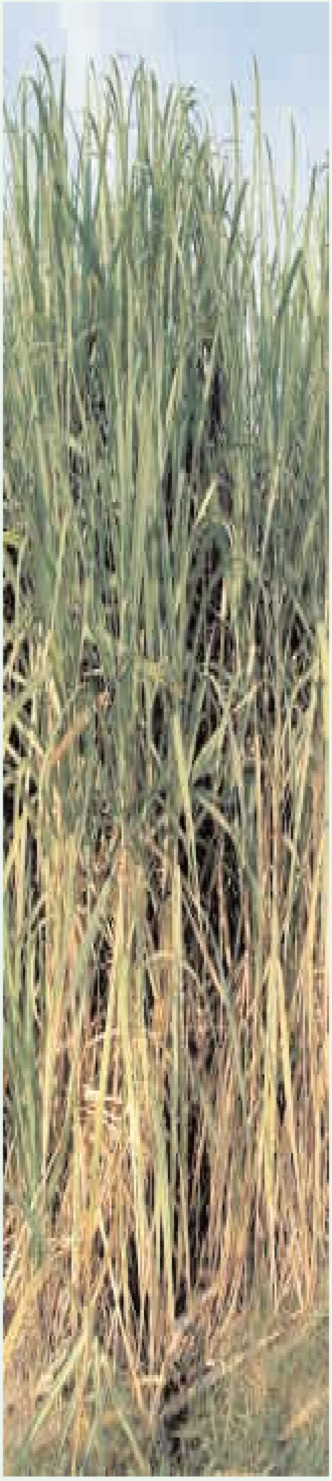

Combined

FERTILIZER SOCIETY OF SA

&

SA SUGARCANE RESEARCH INSTITUTE SYMPOSIUM

Theme:

Micronutrients in Agriculture

The Demands of Subtropical Crops

FSSA-MVSA

SASRI

25 February 2005

Kwa-Shukela Auditorium

Mount Edgecombe

The Symposium

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Foreword

Dr. G. J. van der Linde, Director, Fertilizer Society of South Africa

This symposium was a combined initiative of the Fertilizer Society of South Africa (FSSA) and the SA Sugarcane Research Institute (SASRI). I must also thank the International Zinc Association – Southern Africa (IZASA) for their valuable input in making this symposium a success.

Micronutrients are essential for health in plants, animals and humans. In the case of farm animals and humans the micronutrients include both vitamins and trace elements that are required in minute amounts to maintain normal health (see **Table 1**). Given the very small amounts of these nutrients – parts per million – that are required for health it is almost incredible that deficiencies can occur due to inadequate dietary intake. Humans require at least 50 known nutrients in adequate amounts, *consistently*, to live healthy and productive lives.

Table 1. The known 50 essential nutrients for sustaining human life[1]

Water & Energy (2)	Protein (amino acids) (9)	Lipids (fatty acids) (2)	Macro-minerals (7)	Micro-elements (17)	Vitamins (13)
Water	histidine	linoleic acid	Na	Fe	A
Carbohydrates	isoleucine	linolenic acid	K	Zn	D
	leucine		Ca	Cu	E
	lysine		Mg	Mn	K
	methionine		S	I	C
	phenylalanine		P	F	B_1 (thiamin)
	threonine		Cl	B	B_2 (riboflavin)
	tryptophan			Se	B_3 (pantothenate)
	valine			Mo	B_6
				Ni	folic acid
				Cr	biotin
				Si	niacin
				As	B_{12} (cobalamin)
				Li	
				Sn	
				V	
				Co (in B_{12})	

[1]*Numerous other beneficial substances in foods are also known to contribute to good health.*
[2] *Table from "Farming for Health: The future of Agriculture", R. Welch, Santiago, 1 Dec. 2004.*

Incredibly, micronutrient malnutrition (e.g. Fe, I, Se, Zn, vitamin A etc.) is a massive global problem afflicting over 3 billion people world-wide, in other words over half of the world's population! Current trends in micronutrient malnutrition continue to be increasing in many nations. For example, the global burden of Fe deficiency has risen from about 35% of the world's population in 1960 to over 50% in 2000 (WHO, 2002), and Fe deficiency among poor women is increasing at an alarming rate in many developing countries. Current intervention programmes (i.e. food fortification and supplementation programmes) to alleviate the problem have not proven to be effective or sustainable in many countries (Darnton-Hill, 1999).

According to R. Welch of Cornell University "…this global crisis in micronutrient malnutrition is the result of dysfunctional food systems that cannot deliver enough micronutrients to meet the nutritional requirements of all."

Unfortunately, global food systems are failing to provide adequate quantities of all of the essential nutrients to vast numbers of people. Advances in crop production, incurred during the "green revolution", were dependent mostly on improvements in cereal cropping systems (rice, wheat and maize) and resulted in greatly increased food supplies for the world preventing massive starvation. However, cereals as normally eaten, only supply needed carbohydrates for energy, a small amount of protein but few other nutrients in required amounts. This change in agricultural production to more monoculture cereal systems and away from more varied cropping systems appears to be contributing to micronutrient malnutrition by limiting food-crop diversity (Welch *et al*., 1997).

Nutrition transitions are also causing increased rates of chronic diseases (e.g., cancer, heart disease, stroke, diabetes, obesity, osteoporosis, etc.) in many rapidly developing nations where people are switching from traditional diets to more calorie-rich diets derived from adopting developed nation's food systems (Clugston and Smith, 2002; Sobal, 1999). **Figure 1** shows some recent data on risk factors causing deaths globally. Diet-related diseases are contributing greatly to the burden of disease globally.

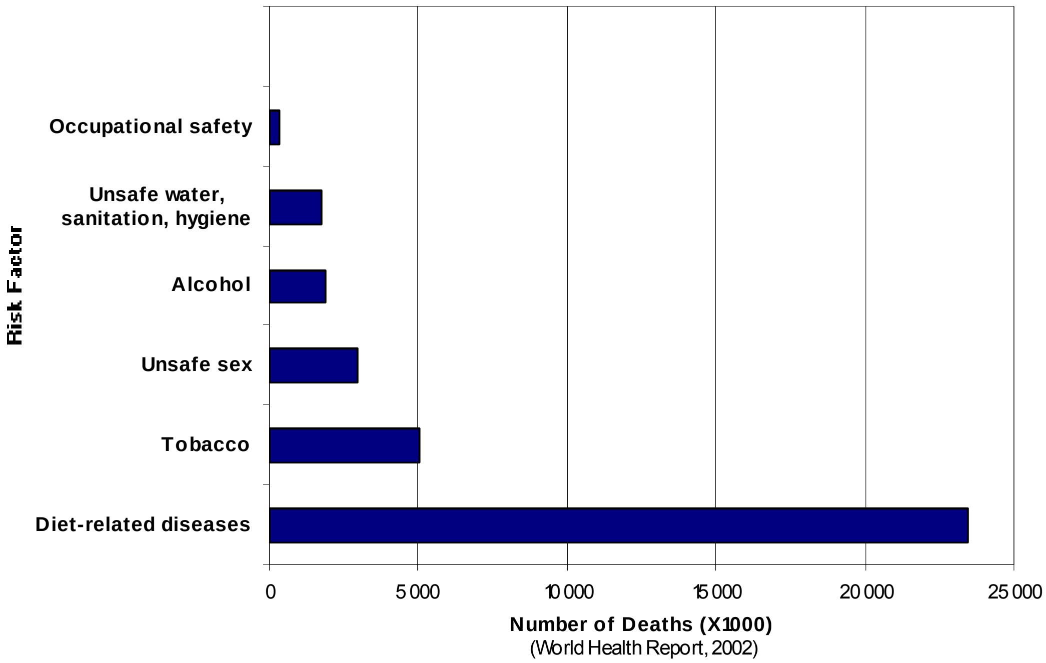

Figure 1. Some major risk factors causing world deaths in 2000

Clearly, there is an urgent need to tightly link the agricultural sector to human health to find ways to reduce the burden of diet-related diseases in the world.

Should agriculture be concerned about human health and nutrition issues? In 1995, the Economic Research Service published a report showing that it cost the U.S. economy over a quarter of a trillion dollars every year to treat diet related diseases (e.g. cancer, stroke, heat disease, diabetes, osteoporosis, etc.), and in lost worker productivity (Frazao, 1996). Obesity in the United States alone causes about 300 000 deaths per year and an economic cost of around $117 million (Rouse and Davis, 2004). Clearly, the nutritional quality and "healthiness" of agricultural products is an important factor in the health of people in the United States and globally.

I do not have figures for South Africa but it will most probably follow the same trend as those of the USA.

Taking the above into account it is very clear that the time has come for South Africa, and the rest of the world, to shift to a new agricultural paradigm – one based on both what is good for the consumer and profitable for the farmer.

A shift in focus from only quantity to both quality and quantity in agricultural output is needed. Improving human health must be a key component of the future of agriculture globally. Farming for health should become the norm in agriculture.

I believe the *Fertiliser Industry* can contribute greatly to achieving this goal of better nutrition and health for all. This symposium will also show us what has been done about micronutrients in South Africa and will point out areas where further research is necessary.

Role of micronutrients in sugarcane

David Nixon, SASRI

Abstract

Whilst much is known about the requirements for major nutrients, relatively little information is available on the micronutrient requirements of sugarcane. This is despite the fact that a number of studies have been conducted in various parts of the industry. Of the 16 elements that are known to be essential for plant growth, six are micronutrients: iron, copper, manganese, zinc, molybdenum and boron. For sugarcane grown in South Africa, iron, zinc, manganese and copper deficiencies have all been detected in certain parts of the industry. Boron deficiency has been identified at Dwangwa Estate in Malawi, but molybdenum deficiency in sugarcane has yet to be observed in Africa. Although there is no justification for suspecting widespread micronutrient deficiencies in the South African sugar industry, iron and zinc deficiencies are economically important growth limiting factors in certain areas. Other problem areas do exist, and for these it may be worthwhile for growers to consider regular application of micronutrients. Green cane harvesting and the increased use of organic manures and green manuring will assist in reducing micronutrient deficiency problems in the future. Growers should be encouraged to use foliar analysis for the diagnosis of any suspected micronutrient deficiencies.

INTRODUCTION

Whilst much is known about the requirements for major nutrients, relatively little information is available on the micronutrient requirements of sugarcane. This is despite the fact that a number of studies have been conducted in various parts of the industry. Of the 16 elements that are known to be essential for plant growth, six are micronutrients: iron, copper, manganese, zinc, molybdenum and boron.

For sugarcane grown in South Africa, iron, zinc, manganese and copper deficiencies have all been detected in certain parts of the industry. Boron deficiency has been identified at Dwangwa Estate in Malawi, but molybdenum deficiency in sugarcane has yet to be observed in Africa.

The quantities of micronutrients taken up by a sugarcane crop are relatively small, as compared to macronutrients. For an average crop of 100 t/ha, the approximate amounts of micronutrients taken up are:

ELEMENT	UPTAKE (kg/ha)
Iron	4.2
Manganese	2.4
Zinc	0.8
Copper	0.3
Boron	0.2
Molybdenum	0.1

SPECIFIC MICRONUTRIENT DEFICIENCIES

Iron

Of all micronutrient deficiencies, that of iron is probably the most commonly seen. Initially a pale striping occurs in the younger leaves, which in time progresses to pronounced interveinal chlorosis along the entire length of the leaf. Sometimes the chlorophyll between the vascular bundles disappears completely and the young leaves turn completely white, whilst the older leaves remain green.

Iron deficiency is often termed ‘ratoon chlorosis’, and is frequently seen in young cane where the soil pH is >8. The condition also occurs on termite-affected soils. The symptoms generally disappear with age, but if untreated there is likely to be some loss in yield.

Iron deficiency can be induced by excessive applications of P, Ca or even N. On acid soils, the presence of toxic levels of manganese can also induce iron deficiency, particularly during periods of cool, cloudy weather. N12 appears to be more susceptible to this ‘acid chlorosis’ condition than other varieties.

Manganese

Manganese is an activator of various enzymes, is important for protein synthesis and is also used in photosynthetic oxygen evolution. Symptoms of deficiency are pale striping of uniform width alternated with normal green colour, which is confined to middle and tip of leaves. Under extreme conditions the entire leaf becomes bleached, and may fray towards the tip. Although chlorotic, the leaves do not wilt.

Zinc

Zinc deficiency was first observed in the Upper Tongaat area. Subsequent field experiments conducted on acid soils in the Upper Tongaat and Doornkop areas showed marked responses to both soil and foliar applied treatments of zinc sulphate. The greater awareness of a zinc deficiency hazard led to the regular use of zincated fertilizer materials.

Zinc deficiency disturbs the development of chloroplasts, causing the leaf to initially assume a very pale green colour, followed by an overall chlorosis of the leaves as the deficiency progresses. Phosphate metabolism is also disturbed, resulting in an accumulation of phosphate compounds. In severe cases, leaf deformation may result through the inhibition of indolacetic acid which is formed from tryptophan by an enzymatic reaction.

Copper

Cu is essential to the activity of various enzymes such as phenolases, ascorbic acid oxidase and cytochrome oxidase. Cu deficiency was first recognised in the Florida sugar industry in the 1930s, and some 20 years later in Australia, where the term ‘droopy top’ was coined to describe the tendency of the leaves to droop, together with the reluctance of the spindle to unroll. In South Africa, copper deficiency was first observed in the Sezela area in the 1950s. Foliar application of copper sulphate gave a spectacular response.

Boron

The necessity for boron in crop development has long been recognised. In sugarcane, the element is essential for sugar translocation, protein synthesis, and seed and cell wall formation.

Boron deficiency was first observed in sugarcane in Ecuador. Within Africa, boron deficiency has been found at Dwangwa Estate on Lake Malawi. Advanced symptoms, consisting of death of the meristem and side-shooting, were observed. Leaf samples showed levels of < 4 ppm, about half that found at other estates in Malawi and Swaziland. Soil B levels were also found to be low. Application of boron via the irrigation water proved to be the best solution to the problem.

Molybdenum

Molybdenum is essential for enzyme activity and is used in nitrogen transformations within the plant. No instances of molybdenum deficiency have been recorded in field-grown sugarcane. However deficiency symptoms produced under controlled conditions affect the older leaves, which develop short longitudinal chlorotic streaks on the apical one-third of the leaf. The stalks become short and slender and older leaves die back.

DIAGNOSING AND AMENDING DEFICIENCIES

In most cases, foliar analysis provided the best diagnostic tool for identifying the nature and degree of nutrient deficiencies. Fairly robust threshold values have been established for the micronutrients, based on trial results and observed responses.

In general, the application of foliar amendments is only worthwhile when the problem has been diagnosed early - less than six months of age. In such cases, use of a dilute solution of the appropriate sulphate salt will provide enough micronutrient to correct the deficiency.

In the case of zinc, diagnosis of a deficiency will give an indication that the use of a zincated fertilizer material, or alternatively the application of solid zinc sulphate (50 kg/ha) as a soil amendment should be considered for future crops.

Other sources of micronutrients include chelate products, bi-products such as filtercake, flyash and CMS, and organic manures such as chicken manure/litter and kraal manure. Trashing of cane, as opposed to burning, also helps to conserve micronutrients in the soil. The use of green manuring and/or crop rotation may also have an increased role to play in improving soil health and consequently the supply of micronutrients in the future.

CONCLUSIONS

Although there is no justification for suspecting widespread micronutrient deficiencies in the South African sugar industry, iron and zinc deficiencies are important growth limiting factors in certain areas. Other problem areas do exist, and for these it may be worthwhile for growers to consider regular application of micronutrients. The increased use of organic manures and green manuring will assist in reducing micronutrient deficiency problems in the future. Growers should be encouraged to use foliar analysis for the diagnosis of any suspected micronutrient deficiencies.

Overview of Past Research and Trends in Micronutrient Deficiency in the South African Sugar Industry

Jan Meyer, SASRI

Abstract

Over the past four decades fairly extensive research has been carried out on the micronutrient requirement of sugarcane in the South African Sugar Industry. The first indication of a benefit to a micronutrient treatment in South Africa was in 1956 when a small area of cane growing on granite derived soils near Sezela were found to be deficient in Cu and a foliar application of copper sulphate gave a quick and spectacular response. From 1961 onwards the value of zinc was demonstrated when four observation trials in the Upper Tongaat area produced dramatic responses to furrow applications and top-dressings of 55kg zinc sulphate per hectare and to a foliar spray of a 1% zinc sulphate in solution. Nutrient surveys conducted in 1965 and in 1969 showed that Zn deficiency was initially fairly widespread in cane grown in the Midland's mistbelt and Upper Tongaat areas mainly on the humic Inanda soils. During the seventies increased use of zincated fertilizers such as zincated 2:3:2 and 2:3:4 mixtures have led to the current favourable situation of near zero Zn deficiency in commercially grown cane in these and other areas.

The results of past trials in which a range of micronutrients were tested are summarized in the paper and apart from Zn, marked responses to foliar applications of ferrous sulphate have also been obtained on young cane showing the characteristic symptoms of interveinal chlorosis. Regular nutrient surveys conducted since 1967, based on foliar diagnosis, have confirmed that there is no widespread deficiency of micronutrients but that there is an upward trend in the incidence of marginal leaf Fe, Mn and Cu levels in sugarcane. Field trials although costly and laborious to carry out, remain the basis of fertilizer research and will still be necessary to guide the industry and FAS towards the maximum economic yields. With the prospect of declining reserves of micronutrients in soils due to factors such as monocropping, introduction of high yielding varieties, the use of concentrated fertilizers and anti-pollution legislation, there can be little doubt that micronutrients are destined to become more important in the sugar industry. Nutrient surveys should be carried out regularly to monitor the situation.

INTRODUCTION

Ever since the discovery by Sachs in 1860, that plants would grow satisfactorily on mineral salts and water, research workers have remained alert to the possibility of micronutrient deficiencies in crops. In sugarcane it was not until the early 1930s that some of the first deficiency symptoms were produced by Martin (1934) in 'controlled' nutrient culture solutions. Since these pioneering investigations, instances of micronutrient deficiency have been reported from a number of cane producing countries, and in recent years, elements such as Zn, Fe, Mn, Cu and B have all received considerable attention.

Several possibilities may account for the increased frequency of micronutrient deficiencies:

- Declining soil fertility under a system of monocropping . Sugar cane is a gross feeder of nutrients and the production of large tonnages of cane over many years on the same soil has resulted in a net export of soil nutrients in the form of molasses and filtercake. As very few countries recycle these by-products back to the fields, the capacity of the soil to supply nutrients is greatly diminished.

- Introduction of higher yield potential varieties that tend to have higher nutrient requirements.

- Micronutrient deficiencies could have existed but may not have been sufficiently severe to produce visible symptoms.

- Concentrated fertilizers with fewer trace element impurities are being more widely used.

- Rapid advances in analytical methods for the detection and quantitative measurement of small quantities of elements in plants and soils.

A comprehensive review of past research on the micronutrient requirement of sugarcane in southern Africa was carried out in 1999 by Meyer *et al* and the purpose of this paper is to summarise the main findings and to report on trends in the micronutrient uptake of sugarcane for the main areas of the sugar industry using the Fertiliser Advisory Service (FAS) database which comprises analyses from over 300 000 soil and 100 000 leaf samples since 1980.

SUGARCANE YIELD RESPONSES TO MICRONUTRIENT TREATMENT

An important characteristic separating micronutrients from macronutrients is the high efficiency value of micronutrients, since very small amounts are sufficient to produce optimum effects while slight deficiencies or excesses can result in severe field declines.

- The first published report of a benefit to a micronutrient treatment in South Africa was in 1956 when a small area of cane growing on granite derived soils near Sezela was found to be deficient in Cu and a foliar application of copper sulphate gave a quick and spectacular response (Du Toit, 1956).

- The first experiments with zinc were established in 1961, when four observation trials in the Upper Tongaat area produced dramatic responses to furrow applications and top-dressings of 55 kg zinc sulphate per hectare and to a foliar spray of a 1% zinc sulphate in solution applied at a rate of 160 litres per hectare. Although the foliar treatments produced the quickest response the effects were not as long-lasting as the soil applied treatments.

- Foliar diagnosis was also used for the first time to monitor the effects of the various treatments on Zn uptake by the crop. Third leaf values improved from an average of 5 ppm for the untreated plots to over 10 ppm where Zn had been applied.

- Since the exploratory trials were conducted, a number of replicated trials which included Zn as a treatment, have been carried out as part of the Upper Tongaat co-ordinated project (Thompson, 1985), mainly on Inanda series soils in Upper Tongaat and Doornkop areas of the sugarbelt.

- A summary of the responses obtained to the application of zinc sulphate applied at an average rate of 50 kg per hectare in the furrow for plant cane and as a top-dressing in ratoon cane is shown for ten trials in **Table 1**. The responses are expressed both in tons cane per hectare (tc/ha) and as a percentage increase in tc/ha over the untreated control.

- Overall, the effect of Zn in the plant crops in nine of the trials resulted in an average increase of 12%, with an additional average residual response of 10% measured in the subsequent first ratoon crops in four of the experiments which were continued beyond the plant crop stage.

Table 1. Summary of field responses to treatments with zinc sulphate

Experiment site number	Area	Soil series	Crop	Average response	
				t cane/ha	% change
1	Doornkop	Inanda	Plant 1R 2R 3R	1.0 17.5 18.0 6.0	+ 2 +11 +10 + 1
2	Upper Tongaat	Inanda	Plant	8.0	+ 2
3	Thrings Post	Inanda	Plant 1R	14.4 5.2	+33 + 7
4	Upper Tongaat	Trevanian	Plant	-2.25	- 3
5	Upper Tongaat	Inanda	Plant	24.5	+39
6	Kearsney	Trevanian	Plant	1.2	+ 1
7	Upper Tongaat	Inanda	1R	8.0	+10
8	Upper Tongaat	Inanda	Plant 1R	10.0 9.0	+14 + 8
9	Upper Tongaat	Inanda	Plant	17.0	+17
10	Eston	Inanda	Plant 1R	3.0 6.0	+ 3 +10
Average response			Plant 1R	10.05.99 9.0	+12 +10

- In three of the experiments the efficacy of Zn treatments was also tested in combination with Mo, B, Cu, Mn and Fe without any apparent additional benefits. The results of past trials in which a range of micronutrients were tested are summarised in **Table 2**. Although substantial benefits were obtained from treatment with Fe (10 to 28%), the responses were not significant. Results for other micronutrients were less convincing, and were often negative. In general foliar applied treatments were more effective than soil applied treatments in correcting Fe deficiency.

- In a another co-ordinated project conducted by the Experiment Station, known as the Weak Sands project (Thompson, 1983), 21 replicated field trials were established on the coastal sands to identify the causes of poor cane growth on these soils. The main treatments included nematicide with and without micronutrients (B, Mo, Cu, Mn, Fe and Zn), compared with a standard FAS treatment. Some micronutrients were applied in the furrow as potassium borate (25 kg/ha), sodium molybdate (0.5 kg/ha), copper sulphate (25 kg/ha) and manganese sulphate (50kg/ha), while Zn and Fe were applied as a foliar application of zinc sulphate(1%) and iron sulphate(2%).

- Although, overall there was a large response to nematicide (average 52%), there was only a slight advantage from a supplementary treatment of micronutrients in five trials situated on Fernwood or Kroonstad form soils, on the South Coast. The responses ranged from 5 to 15% but no trials reached statistical significance.

- At Dwanga Estate boron deficiency symptoms were identified for the first time in 1992 and the average leaf B values of 3,7 ppm were less than half of those found on other irrigated cane estates such as at Sucoma (7,5 ppm) in Malawi, Simunye (8,0 ppm) and Ubombo Ranches(7,7 ppm) in Swaziland. Although no significant responses were obtained to treatment with boron in subsequent trials (personal communication, Whitbread 1992), a programme of boronating the irrigation water was implemented in conjunction with regular monitoring of the B content of irrigation water and uptake by sugarcane through routine leaf sampling.

Table 2. Summary of field responses to treatments with other micronutrients

Treatment	Area	Soil series	Crop	Average yield	
				T cane/ha	% change
Control +B +Cu +Mn +Mo +Si +Zn	Doornkop NS	Cartref	Plant	49.23 46.11 47.35 47.46 47.93 47.68 45.82	0 -6 -4 -4 -3 -3 -7
Control +Zn +Cu +Mo +B	Triangle NS	P2 sandy Loam	5R	182.7 164.5 175.6 171.4 181.2	0 -10 -4 -6 -1
Control +Zn +Zn+Cu +Zn+Mn Zn+Cu+Mn+Mo+B+Fe	Upper Tongaat **	TMS Inanda	Plant	30.3 41.4 39.9 38.5 38.8	0 +37 +32 +27 +28
Control +Fe (SO_4) +Fe (Cl_3)	Cornubia Estates NS	Clansthal	1R (chlorotic)	62.2 68.5 73.7	0 +10 +18
Control +$FeSO_4$ 12lb split +$FeSO_4$ 6lb split +Fe SO_4 6lb split	Cornubia Estates NS	Clansthal	2R (chlorotic) 1 mth split	30.3 38.8 37.0 36.4	0 +28 +22 +20
Control +Wuxal 6 L/ha +8 L/ha +10 L/ha	Tambankulu Estates NS	'R' set soil	1R	117 97 104 105	0 -17 -11 -10

- An assessment of accumulated yield and leaf data from all available trials has confirmed Du Toit's observation (1962) that 13 ppm in the top visible dewlap leaf (TVD) gives the best separation between Zn deficient and non-deficient cane. (Similarly, TVD threshold values have been established for the other micronutrients by interpolation from response curves, and these are 3 ppm, 15 ppm, 3 ppm and 75 ppm for Cu, Mn, B and Fe respectively.

