of basic slag on such soils.

References


Calcium and Magnesium in the Apple Fruit: Their Distribution at Harvest and Redistribution During Storage

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Mineral concentration gradients within apples were investigated originally to determine representative methods of sampling for fruit analysis.\textsuperscript{1} Work on the effects of orchard factors on the chemical composition and development of physiological disorders showed that long-term storage quality was related to calcium and magnesium concentrations in the whole fruit.\textsuperscript{2} Concentration gradients were then investigated in relation to the location of various disorders, the effects of orchard treatments and post-harvest chemical treatments. Current research is concerned with changes in mineral distribution patterns during storage at different temperatures in air and controlled atmospheres.

Concentration gradients have been measured by analysing slices, pieces of slices or borings, or parings representing specific zones. Borings are advantageous because they can be cut from apples of varying size and chopped into equivalent sections on a board scribed with converging lines. Data expressed on fresh rather than dry matter are more pertinent to storage physiology and are easily transformed to proportions, thereby facilitating measurements of small changes in distribution patterns.
There are calcium concentration gradients around the fruit from blushed to green sides and longitudinally from the stalk to the calyx and where concentrations are lower. The largest gradients are transverse and are steep in the outer few millimeters and very steep near the centre due to high concentrations in the small-celled peel and core tissue. Magnesium also has concentration gradients about the calyx/stalk axis and from stalk to calyx but with highest concentrations near the calyx. Transverse gradients are less steep for magnesium except in the outer 1 mm. The disorders breakdown and bitter pit usually develop in the region of minimal calcium and high magnesium concentrations (near the surface at the calyx end). Calcium and especially magnesium move into tissue affected by bitter pit and core flush. Even when no disorders develop, calcium is redistributed during storage: the high proportion in the core declines with corresponding increases in the outer regions where it is apparently immobilised. There is little evidence of longitudinal redistribution. A massive transverse calcium redistribution occurs in apples breaking down. Proportions of magnesium increase in the outer regions for a few weeks after harvest and then in the core. This demand is met from tissues which include the main vascular system and longitudinal redistribution suggests movement via this route. Low temperature breakdown (LTB), worsened by low overall magnesium concentrations, develops near the main vascular system. Magnesium was depleted in this region and the core when an LTB-sensitive variety was stored at injurious temperatures whereas there was an inward movement of magnesium in a resistant variety. Distribution patterns vary with variety and calcium distribution is changed by orchard sprays and post-harvest dips of calcium which increase proportions in the outer tissues. Post-harvest calcium dips displace magnesium which moves towards the core during storage.4

These investigations indicate that calcium is more mobile than hitherto supposed. Rapid increases in calcium and magnesium concentrations near the fruit surface during the first weeks in store merit further study.

References

The Dietary Availability of Calcined Magnesites to Ruminants

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The accepted daily prophylactic dose of calcined magnesite for the prevention of hypomagnesaemic tetany in cattle is 56 g and whilst this reduces the incidence, it does not entirely eliminate the condition, despite the fact that this supplement supplies the total magnesium requirement as given by the Agricultural Research Council.1 This apparent treatment failure could be due to a low availability of the supplementary magnesium and whereas previous studies (e.g. Ammerman et al.5) have examined the comparative availabilities of different magnesium salts, this work investigates the possible variation in availability among calcined magnesite samples.

A complete balance trial is reported in which sheep received magnesite calcined at different specified temperatures in a laboratory furnace. Total dietary magnesium intakes and total faecal magnesium outputs were measured over 1 week for each supplement to provide apparent availability data. There was no difference in the availability of magnesites calcined at 800, 900 and 1100°C, at 45, 46 and 47% (s.e.m. = 4.7), respectively, but the new magnesite and those calcined at 500 and 650°C were all poorly available.
An adaption of the indigestible faecal marker technique is reported for the determination of supplementary magnesium availability whereby calcined magnesite is mixed in known quantities with chromic oxide. Apparent availability is calculated from the difference between the dietary ratio of supplementary magnesium to chromium and the faecal ratio of magnesium derived from the supplement to chromium. To test the comparative accuracy of this method, chromic acid was included in the supplement feed in the balance trial. The availability figures obtained from this tracer technique agreed well with those based on complete balance data.

