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THE FERTILIZER ASSOCIATION OF IRELAND

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Head
Department of Plant Nutrition/Biochemistry
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Paper read to The Fertilizer Association of Ireland

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INTRODUCTION

More than a dozen elements are necessary for the growth of healthy plants. Therefore, if we seek optimum production, none of these must be left in short supply. Conversely no element must be present in excess to an extent where the overall balance is disturbed. When dealing with the so called "major" elements such as N, P and K one is more commonly concerned with the effects of these on the actual yield of crop but in saying this, possible effects on crop quality or palatibility must not be forgotten.

In the case of trace elements, shortage or excess can also lead to yield differences especially on peat soils, but in Ireland with the predominance of grassland farming the accent is generally on providing suitable concentrations within the plant to meet the demands of the grazing animal rather than to satisfy mere plant requirements. In tillage crops on mineral soils the emphasis is again on crop quality rather than on yield and here the best example is probably that provided by shortage of boron, on the swede crop. In this paper a number of trace elements are discussed, both from the point of view of their distribution in the mineral soils of the country and from the standpoint of their content within the plant and the factors which affect this. As trace elements - with the exception of B and to a lesser extent Co - are not added as fertilizers except as contaminants, a knowledge of soil type becomes increasingly important in order to estimate the likelihood of a deficiency or excess of a particular trace element or indeed to anticipate the effects of application.

TRACE ELEMENTS IN SOILS

The total content of any trace element in surface soils is a reflection both of the nature of the soil parent material and on the degree of development or maturity of the soil. In soils formed from igneous parent materials, agriculturally important trace elements will generally be richer where those parent materials are by nature basic or relatively low in silica, than in acidic or high silica materials. Soils formed from basalts, and dolerites, will therefore have higher contents than those formed from granites and rhyolites. In soils formed from sedimentary parent materials such as sandstones shales and limestones, certain predictions can also be made with reasonable accuracy. Sandstones by their very nature are composed of rather resistant minerals generally low in trace elements and where such sandstones are coarse grained (arenaceous) trace element content will be much lower than where the snadstones are clayey (argillaceous). The trace element content of limestones is for the most part a reflection of the purity of the rock - pure limestones and the soils formed therefrom are a poor source of trace elements while impure limestones, whether the "impurity" be clay, shale or organic matter, give rise to soils with higher contents. Shales are relatively rich in trace elements and in general the finer the texture of the rock or its derived soil, the higher will be the trace element content.

An illustration of the effect of parent materials on surface soil trace element content is shown in Table 1.

TABLE 1. Soil parent material and trace element content (ppm)[1]

Soil Series	Parent Material	Co	Cr	Cu	Mn	MO	Ni	Rb	Sr
Kiltealy	Granite	1	20	10	600	< 1	5	230	100
Old Ross	Granite	.7	30	10	1000	< 1	10	180	50
Clonroche	Shale Granite	17	60	10	4000	.1	25	130	25

[1] **Fleming, Gardiner & Ryan (1963)**

The data refer to three Soil Series from Co Wexford which are formed from glacial drift initially granitic but grading into first a mixture of granite and shale, and finally into almost pure shale. The elements rubidium (Rb) and strontium (Sr) are not agriculturally important but they are included here to illustrate the point that they are higher in the granite soil. This is because they show a preference for potassium minerals such as feldspars and micas, important minerals in granite. Elements such as cobalt and manganese, on the other hand, are characteristically low in granitic soils.

The above points refer to the inherent levels of trace elements in different soils. Other soil-forming factors such as leaching, podzolization and organic matter build-up also affect to a marked degree trace element levels in surface soils. A number of cobalt-deficient soils in Ireland have resulted from podzolization where, with time, leaching has depleted surface levels and concentrated the element in lower horizons of the soil profile. Organic matter accumulation tends to concentrate some elements in surface layers and is especially important in the case of lead (Pb).

Availability of trace elements

So far only total quantities of trace elements in soils have been discussed. While these provide a potential bank or reserve for plant roots to feed on, in agricultural practice the availability of such nutrients becomes all-important. Several factors influence this availability. In general, liming reduces the availability of most agriculturally important trace elements but in the case of molybdenum (Mo) and selenium (Se) the opposite holds.

Drainage status can also have a very important bearing on the availability of trace elements. Under conditions of poor drainage the availability of a number of elements is increased because manganese and iron minerals tend to solublize and Mn and Fe thus become more available. Research has shown that a number of trace elements in soils are associated with iron and manganese oxides and when the latter break down their associated trace elements are also made more freely available for absorption by plant roots.

Estimations of plant availability can be made by using suitable soil extractants or more positively by measuring the content of a particular trace element in the growning crop. Using a soil extraction procedure Walsh et al. (1956) showed that the proportions of Co extracted from a poorly drained soil by acetic acid was five times that extracted from a free draining soil. Fleming (1977) measured the amounts of Mo in grass from ungrazed sites on a soil of known parent material but of different drainage

status. Results are shown in Table 2.

TABLE 2 Soil drainage and molybdenum availability

Drainage	Soil pH	Organic Carbon %	Mo in grass[1] (ppm)
Good	6.3	3.1	2.2
Imperfect	6.5	3.5	3.1
Poor	6.5	5.0	3.9
Very poor	6.6	7.5	13.0

[1] Contents (in plant dry matter) are averages of four replications and five cuts, May - Sept 1970

The Mo levels in the grass rose with increase in drainage impedence though the exceptional level of 13 ppm in the very poorly drained soil was in all probability partly due to the concomitant increase of organic matter and soil pH.

INDIVIDUAL ELEMENTS

COBALT

Distribution in Irish Soils

Over a number of years many soil samples have been analysed for Co content. Samples comprised those submitted by Agricultural Advisors in connection with suspected cobalt deficiency problems and those analysed from the countrywide survey of soils for organic matter content carried out by Brogan (1966). When the data for soils of known parent materials were collated the results were as shown in Table 3.

