THE FERTILISER ASSOCIATION OF IRELAND

EXPERIENCES IN THE GROWING OF TILLAGE CROPS

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TRACE ELEMENTS IN AGRICULTURE— SOME CURRENT ASPECTS AND FUTURE DEVELOPMENTS

G. A. Fleming

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EXPERIENCES IN THE GROWING OF TILLAGE CROPS

By Jim McCarthy, Manager for,
Mrs. M. Wright, Ballyburn, Castledermot.
Tillage Farmer of the Year, 1987.

On November 1st 1981, Mrs. Wright inherited two farms, which were out farms of a much larger farming business. Ballyburn has always been in a tillage rotation except for 40 acres which had to be reclaimed. Marshalstown, the second farm was completely neglected. It was used only as a summer grazing area for a large suckler herd. Between both farms we have 415 adjusted acres. Our objectives are to be profitable, in harmony with our neighbours and with our environment.

SOIL TYPE

Ballyburn is typical of South Kildare land. It is light and sandy but easily worked and yields well given a typical damp Irish Summer. It is suited to most crops but Winter Wheat will suffer in a dry summer. Normal rainfall is just under 30'' with April being under 2'' and December being wettest with 3.5''.

Marshalstown is completely different. It is very variable, it goes from sandy to medium loam, heavy clay, and peat overlying impervious clay. Since it was taken over, this farm has been completely reclaimed. The worst 26 acres has 7.5 Kilometres of tile drains and porous fill. This still remains a very difficult farm, but yields well if we obey the Heavy Land Farming Rules.

FARMING SYSTEM

We grow a range of crops. One may argue that in our situation, continuous cereals could be more easily managed and be more profitable. By growing one third of our acreage in break crops, one third wheat and one third winter barley we spread our risks and labour demand. Farm staff is made up of a final year farm apprentice and a part-time man with myself as manager. During 1988, half of the Winter Barley and half of the Wheat was grown for Seed.

	Acres.		*Acres.*
Winter Wheat	120	Oilseed Rape	25
Winter Barley	117	Sugar Beet	24
Spring Wheat	20	Linseed	15
Winter Oats	26	Horse Hay	26
Peas (For Batchelors)	37		

In Ballyburn the rotation is:-

1) Peas
2) Winter Barley Seed
3) Winter Barley Seed
4) Sugar Beet or Linseed
5) Winter or Spring Wheat
6) Winter Barley

In Marshalstown the rotation is as follows;-

In the difficult wetter areas:

1) Horse Hay
2) Winter Wheat
3) Winter Oats
4) Winter Wheat

In the drier parts:

1) Peas or Sugar Beet
2) Winter Wheat
3) Winter Barley
4) Oilseed Rape
5) Winter Wheat
6) Winter Barley

Many of you may be surprised to see us growing peas considering the problems farmers have had with them in recent years. For us they have always been profitable.

Peas Yields	*Tonns/Acres*
1984	1.91
1985	1.63
1986	1.22
1987	1.31
1988	1.26
Average	1.46

We grow peas for human consumption contracted to Batchelors which attracts a premium of approximately £100/te. over the animal feed price. With pea growing there are a number of rules:-

1) A level seed bed, stone free.
2) A two spray Botrytis control programme.
3) Do not desiccate. If perennial weeds are a problem use low rate Round-Up.
4) Wait until the peas are under 23% moisture before harvesting.

Undoubtedly, on our light land, Peas are our best break crop and they are followed by our most profitable crop, Winter Barley for seed. The following is an example of the growing costs and returns for a Winter Barley Seed Crop.

SOIL ANALYSIS

P.	K.	Mg.	Mn.	Cu.	Zn.
21	141	315	250	3.1	3.0

Covert Field. Winter Barley—Basic Pastoral

Previous Crop. Peas-Batchelors, Size 21 Acres

September 18th	2.55 Bags 0.7.30	0-16-68	£13.27
September 26th	Sowed 10.1 Stone		£28.60
November 4th	Cougar 1.1 Pts.		£11.37
	Copper 0.33 Pts.		£1.26
	Aphicide.		£2.53
February 23rd	40% Urea + S	34-0-0	£5.16
March 31st	Punch C 11 Fl. Oz.		£11.00
April 4th	40% Urea + S	98-0-0	£14.45
April 25th	Radar 7 Oz		£8.00
	Cerone 10 Oz		£8.20
April 26th	40% Urea + S	20-0-0	£2.95
	Total fertiliser	152-16-68	
April 28th	Patrol	5 Oz	£3.28
	Zinc	1 Pint	£2.50
	Manganese	0.7 Pint	£1.71
	Copper	0.5 Pint	£1.50
			£116.92

Total Yield 86.6 te. = 4.12 te/acre
Moisture 19% K.P.H. 70.1 Screenings 1.8%
Price/te. Nett of levy = £113.11

Income £113.11 X 4.12 = £466.00
Straw = £ 25.00
Seed Bonus = £ 61.00
£552.00
Costs = £116.92
Margin = £435.08

One may argue that it is counter productive to apply 150 units of N to a crop of Winter Barley after peas and then turn around and apply a large dose of plant growth regulator to the same crop. To explain why, let us look at the components of yield.

Yield = Number of Ears/M² X No of grains/Ear X 1000 Grain Weight.

1. **Number of Ears/M**
   An ear population of 1000/M^2 is not an unachievable target. From our experience if a decent yield is to be obtained we must have 1000 Ears/M^2.

2. **Number of Grains/Ear**
   When you look at a crop you often see some ears with up to 40 grains. It must be reasonable to think that an average of 24 grains/ear can be achieved. The first shoot will always have a larger ear size than any of the tillers on the same plant. Therefore one has to establish enough plants, we think in excess of 300/m^2. If you do not establish enough plants and then try to push the crop in the spring to tiller all you are doing is increasing the risk of disease, lodging and lower yield. Many of the forced tillers will die off at stem extention.

3. **1000 Grain Weight**
   In the 1988 Department Recommended List Winter Barley Trials the average 1000 grain weight for the 16 varieties was 52.7 grammes.

We now have the target yield components. When we multiply them together the results are staggering.

Yield = 1000 X 24 X 52.7 = 1.26 Kg/M^2.
1.26 Kg/m^2. = 12.6 Tonnes/Ha.
= 5.1 Tonnes/Acres

This yield is possible theoretically, alas how many of us are achieving anywhere near this yield in practice. Yes, it may be impossible to achieve these targets at any one time. However we are endeavouring to do so. We establish enough plants and use 150 units of N to feed them. Alas, a dense crop with this much Nitrogen is very prone to lodging, hence the Cerone. It will also be more prone to disease, thus a higher fungicide input will be necessary. Asking your land to produce such a crop will place it under enormous pressure. If it is even slightly deficient in any major or minor element it will fail to deliver. So it is up to me to provide all the necessary elements for high yields.

SOIL FERTILITY AND FERTILIZATION.