The marker technique was employed to compare the availabilities of calcined magnesites in powdered and granular forms (up to 4 mm particle size). Individually penned sheep were fed graded levels of a given calcined magnesite mixed with chromic oxide, and faecal samples were collected after 1 week on each treatment. The regression coefficient of faecal magnesium content on faecal chromium gives the faecal ratio of magnesium derived from the supplement to chromium, hence apparent availability can be calculated. There were only small differences between the availabilities of calcined magnesites of different origins, but powdered products were considerably more available than granular materials. The mean availability of four powdered calcined magnesites from different sources was $50 \pm 8.2\%$ whereas that of five granular products was $18 \pm 7.4\%$.

The chromium technique can be extended to use in the field. Lactating beef cows at spring grass were fed calcined magnesite of different particle sizes, mixed with chromic oxide. Each supplement was given daily for 1 week at the end of which faecal 'grab' samples were taken to provide availability data. The 'fine' particle size range (under 75 μm) was the most available at 48%, followed by 'medium' (150–250 μm) at 28% and 'coarse' (500–1000 μm) at 8%.

The results obtained in both indoor and outdoor situations have shown a wide range of availabilities between different calcined magnesites. In a preliminary experiment, these differences observed in availabilities were well supported by the response to supplementation by plasma magnesium levels in lactating ewes on a magnesium-deficient diet. The results suggest that particle size and temperature of calcination can be important factors in determining availability and will therefore have a bearing on the effectiveness of calcined magnesite in the field.

References

Symptoms of Calcium and Magnesium Deficiency in Vegetables and Glasshouse Crops

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Calcium-related disorders in vegetables may be divided into three groups: (a) those common in commercial practice, such as lettuce tip-burn, internal browning of Brussels sprouts, blackheart of celery and leaf cupping and tip-burn of brassicas; (b) those observed in experimental systems, but rarely seen in the field, such as petiole collapse of umbellifiers, mesophyll collapse and blackening of growing points in many species; and (c) those having a very doubtful association with calcium, such as cavity spot of carrots. Several of these disorders are now of major commercial importance, and growers are looking to the research services for practical remedies.

Magnesium deficiency in vegetables is much less of a problem and the symptom – interveinal chlorosis of old leaves – less variable than in the case of calcium.

In glasshouse crops (as in vegetable crops), a deficiency of calcium is rarely due to inadequacy of the supply. It is usually induced by factors such as the competitive effect of high concentrations of other cations (e.g. K, NH$_4$, Na or Mg) in the substrate which greatly reduce the uptake of calcium, or restriction of the movement of water, and hence calcium, through the plant due to dryness or salinity in the substrate or to excessive humidity in the atmosphere. Blossom-end rot of tomatoes
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and marginal browning of the young, expanding leaves of cucumbers and chrysanthemums are common examples of this disorder.

Fruiting tomato plants frequently show a deficiency of magnesium. This is usually due to high levels of potassium in the substrate, together with a reduction in the absorbing power of the root system as a result of disease or unfavourable soil conditions. Poor root activity may also explain why the cucumber is very prone to magnesium deficiency. In contrast, lettuce and chrysanthemums are rarely affected by this disorder.

These disorders were illustrated and the more important ones discussed.

Absorption of Dietary Magnesium by the Ruminant

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It is only in ruminants that clinical hypomagnesaemia, often leading to fatal convulsions, occurs on diets not apparently seriously magnesium deficient. The condition is seen most often in animals put on to spring pasture (grass tetany). Impaired absorption is the likely cause but no single dietary factor has been implicated and it remains difficult to predict whether or not a pasture will be dangerous from its composition. Understanding of the disorder has improved in about the last decade with the demonstration that the main site for Mg absorption in the ruminant is in the stomachs rather than, as in monogastric animals and pre-ruminant calves, the intestines. With this knowledge has come the recognition that any mechanisms responsible for depressing Mg utilisation almost certainly operate in this area and it has become clear that absorption may be influenced under different conditions by a variety of interacting factors, particularly when Mg intakes are rather low. Factors involved include those affecting directly the availability of Mg such as concentrations of calcium, phosphate, ammonia, chelating agents, microbial cell walls and pH and those having a secondary effect such as protein and carbohydrate intakes. The hypomagnesaemic effects of high potassium and/or low sodium intakes are also being clarified.