TABLE 3 Cobalt contents of Irish Soils

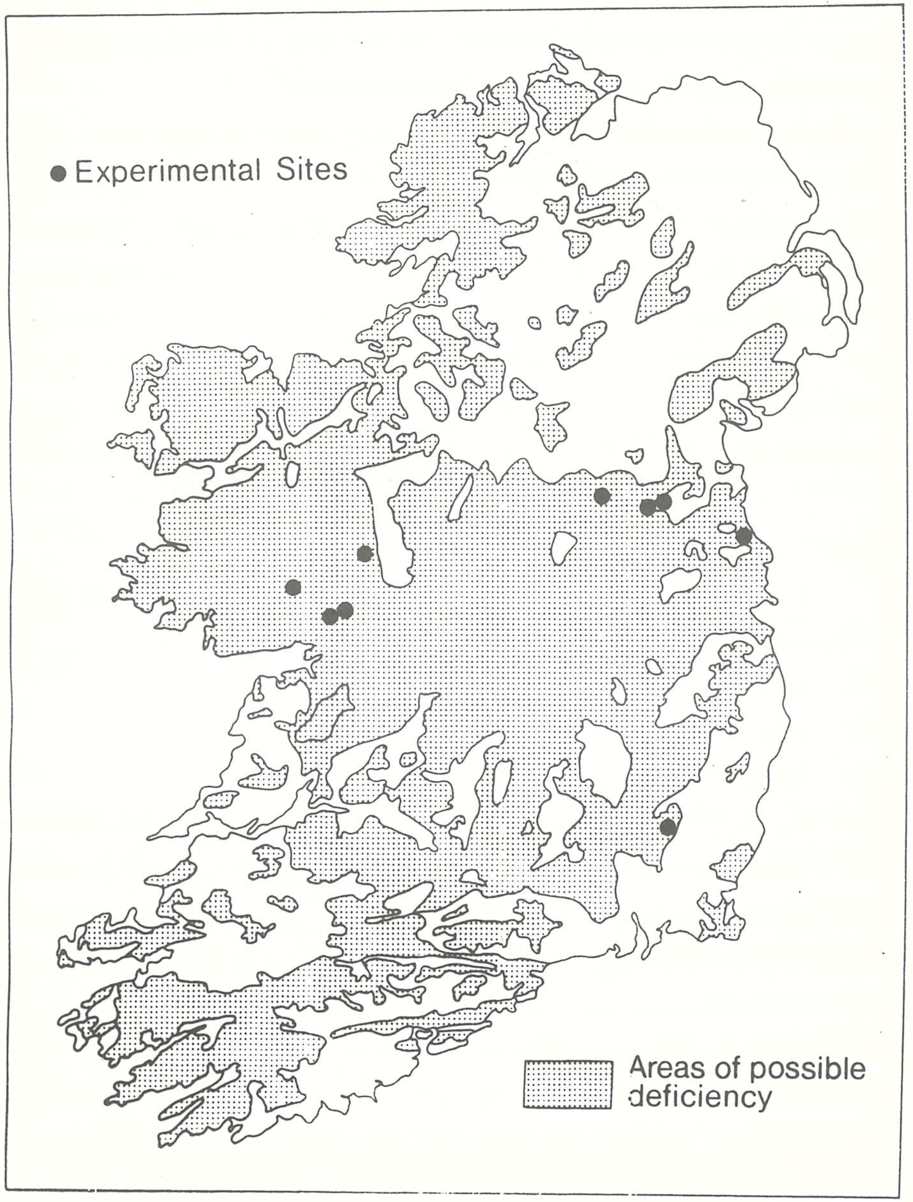
Parent Material	No of Soils	Co (ppm) Range	Co (ppm) Mean
Limestone	278	1.8 - 17.5	6.0
Granite	79	< 1 - 8.0	2.1
Sandstone	75	< 1 - 13.8	3.6
Shale	56	1.6 - 18.4	8.2
Blown sands	19	< 1 - 1	0.4
Basic igneous	7	6.3 - 17.0	12.8

The data refer to Co extracted with strong HCl and can be considered as "totals". Highest mean values were in soils formed from basic igneous rocks, followed by shale soils, limestone soils and finally sandstone and granite-derived soils. Because the availability of Co is conditioned by a number of factors, total Co values can be misleading, in endeavouring to answer the practical questions of delineating cobalt-deficient soils. The figures, however, can be of some value when these other parameters are taken into account. Recent work has shown that the soil manganese content has a powerful effect on the availability of soil Co. In a series of cutting trials (locations shown in Fig. 1) it became evident that the release of applied Co to grass was very much a reflection of the soil Mn content. Where this was high, Co availability was low, and vice versa. Data from three sites representing high, medium and low soil Mn contents are shown in Table 4 and illustrate this point. The herbage Co data are mean values for cuts taken in May, July and September of 1974. Site 1 was on a limestone parent material in Co Galway, Site 2 on granite in Co Wexford and Site 3 on limestone/shale admixture from Co Meath.

The effect of soil Mn content on Co availability is even more strikingly illustrated in data from a similar trial carried out on a peaty podzol on Old Red Sandstone at Coolnakilla near Fermoy, Co Cork (Table 5.) Here the total Co value is only 1 ppm but because the total Mn content is so low (25 ppm) the Co content in the control plot is relatively high (0.11 ppm) and the effect of applied Co quite dramatic.

The Co content in the control plots would be regarded as adequate for ruminant requirements but as the level was obtained in new pasture, doubts must be raised as to the ability of the soil to maintain such a level over any extended period of time. The low value for total Co (1.0 ppm) would suggest that adequate herbage Co levels would not be maintained if this pasture was subjected to grazing pressure over a number of years. However, the very low Mn value suggests that light dressings of cobalt would be sufficient to

Fig 1 Areas of potential cobalt deficiency.



maintain adequate levels in the pasture.

TABLE 4 Effect of applied Co on pasture Co levels

Soil data	**Site 1**	**Site 2**	**Site 3**
pH	6.4	6.7	6.5
Co (ppm)	3.0	2.5	7.0
Mn (ppm)	70	213	1167
Clay (%)	8	11	24
Org. C (%)	2.9	7.7	3.1
Treatment	ppm in herbage dry matter		
$CoSO_4 7H_2O^1$ kg/ha	Co (ppm in herbage dry matter)^2		
0	.05	.03	.02
1.32	.17	.11	.04

[1] **Applied autumn 1973**

[2] **Means of 5 replications and three cuts, May, July and Sept 1974**

With the price of cobalt salts increasing constantly, this factor is not without significance, as the extent of similar soils in the southern part of the country may be quite large.

TABLE 5 Effect of applied Co on a soil of very low Mn content.

Soil Data		$CoSO_4 7H_2O$ kg/ha Apr 1977	Co (ppm) in grass Oct 1977
pH	5.8	0	.11
Co (ppm)	1.0	1	.82
Mn (ppm)	25	2	1.7

Taking all available information into consideration it would appear that the extent of "suspect" cobalt-deficient soils is much greater than heretofore suspected. On the basis of the General Soil Map of Ireland published by the National Soil Survey it is suggested that the possibility of cobalt deficiency should not be overlooked in the shaded areas of Fig 1.

The question of soil intake by animals

It is recognized that a number of factors conspire to determine the amount of Co actually ingested by a grazing animal. Table 6 shows the probable requirements for a number of elements, and with normal feed intakes a figure of 0.1 ppm Co is suggested. Many herbages throughout the country do not contain this amount and reference to Table 4 shows that even after application of cobalt sulphate on soils of high Mn content, herbage Co may still be quite low. In a survey of Co levels in herbage from the Clonroche Series in Co Wexford, values ranged from .03 to .13 ppm with a mean level of .06 ppm, yet cobalt deficiency in sheep does not appear to be a problem on this soil. The Clonroche soil contains quite high levels of total Co (10 to 20 ppm) and total Mn (1,500 to 2,000 ppm).

TABLE 6 Suggested trace element dietary requirements for cattle and sheep[1]

(ppm in dry matter)

Element	Cattle	Sheep
Cobalt	0.12	0.12
Copper	10	5
Iodine (Non pregnant)	0.12	0.12
Iodine (Pregnant)	0.80	0.80
Iron	30	30
Manganese	40	40
Selenium	0.1	0.1
Zinc	35	35

[1] **Scottish Agricultural Colleges Pub. No 29, 1978 p 44**

The relatively low levels in the herbage show that availability of Co is low. One wonders whether soil ingestion is making good the Co not supplied by the herbage. Similarly it is possible that in the short term at least, cobalt applied to soils of high Mn content may, via soil ingestion, be available to the grazing animal. It is a matter of historical record that in the 18th Century lambs suffering from symptoms now recognized as caused by a shortage of Co were cured by frequent drenching with 'red soil and water'. Soil drenching has also been practised in New Zealand with good results. The whole question of soil ingestion and nutrient availability and manner by which these are affected by stocking rate is one on which little factual data exists and

~~would~~ appear to merit some investigation.