We see from our field records that no amount of applied fertiliser will compensate for good natural fertility. For this purpose we intend to build up all our fields to a minimum of 10 p.p.m. P and 120 p.p.m. K. Because of this we apply high levels of P & K on the less fertile fields. A lot of people are not happy with Urea as a source of N for arable crops. We are slow to use anything else. We are very happy with the results we are getting from 40% Urea with 5% Sulphur. It works perfectly as long as it is applied when there is sufficient moisture. Our late N applications are usually in the form of CAN, but if the weather is wet we are happy to proceed with 40% U.A.S.

CROPPING STRATEGY

We get an exceptional return each year from Winter Barley for seed and this gives us our best gross margin.

Winter Barley Yields. (te./Ac)

1984	3.51
1985	3.26
1986	2.73
1987	3.39
1988	3.48
Average	3.27

When we compare our average Barley yields with our average Wheat yields this explains why we grow an equal acreage of both crops.

Winter wheat yields (te/Ac).

1984	3.81
1985	2.85
1986	2.72
1987	3.25
1988	3.93
Average	3.31

The Winter Barley has an unfair advantage, as it is sown on the best land. A lot of our Wheat is grown on very marginal land after Winter Oats and Horse Hay. The following are the details of a crop of Wheat grown on low fertility marginal land after Winter Oats, and it shows what is achieveable in a reasonable weather year:

SOIL ANALYSIS

P	K	Mg	Mn	Cu	Zn
4	36	345	130	3.2	1.8

Moate Field. Winter Wheat—Galahad.

Previous crop Winter Oats. Size—15 acres.

3 bags of 0.7.30 ploughed in			0-21-90	£17.70
Nov. 2nd	sowed 12.8 stone.			£24.00
Dec. 10th	Muriate of Potash		0-0-80	£10.00
February 23rd	Cougar	1 pint.		£10.30
	Isoproturon	15 fl. oz.		£3.90
March 6th	18.6.12	2 bags	36-12-24	£14.00
April 8th	40% Urea + S		100-0-0	£14.75
April 9th	CCC	63 units.		£1.00
	Zinc	1 pint.		£2.50
	Manganese	1.5 pints.		£3.23
	Copper	0.35 pint.		£1.21
	Sportak	10 fl. oz.		£6.71
May 13th	Copper	0.35 Pts.		£1.20
	Manganese	1.25 Pts.		£2.68
	Zinc.	1.0 Pt.		£2.49
May 17th	Radar.	7 fl. oz.		£8.00
	Cerone	7 fl. oz.		£5.79
May 28th	40% Urea + S.		45-0-0	£6.63
	Total Fertiliser		181-33-194	
June 10th	Impact Excel			£9.40
July 2nd	Metasystox			£2.00
	Bond Surfactant			£0.70
	Polyram	1 kg/ac.		£3.25
	M.B.C.			£1.50
			Total	£151.73
Yield = 4.31 tonnes @ £118.25 nett of levy.				£509.65
			Margin	£357.92

SOIL CARE.

Compaction is the hidden thief and it is expensive to remedy. By far the best cure is to prevent it. We keep the grain trailer traffic to a minimum. The combine is also a big offender. For the 1988 season we purchased a large capacity combine. It's gross weight with a full grain tank is sixteen tonnes. It would create two canals each time it moved on our heavy land unless fitted with low ground pressure tyres.

Headlands and tramlines are subsoiled as soon as ground conditions allow after the harvest. All stubble is cultivated so that volunteers germinate. P & K is applied and ploughing is done using a 140 h.p. tractor and reversible plough. Good crop establishment is the most critical factor in ensuring profitable arable farming. The greatest yield losses occur through poor establishment. We have spent a lot of money to ensure that good plant populations are established. Firstly we purchased a 100 h.p. tractor which is fitted with a front 3 point linkage. We also fitted the tractor with dual wheels which are used at low pressure. On the front linkage we fitted a spiral roller which breaks down and firms the soil. On the rear of the tractor we have a power driven rotary harrow on top of which we have a pneumatic grain drill. With this system we are able to establish the crop in one pass thereby helping keep compaction to a minimum.

TRACE ELEMENTS.

We are indebted to Finnain McNaeidhe of Teagasc, Johnstown Castle for the work which he has carried out on trace elements on both our farms as well as his excellent advice. The following are the threshold values which we use:

Copper at under	4 p.p.m.
Zinc at under	3 p.p.m.
Manganese at under	200 p.p.m.

Magnesium is not a problem for us. You will notice that the thresholds levels at which we treat the crops are lower than the Teagasc recommendations. The reason is that we are attempting to produce high yields and we do not want to risk anything limiting yield. Sulphur has to be watched on our light land and we keep it in order by using 40 tonnes U.A.S. When treating deficiencies we use Chelates. For some reason or another Microfeed products give the least scorch when tank mixed. They also have the greatest number of tank mixing recommendations. For these reasons they are our preferred choice.

MANAGING THE BUSINESS.

We monitor our business closely. Each field is assessed individually and margin over materials is recorded. Crops are compared over a number of seasons and they are eliminated if they are not profitable. Such was the case with Triticale. Some will say that we are spending too much on our variable costs (inputs). By spending money on inputs you improve your chances of making a profit. What happens with too many farmers is that they start cutting their input costs, thereby killing the goose that lays the golden egg. What they should be doing is cutting their fixed costs. Each year we take some particular item of fixed costs and see what we can do to reduce or curtail it. For example, we used to buy all our machinery second-hand. We found our machinery repair bill climbing at a frightening rate. By close monitoring, we found that it would be cheaper for us to buy new equipment, especially when the tax implications were taken into account. Fixed costs are the real killer in a lot of farm businesses, not the input costs.

It is my belief that too much research has gone into cutting input costs. I would suggest that researchers should now look at what they can get these crops to yield by examining the optimum use of all inputs as a complete package, rather than looking at each input in isolation.

THE FUTURE.

We are confident that we have a profitable future in arable farming, as long as we make maximum use of the latest technology. Concern about the environment is already moving up the agricultural agenda and this will really come to the fore in the nineties. Gentlemen of the fertilizer industry you and I as a farmer have a joint concern. Nitrates are creating quite a stir and with good reason, but public ignorance of facts is the biggest problem. Artificially applied nitrogen is only part of the nitrate problem. Animal manures, cultural practices and soil type play equally important roles. Like the hormone issue the consumer could demand action which could be duly taken by the legislators, without proper scientific back up. Unless the Fertiliser Industry and farmers join together this is likely to happen. Already there are proposals to ban nitrogen use in parts of the U.K. Nitrate is and shall become even more of a dirty word. You will have to look in another direction for a market in which to ply your wares. P. & K. usage has not increased since the early seventies. There are many farms on which P. & K. deficiency must be limiting output. It will not be long before N application will be limited by law in intensively farmed areas. We must ensure that this legislation is sensibly based and applied.