- Soil tests have proved to be less reliable than plant tissue analysis for determining the micronutrient requirement of sugar cane. In assessing a range of available extractants, the 1 N $(NH_4)_2$ CO_3/0,01 M EDTA extraction procedure (Trierweiler and Lindsay, 1969), showed the best correlation between the amounts of Zn extracted from the soil and the amount taken up by an indicator crop.(Meyer, 1976). Threshold values of 1 and 0.5 ppm were established for clay and sandy soils respectively. No reliable threshold values could be established for the remaining micronutrinets.

NUTRIENT SURVEY INVESTIGATIONS

Since 1967, a number of leaf analysis surveys have been conducted to determine the micronutrient status of sugarcane in various parts of the sugar industry. The main findings are summarised as follows:

1967 Survey

- This involved the sampling and analysis of third leaf laminae from about 190 fields sited mainly on soils derived from Table Mountain Sandstone. One of the main findings was a fairly widespread Zn deficiency on the TMS mistbelt Inanda series soils (Alexander, 1967).

- Deficiency symptoms such as chlorosis, smallness of the leaves, patchy growth and stunting were identified in a number of fields later found to be low in Zn, particularly in the Paddock, Mid Illovo, Upper Tongaat, Doringkop, Entumeni and Eshowe areas. Apart from four instances where leaf Cu contents were marginal, no other nutrient deficiencies were recorded (Du Preez, 1967).

1971 Survey

- In a more comprehensive survey which was conducted by Experiment Station staff in 1971, soil and leaf samples were systematically taken from almost 500 fields distributed throughout the industry, including not only the coast lowlands and midlands areas but also the lowveld areas of Pongola, Swaziland and the Eastern Transvaal (Meyer *et al*., 1971).

- Leaf samples from all regions apparently contained adequate amounts of B, Cu and Fe. However, almost 12% of all the samples were deficient in Zn, the highest incidence of deficiency (13%) once again being detected for cane growing on the Inanda form soils in the midlands area. Surprisingly 8% of all the coast lowland samples also indicated a Zn deficiency mainly on the sandy Cartref soils.

- Mn values ranged from 25 ppm in the irrigated areas of Swaziland to over 70 ppm in the midlands mistbelt area. In all, eleven fields were found to be deficient in Mn, and five of these originated from Swaziland. A further 20% of the Swaziland samples bordered on deficiency.

1989 Survey

- A programme referred to as the *Nutrient Information Retrieval System* (NIRS) was developed specifically to capture and store computerised analytical data from soil and leaf samples in order to carry out surveys in which the frequency distribution of important soil and plant nutrients are categorised into various stages of sufficiency for different extension areas (Meyer *et al.*, 1989).

- The programme was applied for the first time to a data set that comprised analytical data from about 100 000 soil samples and 35 000 leaf samples.

- Overall 8% of the leaf samples were deficient in Zn with more than half of these deficiencies occurred on sandy soils in the Umzinto coast lowlands system.

1996 Survey

- This covered the analysis of leaf samples from 2000 fields covering 10 extension areas in the industry (Meyer *et al*., 1999).

- Four percent of the fields showed deficient levels of zinc with the Durban North coast growers (13%), Midlands South (8%) and South Coast (7%) showing the highest incidence of Zn deficiency. This is well down from the overall 12% level of Zn deficiency recorded in the 1971 survey.

- With Fe, there was a marked increase in the proportion of samples deficient in Fe, from 1% in 1971 to 6% in 1996. Regions with the highest incidence of Fe deficiency included the South Coast (12%) and Durban North Coast (12%).

- For Mn and Cu there was very little change from the 1971 survey with only 1% of the samples showing a Cu deficiency and no samples with deficient levels of Mn.

2003 Survey

- In this survey leaf samples from approximately 3 000 fields covering 10 extension areas in the industry were used (see **Table 3**).

- Compared with the 1996 survey, the overall level of Zn deficiency declined further from 4% to less than 1%, with the South Coast showing the highest incidence of deficient (2%) marginal (9%) levels of Zn.

- There was no further increase in the level of Fe deficiency from the 6% recorded in 1996.

- With the exception of the South Coast, all areas were clear of any Mn deficiency. Of interest, however, is that the proportion of fields containing marginal levels of Mn, more than doubled from 5% in 1996 to the current 11%. Fields in Mpumalanga showed the greatest increase in marginal Mn levels (20%), followed by Zululand South (16%), South Coast (19%) and North Coast (13%).

- Overall the level of Cu deficiency was low (< 1%), with only the Durban North (3%) and North Coast areas showing Cu deficiency. However, in future increased Cu deficiency may be expected given the upward trend in fields with marginal levels of Cu, which increased from 57% in 1996 to 62% in 2003.

CONCLUSIONS AND FUTURE WORK

Although micronutrient deficiencies are important growth limiting factors in sugarcane, regular monitoring through leaf nutrient surveys have indicated that there are no widespread micronutrient deficiencies in the industry. In the past Zn deficiency was common in soils with humic A horizons (Inanda form) as well as grey sandy orthic A horizons (Cartref, Glenrosa and Longlands forms). Field trials with zinc have indicated that substantial profitable yield responses may be obtained to treatment with Zn fertilizer applied to soils. In practice a minimum response of only 1 ton of cane per hectare is needed to cover the cost of 50 kg of Zn fertilizing material.

Increased use in the amounts of zincated fertilizers such as various zincated 2:3:2 mixtures, and ammoniated superphosphate since the early seventies has led to the current favourable situation of near zero Zn deficiency in commercially grown cane. However, for small grower cane major nutrient deficiencies such as N, P and K are fairly widespread and need to be addressed before attempting to correct any micronutrient imbalances.

There is increasing evidence of an upward trend in the incidence of marginal leaf Fe, Mn and Cu levels in sugarcane and pro-active steps based on the use of micronutrient cocktail foliar sprays may need to be considered where leaf analysis indicates a marginal to deficient micronutrient disorder.

Field trials although costly and laborious to carry out, remain the basis of fertilizer research including the micronutrient fertilizer of sugarcane and will still be necessary to guide the industry and FAS towards the maximum economic yields. Other avenues of research that require further attention includes:

- Calibration of the soil EDTA test based on yield response curves for Cu, Fe and Mn.

- Studying the residual effects of zinc fertilizer applications on a range of soils.

- Establishing Zn and other micronutrient toxicity soil threshold levels.

- Calibrating the hot water test for plant available B in soils.

With the prospect of declining reserves of micronutrients in soils due to factors such as monocropping, introduction of high yielding varieties, the use of concentrated fertilizers and anti-pollution legislation, there can be little doubt that micronutrients other than zinc are destined to become more important in the sugar industry. Nutrient surveys should be carried out regularly to monitor the situation.

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Table 3. 2003 LEAF ANALYSIS SURVEY

ZINC

Area	No. of Samples	Mean ppm	Percentage of Total			
			Deficient	Marginal	Adequate	High
			< 13.00	13.0-15.0	15.0-25.0	> 25.0
Malelane	405	21	0	0	92	8
Zululand North	187	20.8	0	1	97	2
Zululand Central	253	20.7	0	0	94	6
Zululand South	44	21.4	0	0	89	11
Midlands North	503	20.65	0	1	92	7
North Coast	515	20.11	1	3	91	5
Durban North	157	21.43	0	1	89	10
Midlands South	354	21.5	0	1	92	7
South Coast	356	18.65	2	9	88	1
Lower South	47	19.83	0	2	98	0

IRON

Area	No. of Samples	Mean ppm	Percentage of Total			
			Deficient	Marginal	Adequate	High
			< 75	75-125	125-200	> 200
Mpumalanga/Kom	405	151	2	36	47	14
Zululand North	187	137	11	30	49	10
Zululand Central	253	132	1	47	48	4
Zululand South	44	114	16	48	36	0
Midlands North	503	120	6	56	36	1
North Coast	515	116	10	56	32	2
Durban North	157	160	1	20	58	20
Midlands South	354	132	0	50	44	6
South Coast	356	117	4	61	33	2
Lower South	47	119	4	62	32	2

MANGANESE

Area	No. of Samples	Mean ppm	Percentage of Total			
			Deficient	Marginal	Adequate	High
			< 15.00	15-30.0	30.0-70.0	> 70.0
Mpumalanga/Kom	405	42	0	20	73	7
Zululand North	187	53	0	12	68	20
Zululand Central	253	46	0	7	89	4
Zululand South	44	41	0	16	82	2
Midlands North	503	49	0	7	84	9
North Coast	515	48	0	13	78	9
Durban North	157	53	0	4	80	16
Midlands South	354	55	0	1	87	12
South Coast	356	41	1	19	76	4
Lower South	47	44	0	9	89	2

COPPER

Area	No. of Samples	Mean ppm	Percentage of Total			
			Deficient	Marginal	Adequate	High
			< 3.00	3.0-5.0	5.0-10	> 10.0
Mpumalanga/Kom	405	5.5	0	55	45	0
Zululand North	187	5.35	0	65	35	0
Zululand Central	253	5.32	0	65	35	0
Zululand South	44	5.43	0	59	41	0
Midlands North	503	5.43	0	59	41	0
North Coast	515	5.21	1	74	26	0
Durban North	157	5.43	3	50	47	0
Midlands South	354	5.26	0	73	27	0
South Coast	356	5.41	1	56	43	0
Lower South	47	5.43	0	62	38	0

The global impact of zinc micronutrient deficiencies

Michiel C. Laker

Abstract

The global impact of zinc micro nutrient deficiencies is discussed from a geomedical perspective. Geomedicine refers to the relationships between the essential mineral nutrient contents of soils and rocks and human health. For developing countries, zinc is the highest rated nutrient deficiency (above iron and Vitamin A deficiencies) on the list of the top ten human health risk factors. Zinc deficiencies lead to increased incidence or bigger severity of a long list of human diseases and disorders. Zinc is, inter alia, very important for maintaining the immune system of humans, including having antiviral properties. It is also required for normal brain growth and functioning. Furthermore, it is important for reducing the vulnerability of humans to diseases like malaria, pneumonia and diarrhoea, which are prevalent in many developing countries. It is important to look not only at zinc intake in the diet, but to especially look at the bio-availability or absorbability of the zinc in food. High fibre and phytate contents, such as found in unrefined staple grains and pulses, strongly reduce the absorbability of zinc. The efficiencies of different crops to absorb zinc from soils differ widely. Amongst the staple grains and pulses maize, rice, sorghum and beans are very sensitive to zinc deficiencies, while the small grains (wheat, oats and rye) are very tolerant to zinc deficiencies. Zinc deficiencies in soils can be absolute deficiencies or induced deficiencies. Absolute deficiencies are related to the parent material, texture, degree of weathering and/or pH and calcareousness of a soil. Induced deficiencies are mainly due to injudicious liming, injudicious phosphorus fertilization or removal of topsoil. Several methods can be used to supply zinc, but fertilization with zinc-enriched commercial NPK fertilizers may be the most appropriate method for developing countries. It is simple to handle and can improve both dietary zinc levels and increase crop yields, thus improving food security.

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INTRODUCTION

In this paper the impact of zinc micronutrient deficiencies will be discussed in terms of a so-called "geomedical" approach. This means that the focus will be on the role of zinc in human health. Thus zinc deficiencies in plants and soils will also be discussed in terms of the impacts thereof on human health.

Geomedicine refers to the relationships between the essential mineral nutrient contents of soils and rocks and human health. Sharp increases in the interest in geomedicine have occurred only since the 1970's (Oliver, 1997). Geomedicine is nothing new, however. The Chinese apparently realised the influence of geochemistry on human health as early as the 4th century A.D. (Oliver, 1997). Hippocrates and Plinius the Elder appear to have written the first records on relationships between geochemistry and geomedicine (Deckers, Laker, Vanherreweghe, Vanclooster, Swennen & Cappuyns, 2000).

Human health status is to a large extent conditioned by the intake of mineral nutrients in their diet (Deckers *et al*., 2000). Since about 98% of human food is produced on land and over 90% of the human diet consists of vegetative products, soil is the main primary source of these nutrients via the plants that absorb them from the soil (Deckers *et al*., 2000).

The mineral nutrient, especially micronutrient, nutrition of humans is very complex and complicated (Oliver, 1997; several papers in Gawthorne, Howell & White, 1982). Some of the key aspects in this regard include:

- Several factors affect the plant-availability of mineral nutrients in soils.

- Different crops, and even different cultivars of a specific crop, differ widely in their ability to absorb a certain nutrient from the soil.

- There are numerous interactions between different nutrient elements, as well as between an element and other chemical compounds in plants and humans.

- Various factors affect the bio-availability of mineral nutrients to humans. An example of such complication is found in the Mseleni area of Maputoland in northern KwaZulu-Natal: The maize and groundnut diet of the local population is severely deficient in calcium. Wild spinach, which is another important dietary item in the area, has a high calcium content. It is, however, also high in fibre, oxalate and phytate, all of which interfere with calcium absorption and lower its bio-availability (Fincham, Hough, Taljaard, Weidemann & Schutte, 1986). The Mseleni area has been the subject of several geomedical studies because of the high incidence of "Mseleni joint disease", a crippling hip disorder, and dwarfism in the area.

Deficiencies of most essential mineral elements which are required to ensure human health occur widespread in the developing countries of the world (Deckers *et al*., 2000). Two of the main reasons for this are:

- These countries are in areas with a much poorer soil resource base than the fertile soils of Europe and North America (Deckers *et al*., 2000). In most of Africa, especially central Africa, this is even more so the case than in other developing countries (Laker, 2003).

- Plant-available nutrient element levels in soils have been drastically reduced due to exhaustive cropping and severe human-induced soil erosion (Deckers *et al.*, 2000).

Poor subsistence farming communities who eat mainly from what they produce themselves on infertile soils with deficiencies of certain critical nutrient elements are at the highest risk.

Micronutrient deficiencies are also relatively common in the diets of people in developed countries, due to accelerated exhaustion of these nutrient elements by increased crop yields, while only a very limited range of mineral nutrients are applied as fertilizers (Abdulla, Svensson, Nordén & Öckerman, 1982). Ironically, almost all geomedical and related studies, especially in Western countries, focus on relationships between mineral element toxicities, due to pollution, and human health status (Deckers *et al*., 2000). At congresses on the biogeochemistry of trace elements practically all papers deal with toxicities. Seldom, if ever, is a paper on deficiencies presented.

On the World Health Organization's (WHO) ***global*** list of the top 20 risk factors for human health, two micro element ***deficiencies*** appear, viz. iron (ranked 9th) and zinc (11th) (IZiNCG, 2004). Lead pollution (ranked 16th) is the only mineral pollution/toxicity factor on the list. On the WHO's list of top 10 human health risk factors for ***developing countries***, deficiencies of zinc (ranked 5th) and iron (6th) are again the two mineral nutrient deficiencies on the list. Here they are very high on the list and their positions are swopped, with zinc deficiency being the most important nutritional factor. It is noteworthy that Vitamin A deficiency, which is presently often described as the most serious nutritional deficiency in human populations in developing countries, and for which major supplementation and plant breeding programmes are undertaken, is below zinc and iron deficiencies on both WHO lists, viz. 7th on the list for developing countries and 13th on the global list. There is no mineral pollution/toxicity factor on the top 10 list for developing countries.

It is clear that a drastic change in mindset is required if significant progress is to be made in improving human health in developing countries. Much more attention will have to be given to research on and monitoring of mineral nutrient deficiencies, especially micronutrient deficiencies.

ZINC IN HUMAN NUTRITION

ROLE OF ZINC IN HUMAN NUTRITION

It was established relatively late that zinc is an essential micro nutrient. The first convincing evidence that zinc is essential for plant growth was found during the period 1914-1916, but it was not generally accepted before 1926 and was finally proven in 1928 (Thorne, 1957). Zinc deficiency in human diets was “suspected” first in Iran in 1961, when zinc deficiency in the diet was found to be related to a syndrome that included five diseases (Oliver, 1997). Since then, an incredibly wide range of human diseases and conditions have been found to be associated with zinc deficiency. These are summarised by Oliver (1997) and IZiNCG (2004). That such a large number of diseases are affected by zinc deficiencies is probably not unexpected when considering that more than 300 enzymes require zinc for their functioning (Alloway, 2004; IZiNCG, 2004). Not surprisingly zinc is described as the *“most ubiquitous of all trace elements involved in human nutrition”* (IZiNCG, 2004).

In 2002 the WHO estimated that one third of the world’s population is affected by zinc deficiency, but that in a specific region this value was as high as 73% (IZiNCG, 2004). WHO also estimated that 800 000 deaths per annum worldwide could be attributed to zinc deficiency. It was estimated that in the developed world more than 130 000 “healthy life years” are lost annually due to zinc deficiency.

The most shocking statistic of the 2002 WHO report, as quoted by IZiNCG (2004), is that in developing countries **more than 28 million healthy life years are lost annually** due to zinc deficiency, with **almost half of these being in Africa** and more than one third in South East Asia. This must surely have a very negative effect on productivity in such countries and could in certain areas pose a significant drawback to an initiative like NEPAD.

Farmers in the Senanga district of western Zambia listed poor human health as one of the main factors responsible for the low agricultural productivity in the district (Kwaw-Mensah, 1996). The main diseases are malaria (the most prevalent), diarrhoea, dysentery, tuberculosis and “coughing”. No zinc studies were made in the area, but the dominant soils are extremely infertile, highly leached light grey sands, soils that are worldwide notorious for their low mineral nutrient levels, including very low zinc levels. One of the most important roles of zinc in human nutrition is to maintain the body’s **immune system** (Nauss & Newberne, 1982; Oliver, 1997). The effects of zinc deficiency in this regard are “profound”, rendering the zinc deficient person extremely vulnerable to a whole range of infections (Nauss & Newberne, 1982). Some of those that have been specifically listed include increased susceptibility to malaria, pneumonia and diarrhoea (IZiNCG, 2004). According to IZiNCG (2004) the 2002 WHO report found that on a worldwide basis zinc deficiency is “responsible” for 18% of malaria, 16% of lower respiratory tract infections and 10% of diarrhoea.

It is of major importance to note that according to Rowland “*direct* ***antiviral*** *effects of zinc ions have been demonstrated”* against the group of viruses responsible for the common cold and that *“there is evidence that zinc ions provide a natural protective mechanism against viruses, especially those causing respiratory tract infections”* (White, 2005). Because SARS is caused by a related virus, Rowland believes that zinc ions may probably even *“prove of benefit in the SARS crisis”.*

Zinc deficiency leads to growth retardation and impaired development of infants, children and adolescents (Oliver, 1997; IZiNCG, 2004). According to IZiNCG (2004) about one-third of the preschool children in developing countries have stunted growth and much of this is probably caused by zinc deficiency. It also appears that zinc deficiency in pregnant women may lead to premature birth and low birth weight (Oliver, 1997).

Furthermore, adequate zinc is essential for normal brain growth and zinc deprivation during the last trimester of pregnancy or during lactation results in reduced brain size (Prohaska, 1982). Early zinc deficiency also leads to brain disfunctions, such as *“impairment of cognitive function, behavioral problems, mood changes, memory impairment, problems with spatial learning, and neural atrophy”* (IZiNCG, 2004).

According to papers cited by Oliver (1997), including a 1996 WHO report, excessive zinc levels in human diets are toxic and leads to impairment of health (Oliver, 1997). Although Alloway (2004) is of the opinion that elevated zinc levels in crops “probably” do not pose toxicity hazards to humans, his judgement in this regard may be wrong. Excess Zn usually arises from pollution (Oliver, 1997; Alloway, 2004). Sources of Zn pollution are mainly industry (Alloway (2004), mining (Oliver, 1997), excess application of sewage sludge (Oliver, 1997) or other zinc-rich sludges and manures (Alloway, 2004), the latter probably from intensive “factory” livestock production systems such as feedlots or chicken batteries. Over-use of zinc-containing pesticides and fertilizers may also contribute (Oliver, 1997).

SOURCES OF ZINC IN THE HUMAN DIET

It is estimated that humans obtain about 90% of their zinc intake from food and 10% from water (Alloway, 2004). By far the largest zinc intake is from staple grains, especially in developing countries. There are very large differences between different crops and even between different cultivars of the same crop in regard to their abilities to absorb zinc from soils, and consequently in regard to their zinc contents. Several factors also affect the availability of zinc to plants in soils and its metabolic efficiency in plants. These will be discussed in more detail in the section on *“Zinc in crops and soils”*.

Zinc deficiency can be due to inadequate intake (due to low Zn content of the food) or due to poor absorption of zinc from the diet, i.e. due to poor bio-availability of the zinc in the diet (IZiNCG, 2004; various other publications). Animal products are by far the best sources of readily absorbable zinc. Red meat, shellfish and fish *“contain substantial amounts of zinc in readily absorbable form”*, with somewhat lesser amounts provided by pork, poultry, eggs and milk (Oliver, 1997; IZiNCG, 2004; Alloway, 2004). Unfortunately these foods are quite inaccessible to many of the world’s poorest populations (IZiNCG, 2004; Alloway, 2004), who also live in the areas with the biggest zinc deficiencies. In other cases social and religious customs do not permit people to eat meat (Alloway, 2004).

Milk, in the form of sour milk, used to make a much bigger contribution than meat to the diet of rural Black people in Southern Africa and probably was a major source of zinc (and calcium) in their diets. Present health regulations require pasteurisation of milk, however, and pasteurised milk does not become sour, it “rots” according to statements by people of Mdantsane township to the author during an informal survey. Thus they cannot use pasteurised milk, thus causing a serious nutrition problem. The majority of Black people in South Africa have primary lactose intolerance and thus cannot use fresh milk. In the Mseleni area *“93% of a sample of healthy adult Zulus”*, for example, had the problem (Fincham *et al*., 1986). Fincham *et al*. (1986) further state that consequently these people avoid drinking unfermented milk, and because they exclude it from their diet, absorption of dietary nutrients is impaired.

Due to the above problems experienced by poor populations, with limited access to animal products and/or inabilities to utilise fresh milk, they have to be more dependent on vegetative products for providing zinc in their diets. The most widely available and consumed vegetative products in such populations are staple foods such as grains and pulses (seeds of legumes, like beans, peas and lentils). Whole grain cereals and pulses have relatively high zinc contents (Oliver, 1997; IZiNCG, 2004), but the bio-availability of the zinc in them is very low and consequently they are not good sources of zinc. This is because uptake of zinc in the intestine is strongly inhibited by two other components which occur in high concentrations in these foods, viz. phytate (inositol hexaphosphate) and fibre (Oliver, 1997; IZiNCG, 2004; Alloway, 2004). Amongst the cereals wheat, rye and unpolished rice particularly have high phytate contents, higher than maize and sorghum (Alloway, 2004). The phytate content of all these foods is elevated when the crops are grown in soils with high phosphorus levels. High calcium aggravates the negative effect of phytate on the bio-availability of zinc. Maize, rice and barley cultivars with low phytate levels have been bred successfully (IZiNCG, 2004). Zinc absorption was increased by 78% in a maize-based diet with a 55% lower phytate content (IZiNCG). Refined cereals have lower zinc contents than whole grain cereals, but the bio-availability of this zinc is much higher, because most of the fibre and phytate have been removed.

The effect of phytate is moderated by proteins in the diet and animal proteins can improve the absorption of zinc from grains and pulses (Alloway, 2004). This demonstrates the importance of mixed diets containing both cereals and animal proteins (Alloway, 2004).

According to IZiNCG (2004) tubers, fruits and vegetables have relatively low zinc contents. On the other hand, nuts have relatively high zinc contents. From a zinc nutrition point it would, therefore, be essential for vegetarians to include adequate quantities of nuts in their diets (Abdulla *et al*., 1982).

REMEDIATION OF ZINC DEFICIENCIES IN HUMAN DIETS

Regarding the role of micronutrients in human health Oliver (1997) advocated that the aim should be to prevent ill health, rather than cure it. Zinc nutrition should be of key importance in such approach since *"this trace element is of signal importance in the immune system and host defense mechanisms"* (Nauss & Newberne, 1982), i.e. its prime function is the prevention of ill health. *"If people were to optimize their intake of trace elements then their health might benefit in the same way as it has done through the controlling of infectious diseases during this century"* (Oliver, 1997).

Various methods and strategies are used to supply additional zinc in highly cost effective ways to groups or populations with zinc-deficient diets (IZiNCG, 2004; various others). However, none of these are as simple and straightforward as they may seem. It would appear that people driving such programmes may sometimes be unaware or lose sight of the potential complications. They appear to be concentrating too much on zinc intake, i.e. the amount of zinc provided in the diet, rather than on bio-availability, i.e. the amount of zinc actually absorbed. The types of methods that are used include:

- Zinc supplementation.
- Zinc fortification of foods.
- Modifying diets or dietary habits.
- Field fortification with zinc.