However, there remains uncertainty about which compartments within the stomachs are the main sites of absorption. Early studies indicating little absorption in the reticulo rumen are supported by some recent work with the calf implying that the omasum may be a main absorption site. On the other hand, in-vitro studies with sheep have indicated active transport of Mg across the rumen wall and responses in blood and urine Mg to infusion of Mg salts into the rumen have sometimes exceeded those obtained on infusion into the omasum. Nonetheless, responses to omasal infusions have been reported. Other studies in this laboratory, in which material leaving the calf omasum was surgically diverted and its composition compared with that leaving the reticulo-rumen, indicated considerable absorption in the omasum and this finding has been confirmed in more recent studies (Banks, J. N. unpublished) with continuously fed animals. However, the latter studies indicated absorption also in the reticulo-rumen. The weight of evidence suggests that Mg absorption may occur at both sites but their relative degrees of importance are uncertain and may be different for sheep and cattle.

The resolution of this problem is important as the composition of omasal contents differs considerably from that of reticulo-rumen contents so that different factors may affect Mg absorption at the different sites. As examples of compositional differences likely to affect Mg absorption omasal contents in the calf have been found to have Na:K ratios and calcium and phosphate concentrations about twice those found in reticulo-rumen contents.

References
The correlation between growth and Mg content in plants is frequently rather poor.\(^3\) Mg deficiency symptoms are not always a reliable guide to go by,\(^5\) since they may also appear on plants of a high yielding crop. Only when deficiency symptoms appear during certain growth stages such as tillering and grain filling can one expect a positive response to Mg dressings.\(^3\) It was the objective of this work to study Mg uptake of barley at different growth stages and relate Mg uptake to growth.

A pot experiment was conducted with spring barley (cv. Aramir). Four soils were used differing in pH (4.8–7.3), clay content (4–44%), organic matter (2.0–4.8%), exchangeable Mg (3–85 mg 100 g\(^{-1}\)) and exchangeable K (20–100 mg 100 g\(^{-1}\)). The exchangeable Mg and K contents given were measured after fertilisation. N and P-dressings were 6 g N per pot and 0.3–1.3 g P per plot. Each treatment consisted of eight replicates. Two pots each were harvested at the beginning of the stem elongation stage and just before ear emergence, respectively. Four pots remained for the final harvest at the ripening stage.

The Mg content in the plants at the first harvest gave the best correlation with grain yield. At the second harvest the Mg content in the plants of the highest yielding treatments were even somewhat lower (5.8–6.2 mequiv. 100 g\(^{-1}\) dry matter) than in the Mg deficient plants (> 6.2 mequiv. 100 g\(^{-1}\) dry matter). Only the deficient plants had deficiency symptoms during the tillering stage.

There was only a significant correlation between growth and Mg uptake up to the first harvest and for uptake into the grain and dry matter production of the grain. Shoot growth and Mg uptake into the shoot were not correlated after the first harvest. Shoot growth was limited by Mg supply on the low Mg soils whereas on the non-deficient soils shoot growth appeared to run ahead of Mg uptake thus diluting Mg in the shoot down to the deficiency level. But this situation did not persist. At the final harvest the original order of Mg contents in the shoot had been restored.

The grain was a preferential but limited sink for Mg. During the grain filling stage Mg was translocated from the shoot into the grain. The 1000-grain weight was a function of the Mg content in the grain. Mg accumulated in the straw only when the requirement of the grain had been satisfied. There was no accumulation of Mg in the grain above a certain maximum (~12 mequiv. 100 g\(^{-1}\) dry matter) even at high supply rates.

Two growth stages were sensitive to Mg supply. These were the tillering and early stem elongation stages and the grain filling stage. Therefore, it seems that early growth and grain growth have a particularly high Mg requirement and Mg deficiency symptoms during these growth stages would indicate real Mg deficiency. Deficiency symptoms during the stem elongation period might only be transient because of intensive growth and are not necessarily a sign of low Mg supply. This growth stage would, therefore, not be suitable for plant analysis. 40–50% of the total Mg taken up was found in the grain. A large proportion of this was retranslocated from the shoot. The plants on the low Mg soils, however, had not stored enough Mg in the shoot to meet the Mg demand of the grain. The result was a low grain yield.

References