COPPER

Distribution in Irish Soils

The distribution of Cu in Irish soils has been summarised by Brogan et al. (1973) but in this study no peats were included nor were any samples taken from over 200 m O'.D. Low levels of copper are commonly associated with peats and there is abundant evidence from AFT work both on blanket peat at Glenamoy and on midland peats at Lullymore, of responses to copper in a variety of crops both agricultural and horticultural (Mulqueen et al. 1961, McGiolla Ri, 1961, Walsh 1969. In mineral soils shortage of Cu is uncommon though occasionally cereal crops may be affected in areas such as east Cork on very light-textured soils.

Land Reclamation

Nowadays with newer land reclamation techniques areas are being brought into production which perviously were virtually unused or at best employed in extensive grazing. Such land includes peatland and hill-land areas which were not taken into account in the survey of Brogan et al. (1973). On peatland it can be assumed that copper fertilization will be the norm rather than the exception but in newly developed hill-land areas where podzolized soils will predominate, shortage of copper and indeed of other trace elements can be

expected. The extent of such shortage will most likely be related to the drainage status and depths of peat cover and may very well be independent of parent material. A good example has emerged from the reclaimed pastures at approximately the 200 metre contour at Coolnakilla, Fermoy, Co Cork. Here the soil is a peaty podzol on Old Red Sandstone and problems in dairy cows symptomatic of low Cu status were encountered (Poole 1977). When herbage was analysed from these pastures the levels recorded were very low and ranged from around 1 ppm in spring samples to 3.5 ppm in autumn samples. These figures are seen in true perspective when compared with the suggested dietary requirements of 10 ppm (Table 6). The question of raising the herbage Cu status became a matter of urgency and accordingly cutting trials involving a number of trace elements were laid down in 1977. A summary of the data to hand is given in Table 7 which shows that a dressing of 20 kg/ha $CuSO_4 5H_2O$ raised the herbage to acceptable levels. The application of twice this amount did not have any significant advantage in the first year. The question of the persistance of the two rates is being followed. The effects of P and K fertilizers on the Cu contents of pastures appear to be slight but N can have variable results. It appears from the data of Reith (1975) that Cu levels can be raised by N application but only when Cu has also been applied. When Cu has not been applied, Cu levels will fall consequent on the dilution effect resulting from increased yields. These points are illustrated in Table 8 where the effects of copper application on clover contents are also apparent. Generally speaking, effects of applied Cu are more apparent in clover than in grasses.

TABLE 7 Effect of copper sulphate on the Cu content of grass, Coolnakilla Farm

$CuSO_4 5H_2O$ kg/ha (Apr 1977)	Cu in herbage[1] (ppm) (Oct 1977)
0	4.0
20	9.7
40	10.5

---

[1] Means of 3 replications

Data from Holland (Oostendorp 1974) would suggest that the effects of copper fertilization are relatively short term and he has proposed top dressings of 2.5 kg/ha copper sulphate every 2 to 3 weeks on pastures for young cattle. Clearly much remains to be investigated on copper and other trace element applications on hill-land. In a number of cases it is quite clear that herbage intake alone will not supply adequate quantities and the dependence upon meal and concentrate feeding then becomes more acute.

TABLE 8: Effect of nitrogen and copper dressings on the copper content of ryegrass and clovers

N - kg/ha per year for three years								
0			100			200		
Cu - kg/ha applied in first year								
0	5.7	28.5	0	5.7	28.5	0	5.7	28.5
Ryegrass								
4.8	5.9	5.5	4.2	6.3	7.1	3.4	6.8	7.4
Clovers								
3.3	7.4	8.6	3.0	7.7	10.1	-	-	-

Data from Reith (1975) - Cu figures are means of three years cuttings.

MOLYBDENUM

Molybdenum is a trace element essential for both plants and animals. Molybdenum toxicity can be a problem of farm animals and here cattle are by far the least tolerant of high molybdenum intakes. Sheep are more tolerant than cattle and horses and pigs are the most tolerant of farm livestock. Growth retardation and loss of body weight is an invariable manifestation of high Mo intakes and diarrhoea is a conspicious feature of molybdenosis in cattle. Anaemia and loss of coat colour develops as intakes are prolonged. The extent to which the various symptoms of Mo toxicity arise in the animal depends on its intake relative to intakes of Cu and S, and the content in the diet of substances such as protein, methionine and cystine which are capable of oxidation to sulphate in the animal body. Intakes of metals such as lead and zinc also have an effect (Underwood, 1977). As the net result of high Mo intake is to deplete the animal's reserve of copper, the maintenance of good health frequently depends on animals receiving supplemental copper.

Origin and location of molybdenum-toxic soils in Ireland

Molybdenum-toxic soils in Ireland are found in three main geochemical environments:

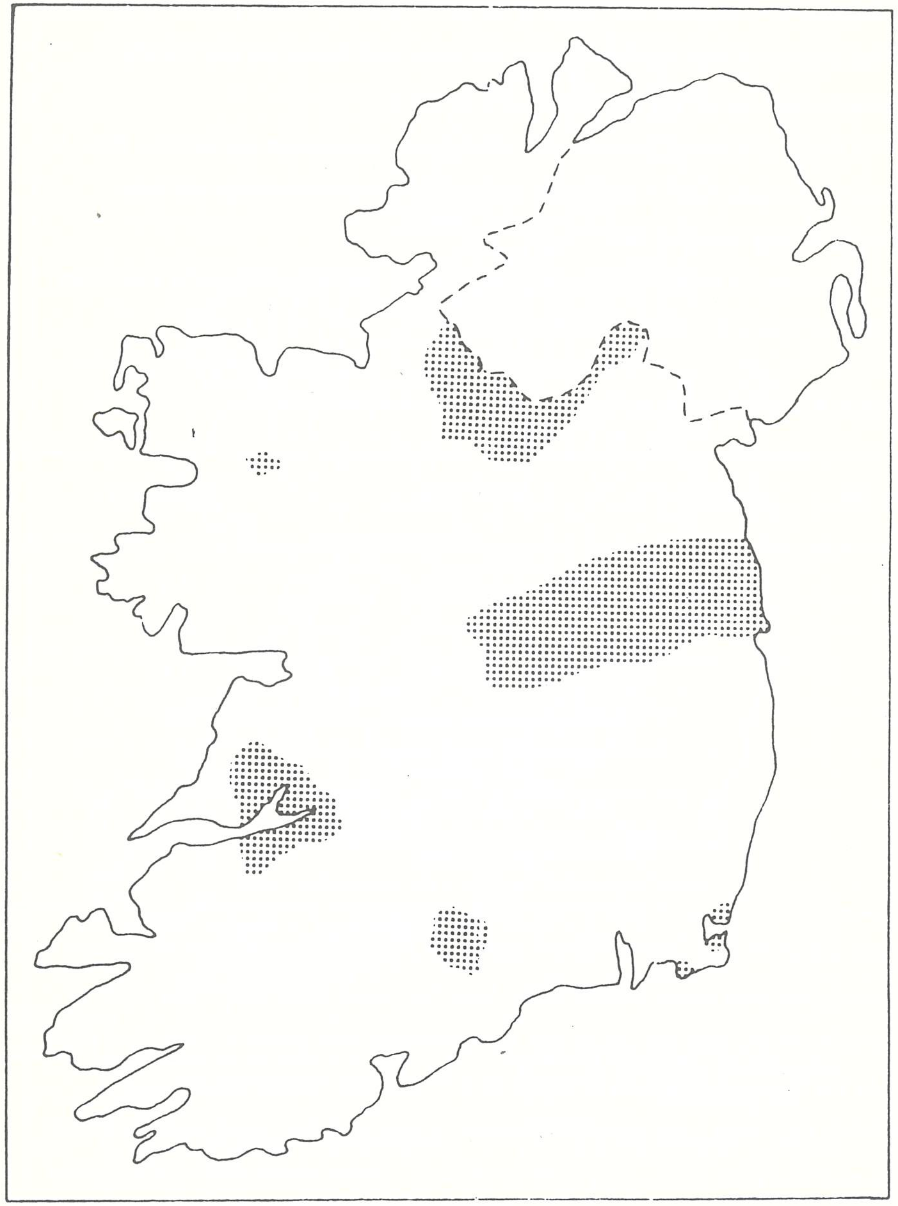
(1) In areas where the soils are formed from or influenced by certain black shales more specifically of Namurian (mid-Carboniferous) age. Such soils are found in parts of Co Clare, west Limerick, north Co Dublin and parts of Co's Meath, Westmeath, Mayo, Leitrim and Tipperary.