Zinc supplementation is done in different ways. The age of the target group, cultural preferences, and the need to include additional nutrients determine the optimal form of the supplement (IZiNCG, 2004). For infants and small children, the highest risk group of all in regard to zinc deficiencies, zinc supplements are often given in the form of flavoured syrup. Chewable tablets have been used for school children. Sachets of dry micro-nutrients or crushable tablets that are added to food at the time of serving is another approach. Rowland pointed out that zinc tablets, like fortified foods, aim to provide zinc through absorption in the intestine and that this can be *"very inefficient"*, because high levels of phytate and the presence of other essential minerals that interfere with zinc absorption, e.g. calcium and iron, can all reduce zinc uptake from the intestine (White, 2005). The same would be the fate of zinc in so-called "multivitamin and mineral" tablets. In addition these tablets themselves usually contain calcium and/or iron. They all also contain Vitamin C, which, according to Rowland, can "trap" zinc ions. In the early 1980's a paper on "At last an anti-cancer diet" pointed out that certain ingredients in multivitamin and mineral tablets can seriously inhibit absorption of some of the micronutrients in the tablets. Unfortunately the author could not trace the reprint again while preparing this paper.

Recent research in Sweden indicated that combined iron-zinc supplements may be less effective in preventing deficiencies of these nutrients in infants than individual supplementation (White, 2005). It is suggested that the well-known interaction between iron and zinc reduces the efficiency of the nutrients in a combined supplement. Ironically, IZiNCG (2004) expressed the opinion that *"in many situations, zinc can be included in programs already delivering daily or weekly nutrient supplements, such as iron ….."*

According to Rowland the mouth and throat would be a better route for zinc absorption (White, 2005). Firstly, zinc absorption in the mouth and throat is very efficient and secondly the negative interactions of phytate and other substances in the intestine are eliminated. Theoretically, zinc lozenges that release zinc in the mouth, thus seemingly present a good option. Unfortunately it is not so simple, as Rowland indicated (White, 2005): *"Although zinc lozenges are available, most products fail to achieve their goals because the amount of zinc they contain is too low rendering them sub-therapeutic or because the formulation contains substances such as Vitamin C that trap the zinc ions."* Rowland also indicated that pleasant-tasting zinc lozenges providing an adequate dose of zinc has eluded most manufacturers, but that new research seems to have overcome this problem.

Zinc fortification of food in/for developing countries usually amounts to the addition of zinc to staple foods. For example, South African millers are now by law required to fortify white and brown bread flour and maize meal with the three most important nutrient deficiencies identified by the WHO, viz. zinc, iron and Vitamin A, as well as Vitamins B1, B2, B3 and B6 and folic acid, a real "shotgun " approach (White, 2005). It would be interesting to know what the efficiency of zinc absorption is in view of the fact that iron is also included in the fortification. Furthermore, it could probably be expected that the brown bread flour may have relatively high phytate (and probably also fibre) contents and it would be interesting to know the effect of these on zinc absorption. South Africa is one of the first group of four countries to receive support from the Global Alliance for Improved Nutrition (GAIN) to improve the nutritional value of their food supplies, the other three being China, Morocco and Vietnam.

Emphasising the potential problems associated with bio-availability of zinc from supplements and fortified foods does not imply that it is suggested that zinc supplementation or fortification is inappropriate or useless. It is simply meant to warn against over-complacency stemming from excessive emphasis on zinc intake rather than zinc absorption. It also highlights the fact that higher zinc levels may in many cases be required in zinc supplements or fortifications to provide the required level of zinc uptake. A Canadian study on infants up to the age of six months, for example, found a decline in the hair zinc content of boys bottle fed with a zinc fortified milk formulation that at all stages met the Canadian Dietary Standard (CDS) and Recommended Daily Allowance (RDA) for zinc (MacDonald, Gibson & Shapcott, 1982). In contrast, breast fed boys did not have this problem, despite the fact that the breast milk never at any stage met the CDS or RDA requirements. In fact, zinc intake by the breast fed infants was only about half of that of the bottle fed infants. Even at six months breast fed infants received 86% of their dietary zinc from breast milk. According to MacDonald *et al*. (1982) their study "*provided further support to the conclusion that the bioavailability of zinc from breast milk is superior to that of cows' milk based formula ….. ".*

It is clear that RDA should not be treated as a magic fixed level, but should be adjusted upward or downward for specific situations according to the bio-availability of zinc in different sources and the composition of the diet of the population. WHO, for example, adjusts RDA levels for zinc upwards for populations where animal products in the diet are limited and in which plant sources are high in phytates. Zinc supplementation or fortification levels should then also be adjusted accordingly.

Fortification of infant formulas, infant cereals and ready-to-eat breakfast cereals is often done in industrialised countries (IZiNCG, 2004). According to IZiNCG (2004), high-fat, micronutrient fortified spreads may provide another option. IZiNCG (2004) stated that food fortification *"has played a major role in eliminating micronutrient deficiencies in industrialized countries".* It is probably totally over-optimistic to suggest that zinc deficiencies in humans have been "*eliminated"* in industrial countries. Although the situation is much better than in developing countries, deficiencies do occur and are in some cases increasing (e.g. Abdulla *et al*., 1982). A recent study at Tufts University in the USA found that the diets of 25% of students did not meet the RDA for iron and zinc, the researchers suggesting that this was possibly because one-third of the students eliminated red meat from their diets (White, 2005).

Modification of diets or dietary habits that cause zinc deficiencies should aim at improving access to and/or intake of food with high levels of absorbable zinc. This would require a more balanced diet, including adequate amounts of animal products (especially red meat) and less unrefined cereals (which have high fibre and phytate levels). According to IZiNCG (2004) strategies to achieve this are necessarily long-term. In many cases it may be very difficult or almost impossible to achieve this. Poor populations in deep rural areas often cannot gain access to the required foods or cannot afford them. In other cases dietary habits that are driven by customs or religious or other beliefs are very difficult to change.

In the case of populations that cannot use fresh milk, due to lactose intolerance, and cannot use pasteurised milk to make sour milk, as indicated earlier, another strategy is required. The most sensible strategy for such areas would seem to be promotion of the production of unpasteurised healthy milk from certified disease-free herds that are regularly tested for brucellosis and bovine TB. Healthy sour milk, giving improved provision of mineral nutrients like calcium and zinc, would thus become available without the disease risks of milk bought behind the bush from untested animals.

It should be noted that in the case of selenium, a very important mineral anti-oxidant involved in preventing many diseases in humans, the effect of pasteurisation of milk is serious even for people using fresh milk. Pasteurisation causes irreversible inactivation of selenium containing glutathione peroxidase in milk and milk powders, making the selenium unavailable for absorption in humans and rendering infants and lacto-vegetarians high risk groups for various diseases (Vanden Berghe, 1982). Even more than in the case of zinc, meat and fish are the best sources of selenium. Vegetarians thus are a high risk group for selenium deficiency, unless they include enough mushrooms, garlic and mustard in their diets to compensate for the deficiency (Vanden Berghe, 1982).

Field fortification with zinc consists of two techniques, viz.

a. Plant breeding to produce zinc-efficient cultivars.
b. The use of zinc fertilizers to increase the zinc content (and yield) of crops, especially staple cereal grains.

These are discussed in the next section on *"Zinc in crops and soils".*

ZINC IN CROPS AND SOILS

No detailed discussion on zinc in crops and soils can be given in this short review. More detailed information can be obtained from sources like the book/CD of Alloway (2004) on *"Zinc in soils and crop nutrition".* Comparison of the book of Alloway (2004) with the unpublished review of Laker (1963), titled *"Sink as plantvoedingstof" ("Zinc as plant nutrient")* reveals that all the basic principles and factors related to zinc in soils and the zinc nutrition of plants were already known some 40 years ago. The 2004 book just contains some newer confirmation of basics known already by 1963. The 1963 review actually included information on one or two important factors that are not discussed in the 2004 book. The review of Laker (1963) also included some South African data that are still valid, but are not included in international reviews. There are also other important South African publications on zinc, *inter alia* the D.Sc.Agric. thesis of Stanton (1964) and the M.Sc.Agric. dissertation of Laker (1964).

The objectives of improving the zinc nutrition of plants include

a. Increasing the amount of readily absorbable zinc available for human nutrition.

b. Increasing crop yields, so as to
   i. Increase the amount of food, especially staple food, available for humans, including poor communities in isolated deep rural areas.
   ii. Increase the profits of commercial crop farmers.

ZINC IN CROPS

There are very big differences between different crops in regard to their tolerances of zinc deficiencies in soils and their abilities to absorb zinc. Tables/lists, compiled from publications on these, are given by Alloway (2004), Laker (1963) and Thorne (1957). Crops that are very sensitive to zinc deficiencies include deciduous fruits, grapes, citrus and pecan nuts. Most importantly they include the staple foods maize, rice, sorghum and beans (dry beans). Of all annual crops ***maize*** is affected the most seriously by zinc deficiencies (Thorne, 1957). Rice and beans have the dual problem of having both poor ability to absorb zinc from the soil and high phytate contents, which lower the bio-availability of the zinc (Alloway, 2004; IZiNCG, 2004).

Crops with high tolerance to zinc deficiencies include peas and the small grains wheat, oats and rye, while barley was rated as tolerant by the sources quoted by Laker (1963), but moderately sensitive in the table of Alloway (2004). Unfortunately crops like wheat and rye have high phytate contents, reducing the bio-availability of the zinc in the human diets. Although these crops have low sensitivities for zinc deficiencies in soils, they will suffer under conditions of acute zinc deficiencies. In parts of Turkey, for example, wheat yields were reduced by 50% due to zinc deficiencies, but Alloway (2004) stated that if maize or beans were grown on the same soils, they would have been even more severely affected.

There are also big differences between different cultivars of the same crop regarding their abilities to absorb zinc from the soil, and consequently in regard to their sensitivities to low soil zinc levels (Alloway, 2004; Laker, 1963). This is particularly well-known for maize, perhaps because maize is inherently so sensitive to zinc deficiencies. According to IZiNCG (2004) differences in zinc concentrations between different maize cultivars can be as high as 50% from the mean.

Barnette & Warner (1935) already reported that maize cultivars that were developed on infertile sandy soils were more tolerant to zinc deficiencies than those which were developed on fertile heavier soils. Alloway (2004) refers to recent (1992) Australian research that found the same for wheat, barley and oats. In the early 1960's the author and colleagues found in the Highveld of South Africa that the then new maize hybrids were much more sensitive to zinc deficiencies than the older cultivars (Laker, 1963). Globally a present problem is that the abilities of the "Green revolution" high yielding maize cultivars to absorb zinc are very poor and thus they are much more sensitive to zinc deficiencies than indigenous cultivars in areas with zinc deficiencies (Alloway, 2004).

In Australia, Reghenzani (2005) found very big differences between different sugarcane cultivars in regard to the expression of zinc deficiency symptoms (**Table 1**). Q113 was in a class of its own in regard to extreme sensitivity to zinc deficiency. All cultivars, except H56-752 *"showed* some *typical Q113 deficiency symptoms with zero Zn application"* (Reghenzani, 2005). Thus H56-752 seems to be at the other extreme, being very tolerant. In Table 1 cultivars are ranked according to percentage of leaves with Zn deficiency symptoms, each point representing 10%. For Q113, for example, this means 90% of the leaves had symptoms.

Table 1 - Ranking of Australian sugarcane cultivars according to strength of expression of Zn deficiency (From: Reghenzani, 2005)

Symptom Rating	Cultivar
9 Severe	**Q113**
5	**Q124**, Q120, **Q123**, Pelorus
4	**Q96**, Q115, Q121, **Q117**, Orpheus
3	Q138, Q122, Q130
1 Mild	CP44-101, H56-752

Cultivars printed in **bold** are susceptible to foliage infection by *Curvularia brachyspora* when Zn deficient.

The low zinc uptake efficiency of Green revolution type high yielding varieties (HYV's) would make the introduction of such cultivars into developing countries or areas with soils that are highly zinc deficient a big risk. This would be aggravated by the fact that these cultivars also require high inputs of NPK fertilizers. High inputs of phosphorus will have additional negative impacts on zinc nutrition. (To be discussed later.) Nana-Sinkam (1995) listed the "Asian technology myth" (Asian technology = Green revolution technology) as one of the four myths of African agriculture. Someone stated that whereas a plant breeding based green revolution worked in Asia, Africa's poor soils would require a soil fertility based green revolution.

Breeding for higher yields should thus concentrate on developing cultivars that are more efficient in utilising a nutrient such as zinc under deficient conditions and from applied fertilizers. The genes for this will probably be found in local cultivars that have developed over decades or centuries through selection by small-scale farmers in such areas. This was the case when the US needed to breed in bigger tolerance to high soil acidity and aluminium toxicity in maize and wheat and the required genes were found in areas like central Africa and South America. In Central Anatolia, Turkey, which is dominated by zinc deficient calcareous soils, the most tolerant wheat cultivars are those which have been developed from crosses with local land races (Alloway, 2004). The local Anatolian bread wheat land races are highly tolerant to zinc deficiencies. In the South African Highveld the opposite was clearly observed in the early 1960's, viz. that all maize hybrids which had one specific parent in common were much more sensitive to zinc deficiencies than other hybrids.

The successful use of gene pools from developing countries/areas in breeding programmes, without proper compensation to the local farmers, who "preserved" the genes for centuries, and the new cultivars being patented as the intellectual property rights of the companies in the developed countries that bred them, is a topic of heated emotional debate, especially in Africa. This was, for example, discussed by Bryant (1994) in her paper *"Corporate patents or global piracy?"*.

To be really effective, the ideal would be breeding of staple grain crop cultivars with both high zinc efficiencies and low phytate contents. According to IZiNCG (2004) breeding of maize, barley and rice cultivars with low phytate contents has been achieved successfully.

PLANT-AVAILABLE ZINC IN SOILS

When looking at the plant-available zinc contents of soils, and especially at deficient zinc levels in soils, one needs to look at two types of deficiencies, viz.

a. Absolute deficiencies.
b. Induced deficiencies.

Absolute deficiencies of zinc in soils

With an absolute zinc deficiency is meant that the soil inherently has low total and/or plant-available zinc contents. There are four main factors related to absolute zinc deficiencies in unpolluted virgin soils, one of which is also related to induced deficiencies. These are:

i. Parent material.
ii. Texture.
iii. Degree of weathering and leaching.
iv. pH and presence of lime.

Parent material has a large effect on the zinc content of soils (Laker, 1963; Oliver, 1997; Meyer, Schumann, Schroeder, Wood & Rampersad, 1999; Alloway, 2004; Reghenzani, 2005). It depends on the amount of zinc-bearing minerals, such as the ferromagnesian minerals (mainly pyroxenes) in the parent material (Laker, 1963; Alloway, 2004). High ferromagnesian mineral content is the reason why soils derived from basic igneous rocks (diabase, dolerite, basalt, gabbro, etc.) have high zinc contents (Laker, 1964; Alloway, 2004; Reghenzani, 2005). Mudstones and shales may have zinc contents of the same order as basic igneous rocks (Alloway, 2004; Kibblewhite, Van Rensburg, Laker & Rose, 1984), but somehow the zinc contents in the soils derived from mudstones and shales seem to be lower than in the soils derived from basic igneous rocks (Laker, 1963; Kibblewhite *et al*., 1984). Alluvial soils tend to have high zinc contents (Laker, 1963; Meyer *et al*., 1999; Reghenzani, 2005), but a factor like high pH and free lime in the profile may lower the plant-availability of this zinc substantially in arid and semi-arid areas.

Soils derived from acid igneous rocks, e.g. granite and its metamorphic variant, gneiss, have low zinc contents (Laker, 1963; Grant, 1980; Alloway, 2004; Reghenzani, 2005). This is due to a combination of these rocks having low ferromagnesian mineral contents and them being dominated by coarse-grained quartz, which gives sandy soils. Sandstones (and limestones) have very low zinc contents, thus producing soils that are seriously zinc deficient (Laker, 1963; Meyer *et al*., 1999; Alloway, 2004). Its Table Mountain Sandstone parent material is a major reason why the *"wonderful Inanda soils"* (Meyer, 2005) of the South African sugar industry are seriously prone to zinc deficiency (Meyer *et al*., 1999; Meyer, 2005).

Soil texture is a major factor related to zinc deficiencies in soils, with sandy soils being much more prone to zinc deficiencies than medium-textured or clayey soils (Laker, 1963; Meyer *et al*., 1999; Alloway, 2004; Reghenzani, 2005). Various factors are responsible for this situation, including:

- Sandy soils are derived from parent materials that have low zinc contents, such as sandstones (Laker, 1963; Meyer *et al*., 1999; Alloway, 2004) or "recent sands" (Meyer *et al*., 1999), referred to as "beach ridges" by (Reghenzani, 2005).

- Zinc is a cation and is adsorbed to the negative charges on the soil colloids (the clay fraction). Thereby it is stored in a plant-available form and at the same time protected against leaching

(Laker, 1963; Alloway, 2004). This capacity is determined by the clay content and type of clay mineral in the soil. Thus soils with higher clay contents generally have higher zinc contents than sandy soils (Alloway, 2004). One must be careful not to over-generalise, however, as will be pointed out under discussions on degree of weathering and leaching.

- Zinc is also provided through continuous steady weathering of zinc-rich weatherable minerals in soils. The weatherable minerals in soils are largely found in the silt fraction. In the South African Highveld, Grobler & Hugo (1963) found a highly significant correlation between the total zinc content of the soils and their silt content (r = 0.79) or (silt + clay) content (r = 0.75). The correlation between total zinc and clay was much poorer (r = 0.40), leading to the conclusion that most of the zinc is present in weatherable minerals in the silt fraction. This is a problem, because the silt contents of these soils are very low, thus probably explaining the very low zinc contents found in soils of the Highveld by researchers such as Grobler & Hugo (1963), Stanton (1964) and various others.

The extremely high ***degree of weathering and leaching*** of most soils in hot, humid tropical and subtropical areas has rendered them very deficient in most macro and micro plant nutrient elements, including zinc (Laker, 2003; Alloway, 2004). In the first place these soils contain little or no weatherable minerals from which a nutrient like zinc can be provided by means of steady weathering. According to Bridges, Batjes & Nachtergaele (1998) *"weatherable minerals are absent"* in Ferralsols, the dominant soils of central Africa and the northern part of South America. Secondly, clay weathering has progressed to the stage where the clay fraction consists mainly of kaolinite and sesquioxides, which have very low cation exchange capacities and are therefore unable to retain large amounts of cationic nutrients, like zinc, against leaching (Deckers, Nachtergaele & Spaargaren, 1998). Positive charges, that will repel cations and enhance their leaching, even develop in these very strongly acid soils. Thirdly, the clay particles in clayey soils of such regions aggregate strongly together into micro-structure acting like *"pseudo-sand"* in regard to soil physical properties like water retention (Deckers *et al*., 1998). These lower water storage capacities lead to further acceleration of leaching under the prevailing high rainfall.

Leaching and resultant infertility is extremely severe in deep, albic (bleached, light grey) sandy soils. It is most extreme under very high rainfall. Africa is in the disadvantageous position that it has more than half of the world's sandy soils. The very large area of very deep, extremely infertile albic sands under high rainfall in western Zambia, eastern Angola, western DRC and the Brazzaville Congo is probably the area with the most serious problems in terms of low soil fertility in Africa, and possibly in the world. Deep albic sands are, for example, the dominant soils in the Senanga district of western Zambia where human diseases like malaria and pneumonia, which could be aggravated by zinc deficiencies, are so prevalent, as indicated earlier (Kwaw-Mensah, 1996).

Soil pH and presence of free lime in the profile have major impacts on the plant-available zinc levels of soils. Alkaline and calcareous soils have low plant-available zinc contents (Laker, 1963; Alloway, 2004). Naturally occurring alkaline and calcareous soils are mainly found in semi-arid to arid areas, where little or no rainfed cropping is possible due to the low rainfall (Alloway, 2004). Major impacts of the zinc deficiencies in these soils are found where zinc-sensitive high income crops, like deciduous fruits, grapes or citrus, are grown on them under irrigation. In the western parts of the South African maize quadrangle there are also extensive areas on which rainfed maize is grown that are underlain by lime pans. From a more favourable soil water availability viewpoint these soils are important for maize production in these areas (De Lange & Laker, 1992). In the north-western Free State it was, however, found that where abundant lime is present relatively close to the soil surface, and especially where it is ploughed up into the plough layer, zinc deficiencies are prevalent in maize (Laker, 1963).

Alloway's (2004) statement that alkaline soils are more prone to zinc deficiencies than neutral and slightly acid soils, is technically true. Zinc-sensitive crops are, however, highly prone to zinc deficiencies even on neutral and slightly acid soils. Thorne (1957) reviewed research indicating that zinc deficiencies are predominantly found in soils with pH (Water) levels of between 6.0 and 8.0. Camp (1945) deemed the critical soil pH (Water) for the onset of zinc deficiencies to be between 5.5 and 6.5. On the sandy soils of the north-western Free State Laker (1963) observed that serious zinc deficiencies in maize set in whenever the pH (Water) of soils were above 5.7. These aspects will be elaborated further in the next section on induced zinc deficiencies.

On the other hand it must be kept in mind that the highly weathered, highly leached soils that are deficient in several elements (often including zinc), mentioned before, are strongly acid soils (Alloway, 2004). Because of the very low absolute levels of zinc in such soils, their favourable pH for zinc availability does not help.

Induced zinc deficiencies

Several factors and practices can induce zinc deficiencies in crops on soils with adequate total zinc contents. Comprehensive reviews of these were given by Thorne (1957), Laker (1963) and Stanton (1964). Alloway (2004) gives brief outlines of the different factors, the basic principles remaining the same as in the older, more comprehensive reviews. Only three of the most common and widespread factors/ practices will be discussed here, viz.

i. Injudicious liming.
ii. Injudicious phosphorus fertilization.
iii. Removal of topsoil.

Injudicious liming is a major cause of deficiencies of zinc (and various other micronutrients) in soils and plants. This was clearly shown in numerous studies reviewed by Thorne (1957), Laker (1963) and Stanton (1964). Reghenzani (2005) also found that zinc deficiency in sugarcane was worse after liming. Large reductions in the efficiency of applied zinc due to liming have also been found. Stanton (1964) refers to research showing that applied zinc is affected more negatively by high lime applications than native zinc present in the soil. Laker (1964, 1967) found that raising the pH (KCl) of soil from the Outeniqua experiment station from 3.7 to 4.9 by liming, reduced the uptake of applied zinc by about 50%. Raising the soil pH (KCl) to 4.3 had no negative effect on the uptake of applied zinc. The respective pH (Water) values would be approximately 4.7, 5.9 and 5.3. These results thus again confirm that liming of sandy soil becomes a problem if the pH (Water) is raised higher than about 5.5 by liming.

The key phrase is *"**injudicious** liming".* In order to achieve optimum crop production it is absolutely essential that strongly acid soils must be limed (Laker, 2004a). In South Africa, for example, the general pattern is that far too little lime is applied. Liming must be done judiciously, however, taking the lime requirement of the specific soil into account and aiming for ***realistic*** final pH levels to be achieved. It has already been pointed out that serious zinc deficiencies generally set in at soil pH (Water) values above 6.0. This is equivalent to a soil pH (KCl) of 5.0. It has also been pointed out that on sandy soils zinc deficiencies generally set in if the soil pH (Water) is raised above about 5.5. From a review of South African research, Laker (2004a) concluded that raising the pH (Water) of soils to just 5.2 will knock out the negative impacts of high soil acidity and sharply increase yields. Thus it is not necessary to lime soils to pH levels that are so high that they will induce micronutrient deficiencies in order to eliminate acidity problems. Laker (2004a) pointed out that some soils may require more than 10 $t.ha^{-1}$ lime to raise their pH (Water) to 5.2, while at the other extreme some do not require more than 0.5 $t.ha^{-1}$.

Great circumspection in regard to liming practices is especially required on poorly buffered soils, such as sandy soils and highly weathered tropical soils. In addition to aiming for appropriate pH levels in such soils, i.e. pH (Water) values not higher than about 5.5 or pH (KCl) levels not higher than about 4.5, frequent light lime applications would be more appropriate than infrequent heavy applications (Laker, 2004a). For the infertile highly weathered Ferralsols which, together with the even more infertile bleached sands, are the dominant soils in central Africa, Deckers *et al*. (1998) stated: *"Moderate applications of lime are beneficial as long as they do not result in accelerated mineralisation of organic matter or create micro-nutrient deficiencies (zinc, copper). Usually 0.5 to 2 tons/ha of lime, or preferably dolomite, will be sufficient to supply calcium as a nutrient and to buffer the low pH in Ferralsols."*

Injudicious phosphorus fertilization is possibly the most important factor responsible for induced zinc deficiencies (Thorne, 1957; Laker, 1963; Stanton, 1964). There is a close interaction between phosphorus level and soil pH in regard to the causing of zinc deficiencies in plants. Stanton (1964), for example, concluded that *"….. soil pH and P application have a controlling influence on the availability of Zn in the O.F.S. soils".*

Again, the emphasis is on *"**injudicious** phosphorus fertilization".* Judicious phosphorus fertilization is a key factor for successful crop production. Most virgin soils are very deficient in phosphorus and optimum crop yields are not possible without adequate phosphorus applications. According to ICSU's Scientific Committee on Problems of the Environment (SCOPE, 1995): *"In developing countries, where 95% of the population increase over the next decades will occur, soil fertility is often low, and it will be difficult to meet the increased demand for food and fibre. …… Too little fertilizer P is actually used in those parts of the world where P input could have a major effect on food production. Phosphorus use may have to double in Asia and quadruple in Africa."* On the other hand excessive P application is not only a waste of money, but also leads to yield reductions, especially where it causes induced micro-nutrient deficiencies (Eloff & Laker, 1978; Laker, 2003, 2004a). High P levels will also increase the phytate (inositol hexaphosphate) contents of crops such as cereals and pulses, thus lowering the bio-availability of zinc to humans in these crops.