TRACE ELEMENTS IN AGRICULTURE—SOME CURRENT ASPECTS AND FUTURE DEVELOPMENTS

G. A. Fleming,
Teagasc,
Johnstown Castle Research Centre,
Wexford.

This paper is dedicated to the memory of Dr. Tom Walsh the first President of the Fertilizer Association of Ireland whose contribution to knowledge of trace elements in Irish agriculture is internationally recognised.

INTRODUCTION

The subject of trace elements in agriculture has seldom been less than fascinating, primarily one feels, because of the spectacular effects which often accrue from the use of such small quantities when used in crop nutrition. Perhaps the most striking example concerns molybdenum in Western Australia where the addition of 100 grams or less of the element per hectare resulted in the successful establishment of subterranean clover, thus changing the whole agricultural pattern in a vast region.

Many examples could be cited—the use the copper on peat soils in Florida and elsewhere, the beneficial effects of boron and zinc on alfalfa and maize in Europe and the U.S. and more recently the sizeable inputs of copper, manganese and zinc for cereal production in areas such as Saudi Arabia.

In the field of animal production the successes have been no less dramatic ranging from the responses to copper and cobalt in cattle and sheep in Australia in the 1930's to the more recent effects resulting from selenium supplementation in several countries.

Interest in trace elements in human health initially centered around iron and iodine; the former in relation to anaemia, the latter because of its involvement with goitre. There is now an increasing interest in the role of trace elements in human nutrition resulting from a growing awareness of the synergystic and antagonistic effects of other dietary components on their metabolism in the human organism. Zinc in prenatal and neonatal development, copper and Wilson's disease, aluminium and Alzheimers disease are now being actively researched in many countries. One cannot fail to mention the outstanding work which is in progress in China in relation to selenium and Keshan disease (a cardiomyopathy mainly affecting children and women of childbearing age), while its role as an antioxidant in tumour immunity is being studied in many research centres.

In this paper I have drawn attention to what I hope are some relevant facets of the behaviour of trace elements in soils together with some thoughts on their use as fertilisers for crops. I believe that in the future, effort will be intensified in defining more precisely the roles of trace elements in the aetiology of animal and human disorders. I have dealt with this aspect at some length for the obvious reason that nutritional factors are important and balanced nutrition is a direct result of clean healthy food which in turn originates from enlightened and correct agricultural practices.

TRACE ELEMENT BEHAVIOUR IN SOILS

A number of factors influence the behaviour of trace elements in soils. These include soil pH, organic matter content, soil texture, soil sesquioxide content and soil moisture. The properties peculiar to a given trace element are also important. For example copper, manganese and zinc possess a strong tendency towards organic-complex formation consequently their behaviour is conditioned by the presence or absence of complex-forming species in the soil system. The size and change of a particular ion are other properties influencing behaviour. These determine the strength or weakness with which the ion is held on finely divided soil components. This is turn influences its availability to plants.

Three examples are now given illustrating some of the factors outlined above. These are the effects of manganese dioxide on cobalt availability, moisture content on molybdenum availability and the effect of nitrogen on the levels of copper, zinc and selenium in herbage.

Cobalt and manganese dioxide

The importance of sesquioxides in regulating trace element behaviour has been referred to above. Technically ''sesqui'' implies a 1 to 1.5 ratio between metal and oxygen e.g. Al_2O_3, Fe_2O_3, Mn_2O_3. In the case of cobalt however, the content of manganese as the dioxide is extremely important. MnO_2 occurs very commonly in soils—especially well aerated soils.

Initial work on cobalt in Irish soils revealed that lowest levels were associated with soils formed from such parent materials as granite, sandstone and quartzite (Walsh et al., 1956). The existence of low-cobalt pastures on such soils leading to cobalt deficiency in sheep and cattle was therefore not unexpected. However, the prevalence of cobalt deficiency in lambs on soils well supplied with cobalt (Poole et al., 1974) was quite another matter. Clearly the availability of soil cobalt in such instances was poor. Australian work (Skerman, 1959) had shown that cobalt deficiency in sheep was prevalent even on soils which had been dressed 14 months previously with cobalt. Further work in Australia (Taylor & McKenzie, 1966) showed that cobalt was very strongly absorbed by oxides of manganese in soils. The size and charge of the cobalt ion was such that it was readily accommodated into manganese oxide structures where it was held very tenaciously. In practice this meant that although total Co contents may have been quite high, available Co contents were extremely low.

In view of the Australian work which showed that the primary scavenger for soil Co was MnO_2, twenty one Irish soils formed from a variety of parent materials were extracted with a hydrogen peroxide-nitric acid mixture as used in the studies of Taylor and McKenzie (1966). This reagent solubilizes MnO_2 with only minimal dissolution of Fe_2O_3. Cobalt and manganese were measured in the extracts and Fig. 1 shows the excellent correlation which existed between Co and Mn in the extracts. This is indicative of a close association between Co and Mn in the soils.

Field trials were also laid down on soils of varying maganese content and cobalt was applied at zero and 1.32 kg/ha $CoSO_4.7H_2O$. The trials were mainly on old permanent pasture. Three harvests were taken (May, July and September) and there were five replications of each treatment. Cobalt was measured in the herbage and results are shown in Table 1 (A level of around 0.1 mg/kg Co in feed dry matter is reckoned to be necessary for sheep).

Fig. 1: Correlation between Co and Mn in soil extracts

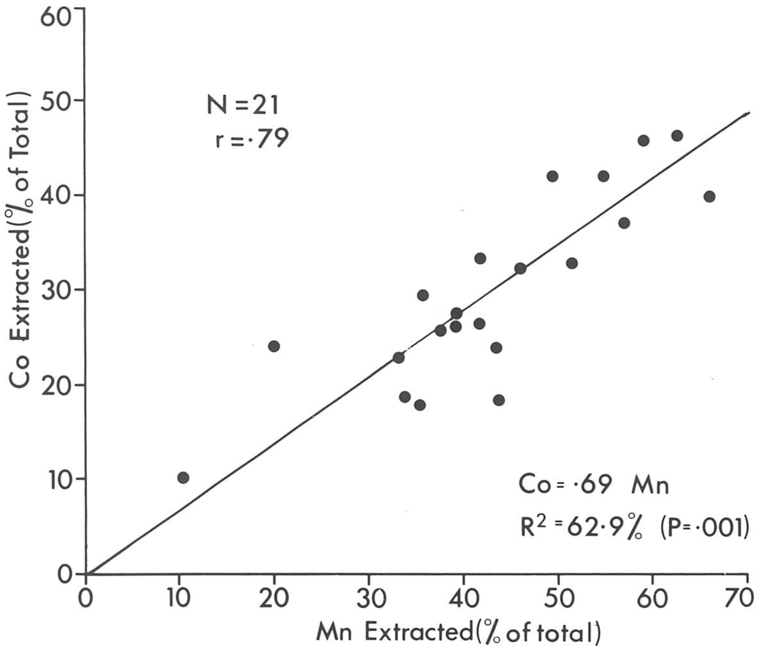


Table 1:
Availability of cobalt from soils of differing manganese contents

Soil Parent Material	*Limestone/ shale*	*Limestone/ shale*	*Granite*	*Limestone*	*Sandstone*
pH	6.5	5.6	6.6	6.4	5.8
Org C (%)	3.1	2.9	7.7	1.9	8.2
Clay (%)	24	22	11	8	9.5
Fe (%)	2.5	2.9	.96	.57	1.4
Co (mg/kg)	7.0	7.7	2.8	2.5	1.0
Mn (mg/kg)	1167	568	213	70	25
$CoSO_4.7H_2O$ kg/ha	Co (mg/kg) in grass*				
0	.02	.04	.03	.05	.11
1.32	.04	.07	.11	.17	.82**