(2) In areas recently reclaimed from the sea. Probably the best known of these areas are the Wexford sloblands but similar though smaller areas are to be found in the Shannon estuary and on the Innisowen Peninsula.

(3) In some midland peats. In this situation it would appear that the deposition of molybdenum is secondary insofar as the element has possibly moved in groundwater from molybdeniferous strata. The weathering of underlying impure limestones (Calp) is thought to be another source - possibly the main one.

In the United States, molybdeniferous soils occur on poorly drained neutral to alkaline soils formed in granitic alluvium of floodplains and alluvial fans of some streams. Some soils in Kirkcudbrightshire in Scotland also appear to have their origins in granitic alluvium at the base of hills where drainage is poor thus giving rise to peat and muck soils. No instances of molybdeniferous soils of granitic origin have come to our attention in Ireland but small pockets

Fig 2 Distribution of molybdeniferous soils in Ireland.



may well exist in parts of Donegal, Connemara and Wicklow. The distribution of molybdeniferous soils in Ireland is shown in Fig.2. It may be compared with the distribution of Carboniferous rocks in Ireland (Fig 3) when the similarity between the occurrence of high Mo soils on the one hand and Namurian and muddy limestone deposits on the other, is clearly evident.

While poor drainage considerably enhances molybdenum availability, there are, for instance, many soils in Co Meath with relatively good drainage yet have undesirably high levels of Mo.

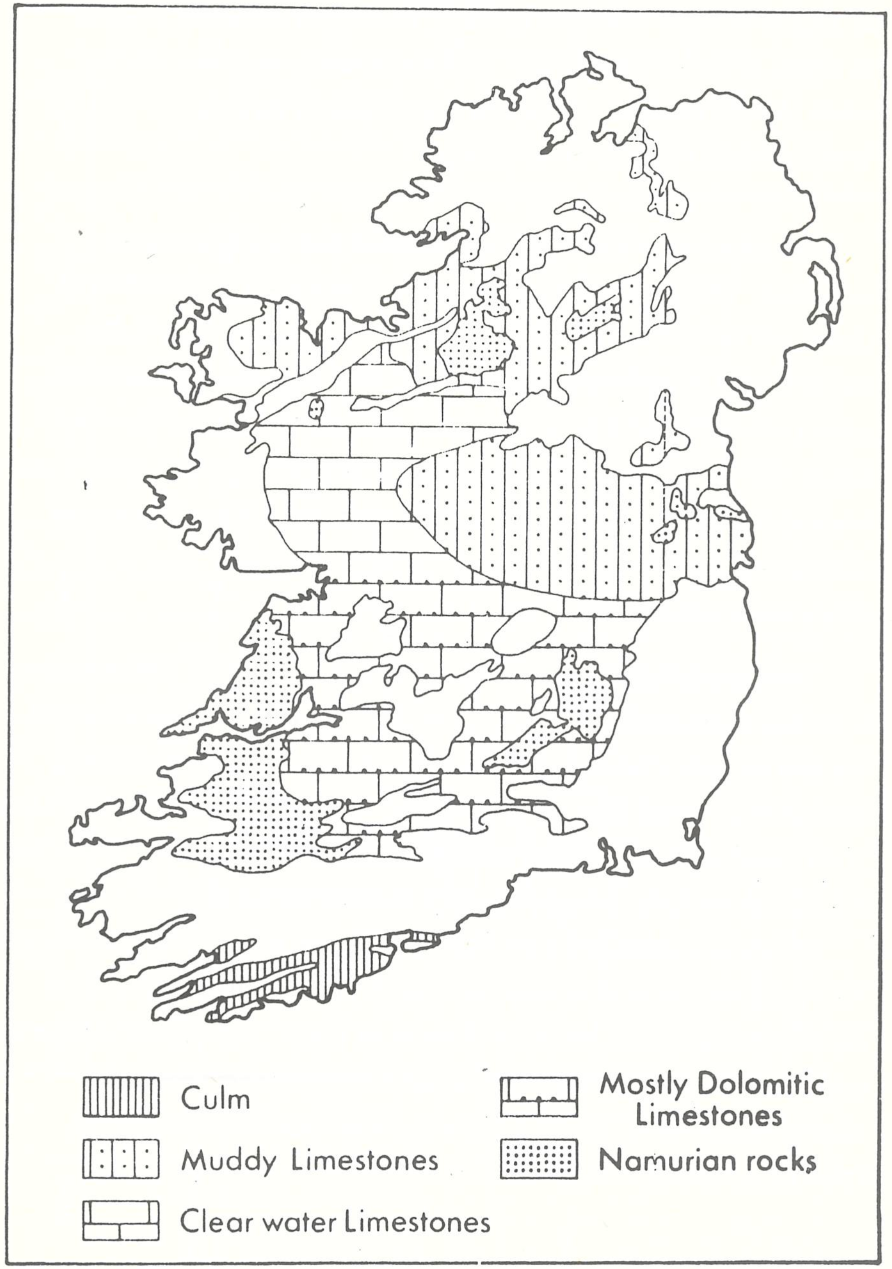
That midland peats can contain high levels of available Mo can be seen from the data of Table 9. The data refer to Mo in

TABLE 9 Molybdenum in Clover from Lullymore Peats

Site No	Peat Type	Mo (ppm)
1	Sphagnum	4.8
2	Fen	0.7
3	Sphagnum	0.7
4	Fen surface	4.7
4	Fen sub-surface	11.7
5	Fen	4.0
6	Fen surface	26.7

clover grown in pots from different peats at Lullymore, Co Kildare. Generally speaking, fen peat being formed under base-rich conditions, contains greater quantities of Mo than the upper and more strongly acid layers of sphagnum peats. While the Mo levels show up to thirty-fold differences between peats from different sites they refer to material grown in pots and the actual levels obtained may well be higher than under field conditions. Nevertheless they underline the

Fig 3 Lower Carboniferous rocks of Ireland (adapted from Charlesworth 1963).



fact that different midland peats can have widely differing Mo contents and availabilities, depending both on the nature of the peat - sphagnum or fen - the amount to which it has been cut away, its moisture status and of course the nature, of the parent material. The data, however, are in line with the known sporadic incidence of molybdenosis is stock in the area.

Factors affecting molybdenum availability.