Increased P fertilization of zinc-inefficient crops like maize, rice, sorghum or beans on zinc-deficient soils in developing areas may be disastrous if it is not accompanied by fertilization with zinc (and, where necessary, other micro-nutrients). This will be even a bigger problem if zinc-inefficient HYV hybrids are introduced and heavily fertilized. In the final instance, balanced fertilization is essential (Laker, 1963, 2004a).

Removal of topsoil often leads to crop failures, due to zinc deficiencies, on the areas where the topsoil has been removed. Topsoil removal is often due to levelling of land for irrigation or other crop management purposes (Stanton, 1964; Alloway, 2004; Reghenzani, 2005) or erosion (Stanton, 1964). These zinc deficiencies are sometimes due to the exposure of calcareous subsoils (Alloway, 2004). Often it is simply a matter of lower zinc contents in the subsoils (Stanton, 1964). For a few virgin O.F.S. soil profiles Stanton (1964), for example, found that the mean 0.1M HCl-extractable Zn content for the topsoils was 0.9 $mg.kg^{-1}$ and for the subsoils only 0.3 $mg.kg^{-1}$. Values lower than 1.0 $mg.kg^{-1}$ are considered deficient (Stanton, 1964). The potentially very serious impact that the severe soil erosion in Africa, including South Africa, could have on the zinc nutrition of crops, and thus on both crop yields and human health, is evident.

ZINC FERTILIZATION

Zinc fertilization of crops can be done in different ways (Laker, 1963; Alloway, 2004). The two most common methods are foliar application of zinc and soil application of zinc fertilizers. Foliar sprays with dilute solutions of a zinc compound like zinc sulphate are used mainly on perennial crops, such as deciduous fruits, citrus, grapes, etc. On annuals it is sometimes used as an emergency measure when a serious deficiency suddenly shows up (Alloway, 2004).

Soil application of zinc fertilizers is by far the most widely used method for zinc fertilization of crops (Laker, 1963; Alloway, 2004). Several different types of compounds are used as zinc fertilizers (Laker, 1963; Alloway, 2004). The most widely used compounds include a wide range of inorganic zinc compounds and synthetic chelates.

Zinc sulphate is the inorganic zinc compound that is by far the most commonly used as zinc fertilizer around the world (Laker, 1963; Alloway, 2004). Other compounds that are relatively widely used, are zinc oxide and zinc carbonate (Laker, 1963; Alloway, 2004), while zinc nitrate and zinc chloride are also used occasionally (Alloway, 2004). Boawn, Viets & Crawford (1957) found that zinc phosphate, $Zn_3(PO_4)_2$, is also an effective zinc source. Boawn *et al*. (1957) found that all zinc compounds that are fully soluble in 0.1M HCl, including zinc oxide, zinc carbonate and zinc phosphate, are utilised as effectively as the water soluble zinc sulphate by plants when applied to soils. Lingle & Holmberg (1957) even found that zinc oxide was more effective than zinc sulphate for correcting a zinc deficiency in sweet corn. Boawn *et al*. (1957) prefer the other 0.1M HCl soluble zinc sources to zinc sulphate, because the latter is hygroscopic and difficult to handle, and according to Dietrichsen & Laker (1979) also relatively expensive. Zinc compounds that are only partially soluble in 0.1M HCl are utilised less effectively by plants (Boawn *et al*., 1957). Alloway (2004) lists zinc frits (fritted glass) as a zinc fertilizer source, but Boawn *et al*. (1957) found no uptake of zinc from two frit materials. Dietrichsen & Laker (1979) found "zinc fertilizer material" (ZFM) to be as effective as zinc oxide in regard to improving vegetative growth of wheat on nearly neutral soils at Vaalharts, although Van de Venter (1963) believed that ZFM should not be used on neutral to alkaline soils.

Zn-EDTA is the synthetic zinc chelate that is most widely used as zinc fertilizer (Laker, 1963; Alloway, 2004). According to Alloway (2004) chelates, e.g. Zn-EDTA, "*are regarded as the most effective sources of plant micronutrients".* According to research reviewed by Laker (1963) this is not definite, because the efficiency of Zn-EDTA differs widely between different soils. Even in those cases where Zn-EDTA may be more effective than a source like zinc sulphate, the high cost of the chelate makes it economically non-competitive (Prasad, 1997; Alloway, 2004).

Zinc is also applied effectively by enriching commercial macro nutrient (NPK) fertilizers with zinc (Van de Venter, 1963; Alloway, 2004; Barnard & Du Preez, 2004). Examples from Australia, India and Zimbabwe are given by Alloway (2004). In South Africa zinc-enriched commercial fertilizer mixtures have been used successfully for about 40 years now. Due to this the zinc levels in cultivated fields have increased considerably over time (Barnard & Du Preez, 2004). Barnard & Du Preez (2004) could not find any reports of zinc toxicity problems resulting from this practice. Band placement of zinc-enriched commercial fertilizers has several advantages, *inter alia*:

a. With band placement much less zinc needs to be applied than with broadcast applications (Laker, 1963), also where zinc fertilizers are applied separately.

b. There is much more concentration of active roots in and around the band, thus also improving absorption of zinc.

c. Due to the formation of localised high acidity in an around the band, uptake of zinc is enhanced (Alloway, 2004). According to Alloway (2004) it is most effective if acid (pH <4) fertilizers are used. Zinc uptake increases with declining pH, rising sharply at pH 3.7. This is in agreement with the findings of Aucamp (2000) on zinc-solubility vs pH relationships. Presence of ammonium containing compounds in zinc-enriched fertilizers is advantageous because of the acidifying effect in the band during nitrification of the ammonium (Viets, Boawn, Crawford & Nelson, 1953; Alloway, 2004).

In 1963, when it was still being debated whether incorporation of zinc in fertilizer mixtures should be allowed in South Africa, Van de Venter (1963) pointed out its advantages over the alternatives. On the one hand separate application of zinc would require additional practices, costing money. On the other hand it would be difficult to achieve homogeneous incorporation of zinc compounds into fertilizers on the farm, apart from the additional labour and other costs to do it. One of the objections against zinc enrichment of commercial fertilizers was that it would increase the cost of the fertilizers, but Van de Venter (1963) argued that this would be less than the additional costs of separate handling or incorporation on the farm. The second objection was that it could lead to the building up of toxic zinc levels in soils. Van de Venter (1963) pointed out that this could likewise occur with separate zinc application. As pointed out earlier, Barnard & Du Preez (2004) could not find evidence of zinc toxicities after about 40 years of zinc-enriched fertilizers being used.

The author is of the opinion that the use of zinc-enriched commercial fertilizers will be the most effective way to ameliorate zinc deficiencies in developing countries/areas/regions in which zinc deficiencies are prevalent. It is unrealistic to expect that small scale farmers in remote areas would or could apply zinc fertilizers separately from commercial macro nutrient fertilizers. In small scale farming scenarios in developing countries application of zinc fertilizers to soils should be a much better strategy than dietary supplementation or fortification to increase the zinc intake of people. Zinc fertilization of zinc deficient soils/crops not only increases the zinc content in the diet, but also gives higher yields, i.e. produces more food.

Extremely poor infrastructure is paralysing possibilities to get inputs like fertilizers to farmers, especially small-scale farmers, in remote areas of developing countries (Laker, 2003). It is even becoming a serious problem in not very remote, relatively developed areas of South Africa (Laker, 2004b). Unless drastic improvements to the infra-structure situations are made, there is no hope of significantly increasing fertilizer use and thus improving food security and the quality of the diets of people in such countries. Dietary supplementation and distribution of fortified food will likewise be hampered by the poor infrastructure. High fertilizer costs, due to scrapping of fertilizer subsidies, have also reduced the use of fertilizers by small-scale farmers drastically in many developing countries (Laker, 2003). SCOPE (1995) stated that despite the potential dangers of *"….. market distortions,* *black markets, environmental problems and the misallocation of resources, ….. for reasons of long-term resource conservation and for the reversal of land degradation, fertilizer subsidies should be considered on P-deficient soils, where environmental costs of the soil depletion may justify the cost of subsidies."* Instead of "P-deficient" one could substitute "Zn-deficient" or any other essential plant, animal or human nutrient. Instead of "environmental costs" it could probably be even more important to substitute "the costs of poor human health".

IDENTIFICATION AND MAPPING OF ZINC DEFICIENT REGIONS/AREAS

In geomedicine the aim is to determine whether there are causative relationships between a certain mineral element deficiency or toxicity and a specific human disease or disorder and then to identify and map areas with different risk levels. A *"recurrent thread"* in epidemiological findings is the local nature of toxicities and deficiencies and of certain diseases, indicating that the causes of these diseases must be sought in the local environment (Oliver, 1997). Such studies require a combination of well-designed soil sampling and analysis and recording and mapping of disease incidences (Oliver, 1997). The former is the task of well-qualified soil scientists and the latter the task of equally well qualified epidemiologists, working together in harmony as close-knit teams. Embarking on such task in new, unknown scientific and/or geographic territory would necessarily require that some relatively broad scale survey, looking at a wide range of mineral nutrients, should be the first step. Using standard geo- and spatial statistics and the kriging techniques adapted by Oliver and Webster (Oliver, 1997) for estimating the risk of diseases, will provide maps and information that can then be used *"to focus further soil and epidemiological research"* (Oliver, 1997).

The above approach (but with much simpler statistics) was used in a major study looking at possible relationships between soil factors and oesophageal cancer incidence in the Transkei (Laker, Beyers, Van Rensburg & Hensley, 1983; Kibblewhite *et al*., 1984). The Transkei has a high average oesophageal cancer incidence, but the incidence various from low in the northeast to amongst the highest in the world in the south. The author guided the soil studies and Dr. Elizabeth Rose the epidemiological studies. The first step was a broad scale comparison between two low incidence districts (Lusikisiki and Bizana) and two high incidence districts (Butterworth and Kentani). Based on the results of this, the second step then involved a detailed study in half of Butterworth district. Mapping of the sites of all oesophageal cancer cases over the previous 23 years, showed that there were two extremely high incidence strips separated by a strip with very few cases. The "cancer free" strip was found to be on the big Gap Dyke dolerite dyke, with the "black areas" either side of it on Beaufort mudstones and shales. Amongst several mineral nutrient differences it was found that the dolerite contained 881 $mg.kg^{-1}$ manganese, compared with only 332 $mg.kg^{-1}$ in the mudstones and shales. This was reflected in lower manganese contents in the soils and maize plants of the high cancer incidence areas, confirming a difference that was observed in the inter-district study.

Oliver (1997) quite correctly emphasises that: *"This approach is likely to be successful in rural communities living by subsistence agriculture because their water and food are derived locally. It is also among such communities that the benefits are likely to be greatest, especially if there are subclinical deficiencies that can be rectified as a result."*

The prime objective of the mapping of mineral nutrient levels, human disease incidences and crop yields should be to identify the "crisis areas" that need immediate urgent attention, whether on a global, continental, regional or national scale. Resources like funding, manpower, etc. can then be focussed on solving the problems of these "crisis areas" as the highest priority.

Since zinc is the top ranked nutrient deficiency factor in human health risk in developing countries, it is logical that zinc should be the primary focus of geomedical studies and surveys in those countries. As indicated earlier, these should include both zinc availability mapping and epidemiological mapping. Since field sampling is a difficult and cumbersome task in remote areas, it is paramount that samples should be analysed for the full range of essential nutrients, and not just for zinc, because resampling cannot be done for studies of different elements.

With a view to relationships with crop yields and food security, information on crop performances should be recorded at the same time. Information on crop performance was, for example, recorded while soil sampling was done during the Transkei oesophageal cancer studies mentioned earlier. In the detailed cluster study in Butterworth district the average maize crops in the areas with high oesophageal cancer incidence were, for example, much poorer than the crops in the low incidence areas. Thus, a quite tight link between soil properties, performance of the main staple food crop and cancer incidence could be established in these subsistence farming communities.

In order to optimise the efficiency of geomedical surveys and maximize the effective use of the available resources, like funds, manpower, etc., it is essential that a study must be very systematic and well-structured. As an initial preliminary screening to identify potential “crisis” regions, countries or areas within countries, maximum use should be made of already available data, using “pedological logic” to get the most benefit out of these data. At a global scale the latter could be used to reconcile the apparent discrepancies and anomalies between statements in different parts of the text of Alloway (2004) and between the text and maps, as well as between different maps depicting areas with the biggest zinc deficiencies in soils and crops in the world in his book. At this scale the maps of Bridges *et al*. (1998) depicting the distribution of the major soil groups could be very useful to help to identify which statements in different parts of the text and which parts of which maps in Alloway (2004) are the most probably correct. From these pieces a more meaningful picture can then be built.

The author is convinced that a more meaningful picture and better prediction potential for the identification of crisis areas in regard to zinc deficiencies in developing countries would be obtained if the distribution of the infertile highly weathered Ferralsols and Acrisols (Bridges *et al*., 1998) are used together with Arenosols, Calcisols and Vertisols, instead of using salt-affected soils (Solonchacks and Solonetz) and Gleysols together with the latter three – as Alloway (2004) did. For example, Alloway (2004) pointed out that zinc deficiencies are widespread in the *“highly weathered soils”* on the internal plateau (Cerrado) of Brazil. The whole tropical area of Brazil, including the Cerrado is absolutely dominated by Ferralsols, together with Acrisols (Bridges *et al*., 1998). Despite the fact that Ferralsols and Acrisols are totally dominant here, Alloway (2004) in his Figure 2.5 indicates that the area is occupied by soils from the five major groups that he used. Alloway (2004) quoted reports that 95% of topsoil samples from the Cerrado had zinc levels below the critical level and that zinc deficiencies are found in a variety of crops there.

If the latter knowledge was combined with the correct dominant soil groups, it would immediately have highlighted that the central parts of Africa, which are also absolutely dominated by Ferralsols (and some Acrisols), should be considered a crisis area in regard to zinc deficiency and should be a high priority for in-depth investigations and intervention. In this regard it is important to note that the Ferralsol dominated area of central Africa is part of a broad band both sides of the equator from there through southeast Asia that has been identified as a very high risk zone for zinc deficiencies in human diets (IZiNCG, 2004). The southeast Asian countries that form part of this band are totally dominated by Acrisols, bringing sense to the latter finding. Somehow Alloway (2004) did not indicate these countries (like Indonesia and Vietnam) as problem areas in regard to zinc deficiencies in crops. The author did observe extremely severe zinc deficiencies in sugarcane in Sumatra – so somehow somewhere there are important communication gaps. It is noteworthy that the area in southeastern China which Alloway (2004) in his Figure 6.4 indicates as a major area with reported zinc deficiency problems in crops is also dominated by Acrisols.

Numerous more examples like the above could be extracted, but these should suffice to illustrate how correct identification of related factors could help to build a jigsaw puzzle that can be used in the planning of interventions. In regard to the latter it is a question on which basis the first four countries were selected for funding (by GAIN) of fortification of bread flour and maize meal, inter alia with zinc, were selected. Only one of the four (Vietnam) is mapped as having high risk of zinc deficiency in human nutrition (IZiNCG, 2004). The other three (South Africa, Morocco and China) are, on a country basis, “intermediate”. Rating of risk of zinc deficiency in the human diets was *“based on the prevalence of childhood growth stunting and absorbable zinc content of food supply”* (IZiNCG, 2004).

Studies in South Africa could serve as models for what can, and should, be done in a country when zinc deficiency is suspected. The problem with maize in the Highveld in the early 1960’s was identified by systematic sampling of soils throughout the Highveld according to a free grid pattern and their analysis (Grobler & Hugo, 1963). Thus it was established that the zinc contents of the soils were on the average lower than found elsewhere in the world. Areas with different zinc levels were mapped out. At the same time Stanton found that 94% of the topsoil samples that he collected in the Free State had plant-available zinc contents that were below the critical level, i.e. they were zinc deficient.

This then led to zinc enrichment of commercial NPK fertilizers, which solved the problem. In contrast only very few zinc deficient soils and maize plants were found in the Transkei during the oesophageal cancer surveys (Laker *et al*., 1983). Yet, only zinc-enriched fertilizers were sold in the area.

An area in South Africa that can probably immediately be classified as a ***zinc deficiency crisis area*** and needs very urgent attention, is the grey sands of Maputoland in northern KwaZulu-Natal, particularly those of the Mseleni area west of Lake Sibaya. In geomedical studies aimed at trying to identify possible relationships between mineral nutrient levels and the high incidence of "Mseleni joint disease" in the area, Pooley (1997) found that the plant-available zinc contents of the grey sands ranged from 0.1 to 1.8 $mg.kg^{-1}$, but had an average of only 0.4 $mg.kg^{-1}$. The critical level is considered to be 1.0 $mg.kg^{-1}$. This means that these soils are extremely deficient in zinc, as was also confirmed by Ceruti (1999). In addition it has earlier in this paper been indicated that the wild spinach, which forms an important part of the diet of the people of this area, is high in fibre and phytates (Fincham *et al*., 1986). As discussed earlier these will severely lower the absorbability of zinc in the diet of the people (Oliver, 1997). The soils also have various other nutrient deficiencies and zinc may perhaps not be related to Mseleni joint disease. There is, however, also an *"unusually high"* incidence of dwarfism in the area (Ceruti, 1999) and zinc deficiency has been identified as a definite factor leading to dwarfism in humans (Oliver, 1997). Thus, the diet of the people in the area is probably highly zinc deficient and this could perhaps be a very important human health risk factor, in addition to causing the high incidence of dwarfism. Furthermore, Ceruti (1999) found very poor maize plant growth in –Zn treatments on these soils. Poor crop production and consequently poor food security may thus also prevail if the zinc (and other) deficiencies are not eliminated. It is quite probable that similar problems may also be prevalent in the grey sand areas of southern Mozambique, across the border.

CONCLUSIONS

Since zinc deficiencies in human diets occur so widespread in the world, and especially in developing countries, and have such big impacts on human health and on staple food production, it is imperative that the highest risk areas should be identified as soon as possible and the necessary steps taken to eliminate the deficiencies. Fertilization of staple food crops with zinc-enriched commercial fertilizers may be the most appropriate way to supply zinc, since it can both overcome dietary zinc deficiencies and improve food security through promoting higher yields. Poor infrastructure in developing countries may paralyse such attempts and needs to be addressed as part of a total "package".

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The role of zinc in pastures for dairy cows

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Abstract

Major changes have occurred in the dairy industry in the past decade. Firstly, the profitability of pasture-based systems, relative to "total mixed ration" type systems, has come to the fore. This has resulted in a significant expansion of dairy farming in the higher-rainfall eastern and southern areas of the country, and more than 64 percent of total milk production is now pasture-based. Secondly, economy of size has become a major factor, with the number of cows on farms increasing markedly and scores of smaller producers closing down. Whereas in the past herds of more than 500 cows were the exception, currently many herds comprise 500 to 1000 cows.

In recent years, research has demonstrated the crucial importance of optimal Zn supplies for the health and sustained productivity of high-producing dairy cows. For this reason, Zn uptake by major dairy forage crops such as the ryegrasses, kikuyu and maize is of particular concern to dairy nutritionists.

In their virgin state, the majority of agricultural soils in South Africa are deficient in plant-available Zn supplies. Fast-growing fodder crops such as silage maize are particularly sensitive to Zn deficiency, and frequently display marked Zn-deficiency symptoms where soil supplies of this nutrient are limiting. Correction of deficiencies using Zn-containing fertilizers such as bulk blends may be ineffective because of the large size and poor solubility of the zinc oxide granules used. There is a need for the fertilizer industry in South Africa to follow the example of overseas countries by introducing Zn sources that are more plant-available.

Pasture species such as ryegrasses, kikuyu and white clover appear to be somewhat less sensitive to Zn deficiencies than the cereal crops. In a number of field trials on highly-weathered soils in KwaZulu-Natal, only annual ryegrass was found to respond to Zn applications. In field lime x Zn trials, soil test Zn values decreased significantly with increasing pH, while large P applications (as double superphosphate) had no effect on soil Zn tests, or on plant uptake of Zn. The AMBIC (ammonium bicarbonate / EDTA / ammonium fluoride at pH 8.0) extract has been found to provide a reliable indication of plant-available Zn supplies in the soil.

Zinc plays a number of important functions in the metabolism of dairy cows. Particularly noteworthy is its role in strengthening the immune system and in the regeneration of keratin, a fibrous protein which lines the teat canals and is a constituent of hooves. Researchers have found that optimizing the Zn supply to dairy cows serves to counteract udder infections and to reduce lameness, both of which are major problems in many dairy herds. Increasing fodder Zn concentrations through fertilization is an effective method of supplying Zn to cows. Significantly, organic forms of Zn have been found to be less antagonistic to Cu absorption in the gut than inorganic forms (such as zinc sulphate). Information extracted from the Cedara Plant Analysis Database reveals that median Zn concentrations in ryegrass, kikuyu and maize samples from farms in the eastern half of South Africa are two to three-fold higher than critical levels for plant growth; clearly, therefore, through repeated applications of Zn-containing fertilizers, the majority of dairy farmers are inadvertently exploiting the benefits of elevated fodder Zn levels.

Molybdenum Relationships in Soils and Plants

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Abstract

The essentiality of molybdenum (Mo) for the growth of higher plants was conclusively established by D. Arnon & P. Stout in 1939. At the time, they believed that field cases of Mo deficiency in plants were unlikely to ever occur, owing to the exceedingly low amounts of Mo required. By 1942, however, A. Anderson had identified Mo deficiency in clover production in several South Australian pastures, and had shown phenomenal increases in pasture production through the application of 5 g ha^{-1} Mo. Following on this, Mo deficiency has been found to limit crop and pasture production on millions of hectares of land throughout the world.

In South Africa, several cases of Mo deficiency were identified during the 1960's in maize and lucerne, and also in a variety of fruit and vegetable crops in the winter rainfall area of the Western Cape. The importance of Mo in maize production was further demonstrated during the 1970's and 80's, and Mo re-enforcement of seed has long been a standard practice in the South African maize industry. Prior to 1990, little emphasis was placed on the importance of Mo in soyabean production in South Africa. During the 1990's, however, yield responses of up to 170 per cent due to Mo seed treatment were recorded with soyabean on acid, heavy Hutton soils in KwaZulu-Natal, highlighting the crucial role of this element in ensuring maximum soyabean yields.

Of all the essential trace elements required for the growth of higher plants, Mo is required in the least amount, and leaf Mo contents of 0.1 – 0.5 mg kg^{-1} are typically considered adequate. Molybdenum is required for the functioning of several complex enzyme systems involved in nitrogen metabolism in plants. It is a vital constituent of nitrate reductase, which catalyses the reduction of nitrate (NO_3^-) to nitrite (NO_2^-) as the first step towards the incorporation of nitrogen into protein. In nodulated legumes, Mo is necessary for the reduction of atmospheric nitrogen (N_2) to ammonia by nitrogenase, and in certain legumes such as soyabean and cowpea, for the oxidation of purines by xanthine dehydrogenase. Symbiotic bacteria require about ten times more Mo for N_2 fixation than does the host plant (for protein synthesis). Hence, Mo deficiency commonly occurs in legumes before it does in other plants, when grown in the same soil.

Information on the Mo status of soils in South Africa is noticeably lacking. Data from a soil survey, covering 200 virgin soil profiles in north eastern South Africa, indicated that Griggs ammonium oxalate (pH 3.3) extractable Mo contents varied from 0.003 to 1.5 mg kg^{-1}. Extractable Mo, on average, showed a significant increase with increasing soil depth, but this was not constant across all soil types. Avalon, Griffin and Westleigh soil types showed greater increases in Mo with increasing depth, than did Hutton and Clovelly soil types. Several soil types, including Valsrivier, Rensburg and Arcadia, showed a decrease. Differences in soil parent material and degree of weathering are known to impact on soil Mo status, and soils derived from sandstone, quartzite and granite were found to contain the least amount of extractable Mo (0.07 mg kg^{-1}), while those formed from shale contained between 0.1and 0.14 mg kg^{-1}. Dolerite and diabase derived soils contained approximately 0.1 mg kg^{-1} and were somewhat lower than those formed from basalt, andesite and iron-rich shale and gabbro (0.17 - 0.19 mg kg^{-1}). Soils particularly rich in Mo were those derived from dolomite and chert rich dolomite (0.5 mg kg^{-1}). The amount of oxalate extractable Mo was found to be significantly positively correlated with exchangeable K, AMBIC P, pH, oxalate extractable Fe, and especially with oxalate extractable Mn, and negatively correlated with exchangeable acidity.