*Means of 5 replications and 3 cuts
**1 kg/ha $CoSO_4.7H_2O$ applied in this case

A number of other soil parameters were measured, soil pH, organic carbon, clay content, total iron content and total cobalt. Table 1 shows that the effect of applied Co was greatest on the soils of lowest clay, total Fe, total Mn and total Co content. The effects of soil pH and soil organic matter content were less clear, but in subsequent work the application of cobalt sulphate to peatland pastures was very successful in terms of raising herbage Co.

In practice applied Co is absorbed on clay and on oxides of iron and manganese (e.g. Fe_2O_3 and MnO_2) which typically occur as finely divided coatings on silicate particles in soils.

In recommending the application of cobalt sulphate to pastures the soil content Mn is a most useful measurement. "Total " Mn as determined by strong acid extraction is a good indication of MnO_2 content. Where soils analyse in excess of around 500 mg/kg Mn, soil dressings of cobalt sulphate need to be increased from the normal rate of 2 kg/ha to about twice this amount. Where total Mn values are in excess of 1,000 mg/kg direct animal supplementation is the preferred option though soil application may prove beneficial for one grazing season if applied in spring and if grazing is close. Animals can receive meaningful amounts of Co from soil ingestion under such circumstances.

Molybdenum and soil moisture

Whereas cobalt has a special affinity for manganese oxides in soils, molybdenum is frequently associated with oxides of iron. In well-aerated soils iron will be present as Fe_2O_3 but under conditions of high soil moisture more reduced forms of Fe predominate. This is because soil pores are now filled with water rather than air and this inevitably leads to more reducing conditions. In this environment the iron oxide minerals become unstable and release associated trace elements into the soil solution. The availability of Mo is therefore greater when soil moisture is high. This point was dramatically illustrated in 1985 when summer and autumn rainfall was high. During that year herbage samples were obtained from two areas in the midlands as part of a general nutrient survey. Table 2 shows the large differences in herbage Mo content which were found between spring and autumn of that year.

Table 2:
Seasonal variation in Mo content of mixed herbage*

Date	Area 1	Area 2
	Mo mg/kg	
April, 1985	1.9	1.8
October, 1985	7.6	10.6

*Data are means of 8 fields in each area

Other factors including soil pH and botanical composition effect the Mo content of herbage but in the case cited no lime had been applied during 1985 and the samples were predominantly grass rather than grass/clover mixtures. The effect of increased soil moisture in increasing herbage Mo has been demonstrated in pot trials (Kubota et al., 1963). It would seem that the data of Table 2 represent this effect in the field. Investigations in molybdeniferous areas in general have shown that—other things being equal—highest levels of pasture Mo are found in the areas of poorest drainage.

The data of Table 2 underline the dangers of a "once only" herbage sampling when investigating molybdenum-related problems. Ideally samples should be taken in spring and autumn in order to assess the degree of seasonal variation in Mo content.

Effect of nitrogen on copper, zinc and selenium levels in herbage

Nitrogenous fertilisers can exercise a significant control over the trace element content of crops. Intensive grassland farming invariably involves the use of generous quantities of nitrogen. Concern has naturally been expressed about the effects of such fertilisation on the trace element content of herbage. An increase in the copper content of herbage following nitrogen application has been noted in the past (Stewart & Holmes, 1953; Hemingway, 1962). More recently it was observed that the effect of nitrogen on the Cu content of both ryegrass and clover was contingent on the initial Cu status of the soil (Reith, 1975). When this was low, nitrogen application reduced the Cu content of both species; when it was high, i.e., after copper had been applied, nitrogen increased Cu content.

A field trial to study the effects of nitrogen on herbage levels of copper, zinc and selenium in an established perennial ryegrass pasture was begun by the author in 1987. Results for the first year are shown in Table 3.

Table 3:
Effect of applied nitrogen on herbage levels of Cu, Zn and Se in herbage*

Trace elements (kg/ha)		Nitrogen (kg/ha)	
	0	50	100
$CuSO_4 \cdot 5H_2O$		Cu mg/kg	
0	9.6	14	15
8	9.7	14	17
16	9.6	16	17
$Zn\ SO_4 \cdot 7H_2O$		Zn mg/kg	
0	20	29	34
8	28	40	43
16	30	47	52
$Na_2\ Se\ O_3$		Se mg/kg	
0	.07	.07	.07
.15	.59	.25	.21

*Means of four replications

The soil levels of Cu and Zn (extractable by .05 M EDTA) were 2.5 and 2.4 mg/kg respectively. Se content (total) was 0.27 mg/kg. Nitrogen rates were zero, 50 and 100 kg/ha N applied after each cut. The nitrogen was applied as Supernet (ammonium sulphate-calcium ammonium nitrate—27% N and 5% S). All treatments including basal P and K were applied in June. The first harvest (July) was discarded as previous work had shown that contamination with applied trace elements would most likely have been quite serious. Table 3 therefore shows data from the second harvest taken in September, i.e., twelve weeks after trace elements had been applied and six weeks after the last nitrogen application.

In the case of copper, no effects from applied Cu were observed but nitrogen increased herbage Cu contents by approximately 50 per cent. Soil mobility of zinc was greater and applied Zn had an effect approximately equal to that of N in terms of herbage Zn content – an increase of some 50 per cent. Yields of herbage dry matter were increased by 65 per cent by the low N rate and by 78 per cent by the high N rate.

The effect of nitrogen on Se herbage content differed from that of Cu and Zn. No effect on Se content was apparent where no selenium was added. Application of sodium selenite resulted in a considerable increase in herbage Se but levels were reduced following N application. In relation to Se however it must be noted that because of the small quantity involved, application was by spraying and uptake into herbage was therefore a combination of foliar and root absorption with the former being probably the more important.

With regard to the effect of nitrogen on crop trace element content in general it would be interesting to determine for different soils, the critical soil level of each trace element below which additions of nitrogen result in lowered crop contents. Clearly in the case described, levels of extractable Cu and Zn were above this value.

TRACE ELEMENT DEFICIENCIES-PRINCIPAL CAUSES

It is convenient to consider trace element deficiencies under three headings.