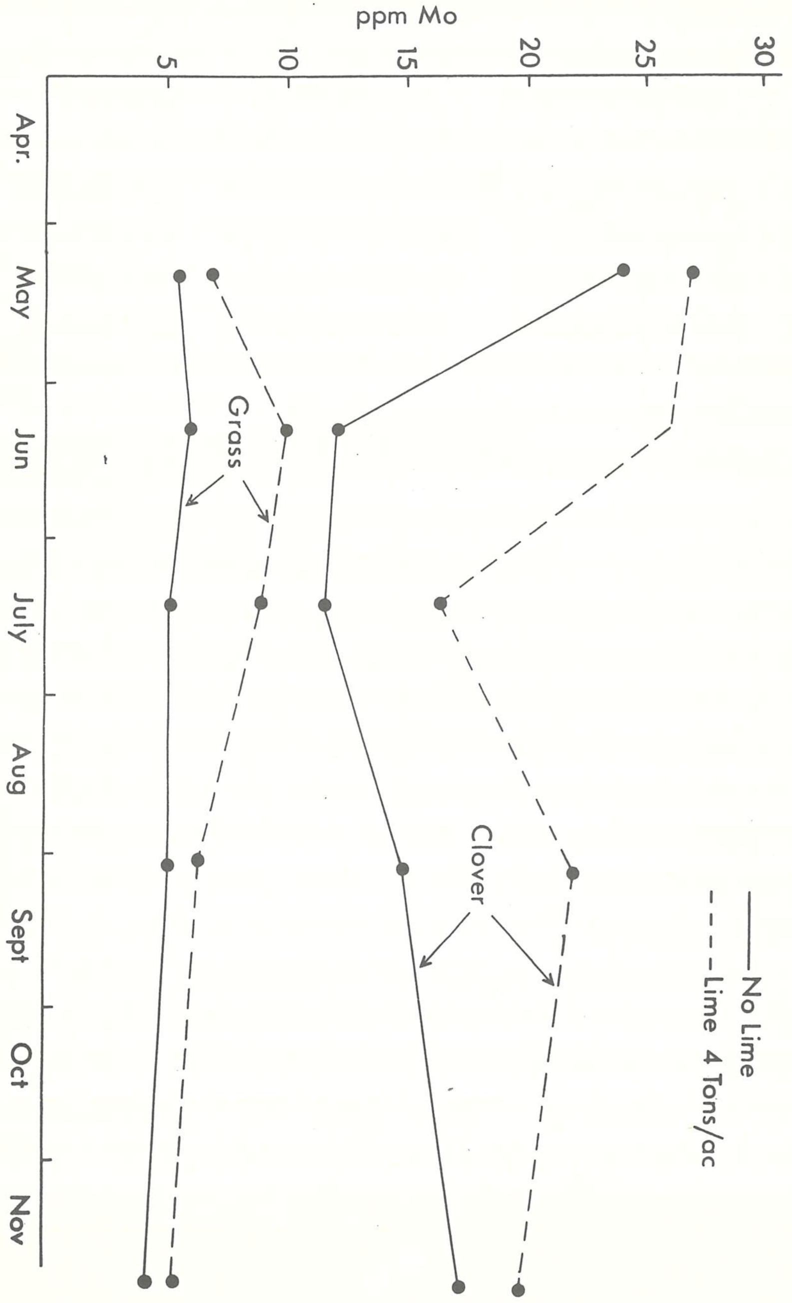
High pH and poor drainage are the dominant factors influencing Mo availability. Of great concern in this regard are certain soil in parts of Co's Leitrim and Meath where the natural soil pH is in the region of 5.5 or less. Clearly these soils require lime for maximum grassland production yet liming above a pH of 6.0 cannot be recommended as undesirable levels of Mo in the pasture may result. The management of these pastures must entail minimal use of lime and an increased use of nitrogen. Nitrogenous fertilisers will discourage clover growth and thereby reduce total pasture uptake of Mo.

Molybdenum in Grass and Clover and effects of Lime.

Some quantification of the statements just made regarding lime and clover in relation to the molybdenum content of pastures will be apparent from Fig.4. The data are from a field trial on the Kilmore (Co Wexford) slobland, where lime had been applied three years previously. It can be seen that the Mo content of the clover was at times higher than that of the grass by a factor of nearly five. It is perhaps not fully realized that such a disparity can exist.

While liming increases the Mo content of herbage it must be pointed out that it is not the only form of fertiliser to do so. Phosphatic compounds that do not contain sulphate can also increase Mo in the plant. The effect of some of the newer CCF's which contain virtually no sulphate has not been assessed experimentallly and it is quite possible that they could have an enhancing effect on the uptake of Mo.

Fig 4 Molybdenum in grass and clover - effects of lime and season.



Soil Moisture Status

The water content of soils can have a pronounced effect on the Mo content of herbage. When drainage is poor,soil pores become filled with water rather than air with the result that, due to a lack of oxygen, reducing conditions obtain. In such a situation the release of Mo from soil minerals becomes greater and so availability is enhanced. This is reflected in increased herbage levels as is shown in Table 2. In a molybdeniferous area, soil drainage, if carried out, could lead to a lower content of Mo in the sward, though it must be pointed out that the improved drainage status could in turn lead to an increase in clover content.

It is clear from the above that the management of molybdeniferous soils can present quite a few problems.

Reducing the molybdenum content of pastures.

From the above data it will be clear that reducing the clover content will considerably reduce the overall Mo status of the pasture. Use of nitrogenous fertilizer will bring about this situation and here sulphate of ammon is recommended in preference to other forms. The reason apart from the obvious effects produced by dilution are as follows:- (1) Sulphate of ammonia produces a slight acidifying effect which decreases molybdenum uptake, (2) the sulphate ion has a well known antagonistic effect on Mo and (3) the ammonium ion also shows this antagonistic effect. Of these three effects, No 2 is held to be easily the most important. The data in Table 10 show the effects of both sulphate of ammonia and gypsum (Calcium sulphate) on the Mo content of grass. The data are from a field cutting trial in Co Meath and the material was harvested in June.

It is apparent that both gypsum and sulphate of ammonia are effective in reducing the molybdenum content of grass. Very large amounts of gypsum are, however, required. The use of sulphate of ammonia seems quite promising.

TABLE 10: Effect on gypsum and sulphate of ammonia on the molybdenum content of grass

Gypsum (tonnes/ha	Mo[1] (ppm)	Sulphate of Ammonia kg/ha	Mo[1] (ppm)
0	8.5	0	12.0
7.5	7.4	50	6.1
15	4.0	500	3.9
30	2.0	1000	3.6

[1] Means of four replications

The effect of other nitrogenous fertilizers does not appear to have been studied in detail but work in Scotland has shown that nitrochalk had no consistent effect on herbage molybdenum content (Reith & Mitchell 1964).