The adequacy of Mo for plant growth is determined by a number of soil and plant factors. Soil factors that impact on Mo uptake include the following: level of extractable Mo, clay content and mineralogy, organic matter, redox potential, availability of other nutrients and pH. Poorly drained soils rich in organic matter are very often found to produce crops and pastures with excessively high contents of Mo, while acid soils containing appreciable amounts of non-crystalline oxides and hydroxides of Fe and Al frequently retain Mo in a non-plant available state. It is widely recognised that liming, by raising pH, increases Mo availability to plants, and it has been suggested that pH elevation is the best way of ensuring adequate Mo nutrition. However, there is evidence to indicate that numerous soils are inherently so low in Mo, that availability is inadequate for optimal growth, even at near neutral pH values. In addition, studies with maize, soyabeans and dry beans on acid, heavy textured soils in KwaZulu-Natal indicate that uneconomically high quantities of lime may be required to ensure against Mo deficiency. Other soil nutritional factors reported to influence Mo uptake are P and S. In spite of several reports indicating that S depresses Mo uptake due to anionic competition between SO_4^{2-} and MoO_4^{2-}, (the forms in which these two nutrients are absorbed by roots), gypsum applications of up to 5 Mg ha^{-1} on kaolinitic clay soils in KwaZulu-Natal were not found to significantly depress Mo accumulation by soyabean. Phosphorus, on the other hand, has been reported to enhance Mo uptake. In the case of soyabean grown on highly Mo responsive soils, this effect is sometimes masked. The dramatic increase in the number and size of nodules with improved P nutrition leads to an accumulation of Mo in the nodules, at the expense of leaves and seed (the plant parts most commonly assayed for Mo uptake effects). In the presence of Mo deficiency, the functionality of the nodules is greatly reduced, and soyabean response to P is adversely affected. Significant negative residual soil N x Mo interactions on yield have also been noted with soyabean, at some locations in KwaZulu-Natal. This suggests that, under conditions of lowered nitrogenase activity (N_2 -fixation), residual soil N may substitute for reduced fixation, provided that NO_3^- loading of the plant is not excessive (adequate nitrate reductase activity). The extent to which crops respond to supplementary Mo may also be influenced by several plant related factors, including species, genotype, and Mo reserves in the seed. Crop Mo requirement typically decreases in the order; legumes > cruciferous crops and cucurbits > grasses. Seed with adequate Mo reserves typically provides sufficient Mo for optimum growth of the plant. However, unless the mother crop is sprayed with Mo, the resultant seed produced usually shows a dramatically lowered Mo content. While many plants can accumulate Mo in concentrations far in excess of their requirement without resulting in phytotoxicity, the indiscriminate use of supplementary Mo can have serious consequences for livestock. The consumption of feed matter containing greater than approximately 5 mg kg^{-1} by ruminants may result in Mo toxicity (molybdenosis), especially if dietary copper intake is low.

Owing to the numerous interactive effects involving Mo, the identification of soils on which supplementary Mo is likely to be beneficial is complex. Although the acid ammonium oxalate method of Grigg has been the most extensively used procedure for estimating plant available Mo in soils, it is insensitive to the positive effect that pH elevation has on plant available Mo, and also to Mo buffering effects in soils. In summary, the commonly held viewpoint which is supported by local findings is that, until the interaction of Mo with other soil properties and nutrients is better understood and characterised, the prognostic value of Mo soil tests alone is likely to remain uncertain. The best approach for identifying Mo-deficient soils at this stage appears to be through simultaneous consideration of soil test values, pH and mineralogy, especially the amount of sesquioxides.

Micronutrient and heavy metal excess and toxicity in Southern African soils

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Abstract

Examples of naturally occurring, high or toxic levels of micronutrients and the heavy metals Ni and Cr are discussed. Al, Fe and Mn are excluded, as toxicity is generally associated with wet or acidic soils that can be rectified by drainage or liming. Anthropogenic causes such as (inadvertent) over-application of micronutrients and pollution are also considered.

Naturally occurring copper toxicity occurs near copper ore outcrops in areas where copper is mined. Plant and soil levels associated with one such anomaly are given for maize and the mechanism of toxicity appears to be suppression of manganese uptake. Copper applied for wheat on granite sands generally low in copper, easily reaches toxic levels when applied at too high a rate or where the soil is in fact not deficient in the first place. In these cases leaves may have the appearance of iron deficiency induced by high copper.

Boron toxicity occurs where B weathered from parent materials of marine origin accumulates in dry climates. The leaf edge yellowing/browning symptoms are well known even though boron toxicity is not common in cropping areas of Southern Africa. Deficiency is more widespread and is often associated with sandy or calcareous soils; here inadvertent over-application of boron to soil will give classic symptoms of toxicity. Over-application via leaf sprays can just as easily occur and an example for sweet corn is described, where quite different symptoms of leaf and stem distortion and twisting, more associated with interference of calcium uptake, occurred.

High zinc occurs near zinc mining operations and toxic levels have been recorded which may be toxic to grazing animals. Levels in agricultural soils, even when high, are generally considered not to be high enough to be toxic. The interference of zinc with the uptake and utilisation of other nutrients such as copper and iron is considered.

That nickel is a universal essential plant nutrient element has yet to be demonstrated, but amongst other things there is evidence that it is an essential component of urease, thus affecting nitrogen transformation reactions in certain legumes and micro organisms. Ni along with Fe, Mn, Cr and sometimes Co is concentrated in ultramafic rocks and its toxicity is well known in soils derived from such parent materials. Ni in soil is associated with oxides of Fe and Mn and with organic matter in surface horizons and is easily assimilable by plants and thus easily extractable. Ni causes stunting and an interveinal chlorosis similar to iron deficiency in most crops. In fact, the cause of nickel chlorosis in maize is demonstrated to be low ferrous iron (Fe^{2+}) concentration but masked by normal or high total iron in the leaves.

Chromium is essential in animal and human nutrition but so far has been shown to only "enhance" growth of certain plants in soils very low in Cr. Small amounts of Cr either as soluble Cr^{3+} or Cr^{6+} are extremely toxic to plants especially roots. Total Cr is often high in ultramafic rocks but as Cr^{3+} in the refractory mineral chromite is very insoluble, toxicity is rare and difficult to demonstrate. Chromium toxicity in field ultramafic soil and in hydroponic culture is demonstrated to harm flowering (tasseling) of maize. It is further shown that an ultramafic soil high in total Cr became very toxic to maize after years in storage. The soil was high in easily reducible manganese oxides that were capable of oxidizing bound Cr^{3+} to soluble, toxic Cr^{6+}.

INTRODUCTION

The balance between sufficiency and excess is fine for some essential trace elements. This is well known for boron but is not so appreciated for other traces like copper. Examples ranging from Cu deficiency, to excess, to toxicity are described. Zinc toxicity is virtually unknown in field situations except in polluted soils and near Zn anomalies associated with mining. It is apparent that zinc excess (above sufficiency) is common in many soils; the implications of this are discussed as well as Zn toxicity in glasshouse and hydroponic production. Nickel (essential in some plant biochemical pathways) and chromium, both essential in human nutrition, are present in toxic amounts in ultramafic soils, which cover a significant area in Southern Africa. Mechanisms of toxicity are discussed, as these are important in knowing how to treat affected soils and crops.

COPPER EXCESS AND TOXICITY

Cereals especially wheat are sensitive to copper deficiency which is manifested by drooping, purplish ears devoid of grain. Deficiency is mostly associated with sandier soils low in organic matter in Southern Africa. For instance, granite sands in Zimbabwe have had to have copper application where irrigated wheat is grown in rotation with maize and tobacco. High zinc and P applications for these preceding crops were at first thought to aggravate copper deficiency. Pot trials showed that this was not the case (**Figure 1**); the photograph shows grain response to Cu despite Zn and P additions in some treatments [1].

Figure 1. Wheat response to Cu in a Cu deficient soil. Despite Zn & P additions in factorial design, no interference with Cu occurred (I only of 6 reps. shown for clarity).

Low soil copper was the problem at responsive field trial sites (**Figure 2**); the chart shows however, that yield was repressed at double the recommended rate of soil Cu application. At another site soil copper was adequate and yield was repressed by copper application to soil and in most cases to leaves (**Figure 3**) [2]. It was also observed in the field, that soil applied copper sulphate inadvertently applied at twice the intended rate (20 kg $CuSO_4$/ha instead of 10 kg $CuSO_4$/ha), induced what appeared to be Fe-chlorosis in a strip where an overlap during application occurred.

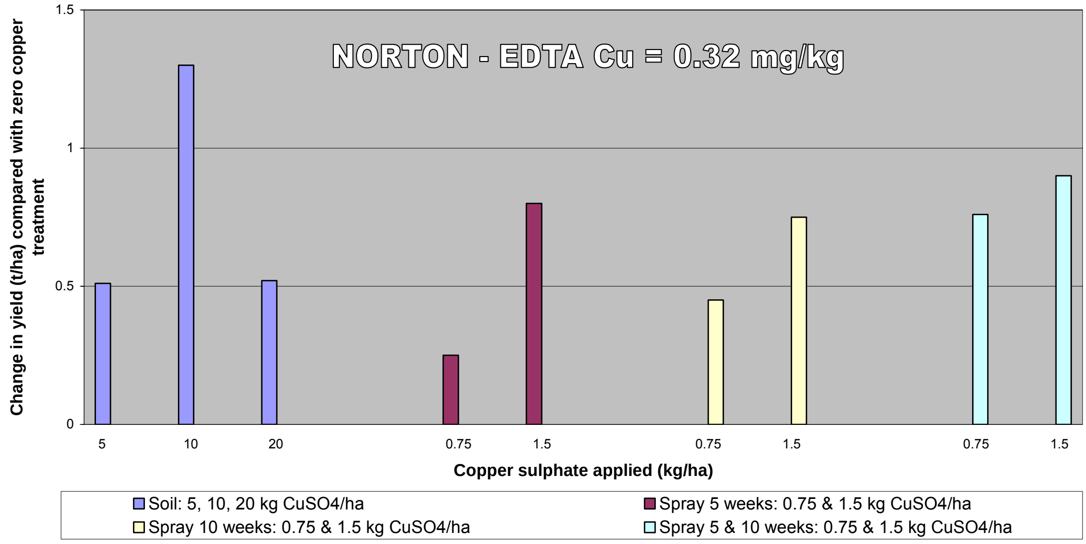

Figure 2. Effect of rate and method of copper sulphate application on wheat yield: Norton site.

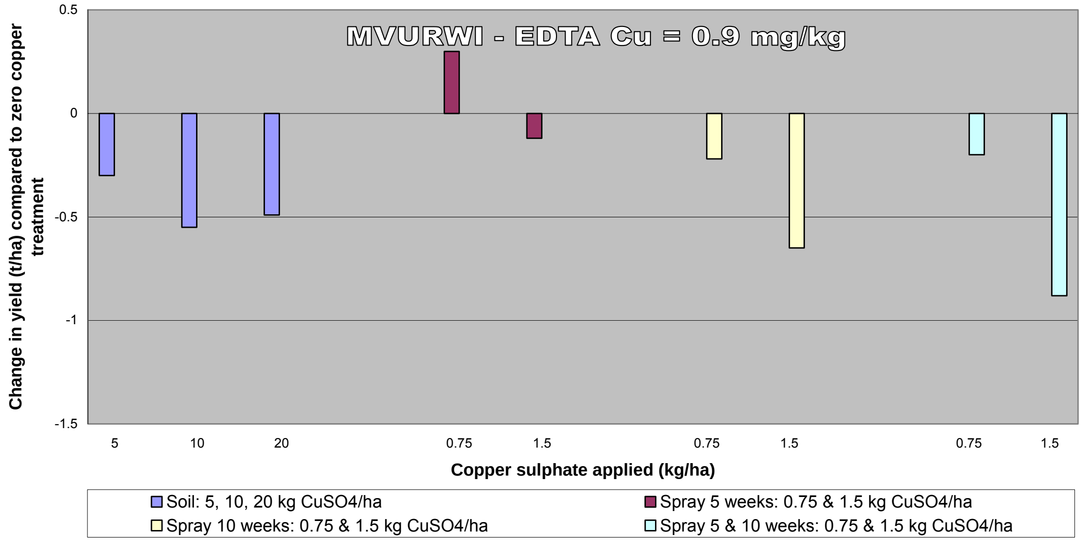

Figure 3. Effect of rate and method of copper sulphate application on wheat yield: Mvurwi site

Other examples of anthropogenic copper excess and toxicity are shown in **Table 1**. When soil EDTA-Cu is 10-20+ mg/kg from applied sources, antagonism with other elements or toxicity occurs. On unbuffered soils, proteas, fynbos and wheat are sensitive to soil EDTA-Cu levels around 10 mg/kg or perhaps less. Legume pastures and earthworms appear to be tolerant of slightly higher levels around 20 mg/kg. Much higher levels present in orchards and vineyards eventually affect surface roots and growth adversely. Similarly, poor growth on older bowling greens is associated with EDTA-Cu levels often above 100 mg/kg.

Table 1. Crops and organisms affected by high levels of applied copper

CROP	PREVIOUS HISTORY	SYMPTOM	COPPER STATUS	SOLUTION
Proteas, Leucodendron Fynbos [3]	Old Apple Orchard; years of copper sprays (Bordeaux mixture). SaL	Leaves yellowing, browning, poor development	10 mg/kg EDTA-Cu in top soil	Deep ploughing of profile to be tried.
Medics and clover pasture [3]	30 year old apple orchard; years of copper sprays (Bordeaux) Sandy soil	Yellowing; poor establishment	Depth EDTA Cu (cm) (mg/kg) 0-10 cm 20 10-20 cm 5-6 20-30 cm < 0.5	Deep ploughing to 1 metre rectified.
Wheat [1]	Wheat/maize rotation; possibly high zinc in soil. SaL	Purpling of heads ; poor grain set Chlorosis similar to Fe-deficiency	Low soil Cu; 10 kg $CuSO_4$/ha ↓ (Spray overlap) 20 kg $CuSO_4$/ha applied to soil	Cu deficiency rectified. ↓(overlap) Temporary (?) Cu/Fe antagonism
Citrus France Florida RSA [4]	Many years of Bordeaux sprays Areas of lighter soils → low pH from N fertilizer.	Reduction in tree vigour, chlorosis, die back of twigs. Fe chlorosis	50-100+ mg/kg EDTA-Cu	150-250 g EDTA-Fe chelate/tree + lime. Deeper roots get iron and surface roots gradually grow back.
Bowling greens Cynodon [5]	Many years of copper sprays e.g. copper oxy-chloride. On old greens. Sandy.	Reduction in vigour, pale growth (chlorosis) when soil Cu is very high.	EDTA-Cu > 10 mg/kg for 55% of greens (n=66); 30% were in range 55-355 mg Cu/kg	Cease applying Cu (and Zn) fungicide sprays; keep pH neutral.
Earthworms [6]	Cu sprayed on field plots as for vineyards & soil Cu & earthworms measured.	Reduction in earth-worm biomass of ±70% and earth-worm numbers of ± 56% .	Soil Cu increased by ± 385 % to 22 mg/kg and earth-worm body Cu by ± 163%.	Illustrates harm done to earthworms after 1 year of spraying Cu

Naturally occurring copper toxicity occurs near copper ore outcrops in areas where copper is mined. Plant and soil levels associated with two such anomalies are given for maize and the mechanism of toxicity appears to be suppression of manganese uptake without significant accumulation of copper in leaves (**Figs. 4 & 5** and **Table 2**). Soil EDTA-Cu levels above 300 mg/kg caused severe chlorosis and reduction in leaf and node size (compared to Fe or Mn deficiency) and suppressed leaf Mn below the sufficiency level of 20 mg Mn/kg [5].

Figure 4. Copper toxicity symptoms on maize growing in high copper soil in Cu mining area.

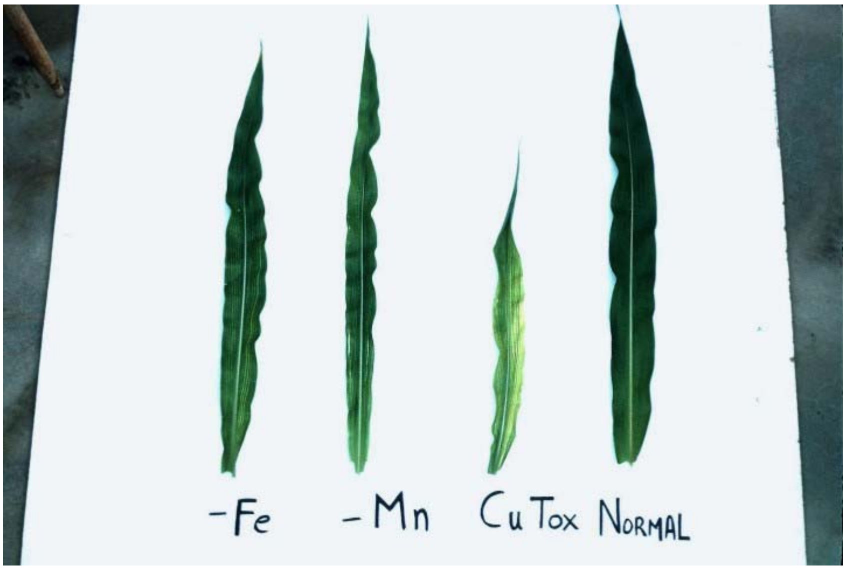

Figure 5. Cu toxicity in maize compared to iron and manganese deficient and normal leaves.

Table 2. Soil and leaf analyses for maize grown at two sites naturally high in soil copper, showing low leaf Mn in chlorotic leaves [5].

Alaska Soil: Maize; Chlorotic patch sampled (copper anomaly); 400 kg/ha compound 'Z' plus 300 kg/ha AN top dressed													
	Texture	pH	Total N	Resin P	K	Ca	Mg	S	Fe	**Mn**	**Cu**	Zn	B
		(0.1MCaCl2)	(%)	(mg/kg)	Exchangeable (cmol(+)/kg)			(mg/kg)	EDTA (mg/kg)				
Soil	mgSaL	5.6	0.086	42	0.22	2.9	1.33	-	-	-	**300**	-	-
			N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Fe (mg/kg)	**Mn** (mg/kg)	**Cu** (mg/kg)	Zn (mg/kg)	B (mg/kg)
Maize Leaves	Normal leaves		1.77	0.19	1.9	0.6	0.33	0.22	103	**36**	**31**	31	11
	Chlorotic leaves		2.07	0.27	1.7	0.5	0.55	0.28	165	**19**	**26**	25	11
Angwa Soil: Maize; Chlorotic patches over 2-3 ha; 400 kg/ha compound 'Z' banded plus 300 kg/ha AN top dressed													
Soils	Texture	pH	Total N	Resin P	K	Ca	Mg	S	Fe	**Mn**	**Cu**	Zn	B
Poor		(0.1MCaCl2)	(%)	(mg/kg)	Exchangeable (cmol(+)/kg)			(mg/kg)	EDTA (mg/kg)				
0-10 cm	mgLS	5.4	0.102	240	0.4	7.6	1.4	-	-	-	**530**	-	-
20-30 cm	mgLS	5.5	0.084	252	0.33	7.6	1.3	-	-	-	**-**	-	-
Good													
0-10 cm	mgLS	5.1	0.120	408	0.36	8.3	1.3	-	-	-	**260**	-	-
20-30 cm	mgSaL	5.2	0.010	348	0.31	8.9	1.2	-	-	-	-	-	-
			N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Fe (mg/kg)	**Mn** (mg/kg)	**Cu** (mg/kg)	Zn (mg/kg)	B (mg/kg)
Maize Leaves	Good		2.15	0.64	2.3	0.4	0.18	0.14	60	**24**	**18**	22	7
	Chlorotic upper		2.23	0.45	2.26	0.44	0.16	0.16	48	**14**	**20**	33	11
	Chlorotic cob		2.23	0.52	2.39	0.49	0.22	0.21	48	**14**	**19**	24	9
	Normal ranges		2.7-3.5	0.25-0.45	1.7-2.5	0.2-0.5	0.15-0.4	0.2-0.5	30-200	20-150	6-20	20-70	6-25

BORON EXCESS AND TOXICITY

Boron toxicity occurs where B weathered from parent materials of marine origin e.g. argillaceous shale, accumulates in dry climates. The leaf edge yellowing/browning symptoms are well known even though boron toxicity is not common in cropping areas of Southern Africa. Deficiency is more widespread and is often associated with sandy or calcareous soils. Inadvertent over-application of boron to soil will give classic symptoms of toxicity. Over-application via leaf sprays can just as easily occur. **Figures 6-9** show distortion of sweet corn resulting from 3-4 leaf sprays of boron at approximately 4 times the recommended rate of application (1 kg Solubor/ha), applied up to 6 weeks after emergence.

Figure 6. "Gooseneck" symptom

Figure 7. Severe stunting

Figure 8. Severe distortion

Figure 9. Distortion and "crinkled" leaves

Figures 6, 7, 8 and 9. Distortions of sweet corn plants after 3-4 sprays of "Solubor" at approximately 4 times recommended rates. Plants ± 9 weeks old.

Table 3 shows a toxic boron level (> 100 mg/kg) in "growing point tissue" (maize ± 6 weeks old) and very high B in leaves (maize ± 9 weeks old). High B absorbed by leaves was accompanied by lower Ca but higher K in “growing point tissue” and “crinkled” leaves. The mutual antagonism between Ca and B is well known; high Ca suppressing B uptake and vice versa. Potassium uptake is apparently enhanced because of reduced Ca uptake.

These phenomena are usually related to soil-root uptake mechanisms, but in this case excess B also appeared to antagonise Ca in the leaf tissue, preventing or hindering Ca from performing its normal role in cell and cell wall development (e.g. in “crinkled leaves”). As growth continued (“upper” and “lower” leaves), boron concentration was diluted along with its inhibitory effect on Ca utilisation and Ca concentrations increased and leaf development normalised. Other metabolic activities may well have been upset by high B, and had Ca been sprayed with the boron, less distortion may have occurred.

Table 3. Analysis of sweet corn leaves over-dosed with boron (planting date 7/10/04)

Date sampled	Leaf description	P %	K %	Ca%	Mg%	Fe mg/kg	Cu mg/kg	Zn mg/kg	Mn mg/kg	B mg/kg
19/11/04	Growing point tissue	0.63	3.91	**0.25**	0.13	166	8	48	61	**371**
9/12/04	Upper	0.44	2.59	0.48	0.13	156	10	60	84	**88**
9/12/04	Lower	0.49	2.45	0.59	0.15	185	10	69	120	**81**
9/12/04	Crinkled	0.48	3.52	**0.19**	0.11	136	8	74	43	**56**
	Normal leaves 7-8 weeks	0.4 - 0.7	2.5 - 3.5	0.5 - 0.9	0.2 - 0.6	60 - 200	6-20	20-70	30 - 300	**8-25 > 100 toxic**

ZINC EXCESS AND TOXICITY

Excess soluble zinc (500-1500 mg/kg in soil) is taken up almost linearly by wheat, grasses and potato plants (100-200 mg/kg in tissues) without apparent harm. Thus zinc although quite mobile within plants, is not considered to be highly phytotoxic. Despite tolerance of most plants to high levels of zinc, there is concern because of prolonged use of Zn fertilizers and in areas of industrial pollution [7]. Soil Zn levels in South African cultivated lands are not considered excessive; a survey of metals in soils in the Loskop dam catchment area showed levels in cultivated maize soils (0.2-9.2 mg EDTA-Zn/kg and mean = 2.88) did not differ significantly from virgin soils (0.2-11.3 mg EDTA-Zn/kg and mean = 1.88) [8].

Chicken manure and composted sewage sludge are generally high in Zn and therefore of concern, not only as potential sources of toxicity to plants, but also to humans where these materials are used for vegetable production. An overseas study showed potential dietary toxicity Zn levels in soil (when the threshold of 20 mg/kg in edible plant material was exceeded), varied from 19-176 mg DTPA-Zn/kg for different parts of 3 vegetables. Shoot dry matter yield reduction thresholds in soil (threshold of 10% yield reduction) were from 56-103 mg DTPA-Zn/kg. In one case yield reduction threshold was not reached when the potential dietary toxicity threshold was exceeded [9]. The lower levels of these thresholds are exceeded not infrequently in South African vegetable producing soils.

NICKEL EXCESS AND TOXICITY

That nickel is a universal essential plant nutrient element has yet to be demonstrated, but amongst other things there is evidence that it is an essential component of urease, thus affecting nitrogen transformation reactions in certain legumes and micro-organisms [7]. Ni along with Fe, Mn, Cr and sometimes Co is concentrated in ultramafic or serpentine rocks and its toxicity is well known in soils derived from such parent materials. Ni in soil is associated with oxides of Fe and Mn and with organic matter in surface horizons and is easily assimilable by plants and thus easily extractable.

Serpentine rocks and soils associated with the Bushveld Igneous Complex in North West Province and Mpumalanga have significant amounts of extractable Ni and Cr; ammonium acetate extractable amounts were found to vary from 17-65 mg Ni/kg (n= 6) [10]. The Great Dyke in Zimbabwe has significant areas of potentially arable soil but for high Mg, Ni and Cr. The red (kaolinitic) soils of the Dyke are high in NH_4 acetate exchangeable Ni particularly in surface horizons (3-101 mg Ni/ha, n=108). Black vertisols (smectitic) are devoid of Ni. Red alluvial soils along the banks of streams are highest in Ni, indicative of transport and accumulation with clay (and perhaps organic matter) [11].