Inherited
Developed
Induced

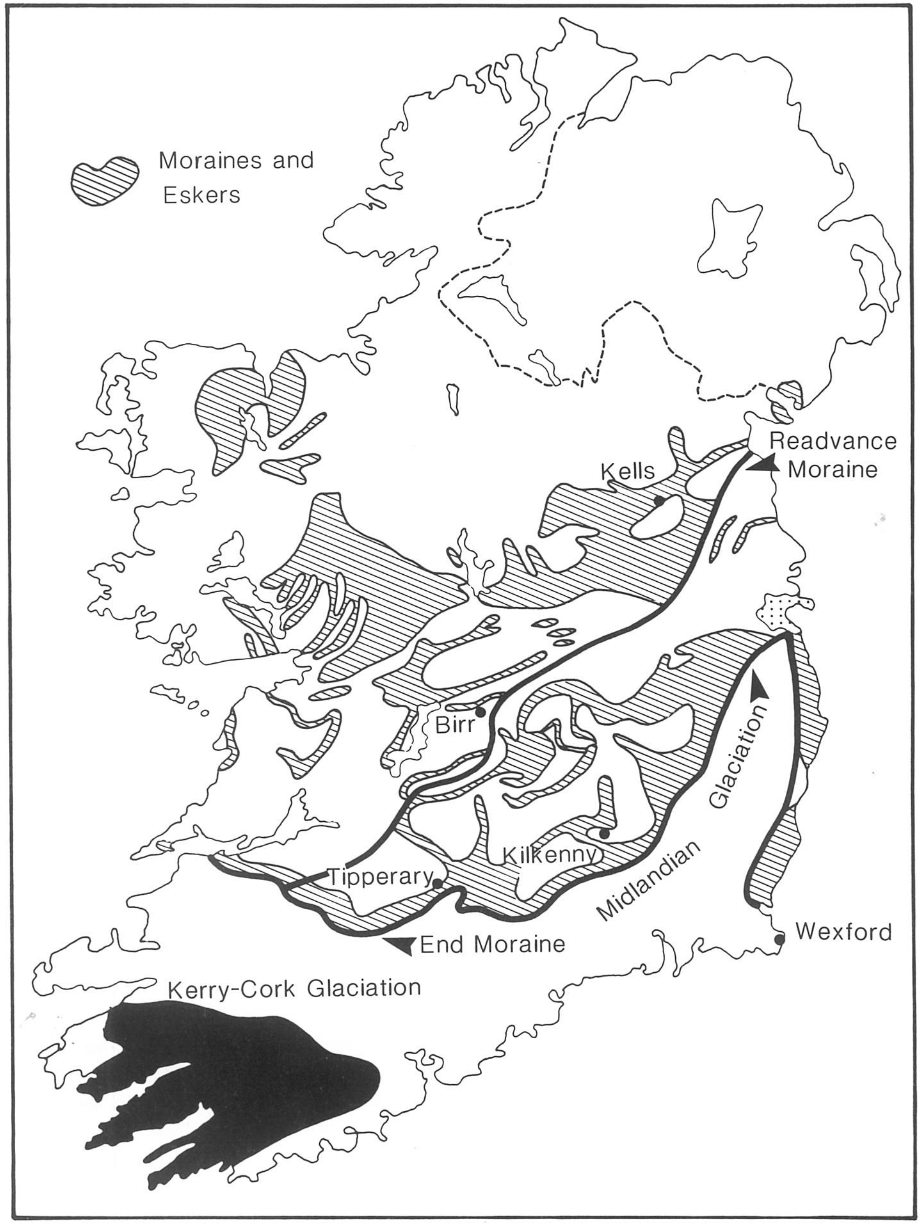
Inherited deficiences

Inherited deficiencies occur when a soil is so depleted of trace elements that a particular crop or animal does not receive sufficient to meet its requirements. Copper deficiency in crops on some peat soils is a case in point, and cobalt, copper or selenium deficiency in animals on many granitic, sandstone or volcanic ash soils can also be ascribed to an inherent shortage of these elements. Geochemical principles can be of great help in predicting the likely status of a particular soil with respect to different trace elements. In relation to granitic soils or indeed soils formed from other acid igneous rocks, trace elements such as cobalt, copper and zinc do not concentrate in the minerals which predominate in these rocks. This is largely a question of the size and charge of the trace element ion. Such ions which by their nature occur in trace quantities in host minerals, do so because their sizes and charges are compatible with those of the major constituents of the host minerals. Cobalt, copper and zinc therefore are readily accommodated in ferromagnesian minierals which are characteristic of basic igneous rocks such as basalts and dolerites rather than of acid igneous rocks as typified by granites and rhyolites. Inherent shortages of important trace elements in sandstones are explained by the residual nature of such rocks, i.e., they are composed predominantly of very resistant minerals essentially poor in trace elements. Boron may be an exception but this element if present is usually associated with the highly resistant mineral tourmaline.

It is obviously easier to predict the likely trace element status of a soil formed *in situ* from bedrock than of a soil whose parent material is essentially transported glacial overburden. Here it is necessary to know the pattern of glacial movement together with the texture of the soil-forming material. Some glacial deposits will be heavy-textured clay and silts; others will be light-textured sands and gravels. The occurrence of zinc deficiency in cereals (MacNaeidhe, Fleming & Parle, 1986) illustrates the point. Here zinc deficiency was first reported on stony hillsides in an area south west of Dundalk. Field examination revealed that these areas were actually part of the Kells readvance moraine of the Midlandian glaciation (Fig. 2).

Fig. 2: The Midlandian glaciation in Ireland

Adapted from J. K. Cherlesworth (1963) "Historical Geology of Ireland"
Oliver & Boyd, Edinburgh and London.



Parts of such glacial deposits would inevitably be coarse textured materials with a resultant inherently low level of trace elements such as zinc. The recognition of this principle has been of value in locating other areas of zinc deficiency in Ireland. At present zinc deficiency in cereals has been confirmed in parts of Counties Louth, Cork, Tipperary, Waterford and Wexford.

Developed deficiencies

These result from soil-forming processes which have taken place over time. Podzolization and organic matter accumulation are examples. In podzolized soils trace elements have been leached from surface horizons and deposited further down the soil profile. The vast areas of trace element-deficient soils in Australia are largely the result of the age of the soils. Because of their age they have gone through several cycles of weathering and have thus become depleted of trace elements.

Organic matter accumulation frequently follows podzolization. The podzolization process results in the formation of an indurated iron pan. Soil drainage is thus impeded with the result that organic matter accumulates. This further reduces the soil trace element content. Peaty podzols are therefore classically associated with trace element deficiencies.

Induced deficiencies

These deficiencies result from the addition to the soil of amendments calculated to improve the overall soil fertility. Lime is the chief agent in this regard but N, P, and K fertilisers exercise their own effects. The main reaction occurring when acid soils are limed is the replacement of exchangeable aluminium by calcium, and its precipitation as aluminium hydroxide

$$2AlX_3 + 3CaC0_3 + 3H_20 \rightarrow 3CaX_2 + 2Al\,(OH)_3 + 3C0_2$$

X = Exchange site

This freshly precipitated aluminium hydroxide is then available for the adsorption of trace elements. Absorption of boron is particularly strong.