SELENIUM

Toxicity

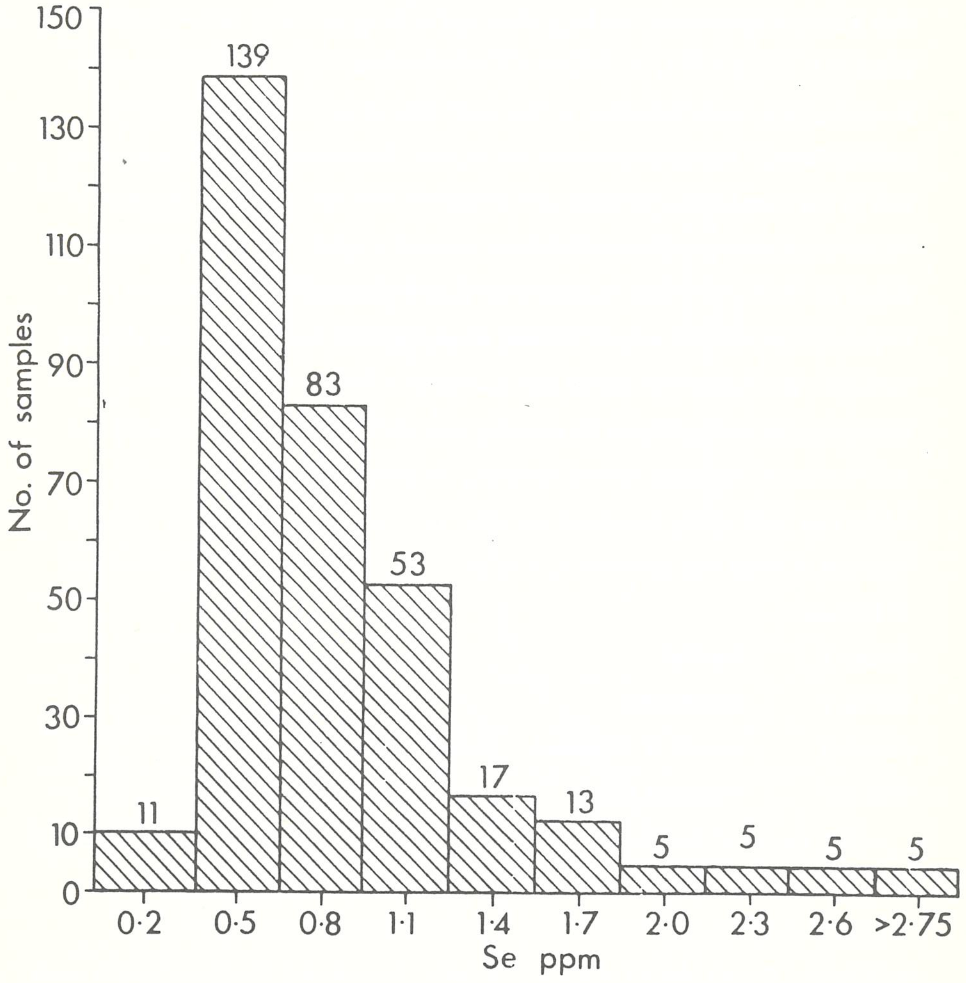
The toxic aspects of selenium have been studied intensively since the discovery in the early 1930's that the element was the causative agent in "Blind Staggers" amd "Allkali Disease" (Moxon 1937). More recently Schwarz and Foltz (1957) have demonstrated the essentiality of Se for animals, and on a world scale, problems arising from Se deficiency far outweigh those attributable to excess.

Selenium toxicity is of course known in this country and the "classical" areas of occurrence are in west Limerick, south Tipperary and Co Meath. The parent material of the seleniferous soils are black shales of Namurian age and where the drift cover is such that the soils are influenced by these shales, soils containing potentially toxic levels of Se are found. The worst areas occur in low lying valleys where drainage is poor and the organic matter levels high. The geochemistry of Se is quite similar to that of Mo but molybdeniferous soils are far more widespread than seleniferous soils. In practice the management of seleniferous soils must be such that stock are allowed only limited access or preferably none at all.

The delineation of really toxic areas then is of vital importance to the farmer. Problems of selenium toxicity generally will not manifest themselves if animals have free range as, probably due to unpalatability, they will naturally avoid seleniferous vegetation. Where farm size is small the danger becomes proportionally greater and subdivision of land in areas which contain seleniferous soils should be undertaken with care. The occurrence of seleniferous soils in Ireland has been well documented (Walsh et al. 1951, Fleming and Walsh 1957, Kiely and Fleming 1969) but some unrecorded toxic areas no doubt still exist. As the National Soil Survey Programme continues these areas will come to light.

It is of interest to record that in the two dry summers of 1976 and 1977 the number of reported cases of selenium toxicity was greater (Twomey et al. 1977). With the shortage of grass which existed during these periods of drought it was inevitable that animals consumed material which they would normally have avoided. This seems the most likely explanation for the increased incidence of selenium toxicity during these years.

Fig 5 Frequency distribution of selenium in Irish soils.



Deficiency

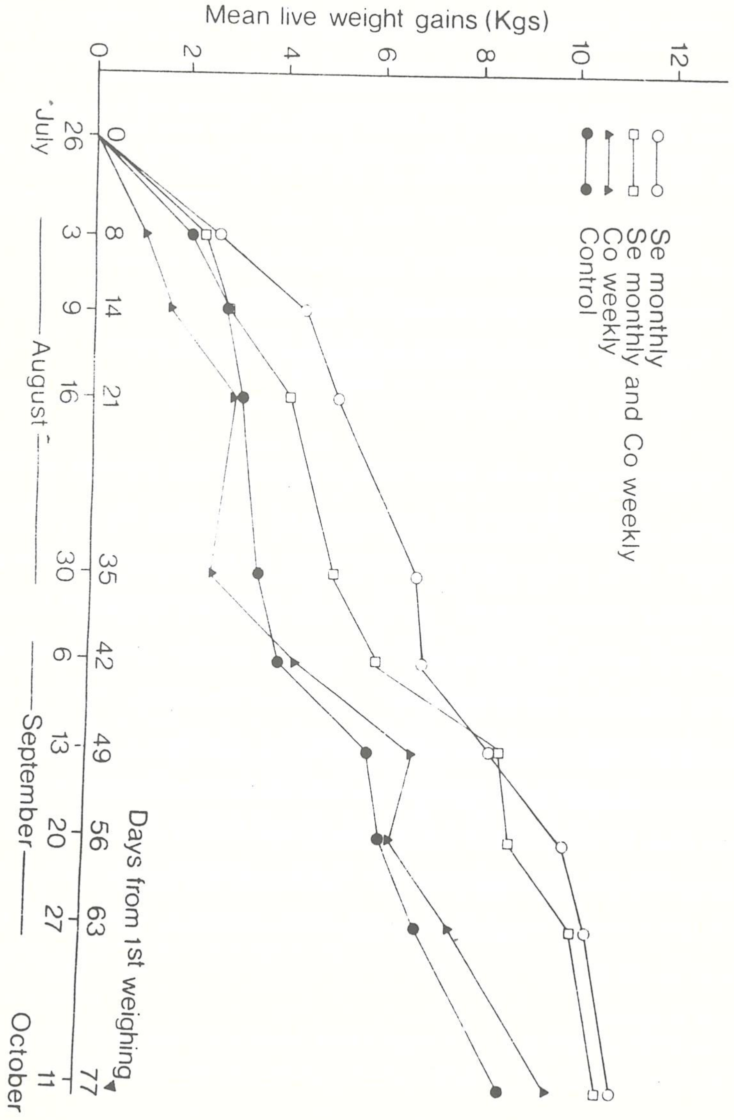
The frequency distribution of Se in Irish soils (Fig 5) shows that quite a number exist having levels of 0.5 ppm or less. This does not necessarily mean that selenium deficiency will be widespread as there are other factors, notably Vitamin E status, which are involved in selenium-responsive diseases in animals. Nevertheless it draws attention to the possibility of the existence of Se-deficient soils. Fig 3 is relevant in this regard. Inspection of this figure shows that in the west of Ireland much of the bedrock is a "clear water" limestone. As the trace element content of limestones is very much a reflection of their degree of "impurity" soils formed from pure limestones (and subjected to relatively high rainfall) would, a priori, be expected to have a low trace element content. Because of this and in the absence of a reliable soil test for estimating the availability of Se a dosing trial with lambs was conducted at AFT's Western Research Centre, Belclare, Co Galway in 1976. The soil which had been newly reclaimed was sown to a ryegrass-clover sward. After a light cut of silage had been taken, four groups of lambs (42 pe plot) were dosed as follows:-

Group 1	Control
Group 2	Cobalt only
Group 3	Cobalt + Selenium and
Group 4	Selenium only.

The results of the trial (Fig 6) indicated significant live-weight gains following Se administration. No response to Co was noted.