The symptoms of Ni toxicity in maize are an interveinal chlorosis (see insert in **Table 4**) and stunting with inhibited root growth at higher levels. Severe chlorosis was associated with high soil exchangeable and leaf Ni (means of 58 and 47 mg Ni/kg respectively) and 17% vegetative yield reduction (p=0.05, n=22). Thresholds in soil and leaf for 90% of maximum yield were respectively 27 and 17 mg Ni/kg in soils with low Ca:Mg ratio (Ca deficiency), and 40 and 30 mg Ni/kg in soils with high Ca:Mg ratio (Ca sufficiency) [11].

For a high Ni soil (90 mg/kg exchangeable Ni) amendments were applied; sewage sludge gave the best response compared to lime, gypsum and Fe-spray (responses were 38, 11, 9 and 21 percent respectively (p=0,05). Lime reduced uptake and toxicity of Ni as did Fe-spray which also synergised Zn uptake. Sludge supplied Fe, Zn and other nutrients and reduced Ni uptake, presumably by chelation and bulk soil dilution [11,12].

Table 4. Iron status of normal, Fe deficient and Ni-chlorotic maize leaves (means of 3 replicates; sand culture)

	Total Fe (mg/kg)	Fe (II) (mg/kg)	Ni (mg/kg)
Green Leaves	204	79	2
Fe-chlorotic	154	61	4
Ni-chlorotic	149	39	70
S.E.	5.9	2.5	2.8
L.S.D. (p=0.05)	16.2	7.8	8.1

Because Ni toxicity resembles Fe deficiency and a response to Fe sprays was obtained, leaves of Ni-chlorotic, Fe-deficient and normal plants were analysed in order to elucidate the mechanism of Ni toxicity (Table 4). Physiologically active iron or Fe (II) as well as total Fe was measured [13].

Total Fe content of Ni-chlorotic leaves remained high which indicates little or no interference by Ni with Fe chelation during translocation of Fe in the root or during uptake via xylem to the leaves. However, Fe (II) content of Ni-chlorotic leaves was reduced, and biochemical reactions involving Fe (II) are apparently inhibited by Ni in leaves; up to six biosynthetic pathways during chlorophyll production may be affected [11,12].

CHROMIUM EXCESS AND TOXICITY

Chromium is essential in animal and human nutrition but so far has been shown to only “enhance” growth of certain plants in soils very low in Cr [7]. Small amounts of Cr either as soluble Cr (III) or Cr (VI) are extremely toxic to plants especially roots as shown by sand culture experiments. Total Cr is often high in ultramafic rocks but as Cr (III) in the refractory mineral chromite is very insoluble, toxicity is rare and difficult to demonstrate; total Cr in Great Dyke soils varies from 15-5400 mg Cr/kg [11].

Chromium distorts roots in a similar way to aluminium and only small amounts are translocated to leaves of maize making confirmation of toxicity difficult by leaf analysis. However, in field ultramafic soil and in high Cr treatments in sand culture, abnormal flowering (tasseling) of maize (**Figure 10**) was seen, confirming this as a symptom of chromium toxicity [11].

Figure 10. Abnormal tasseling in maize due to Cr toxicity; sand culture

Figure 11. Extreme stunting due to Cr toxicity in Soil 39 and no response to lime, gypsum or superphosphate treatment

Several ultramafic soil samples high in total Cr developed extreme toxicity after years in storage; maize was extremely stunted with choloritic and purplish leaves (Figure 11 shows one of the soils; soil 39). Cr (VI) was identified in extracts of these soils which also contained Fe-Mn concretions and high readily reducible Mn i.e. higher oxides, which are theoretically capable of oxidizing Cr (III) to Cr (VI) in solution (Table 5) [11,14].

Table 5. Soil analysis data for three toxic ultramafic subsoils (after growth of maize)

Soil Reference and sampling depth	Tex-ture	pH	Exchangeable				Total Cr mg/kg	Reducible Mn mg/kg	Dry matter maize yield g
			$cmol(+)kg^{-1}$		mg/kg				
			Ca	Mg	Ni	Cr			
39-0 (30-50 cm)	SaCL	5.5	5.5	11.6	26	23.4	305	780	0.9
33-0 (30-50 cm)	SaCL	5.3	5.0	15.0	42	10.7	1013	530	2.6
84-0 (30-50 cm)	SaCL	5.4	1.0	5.6	28	3.0	8600	102	5.7
Mean for population (n=96)		5.5	4.1	11.2	37.8	0.57	970	312	20.5
S.E.		0.03	0.04	0.2	0.9	0.17	11	214	0.5

Texture key: SaCL = Sandy clay loam.

To elucidate the mechanism of Cr toxicity, Mn compounds were added to other high Cr soils from storage. Potassium permanganate ($KMnO_4$) induced identical Cr toxicity in a few well aerated sub soils but not in top soils. Manganese dioxde (MnO_2) addition did not induce toxicity. These subsoils were somehow predisposed to oxidation, which suggests an intermediate form of Cr (III) capable of oxidation, weathered from chromite. Table 5 shows results of 5 soils treated with $KMnO_4$ which oxidized Cr (III) to Cr (VI) in some of them, inducing toxicity (yield reduction and leaf purpling) in maize [11].

Table 6. Soil and maize analytical data for high total Cr containing soils treated with $KMnO_4$

Soil Reference and sampling depth	Texture	Total Cr mg/kg	Extractable Cr mg/kg	Dry matter maize yield g	Purpling of leaves
22 (0-15 cm)	SaL	600	0,48 (0,12)	20,6 (13,8)	no
80 (40-60 cm)	Sa	887	0,80 (0,04)	24,4 (19,9)	no
44 (30-40 cm)	SaCL	450	7,92 (0,36)	7,9 (17,0)	yes
65 (30-50 cm)	SaCL	925	5,36 (0,04)	12,4 (21,3)	yes
90 (20-40 cm)	SaCL	3500	4,68 (0,44)	12,0 (15,8)	yes

Values for extractable Cr and yield in parenthesis are for control soils i.e. not receiving $KMnO_4$.

A two stage mechanism was proposed: Firstly a slow hydrolysis of Cr (III) in chromite to $Cr(OH)_3$ which becomes adsorbed on the surfaces of Mn oxides. Secondly, oxidation of adsorbed Cr (III) by the reduction of higher Mn oxides to Cr (VI) [11,14].

The first stage may occur in any soil containing high total Cr when moist and slightly acid, neutral or alkaline conditions prevail. The second stage requires in addition, the presence of lower Mn oxides such as hausmannite (Mn_3O_4) and manganite (MnOOH), most likely to exist under mildly oxidising conditions such as may occur in the concretionary subsoils. Well aerated subsoils and topsoils containing high total Cr that are not toxic, are likely to contain only forms of MnO_2 such as birnessite that are theoretically less capable of oxidizing Cr (III).

For anthropogenic sources of Cr (III) such as slag from steel works or tannery wastes, a similar oxidation process to Cr (VI) is likely in poorly drained soils where water table fluctuations occur. Such oxidised Cr could become hazardous locally and in drainage water.

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Thee use of micronutrients in sub-tropical food production

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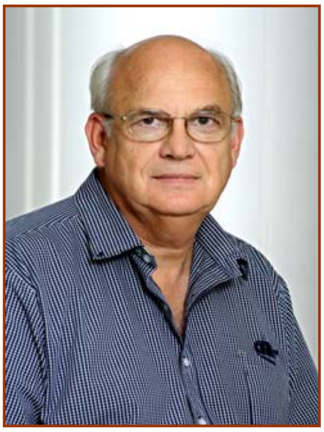


Abstract

Micronutrients contribute towards the production of quality subtropical fruits. To prevent over supply and maintain optimal levels of the six micronutrients within the trees, existing diagnostic methods like leaf analysis, need to be applied annually.

Soil applications, fertigation and foliar sprays can be utilised to increase or maintain the micronutrient status of trees. However, the absorption of micronutrients by subtropical crops is restricted by many factors like inherent plant properties, soil and climatic conditions.

To supply micronutrients effectively, one needs to evaluate the reasons and conditions causing the deficiency or short supply before the most suitable method of application and formulation of the nutrient are selected.

All the different methods to apply the micronutrients have limitations. Ensure that the basic requirements of the selected method are being satisfied during the actual application.

When selecting the formulation, use benchmarking to ensure that the product has a potential to supply the specific nutrient to the plant.

INTRODUCTION

Like all other plants, subtropical crops also require the optimal supply of B, Cu, Fe, Mn, Mo and Zn to produce good quality crops, economically. Being micronutrients, it is often difficult to show the positive effect of maintenance applications in commercial orchards. However, when correcting a severe deficiency of one or more of these elements, it is quite obvious to what extend yield and quality can be affected (**Table 1**).

Table 1. The effect of Zn applications on the production of coffee

Treatment	Production in kg/ha	Kg beans/kg Zn applied
Control	1 297	0
Soil application 150 kg Zn/ha	2 126	16.30
Foliar sprays 45 kg Zn/ha	1 655	37.30

(After Malavolta, 1986)

Although a costly exercise (± R25-00 per tree), the decision to correct or not, a severe iron deficiency in citrus, is the difference between no crop or a fair to good crop (**Table 2**).

Table 2. The response (kg fruit per tree) of Palmer navels in Kirkwood on treatments with Fe-EDDHA

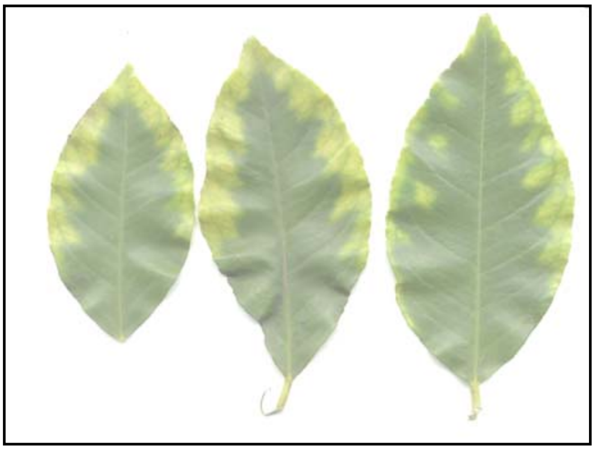
Treatment	Yield	Income/cost (2003)
Control 1 (72% of canopy is chlorotic)	34	-
Control 2 (50% of canopy is chlorotic)	42	-
300g Fe-EDDHA per tree to Control 1	89	11
300g Fe-EDDHA per tree to Control 2	171	26
EDDHA = Ethylene-di-imino bis-2-hydroxy phenyl		

It was estimated that treating citrus in California to avoid any micronutrient deficiencies, added some US$ 91 million to their income during 1954/55. Currently producers of subtropical crops apply micronutrients but they need to know more about which, when and how to supply the micronutrients.

The six micronutrients consist of four cations and two anions, which react differently to leaf, soil and environmental conditions. To complicate matters even more, the availability of these microelements varies from deficient to excess depending on the location in Southern Africa.
It is therefore important to diagnose the micronutrient status of subtropical crops before it will reduce the yield and/or quality.

Although required at low concentrations, these micronutrient elements can also be very toxic to plants if present in too high concentration. Over application is a real thread in practise.

Photo 1. Symptom of an excess of manganese in Eureka lemons due to frequent applications of Mancozeb.



Therefore subtropical fruit industry needs to apply reliable methods to diagnose and correct or maintain the micronutrient status of the orchards.

DIAGNOSTIC METHODS

The three most applied diagnostic methods in the production of subtropical crops are experience, observations and leaf analyses.

EXPERIENCE

Some crops are bound to run into a zinc deficiency during the production season even though the leaf analyses showed an adequate level. This is due to inherent properties of these crops. Pecan nut trees need four to six and citrus and avocado trees at least one foliar spray with zinc to maintain an adequate zinc status. Macadamia trees need boron sprayed on the blossom to improve fruit set notwithstanding the boron status being normal.

Based on experience, zinc and boron will almost always form part of the foliar spray program for these crops.

OBSERVATIONS

This, perhaps the oldest method to diagnose micronutrient deficiencies, is reactive and has little value in today's demanding production process. However, this is one of a few reliable methods to diagnose an iron deficiency.

This method is also frequently misused to sell micronutrient concoctions.

LEAF ANALYSES

Although sophisticated instrumentation is applied in the analytical process, the success of this method to diagnose the micronutrient status of crops depends on the sampling process and interpretation of the results generated. The most limiting factors when using this method are the sample it self, contamination and bioactivity of the nutrients.

Sample

The optimum range of concentrations for each micronutrient element for each crop is based on leaves of a specific age, taken at a specific physiological stage of the tree and from a specific position on the plant. This is called the diagnostic leaf. Any deviation from the diagnostic leaf will compromise the interpretation of the analytical results.

Contamination

Contamination by any foliar spray containing one or more of the micronutrients is a real problem in the analytical and interpretation processes. Apart from nutritional sprays with any of the six micronutrients, fungicides and other pesticides contribute to the eventual concentration of the micronutrient elements in the leaf material. Washing the leaves prior to analysis usually dilutes the effect but seldom removes all contaminants. Mancozeb, a fungicide contains organic formulations of manganese and zinc, which distort the results of manganese but seldom that of zinc.

Bioactivity

The total amount of iron in a leaf is not always active in the physiological processes. When a leaf analysis result indicates an iron concentration in excess of the minimum value of the optimal range (about 30mg Fe/kg), the result is useless to diagnose the iron status of the tree. Conditions within the plant can precipitate iron in a bio-inactive form.

The slow rate of transport of copper and boron to sites of high bioactivity can result in a temporary deficiency lasting a few hours or days. Symptoms of a copper deficiency manifested in the basal leaves of citrus when the growth rate of a twig is high (**Table 3**).

Table 3. The effect of a low rate of Cu supply on the development of leaves on a new twig of navel orange trees.

Leaf number	Leaf mass g/leaf	Copper content in mg/kg of different age leaves		
		30 days	60 days	7 months
1 Basal	10.26[1]	2	6	11
2	11.53[1]	2	6	12
3	4.12	5	7	14
4	2.55	6	7	15
5	2.11	6	8	14
6 Tip	1.73	7	8	14

(1) These leaves expressed symptoms of a copper deficiency.

Likewise, although the boron status of the mango and macadamia trees is within the optimal range, proper pollination of the flowers is reduced by the slow transport of boron. Foliar sprays are required on the flowers to offset this limitation.

APPLICATION METHODS

Various methods have been tested and many variations on the effective and, unfortunately also on the ineffective ones, are currently in use. These methods can be grouped into mechanical or hand applications to the soil, fertigation and foliar sprays. Injections of micronutrient formulations into the trunk, is to my knowledge commercially only practised in avocado production.

SOIL APPLICATIONS

Although a total lack of any of the micronutrients will cause a deficiency, the most common reasons for the development of any micronutrient deficiency are soil conditions. Unfavourable soil conditions reduce the concentration of the available ion (**Table 4**).

Table 4. The effect of various soil conditions on the efficacy of micronutrient elements.

Soil condition	Effect on efficacy
> pH	< Cu, Fe, Mn and Zn
< pH	< Mo
> HCO_3	< Fe and Mn
< Aeration	< Fe > Mn
> PO_4	< Zn
> Leaching + < pH	< Cu, B, Mn and Zn
> Organic matter	< Cu

The most common example is that of a high pH in the soil, which reduces the availability of Cu, Fe, Mn and Zn. Likewise, a low pH will reduce the availability of Mo, enhance solubility and leaching of B, Cu, Mn and Zn resulting in a decrease in the total concentration of these elements in the soil and deficient supplies in the long run.

Water logging is another soil condition that will reduce the concentration of available iron. This happens due to the formation of bicarbonate, which is taken up by the plants, increase the pH of the cell sap and precipitate the iron.

Plants may loose their ability to take up micronutrients from the soil. Young citrus trees will utilise the zinc in the rooting zone with ease, an ability they seem to loose after maturity. Infestation by microbes can also affect the mobility of micronutrients in the plants. The “greening” virus causes accumulation of zinc in the stem and trunk of citrus, causing zinc deficiencies in the leaves.

High concentrations of phosphorus will precipitate deficiencies of micronutrients like zinc. When any of these conditions prevail in the soil, the efficacy of a soil application of the micronutrients is reduced. Some of these detrimental conditions can be over come by the formulation of the source or carrier of the micronutrient.

Boron is one micronutrient that can be applied to the soil effectively under a wide range of conditions. In most cases the uptake from one application to the soil is sustained for a number of years.

Therefore when considering the application of micronutrients to the soil surface, one must first evaluate the conditions that could limit the availability of the micronutrients.

FERTIGATION

Fertigation through drippers (especially daily daylight fertigation - DDF) is one such method that can reduce the detrimental effects of some of the mentioned soil conditions on the availability of the micronutrients. This is mainly due to the small volume of soil (see **Table 5**) being irrigated and fertigated. With such a small volume the pH of the soil, water logging and accumulation of elements can be more effectively managed than with a large volume of soil under conventional systems.

Table 5. Comparative volumes of soil (per tree) irrigated by micro jets, inline drippers (double line) and Daily Daylight Fertigation-systems

System	Litres of soil treated	Surface/volume
Micro jets	4 550	6.19
Double line drippers	1 680	11.43
Daily daylight fertigation	150	11.73

The efficacy of fertigation through microjets or any other system that treats a large volume of soil, is limited to the same extend than mechanical or hand applications. With DDF the adverse conditions in the small volume of soil can much quicker and easier be corrected. Aeration is also improved with DDF due to the favourable ratio of surface to volume.

FOLIAR SPRAYS

Foliar sprays to supplement the micronutrient supply or to support a certain physiological process are very common in the production of subtropical crops. The conditions in some orchards however might render the use of spraying machines impossible. Banana plantations can allow only small machines while avocado and macadamia trees can grow so big that spraying machines cannot be used. Fortunately pruning is a fairly new approach in the production of subtropical fruit, which will improve the efficiency of foliar sprays.

The mechanism by which micronutrients are absorbed by the leaf is still a fairly controversial issue. Two main mechanisms are proposed namely absorption through the stomata and inter cellular fibril pores in the epidermis of the leaves.

- ***Stomata***

The size of the stomata varies from very large (1000 nm) to relatively large and they are very abundant (20 per mm^2 in succulents to 800 per mm^2 in some tree species), especially in the under side (abaxial) of the leaf. This theory is supported by the fact that more nutrients are absorbed through the under than the upper side of the leaf. However, the stomata are filled with gasses and exchange of gasses is their primary function. A high pressure is required to displace these gasses by water. Further more, in trials done in the Sundays river valley, much more potassium was absorbed during the night than during day time.

- ***Inter fibril pores in the cuticle***

These spaces are plenty (10^8 per mm^2) on both surfaces of a leaf but are quite small (1 nm in diameter). However, these paces are filled with water and other hydrophilic substances and water can passes through. The diameter of the urea molecule is 0.44 nm and will pass quite easily through these pores. Substances with much larger molecules like that of Fe-EDTA will not pass.

The density of these pores is higher in the walls between guard cells of the stomata and subsidiary cells. These cells also have different permeabilities and are most likely the sites of absorption of larger molecules like Fe-EDTA and systemic pesticides. The different properties of the pores next to the guard cells also explain the phenomenon that the absorption is higher on the under than the upper side of the leaf.

What size of molecules can be absorbed? From experience we know that a variety of pesticides are absorbed very well through the leaves. **Table 6** compares the molecular masses of some substances effectively absorbed through leaves. The molecular mass has no relation to the diameter of the molecule and serves only as a guideline.

Table 6. The molecular mass of substances effectively absorbed by plant leaves

Substance	Molecular mass
Water	18
Urea	60
Glucose	180
Fructose	180
Glyphosate	169
Dimiton-S-methyl	230
H-EDTA	292
Fosetyl-aluminium	354

For a foliar spray to be effective some basic requirements are regarded essential.

Concentration

The aim of any spray with micronutrients is to increase the concentration of that element substantially. Hence a minimum mass of the element needs to be sprayed on to the leaf and absorbed by the plant. Once the mass of the leaves to be treated is known, it is simple to calculate the minimum mass of the micronutrient to be absorbed. Yet, looking at the large number of micronutrient formulations available, only a few will get over this hurdle.

Another way to estimate the effective concentration of any micronutrient formulation is to benchmark it against the single element formulations known to be effective. For example we know that Solubor[R] at 150g per 100 litres water is effective to raise the concentration of boron by 20 to 40 mg per kg leaf material (20 to 40 ppm). Such an effective foliar spray solution will contain 300 mg B per litre. Any "unknown" formulation containing much less than 300 mg B per litre will be suspicious.

Volume

The effective mode of absorbing micronutrients by the foliage is in the soluble form. Once the nutrient solution has dried out, absorption ceases. The volume of water applied on the leaves and the conditions controlling evaporation are therefore important. On average 2 500 to 3 000 litres of water is applied to mature citrus orchards.

The volume of water that can be held by a leaf is determined by the degree of wetting and the size of the droplets. The presence and condition of waxy and other hydrophobic substances determine the degree of wetting. The size of the nozzles on the spraying machine, application pressure and additives will influence the size of the droplets.

Formulation

The formulation of a preparation for foliar application of micronutrient elements consists of the carrier of the nutrient and additives to enhance absorption.

The carrier is usually an inorganic ion, chelating agents such as sugars and amino acids or even other "magic" materials. The additives may include pH buffers, spreaders, rewetting agents etc. Surfactants that will spread the solution into thin layer on the surface of the leaf will increase evaporation of the solution and hence decrease the absorption.

Condition of the trees

A prerequisite for efficient absorption is a good leaf cover and well watered tree. This is more important for the macro than the microelements. The lower the concentration of the element in the leaf, the less will be its redistribution within the plant after absorption.

Climatic conditions

Any climatic condition that will decrease the contact time of the droplet with the surface of the leaf will reduce the efficacy of the spray. These include dry winds, low humidity and high temperatures. **Table 7** illustrates the influence of temperature, humidity and droplet size on the effective contact time.

Table 7. The influence of relative humidity (RH), temperature and droplet size on the effective contact (ECT) time of foliar applied nutrient solutions.

RH %	Temperature °C	Droplet size microns	ECT seconds
70	20	100	20
		50	5
40	20	100	9
39	27	100	6
45	17	500	840

Effective absorption of foliar applied micronutrients requires a fairly long contact time. In **Table 8**, the absorption of Fe^{55}, Mn^{52} and Zn^{65} by bean leaves after increasing contact periods, illustrates the importance of a lengthy contact of the nutrients in solution on the surface of the leaf.

Table 8. The % absorption of Fe^{55}, Mn^{52} and Zn^{65} from a nutrient solution by bean leaves during 6, 48 and 192 hours of effective contact

Element	6	48	192
Fe	3	8	15
Mn	11	22	40
Zn	30	60	70

(After Tukey)

AERIAL SPRAYS

The most limiting factor in aerial application of the micronutrients is the low-low volume of the nutrient solution applied. This results in a very quick drying out of the nutrient formulation and restricted time for absorption. The effective contact time is in most cases too short for the spray to be effective. Some micronutrients like boron can however be applied successfully through aerial spraying. The reason is most probably due to the fact that non-absorbed boron is washed down to the soil from where it is utilised effectively.

RESPONSIBILITY OF SUPPLIERS

The fact that the influence of a mild deficiency of any micronutrient element on production of quality subtropical crops is very difficult to illustrate leaves this market open for gimmick formulations. This is further aggravated by the very endeavour to keep the micronutrient status of the trees in the optimal range. Many available formulations are so diluted that it will not in the interim harm the crop while leaving a back door open to escape.

I would like to call on the suppliers to evaluate their formulation properly and do the right thing to put only reputable formulations on the market. **Table 9** stresses the dilemma experienced by producers of subtropical crops, to select the effective formulation in terms of concentration of the nutrients in the final spray solution. The benchmark formulations are known to be effective at a specific concentration. The concentration of the micronutrient elements in some products is less than 5% of that of the benchmark product.

Table 9. The variation of the concentration of micronutrient elements in formulations for foliar applications, benchmarked against products know to be effective.

Benchmark		Concentration of various products
Solubor^R	300 mg/litre	82.50 to 310
$Zn(NO_3)$	82 mg/litre	2.62 to 106
Cytokines	1 to 5 mg/litre	0.000014 to 10

CONCLUSIONS

Micronutrients contribute towards better yield and quality of subtropical fruit. Ways and means to improve deficient levels and maintain optimum levels should be a standard practise on all subtropical fruit farms. Applications of these elements should be based on actual evaluations of the micronutrient status of the trees. The available diagnostic methods are reliable but should be used with a proper knowledge of its limitations.

Before embarking on a method to correct the deficiency or maintain the optimal status, ensure that the best formulation and method is selected for the individual orchards.

Use formulations that can be benchmarked and have the potential to do the job.