Deficiency of boron and indeed other trace elements is frequently induced by lowering of soil moisture. Many trace elements are associated with the more organic-rich surface horizons of soils and when these dry out deficiencies—especially in shallow-rooted crops—result. Here the deficiency is induced by an initial moisture shortage. Boron deficiencies in turnips or alfalfa are classical cases. Copper and manganese deficiencies in cereals are also exacerbated by low surface-soil moisture. The induction of zinc deficiency by high phosphorus fertilisation is well known.

Application of nitrogenous fertilisers gives rise to trace element deficiencies when the initial soil supply is low. The extra growth resulting from fertilisation may make excessive demands on such a soil. When trace element status is adequate however, the opposite effect may ensue (Table 3) and crop content will increase following nitrogen application.

The paradoxical situation whereby a trace element deficiency can be induced by application of the particular trace element is known. Knezek & Greinert (1971) reported a case where application of Mn EDTA on organic soils accentuated Mn deficiency in plants. Use of the compound on organic soils high in Fe is believed to have resulted in a replacement of Mn by Fe in the chelate. The Mn released from the chelate was fixed rapidly in the soil and the Mn uptake by the plants was further suppressed by an Fe-Mn interaction!

CONTROL OF TRACE ELEMENT DEFICIENCIES IN CROPS

The control of trace element deficiencies in crops is basically achieved in two ways

- soil application of the deficient trace element before or at sowing time
- foliar application during the growing season.

Soil application

Soil application is calculated to correct the particular deficiency in the long term and would for instance be considered in continuous cereal growing. Such an approach has met with success in the case of copper and zinc but not with manganese, unless this element is placed with the seed. The method is employed with sugar beet whereby the seed is coated with manganous oxide. Seed treatment is also used in correcting molybdenum deficiency. MacNaeidhe and Fleming (1984) have demonstrated the value of soil-applied copper to barley grown on peat but stress that in the first year, supplementation with a foliar spray of either copper sulphate or a copper chelate will be necessary.

The soil application of copper sulphate for grassland can also have longterm effects (Fleming, 1987). Copper sulphate applied once to a low-copper ryegrass pasture at a rate of 20 kg per hectare raised herbage Cu for seven years (Table 4).

Table 4:
Effect of copper sulphate on the copper content of perennial ryegrass

$CuS0_4.5H_20$ kg/ha (April, 1977)	Cu in grass (mg/kg)*							
	1977	1978	1979	1980	1981	1982	1983	1984
0	4.0	6.7	5.9	4.0	5.0	6.0	4.8	4.5
20	9.7	6.7	11.3	8.6	8.0	10.2	5.7	9.9

*Means of 3 replications and 3 cuts (May, July, October)

Copper fertilisation of pasture is aimed at increasing Cu levels with a view to meeting animal requirements rather than to satisfy plant demands. Only in extreme cases will grass growth be influenced by copper fertilization. It is pertinent to point out that because of other conditioning factors, copper fertilisation will not necessarily prevent copper deficiency in livestock.

Foliar application

Foliar application of trace elements is currently the most popular method for correction of deficiencies. It is interesting to note the increase in the use of sprays—mostly copper and manganese—over a four year period in the U.K. (Table 5). The increased use on winter wheat is especially noteworthy.

Table 5:

Use of trace element (micronutrient) sprays in the U.K. (Church, 1985)

Crop	Percentage of crops receiving trace element sprays 1980	1984
Spring cereals	4.2	7.5
Winter cereals	4.5	11.2
Potatoes	7.1	13.5
Sugar beet	18.2	25.6
Grass	0.5	0.6

Increased yields of cereals have been obtained in Europe over the past decades and it could be argued that such increases necessitate the application of greater quantities of trace elements. Whilst this is undoubtedly true in individual cases it is not necessarily always so. Tinker (1986) considers that certainly in the U.K., there is an overall positive trace element balance in most tillage fields consequent on inputs from trace element fertilisers and from wet and dry deposition. In practice, trace element deficiencies very often appear in spotty areas in othewise healthy crops. As profit margins, especially for cereals, are often quite narrow, the use of trace elements is perhaps a form of insurance against possible losses in yield particularly in the event of unfavourable growing conditions.

Chelate compounds

Chelate compounds for the correction of trace element deficiencies have now been in use for approximately forty years. Much of the initial studies were concerned with the correction of iron deficiency but subsequently their use extended to other metals, notably copper, manganese and zinc. The outstanding feature of soluble metal chelates in soils concerns their ability to increase the solubility of added or indigenous metal cations. As a result the mobility of these ions is increased both by diffusive and convective transport. Chelates have made a significant impact on the control of trace element deficiencies. Information on their compatibility with various crop protection chemicals has had a considerable influence on their popularity. Price, by comparison with conventional metal salts is still a factor and in common with the latter, some problems concerning rate, frequency and timing of application remain. These are particularly relevant in the case of winter cereals.

From the practical standpoint chelate compounds have certain advantages over conventional salts. Because they are supplied in liquid form there are no problems with spray-tank mixing. They also cause less scorch to crops than inorganic salts e.g. copper sulphate, but occasionally some scorch is apparent (MacNaeidhe & Fleming, 1984). Some chelates also contain sulphur which, it is claimed, confers fungicidal properties on the preparations.

Recent work on the correction of zinc deficiency in spring cereals in Ireland (MacNaeidhe & Fleming, 1988) shows the magnitude of the effects which can be obtained (Table 6). It should be noted that the increases in ear numbers per unit area were not necessarily associated with concomitant increases in grain yield.

Table 6:

Effect of foliar treatment with zinc on grain yield of spring barley

Treatment	Rate per ha	Ear numbers per m²	Grain wt. per m² (gms)
Zinc sulphate	5 kg	658	647
Zinc sulphate	10 kg	627	394
Zinc EDTA	3 litres	759	527
Zinc EDTA	6 litres	609	808
Control	Nil	308	208
S.E.		87.6	73.5

Other trace element formulations

Other trace element formulations, e.g. lignosulphonates and inorganic salts suspended in special liquid carriers are also in use and the latter in particular have given yield increases of over 20 per cent in spring barley grown on a sandy soil in the U.K. (Alloway, private communication). Soil pH was 7.6 and EDTA – extractable Cu 0.44 mg/kg. A particularly interesting facet of this investigation was the fact that no symptoms of copper deficiency were apparent in the crop.

Our own experience having tested a number of inorganic and organic trace element sources has been that, propertly applied, they are all capable of giving acceptable results; no one formulation has apeared consistently superior when tested on different soils over a number of years.

SOIL INGESTION BY ANIMALS

It is well known that involuntary ingestion of soil together with herbage takes place during grazing. The beneficial effects of such ingestion were recognised in the eighteenth century (Fraser, 1794) when cobalt deficiency in sheep in England was successfully treated by dosing with a suspension of soil in water. Likewise the classical cure for piglet anaemia involved the provision of upturned sods from which the young pigs received sufficient amounts of iron to offset the condition. On the other hand increased tooth wear of sheep resulting from ingested soil has been reported (Healy and Ludwig, 1965, Nolan and Black, 1970).