The Se level in the pasture at the commencement of the experiment was 0.02 ppm. Cobalt levels averaged 0.10 ppm. In assessing the experiment it must be stated that the results were obtained in a newly sown pasture on a reclaimed soil in a very dry year. Whether further responses to Se will be forthcoming on

Fig 6 Effect of selenium and cobalt on live weights of lambs.



these soils must await further investigation.

Selenium addition to soils.

As the balance between too little and too much can frequently be delicate it is important to assess the effect of different levels of added selenium to soils. At AFT's farm at Coolnakilla such a trial is in progress. As recorded earlier in this paper, the Cu status of dairy cows on this farm was very low but levels of blood Se were also low (Poole 1977) although pasture levels were reasonable. The effects of sodium selenite applied at two different rates are shown in Table 11. To date data are available only for the first year.

TABLE 11 Applied Se and uptake by grass (Coolnakilla Farm 1977)

Se^1 gm/ha	**Se (ppm) in grass**	
April	July	October
0	.06	.04
70	.26	.11
140	.37	.21

[1] Applied as sodium selenite Na_2SeO_3

The rates are similar to those used elsewhere in the world on low selenium soils. Levels were raised considerably but were well within safety limits from the standpoint of Se toxicity.

The effect of Sulphur

As in the case of Mo, the addition of sulphur to soils can lower the

available Se content and this has been demonstrated under field conditions in Ireland (Fleming 1978). Recently, pasture responses to sulphur have been recorded (Murphy 1978). This raises the question of the effect of added sulphur on pasture Se content, and the possible consequences for animal health in areas which respond to sulphur fertilization but which at the same time may be marginal for selenium. Clearly this is a situation which must be kept under review and at present herbage from sulphur-responsive sites is being monitored for Se content.

BORON

Of the elements discussed in this paper boron alone does not appear to be required in animal nutrition. Its importance for plant life has long been recognized and even during the latter half of the last century some investigations into the B content of plants were undertaken. Bertrand (1912) was of the opinion that traces of B were necessary for plants and was at that time recommending its use in commercial fertilizers. The proof of the essentiality of B for higher plants in general is accredited to Sommer and Lipman (1926) but the agronomic significance of the element was really highlighted by the field trials of Brandenburg (1931) who demonstrated that heart rot of sugar beet and mangolds was due to B deficiency. In a very short time borax was accepted as a fertiliser constituent for a number of crops.

Boron in Soils

The total B content of normal soils ranges from 2 to 100 ppm (Swaine 1955) but the majority of soils fall within the range of 5 to 80 ppm. Lowest values are found in soils derived from acid igneous rocks and fresh water sedimentary deposits. Higher values are found in shale-derived soils, loess and alluvium. As a general rule total B values are low in soils that are coarse textured and low in organic matter, while higher values are associated with soils of finer texture. From the agronomic viewpoint the total B values are of far less interest than the water-soluble B contents. Water-soluble B is recognized as a reasonably good indicator of B availability but for correct interpretation of values, such factors as soil pH, organic matter and texture must be taken into account. The following illustrates the point. All other things being equal, the effect of a given increase in water-soluble B on plant B content will be much greater in a light-textured soil than in a heavy-textured one.

Boron and Liming

Boron differs from its anionic counterparts Mo and Se, in that its availability is decreased by liming. When acid soils are limed calcium is substituted for aluminium on the exchange complex. The Al thus released is converted to aluminium hydroxide in the new environment, and freshly precipitated $Al(OH)_3$ is known to absorb or "fix" B very effeciently. In limed peats it seems that fixation of B occurs following the formation of boric acid esters with higher alcohols. The various factors affecting B availability are more fully discussed elsewhere (Fleming 1979), but an important point in connection with liming and boron concerns the higher requirement of plants for B in the presence of higher levels of Ca. High levels of Ca then tend to induce B deficiency and so do high levels of K.

Boron in Irish Soils

Quantitative data on the extent of B deficient soils in Ireland are not

readily obtainable. Walsh and Golden (1952) identified a number of B deficient soils both in the midlands, south and south-east, while Brickley (1943) working in Co Kildare, found that swedes responded both to soil dressings of borax and also to a borax spray. On a site on the Clonroche Soil Series in Co Wexford Fleming & McGrath (1971) compared Borax and Portabor (a calcium borate) on six varieties of swedes. Results were interesting in that symptoms which appeared to be caused by B deficiency were complicated by those of a bacterial soft rot. The effect of boron additions on the percentage of "affected" swedes was disappointing (Table 12) indicating that true B deficiency did not occur to any great extent. It emerged clearly from the experiment that the percentage of "affected" swedes was very much influenced

TABLE 12 Variety and swede quality

Variety	Percent affected roots		
	B_0	B_1	B_2
Bangholm	9.6	11.4	6.5
Willhelmsburger	11.3	10.9	11.7
Broadlands	16.5	16.2	15.4
Tipperary	31.1	42.4	42.5
Magnificient	38.2	46.2	43.7
Peatland Harvester	39.0	37.5	32.8

B_0 = No boron, B_1 = 3.8 kg/ha B, B_2 = 7.6 kg/ha B

by variety. Bangholm, Broadlands and Willhelmsburger were much less affected than Tipperary, Magnificient and Peatland Harvester.

O' Sullivan (1972) in a series of experiments carried out from Johnstown Castle found B deficiency in 13 out of 24 soils throughout the country. Deficiency occurred on soils of differing textures, acidities and organic matter contents. O' Sullivan (1976) carried out a trial on the Screen Soil Series, a light textured soil in Co Wexford (Clay content 10%). Results are shown in Table 13. It is interesting that levels of B in leaves of under 25 ppm were associated with an unacceptable level of B deficiency. As a result of this work it would seem that the present level of B (.33 %) in fertilizer for swedes is too low by at least a factor of 2.

TABLE 13 Boron deficiency and leaf analysis of swedes (Bangholm)[1]

B kg/ha	B in leaves (ppm)	Deficient roots %
0	11.5	98
2.4	16.5	79
4.8	22.4	38
7.2	23.6	20
9.6	35.0	12

[1] (O' Sullivan 1976)

Because of the use of boronated fertilizers on susceptible crops the difficulty of quantifying the true extent of B deficient soils becomes apparent. Obviously coarse textured soils, soils of high pH (greater than 7.0) would be suspect, as would peats. Using water-soluble B figures as criteria of availability the following can be put forward but only as a rough guide:-

Category (1) Less than 1 ppm water-soluble B. Soils may not supply sufficient B to support growth of crops such as sugar beet, swedes, brassicas and apples.

Category (2) 1 to 5 ppm water-soluble B. Soils usually allow satisfactory growth of plants.

Category (3) Greater than 5 ppm water-soluble B. Soils may supply toxic quantities of boron.

Residual Effect of Boron

Concern is sometimes expressed about the possible residual effects of high levels of applied B, on crops grown the following year. On the Clonroche Soil Series in Co Wexford, the author carried out trials on sugar beet using levels as high as 72 kg/ha borax (8 kg/ha B). Effects on succeeding barley crops were measured. The trials were in the north, centre and south of this extensive Soil Series. They showed that there was no residual effect from 72 kg/ha borax (8 kg/ha B) either on the appearance of the crop at the grass corn stage, or indeed in yield of grain (Fleming & McGrath, 1971). While these results apply only to this soil it is felt that even on lighter textured soils a doubling of the present recommendation of B for swedes would not have any deleterious effect on a succeeding cereal crop since B is readily leached from light soils.