Slide
Presentations

WELCOME TO THE

COMBINED

FERTILIZER SOCIETY OF SOUTH AFRICA & SA SUGERCANE RESEARCH INSTITUTE SYMPOSIUM

ON

MICRONUTRIENTS IN AGRICULTURE

Friday 25 February 2005

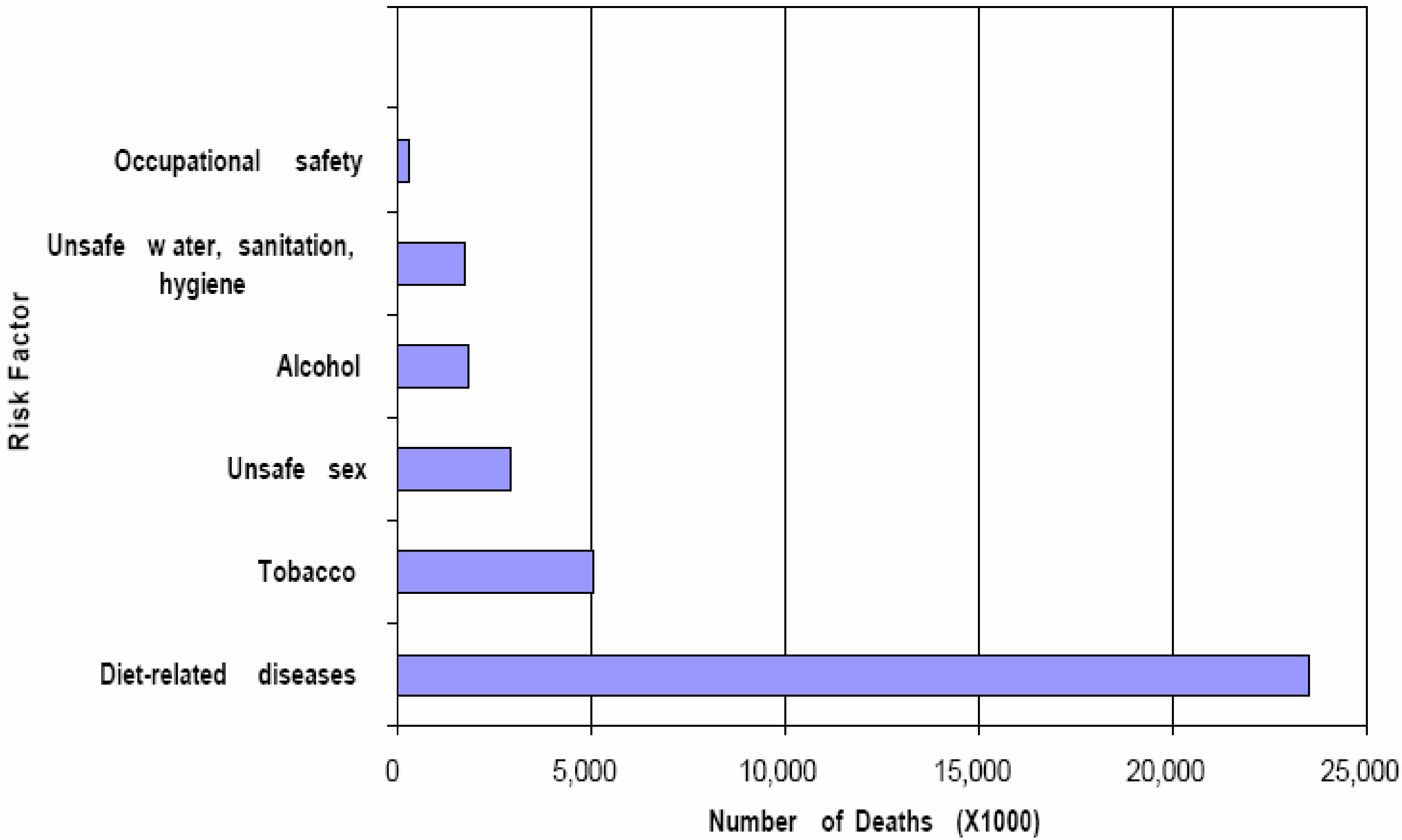
Food Systems, Diet and Disease

- Global food systems are failing to provide adequate quantities of essential nutrients and other factors needed for good health, productivity and well being for vast numbers of people in many developing nations.
- *Green revolution* cropping systems have resulted in reduced food-crop diversity and decreased availability of micronutrients.
- Nutrition transitions are causing increased rates of chronic diseases (cancer, heart disease, stroke, diabetes, osteoporosis) in many developing nations.
- Holistic, sustainable improvements in the entire food system are required to solve the massive problem of malnutrition and increasing chronic disease rates in developed and developing countries.

WHO Global Strategy on Diet, Physical Activity and Health 57th World Health Assembly 2004

- Acknowledged that malnutrition, including undernutrition and nutritional deficiencies is still a major cause of death and disease globally.
- Non-communicable diseases are of crisis proportions in developed countries and is rapidly increasing in developing countries. In 2001, chronic diseases (many diet related) accounted for almost 60% of the 56 million deaths annually and 47% of the global burden of disease.
- National food and agricultural policies should be consistent with the protection and promotion of public health.
- Agricultural policy and production have great effects on national diets. Governments can influence agricultural production through many policy measures. As emphasis on health increases and consumption patterns change, Member States need to take healthy nutrition into account in their agricultural policies.

Some WHO Major Risk Factors Causing World Deaths in 2000



(World Health Report, 2002)

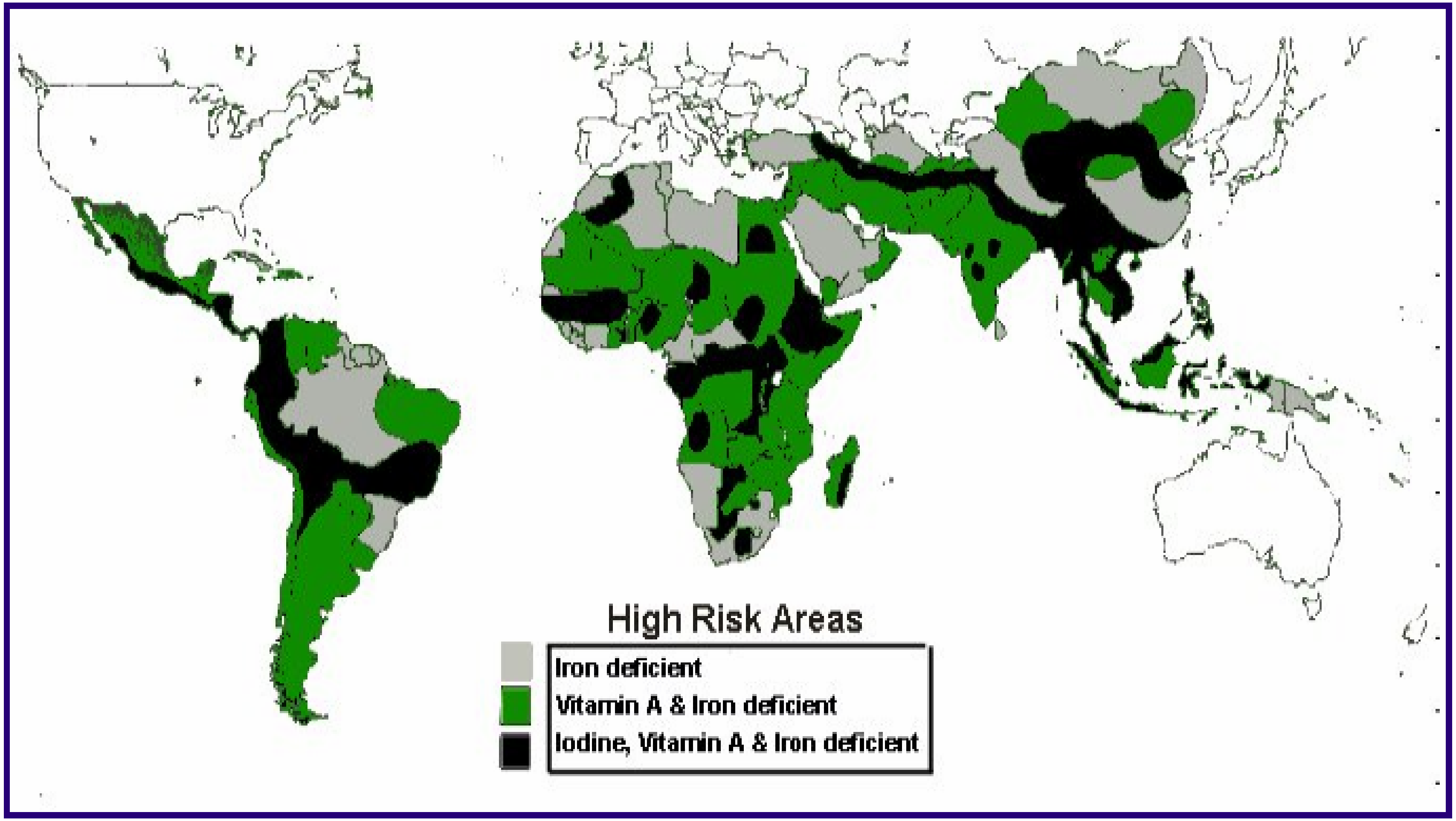
The Known 50 Essential Nutrients for Sustaining Human Life*

Water & Energy (2)	Protein (amino acids) (9)	Lipids-Fat (fatty acids) (2)	Macro-Minerals (7)	Micro-Elements (17)	Vitamins (13)
Water	Histidine	Linoleic acid	Na	Fe	A
Carbohydrates	Isoleucine	Linolenic acid	K	Zn	D
	Leucine		Ca	Cu	E
	Lysine		Mg	Mn	K
	Methionine		S	I	C (Ascorbic acid)
	Phenylalanine		P	F	B_1 (Thiamin)
	Threonine		Cl	B	B_2 (Riboflavin)
	Tryptophan			Se	B_3 (Pantothenic acid)
	Valine			Mo	Niacin
				Ni	B_6 (Pyridoxal)
				Cr	Folate
				V	Biotin
				Si	B_{12} (Cobalamin)
				As	
				Li	
				Sn	
				Co (in B_{12})	

*Numerous other beneficial substances in foods are also known to contribute to good health.

R.Welch Cornell University:- Farming for Health: The future for Agriculture. Chile, 1 Dec 2004

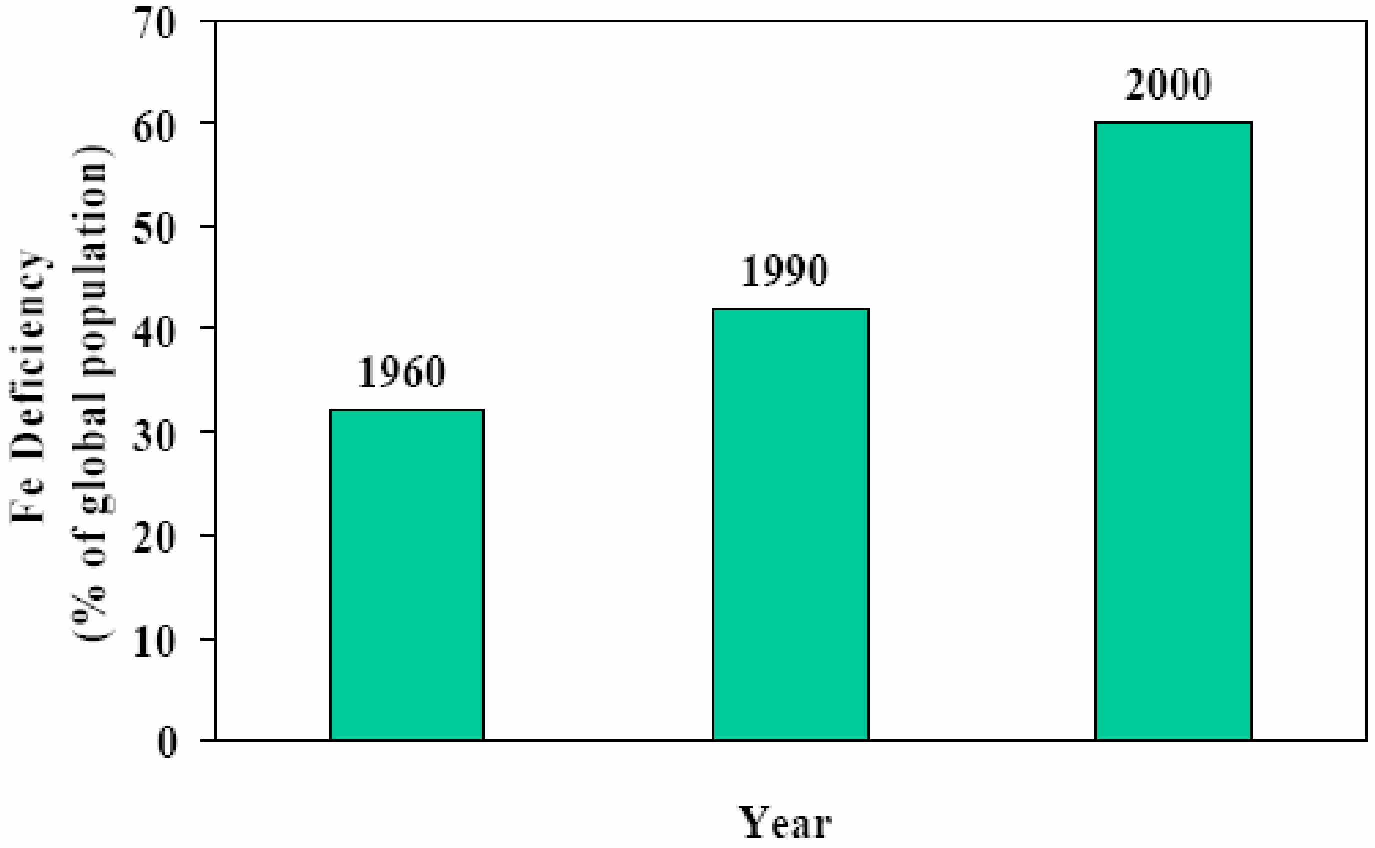
Global Micronutrient Deficiencies



> 3 billion people afflicted

(Map from USAID)

Change in Prevalence of Iron Deficiency Globally



Data from WHO, 2002

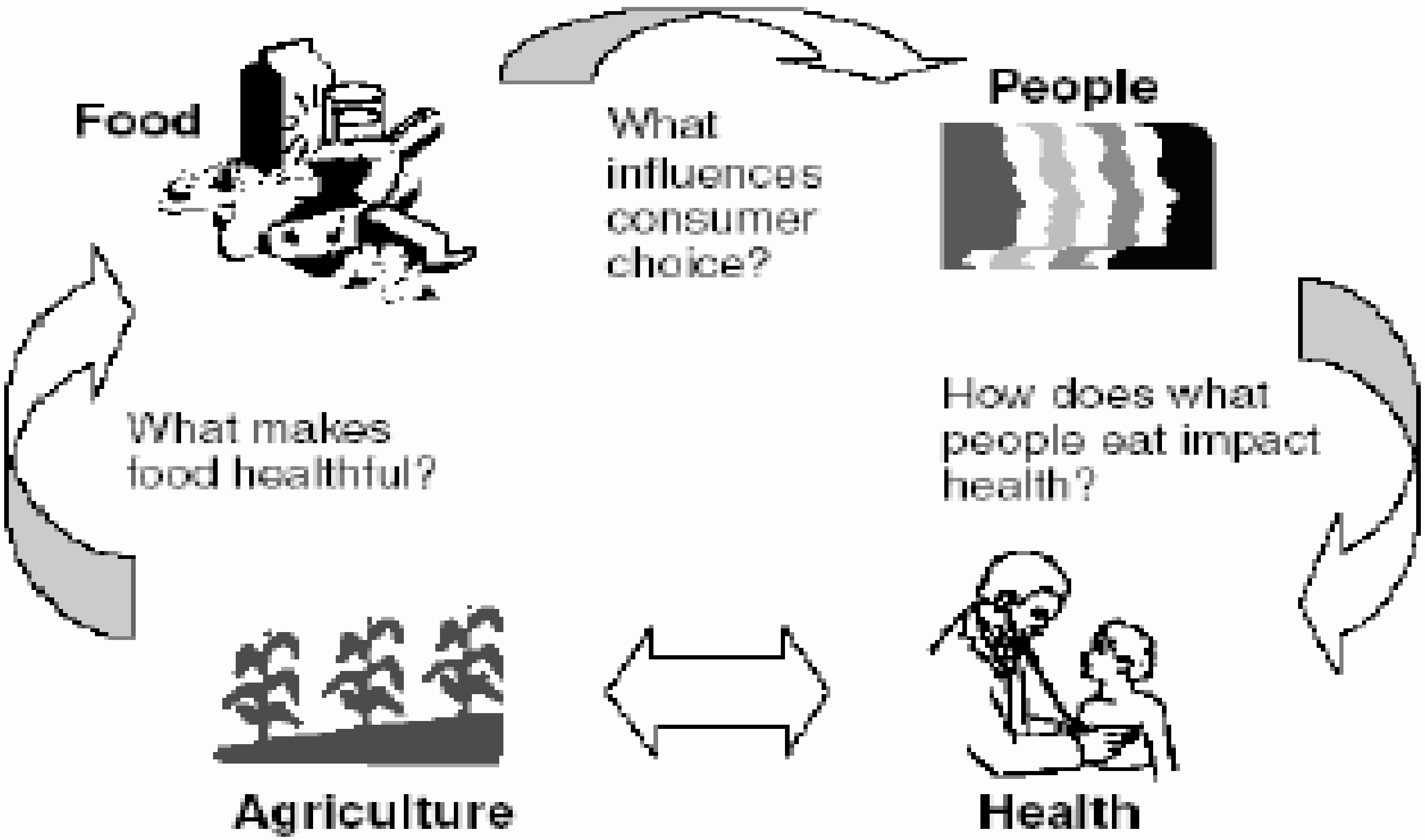
Global Food Systems' Problems

- Agriculture's primary focus is on production alone, with little concern for nutritional or health-promoting qualities.
- Nutritionists tend to emphasize unsustainable medical approaches to solve malnutrition problems
  - supplements
  - food fortificants
- Simplistic views are the norm – looking for "silver bullet" approaches for solutions

It is time for South Africa (and the rest of the world) to shift to a new agricultural strategy - one based on both what is good for the consumer and profitable for farmers.

The time is ripe for an integrated approach to nutrition, health, and disease prevention (Van Hubbard, Director, National Institutes of Health)

We Need a shift in focus: From only Quantity to Quality and Quantity!

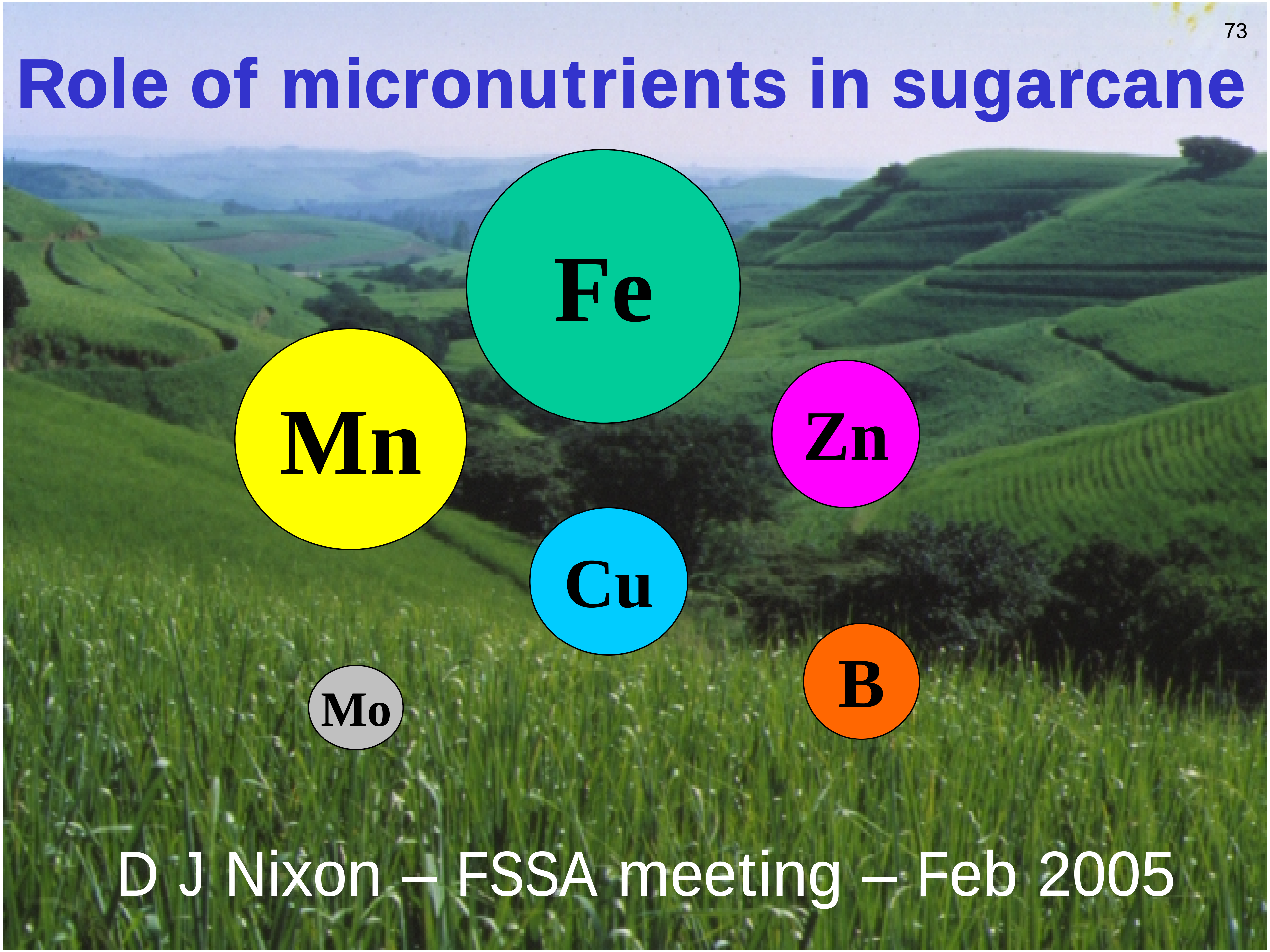


Making a closer connection between agriculture and health will require that research address gaps at the intersection of agriculture and food, food and people, and people and health.