The amount of soil ingested by grazing animals varies to a considerable extent and close-grazing animals such as sheep may, under extreme conditions, ingest over 400 gm of soil per day (Field and Purves, 1964). Normally amounts are much smaller and typical data are shown in Table 7.

Table 7:

Intake of herbage and soil by animals

Animal	Herbage (gm/day D.M.)	Soil (gm/day D.M.)	Soil intake as % of herbage D.M.
Sheep	600	100	17
Cow	13,000	1,000	8

D.M. = dry matter

A number of factors affect the amount of soil ingested by animals. Amongst the most important are soil type, stocking rate and season.

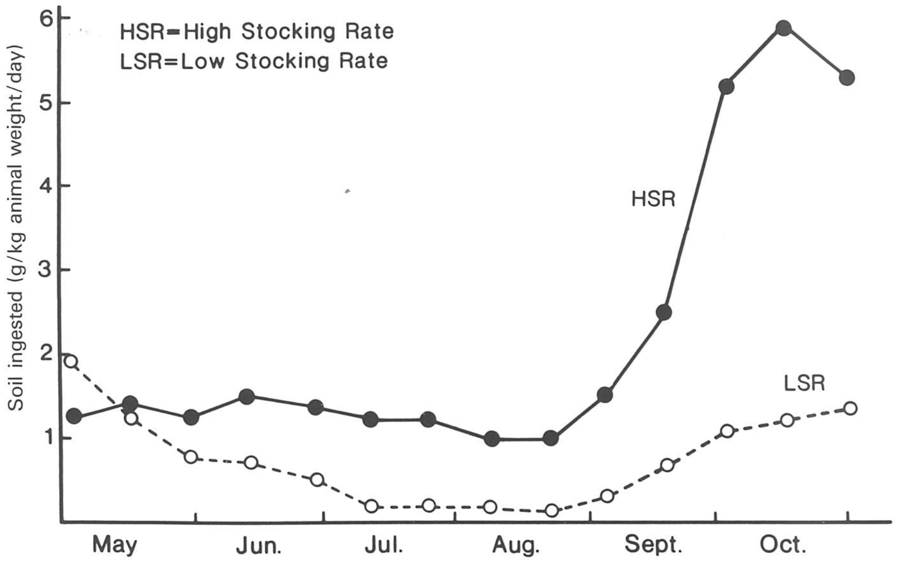
Soil type

Soils with good structure are associated with low soil contamination of pasture and vice versa. When structure is poor and drainage bad, treading by animals results in much poaching. Consumption of grass is then attended by relatively large soil intakes by animals. In modern farming practice, however, soils with good drainage and structure are most likely to suffer from over stocking and thus soil ingestion becomes of greater consequence.

Stocking rate and season

It is to be expected that soil intake by animals will increase when stocking rate is increased. Likewise seasonal effects can be anticipated; when for instance rainfall becomes more abundant, soil contamination of pasture is enhanced and thus soil intake rises. Some quantification of these factors is shown in Fig. 3.

Fig. 3: Effects of stocking rate and season on amounts of soil ingested by sheep (McGrath et al., 1982)



In this experiment, sheep at two stocking rates were used and soil intake measured by calculation of faecal soil content. In both the high (HSR) and the low (LSR) stocking rates, animal numbers were reduced as the season advanced and grass on offer became more scarce but the mean stocking rates were – HSR 30 and LSR 20 sheep per hectare.

The data clearly indicate greater soil ingestion by the animals on the high stocking rate whereas for both rates ingestion increased as the season advanced and the quantity of grass declined. This is especially evident in the case of the high stocking rate.

In recent years soil ingestion has been identified as a factor in copper deficiency in cattle and sheep. Increased soil ingestion can inhibit copper absorption. A trial carried out by An Foras Taluntais (now Teagasc) some years ago showed that the level of liver copper in sheep was related to stocking rate (Table 8).

It is clear that the soil ingestion factor must not be ignored in the investigation of copper deficiency problems. From the soil aspect much remains to be done to identify those soils which exert the greatest effects on copper absorption by animals.

Table 8:
Stocking rate and copper content of sheep liver*

Mean stocking rates	Liver Cu content (mg/kg dry weight)
High (30 sheep/ha)	98
Low (20 sheep/ha)	300

*Adapted from Poole et al. (1983)

FUTURE DEVELOPMENTS

In assessing the results of past or ongoing research, one has the benefit of access to factual data suitably presented in the scientific literature. No such advantage accrues to him who attempts to look into the future and any opinions, throughts or perspectives will inevitably be coloured by ones own particular interests, leanings and – dare I say it – prejudices! The current literature however suggests that much future activity in trace element research will be concentrated in areas where the identification and roles of *compounds* involved in plant, animal and human metabolic processes are of fundamental importance. Emphasis therefore will not be so much on actual elements but on the chemical species of which they form a part. Increased effort will also be devoted to the factors which condition the *availability* of a particular nutrient. The role of trace elements in *human health/nutrition* is an ever-expanding field and we can look forward to even greater activity in this general area.

Speciation of trace elements in soil systems

For the past 50 years or more soil scientists have tackled the problem of suitable extractants for different trace elements. Over time, a number of extractants have emerged and although there are – predictably – no universally acceptable ones, some have gained remarkable popularity. One has in mind hot water for B, EDTA for Cu and perhaps DTPA for Zn. The selection of a particular extractant for assessing trace element availability should logically assume a knowledge of the method of binding of the particular element. With this end in view attempts have been made in the past to identify the partitioning of trace elements between different soil fractions (Le Riche & Weir, 1963; Chao, 1972; Tessier et al., 1979; Schuman, 1985).

Determination of trace elements in different fractions, e.g. exchangeable, carbonate bound, iron oxide/manganese oxide occluded and organic matter complexed, has been attempted by sequential extraction with appropriate reagents, and generally this approach is to be welcomed. The following question however must be posed. Are soil scientists attempting too much in this regard? Should not each trace element be treated on its own merits inasmuch as each has its own chemistry and its own individual behaviour in soils? When one considers that any given trace element may behave quite differently in different soils, and that the final validation of any soil extractant will be seen in terms of its performance in field correlation trials, one is forced to the conclusion that situations exist where each trace element should be treated individually. In other words we must ensure that – even at some possible cost to analytical expediency – the extractants chosen represent the best possible ones for the trace element in question. This idea one feels is given greater credence when, for instance, cereal yields of 7 to 10 tonnes/ha are frequently the norm and thus a greater premium may be placed on soil trace element status.