Boron and soil moisture - fixation of boron

It is generally accepted that boron availability decreases under dry soil conditions. In laboratory and greenhouse studies fixation has been noted when soils are dried, and increasing soil temperatures lead to greater boron fixation (Berger, 1949). It is doubtful, whether under field conditions, temperatures sufficiently high to induce appreciable fixation are attainable, yet the ~~increased~~ incidence of boron deficiency is classically associated with dry summer conditions. The explanation would appear to lie not in fixation processes, but in the plant's inability to extract boron from soil due to lack of moisture in the root zone. When the surface dries out roots must perforce explore deeper horizons and it is known that boron availability in the great majority of arable soils decreases with depth.

Apart from the effects of soil moisture on the B status of crops it is very clear that even at the present time enough information is not available regarding the capacity of different Irish soils for the fixation and/or release of B. On soils of pH greater than 7.0 it may be necessary to supplement the boron soil dressing with a foliar spray. The proprietary product "Solubor" or Boric acid may be used for this purpose.

THE CORRECTION OF MICRONUTRIENT DEFICIENCIES

Because of the diversity of soil and climatic conditions which are met with in practice, the difficulty of being specific concerning the correction of micronutrient deficiencies is at once apparent. For instance, in the correction of Mn deficiency in cereals, it is known that soil treatment must involve placement of the manganese salt while in soils of high pH one spraying will probably suffice if the weather is showery, whereas under drier conditions a second spraying may be necessary. Similarly with B deficiency in swedes, dry conditions at the "wrong" time may mean that boron applied at sowing time may need to be supplemented with a spray when leaf cover becomes sufficient to ensure adequate retention of the spray.

It is also necessary to distinguish between fertilizing for the plant itself and for the animal consuming the plant. The latter consideration comes into play

in connection with Co and Cu on pasture. On soils where the supply of these elements is too low to meet animal requirements they must be supplied either at sowing time or to the established pasture. In the latter case the elements may be be sprayed on but if this is done, sufficient time must elapse before animals are allowed to graze. The application of Cu must be very carefully carried out, the amounts applied being relatively large (20 kg/ha or thereabouts) it is imperative that there be sufficient rainfall to ensure effective washing of the copper from the leaves of the grass. Closing of the pasture for a few weeks during good growing weather followed by grazing that is not too severe should provide a sufficient safeguard.

Where the crop itself is in short supply of a particular nutrient, spraying is an excellent method for making good the deficiency but a warning must be sounded regarding the strength of spray used. Sensitive leaves may be scorched after spraying and the rule of thumb is to keep the concentration of micronutrient salt below 2 percent w/v. The compatability of micronutrient salts with various herbicides is another practical consideration. It is not possible to go into this question here but compatability charts are available from herbicide manufacturers and these should be consulted whenever in doubt.

Peatland is a special case and the application of several micronutrients may be necessary as basal dressings in addition to N P K and possibly S. Soil application or spraying may be used on peats and for a fuller account of amounts recommended, the publication compiled by the Research Staff of Kinsealy Research Centre (1976) may be consulted (see reference). Some recommendations for the application of micronutrients to soils and crops are given in the Appendix. These can be used as a general guide. For more specific information on both agricultural and/or horticultural crops the following publications are very useful (Shorrocks 1974, for B. Bradford 1966 - several micronutrients, Murphy & Walsh 1972). The latter publication gives some information on the use of chelated and fritted trace elements. No such information is provided in the Appendix as experimental data concerning their use in this country is not sufficient to warrant their inclusion.

TRACE ELEMENT RESEARCH - THE FUTURE

Modern intensive agriculture involves the use of different trace elements in the form of fertilizers, animal feedstuffs and plant protection chemicals. While future research wil continue along existing agronomic and animal nutrition lines, the effects of trace elements on food quality will probably come more into prominence. An excellent example of the effects of a trace element on food quality is afforded by the work of Murphy et al. (1977) at Moorepark Research Centre, linking Cu levels and the keeping quality of butter. The impact of "undesirable" trace elements and in particular heavy metals on the environment generally will certainly merit further attention.

In Ireland the development of hill and marginal land will present a great challenge insofar as exological and management changes consequent on replacing existing plant species with high yielding ryegrass varieties must have far-reaching consequences. The effect of high nitrogen dressings on the trace element content of mew grass species must be closely followed. Iodine (1) may be interesting in this regard. At present, information on the I status of our pastures is meager but it is known that species plays an important part in the uptake of the elemet. New Zealand research has shown that I content of grasses is a strongly inherited characteristic - a point of significance for the plant breeder. I levels in grass are also depressed by high nitrogen dressings. While it is true that overt symptoms of I deficiency in animals are not common, the levels of I in the newer grass species and varieties must be determined both under cutting and grazing systems.

It is unlikely that fertilizers incorporating a number of trace elements will come on the market and it is not desirable that they should. Promotion of such products is based on the concept that soils must be fertilized with all trace elements required by plants and animals. Such a concept is fallacious and in any event the rising cost of trace element salts will prove a constraint. The aim must be firstly to establish where particular deficiencies occur and then to treat them either by soil application spray treatment or direct animal supplementation whichever method is deemed best. For instance the use of cobaltized fertilizers on Co deficient soils of low Mn status can now be recommended but their use on soils of high Mn status cannot be advocated at this time. Here the effect of soil intake by the grazing animal is the great unknown.

Work in the United States revealing the protective action of Se against some carcinogens in laboratory animals has alerted researchers to the probable need for maintaining certain levels of Se in animal and human diets. While these are essentially problems for nutritionists, the regulation of Se levels in crops is clearly an agronomic task.

Finally, additions of such elements as arsenic (As), mercury (Hg), lead (Pb) and cadmium (Cd) to the environment generally must be monitored and controlled. The extent to which our soils are capable of acting as sinks for such elements whether they arise from industrial or agricultural activities must be known. In this respect it is encouraging that in areas of proposed industrial development, the establishment of existing levels of many heavy metals and the acceptance of the need for the future monitoring of them is becoming the norm.

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APPENDIX

Suggested application rates of micronutrients to soils and crops[1]

Element	Crop	Compound	Percent element in Compound	Rate Compound kg/ha	Application Method
B	Sugar Beet	Borax ($Na_2B_40_7.10H_20$)	11.3	25	Soil
B	Swedes	Borax ($Na_2B_40_7.10H_20$)	11.3	50	Soil
B	Sewdes	Solubor ($Na_2B_40_7 5H_20$ + $Na_2B_{10}0_{16}.10H_20$)	20.5	10	Spray 1.5%
Cu	Cereals	Copper Sulphate ($CuS0_4.5H_20$)	25.6	20	Soil
Cu	Cereals	Copper Sulphate ($CuS0_4 5H_20$)	25.6	6.7	Spray 1%
Cu	Pasture	Copper Sulphate ($CuS0_4.5H_20$)	25.6	20	Soil or Spray
Co	Pasture	Cobalt Sulphate ($CoS0_4.7H_20$)	21.0	1 or 2	Soil or Spray
Mn	Cereals	Manganese Sulphate ($MnS0_4.4H_20$)	24.6	10	Spray 1.5%
Mn	Sugar beet	Manganese Sulphate ($MnS0_4 4H_20$)	24.6	10	Spray 1.5%
Mo	Various (Peatland)	Sodium Molybdate ($Na_2 Mo0_4.2H_20$)	39.7	1	Soil
Mo		Sodium Molybdate ($Na_2Mo0_4.2H_20$)	39.7	0.6	Spray 0.1%
Zn	Various (Peatland)	Zinc Sulphate ($ZnS0_4.7H_20$)	22.6	20	Soil
Zn		Zinc Sulphate ($ZnS0_4.7H_20$)	22.6	5	Spray 0.75%

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[1] Spray concentrations and rates/ha are based on a 60 gallon sprayer.
60 galls/ac = 148 galls/ha = 666 litres/ha