Trace elements in the fertilisers

A similar philosophy to that just outlined can be advocated in relation to the incorporation of trace elements in fertilisers, i.e. one disorder-one cure. While realizing that circumstances exist where more than one deficiency may be present – one has in mind combined copper and zinc deficiencies on some sandy soils or perhaps copper and manganese shortages on peats, there seems little point in formulating compounds with a complete range of added micro-nutrients. While recognizing the practicalities of fertiliser manufacture and formulation, one must resist a "hit and miss" approach whereby the provision of a whole gamut of nutrients will hopefully supply the one which is causing the problem. Clearly at this stage of agricultural development where optimum usage of nutrients was never more important, the rational approach should involve more specific attempts at problem solving. It would be churlish to pretend that such strategies are not being essayed at the present time-the hope for the future is that they will be implemented with even greater direction and purpose.

Animal biochemistry/nutrition

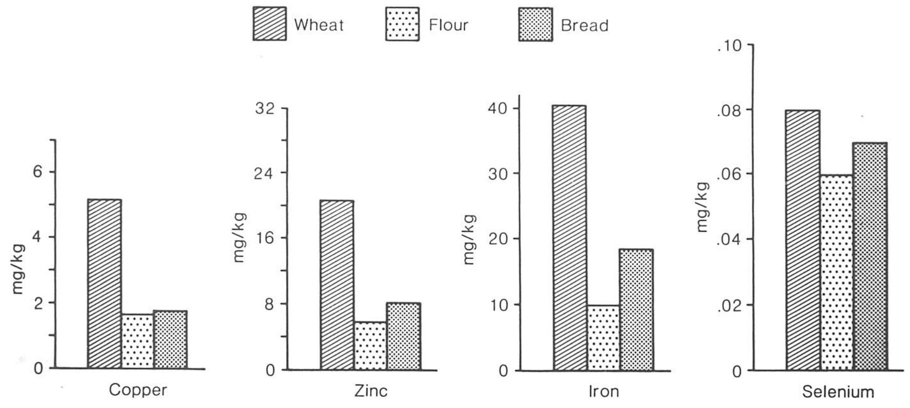
Copper deficiency especially in ruminants is now recognized as a major problem in many parts of the world. The copper species in intensively managed herbage are but poorly characterised and their absorbability is conditioned by the rate of microbial breakdown in the rumen. The availability of ingested copper is to a great extent determined by the efficiency with which reactive sulphide is removed from the digestive tract and by the presence of copper species which are sufficiently stable to react with such sulphide but at the same time sufficiently labile to yield absorbable copper species (Wolf et al., 1986). Iron and molybdenum are highly important conditioning factors in this whole process and it is gratifying to see the progress which is being made in this vital area (Suttle et al., 1984; Mills & Davies, 1987). Studies on the role of the cysteine-rich metallothionein in the absorption and retention of copper and zinc in ruminants are also exciting and I believe that we can look forward to further and even more intensive investigations into trace element cycling in animal systems and in particular to the elucidation of further biochemical pathways to metalloproteins.

In Ireland a practical problem in this general area concerns the definition of the role of trace elements in calf mortality. The incidence of calf mortality is often unacceptably high and there is much speculation concerning the efficacy of trace elements in dealing with the problem. Research is urgently needed to end this speculation and replace it with some factual information. Selenium, iodine and zinc would appear to warrant special attention here and research effort must take cognizance of the different soil factors which control the supply and availability of these elements.

Human nutrition

The ultimate objective of agriculture is the production of healthy food. Increased use of fertilisers coupled with advances in cultural practices have proved so successful that we now have in many developed areas the problem of over-production. Food production alone is not now seen as being sufficient. Questions are being asked and will continue to be asked about the quality of such food. The subject of food additives is obviously one of vital importance but does not really come within the scope of this paper. The recognition of the fundamental involvement of trace elements in human nutrition is now firmly established and will continue to exercise the minds of researchers in the future. Many examples of their relevance in nutrition could be given but perhaps that of selenium will serve to illustrate the point. Selenium, known as a toxic element for many years, was eventually recognized as essential in animal nutrition (Schwarz & Foltz, 1957). The shortage of selenium in some soils of New Zealand, the United States and Scandinavia – to mention but a few areas – has led to the incorporation of the element into fertilisers with the object of increasing its concentration in animal and human foodstuffs. In Europe, Finland has been to the forefront in this regard. In relation to bread, concern has been expressed in the U.K. about the declining level of selenium in this food product consequent on the reduction in importation of the relatively selenium-rich Canadian wheat (Barclay & McPherson, 1986). Results of some recent studies carried out in Ireland may be of interest here (Fleming, 1988). Wheat, flour milled from the wheat and bread made from the flour were analysed for selenium, copper, zinc and iron. The results are shown in Fig. 4.

Fig. 4: Trace elements in wheat, flour and bread



The reduction in the levels of copper, iron and zinc in flour consequent on refining has been considerable though some of the losses were restored by the yeast added in the bread-making process. Of particular interest however were the relatively small differences in selenium content which existed between wheat, flour and bread. This draws attention to the more general problem of the effect of food processing and indeed cooking, on the trace element contents of the foods we consume. Although some studies have been carried out in this area much more needs to be done.

Bioavailability of trace elements

The next logical step is the assessment of the real availability of trace elements to an animal or a human. This *bioavailability* can be thought of as the ability of a *chemical species* of a trace element to meet the physiological requirements of an organism. The concept of the chemical species as distinct from the total quantity of trace element now comes into focus. It is for instance a rather sobering thought that less than 5 per cent of the total Cu in fresh grass may be absorbed by ruminants (Suttle, 1981).

It is of particular interest that macronutrients such as calcium, potassium, magnesium and sodium in foods primarily form water-soluble ionic compounds and as such, determination of total quantities serve as reliable indices of bioavailability. Speciation is not a major issue though some concern is expressed about insoluble compounds of calcium and magnesium. Trace elements on the other hand possess a more complex chemistry and form a number of compounds of differing bioavailabilities. Some examples are as follows:

- The bioavailability of zinc and iron from cereals is conditioned by the level of phytic acid present. This compound—the hexaphosphoric ester of inositol—occurs mainly in cereal grain and forms very sparingly soluble salts with a number of divalent cations. The bioavailability of iron and zinc is therefore less from brown bread than from white bread because of the greater content of phytin (the Ca-Mg salt of phytic acid) in the former (Downey et al., 1982).
- There is a lower bioavailability of zinc from bovine milk than from human milk and this is attributed to the stronger bonding of zinc by colloidal calcium phosphate complexes in bovine milk (Singh et al., 1986).
- The total iron contents of bovine and human milk are generally similar yet the bioavailability of iron from human milk is greater. This is indicated by the greater resistance to anaemia of breast-fed babies compared with bottle-fed infants (Hegarty, 1981).
- Tracer studies with ^{75}Se have shown that the availability of selenium to humans is greater from selenomethionine—the major form present in cereal grain—than from selenite.

The above examples hopefully illustrate the need for the identification of trace element chemical species in human and animal foodstuffs, and calls into question the value of total analyses in this regard. Knowledge of the total quantities of trace elements is obviously of importance but the realization that these are frequently of limited use as indices of biovailability must be stressed.

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