Conclusion

- **Improving human health must be a key component of the future of agriculture globally.**
- **Farming for health should be the norm in agriculture.**
- **I believe the *Fertiliser Industry* can contribute greatly to achieving this goal of better nutrition and health for all.**

Role of micronutrients in sugarcane



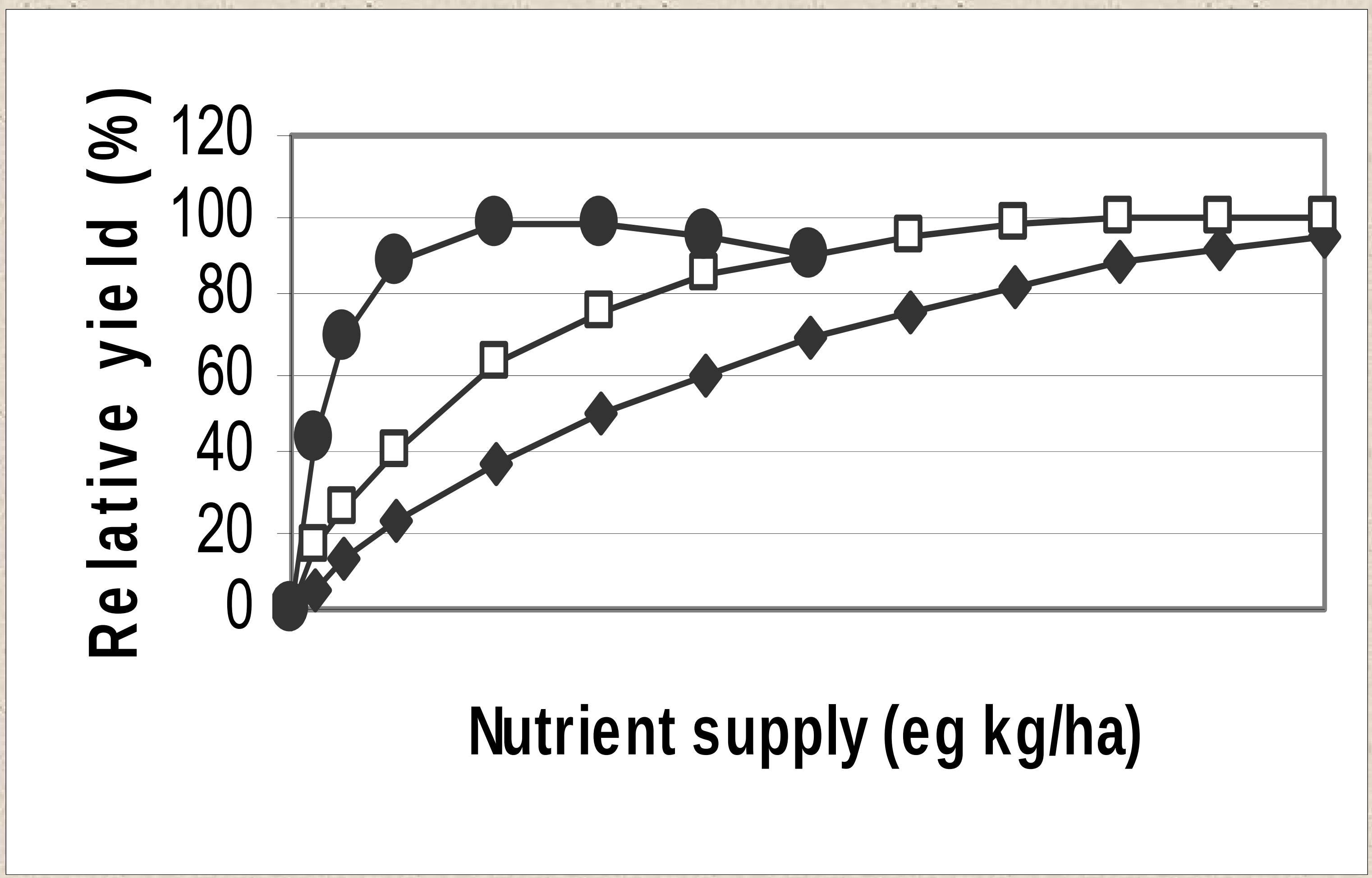
D J Nixon – FSSA meeting – Feb 2005

Uptake of micronutrients (kg) by a cane crop of 100 t/ha

Element	Uptake (kg/ha)
Iron	4.2
Manganese	2.4
Zinc	0.8
Copper	0.3
Boron	0.2
Molybdenum	0.1

N (◆) P (□) Micronutrients (●)

(Marschner, 1986)

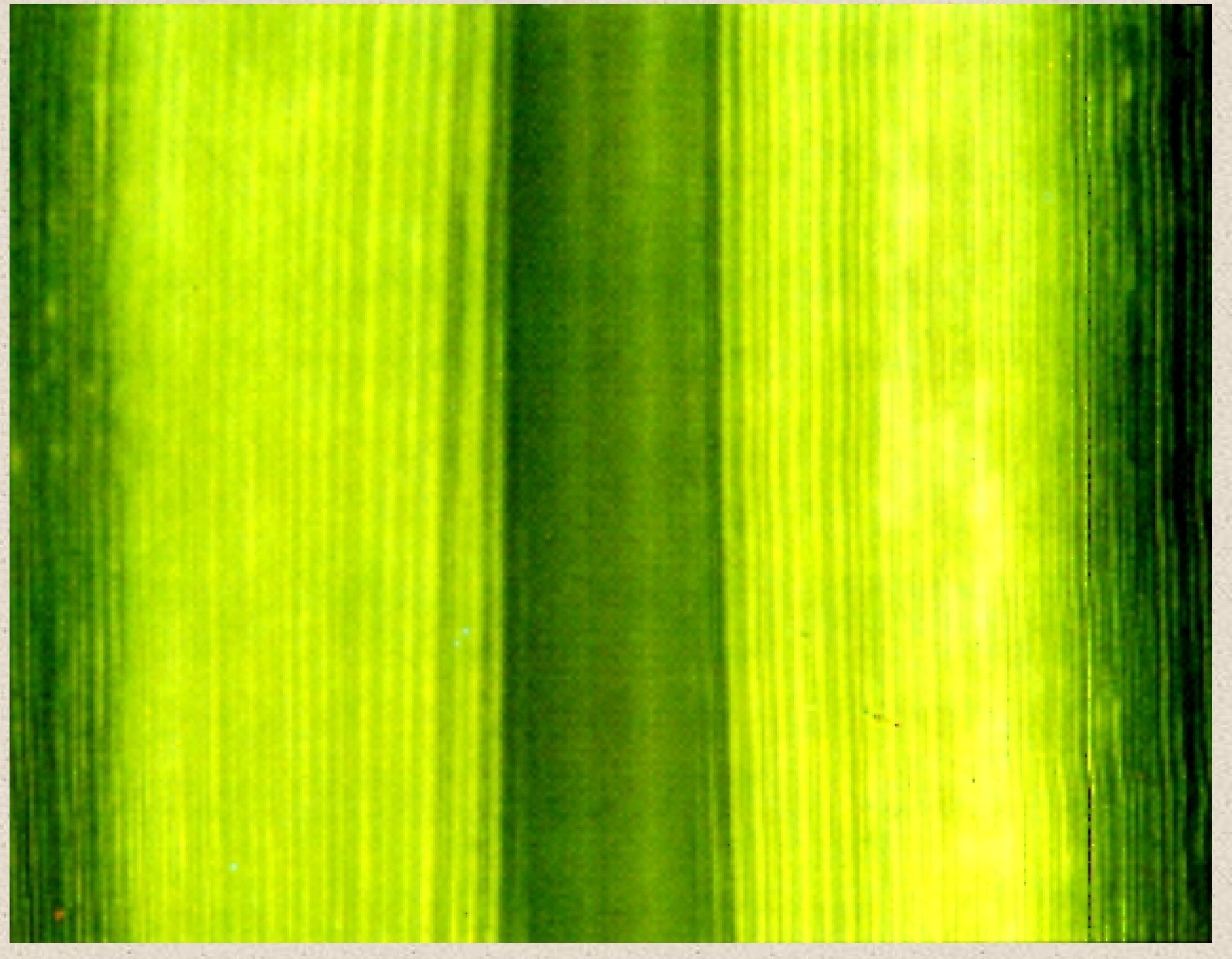


Specific problem areas

- Acid soils (Fe, [Mn toxic]) e.g. Midlands
- Alkaline soils (Fe, Zn) e.g. Mpumalanga
- Depletion of soil reserves
  - e.g. Umfolozi Flats (Zn)
- Salinisation in irrigated areas (B)
  - e.g. Dwangwa, Malawi - possible in SA?
- Localised effects e.g. *Isiduli*, filtercake (Fe)

ZINC DEFICIENCY

ZINC DEFICIENCY



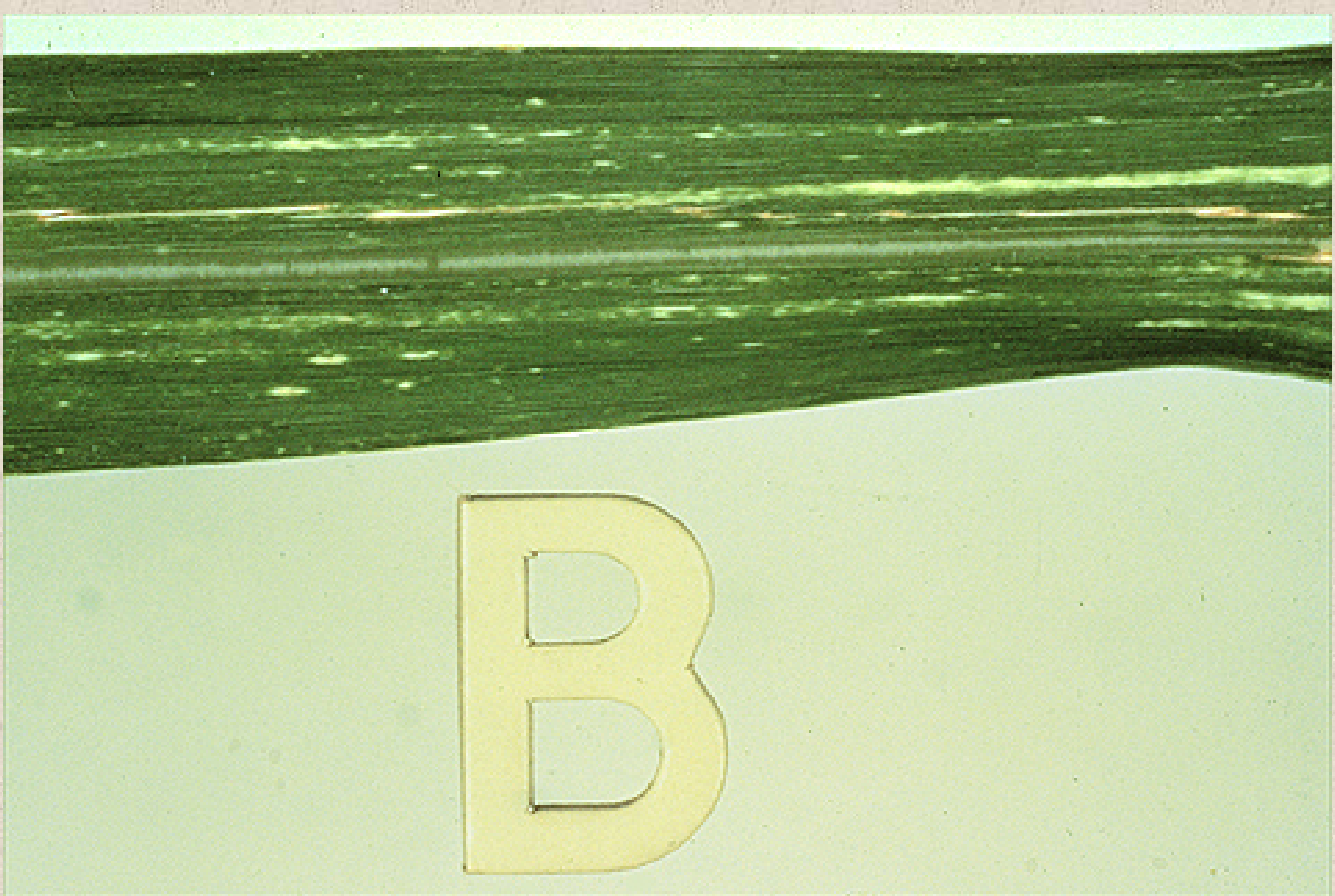
IRON DEFICIENCY

IRON DEFICIENCY

MANGANESE DEFICIENCY

BORON DEFICIENCY

BORON DEFICIENCY



COPPER DEFICIENCY

COPPER DEFICIENCY

MOLYBDENUM DEFICIENCY

Leaf thresholds for micronutrients

Element	Threshold (ppm)
Zinc	13
Iron	50
Manganese	15
Copper	3
Boron	3

Soil test for zinc

$(NH_4)_2CO_3$ - EDTA extraction

Clay %	Threshold
<15%	0.5 ppm
>15%	1.0 ppm
Lime req.	1.5 ppm

Micronutrient sources

- Foliar sprays – mainly as sulphate
- ‘Speciality’ products - chelates
- Mill wastes - Filtercake, flyash, CMS
- Organics - chicken litter, manure
- Trashing
- Green manures/crop rotation

CONCLUSIONS

⇒ No widespread micronutrient deficiencies within the sugar industry, <u>but</u>

⇒ Certain problem areas do exist within the industry which require attention

⇒ Increasing role of green manures and organic materials to improve supply

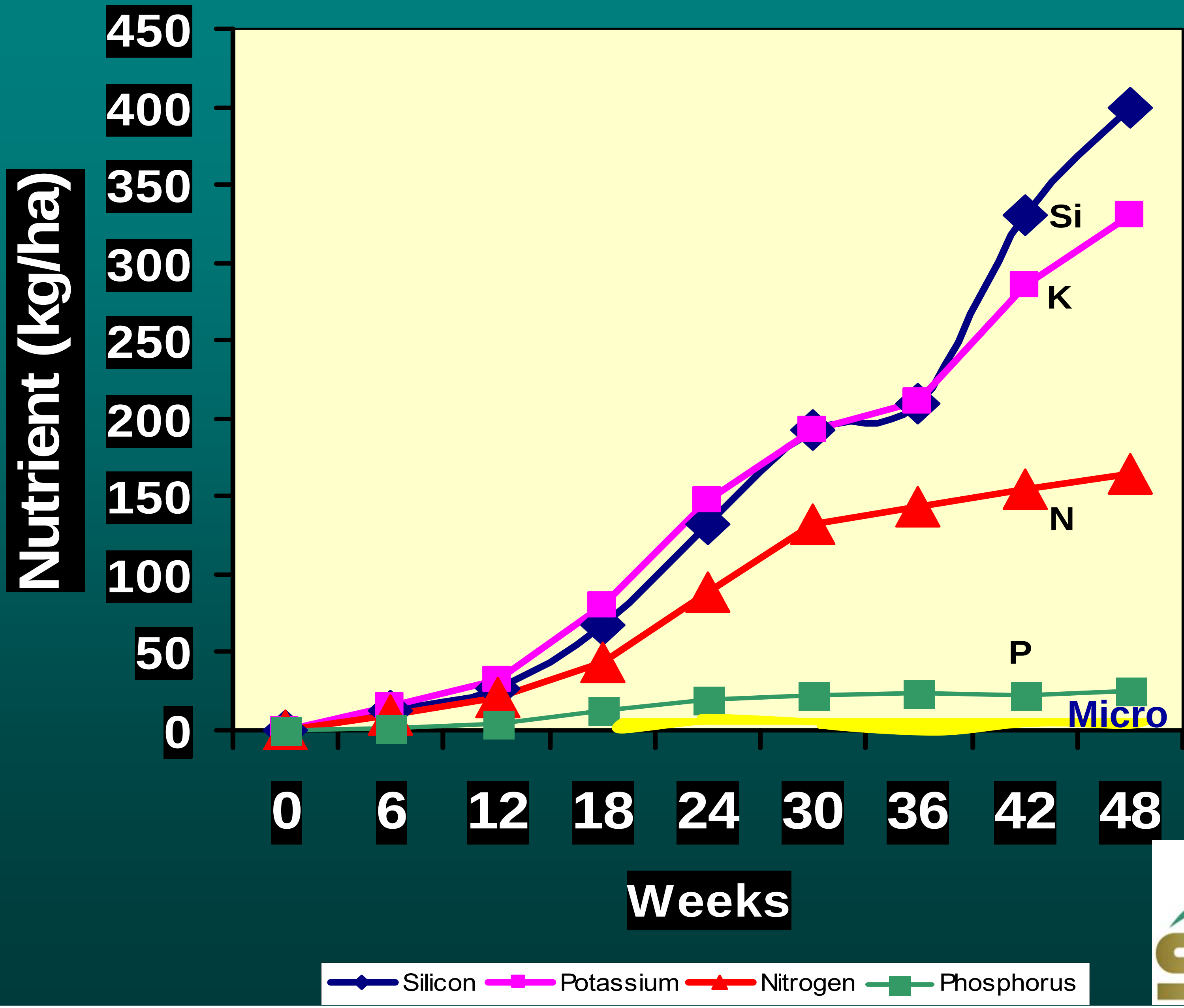
⇒ Diagnosis/recommendation is available via FAS - Foliar analysis is the best tool


Thank you

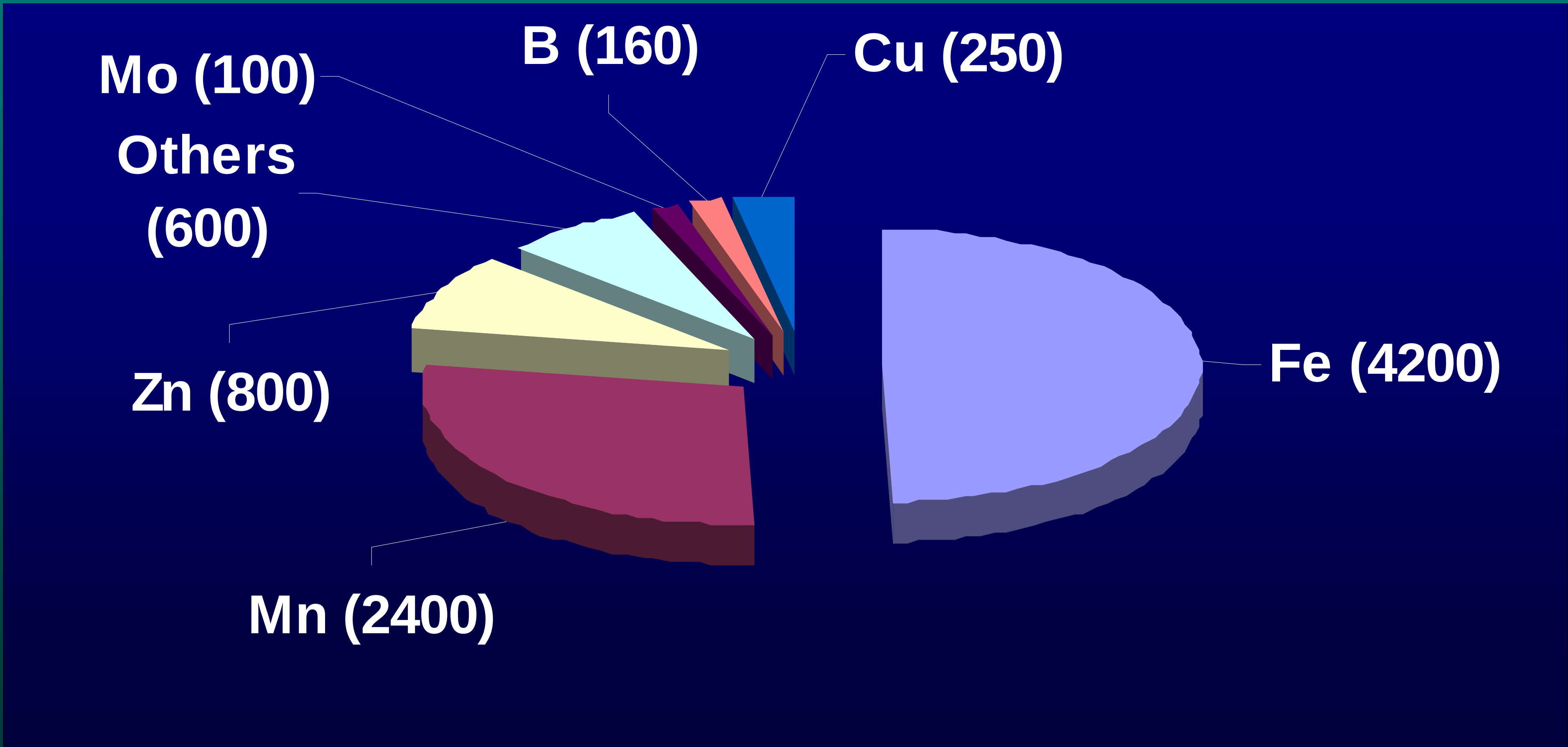

PAST RESEARCH AND TRENDS OF
MICRONUTRIENT DEFICIENCY IN SUGAR CANE
by Jan Meyer
SA Sugar Cane Research Institute
sasri
FSSA-SASRI Symposium, Kwa-Shukela-February 2005

CONTENTS

Relative nutrient uptake by a 100 t/ha sugar cane crop



Comparative uptake of micro-nutrients (g) by a 100 t/ha cane crop



Early Micronutrient Discoveries

- 1932 Florida-Cu (Allison)
- 1934 Hawaii-Cu, Fe, Mn (Martin)
- 1956 Australia-Cu (Anderson)
- 1956 South Africa-Cu (Du Toit)
- 1962 South Africa-Zn (Du Toit)
- 1969 Ecuador-B (Tollenaar)
- 1977 Australia-Zn (Reghenzani)
- 1981 Malawi-B (Whitbread)

Reasons for increased micronutrient deficiencies?

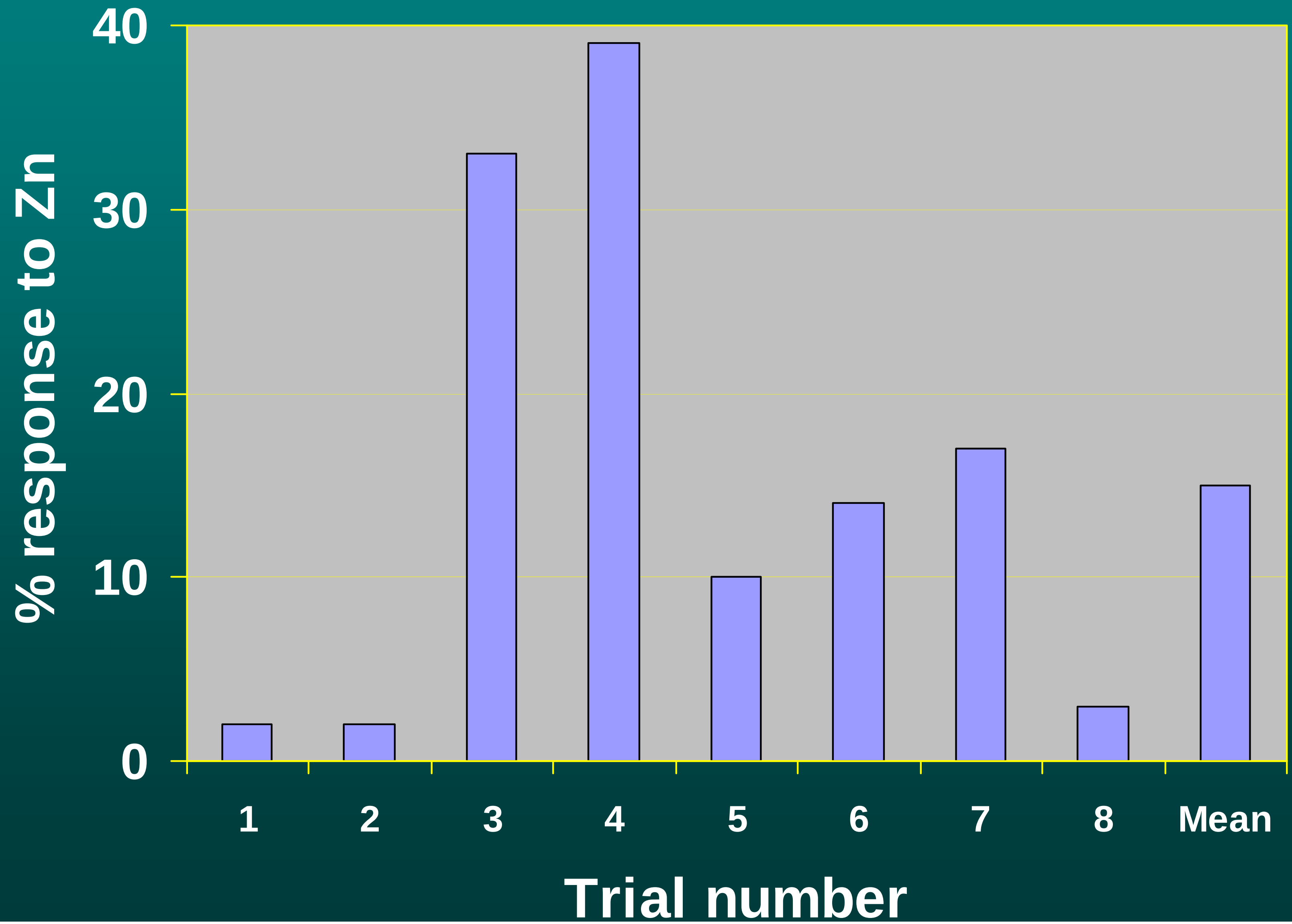
- Declining soil reserves
- New high yielding cane varieties
- Nutrient export, minimal recycling
- Higher purity NPK fertilizers
- Advances in soil and leaf analysis

PREVIOUS MICRONUTRIENT RESEARCH IN SA

- 1961-4 Exploratory trials with Zn
- 1971-First Industry-wide nutrient survey
- 1975-83 Upper Tongaat project-6 trials
- 1976-80 Soil and leaf calibration tests
- 1979-83 Weak Sands project-21 trials
- 1989-Second nutrient survey
- 1996-Third survey based on 2000 fields
- 2003-Fourth survey based on 3000 fields
- MAJOR OUTCOMES??

Responses to zinc sulphate

Plant cane - Inanda Form (Upper Tongaat)



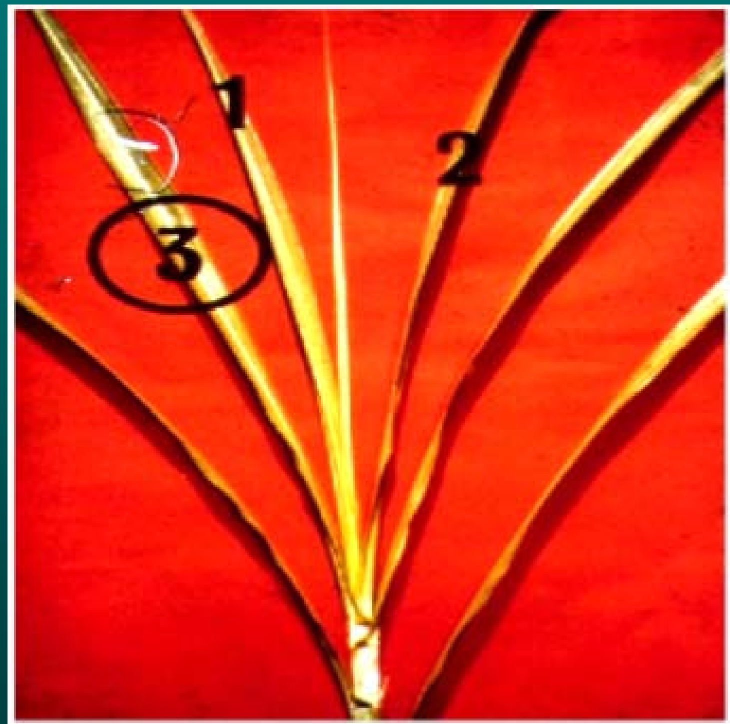
Summary of field responses to Fe

Treatment	Area	Crop	Average yield	
			T cane/ha	% change
Control +Fe (SO_4) +Fe (Cl_3)	Cornubia Estates NS	1R (chlorotic)	62.2 68.5 73.7	0 +10 +18*
Control +$FeSO_4$ 12lb split +$FeSO_4$ 6lb split +Fe SO_4 6lb split	Cornubia Estates NS	2R (chlorotic) 1 mth split	30.3 38.8 37.0 36.4	0 +28* +22* +20*

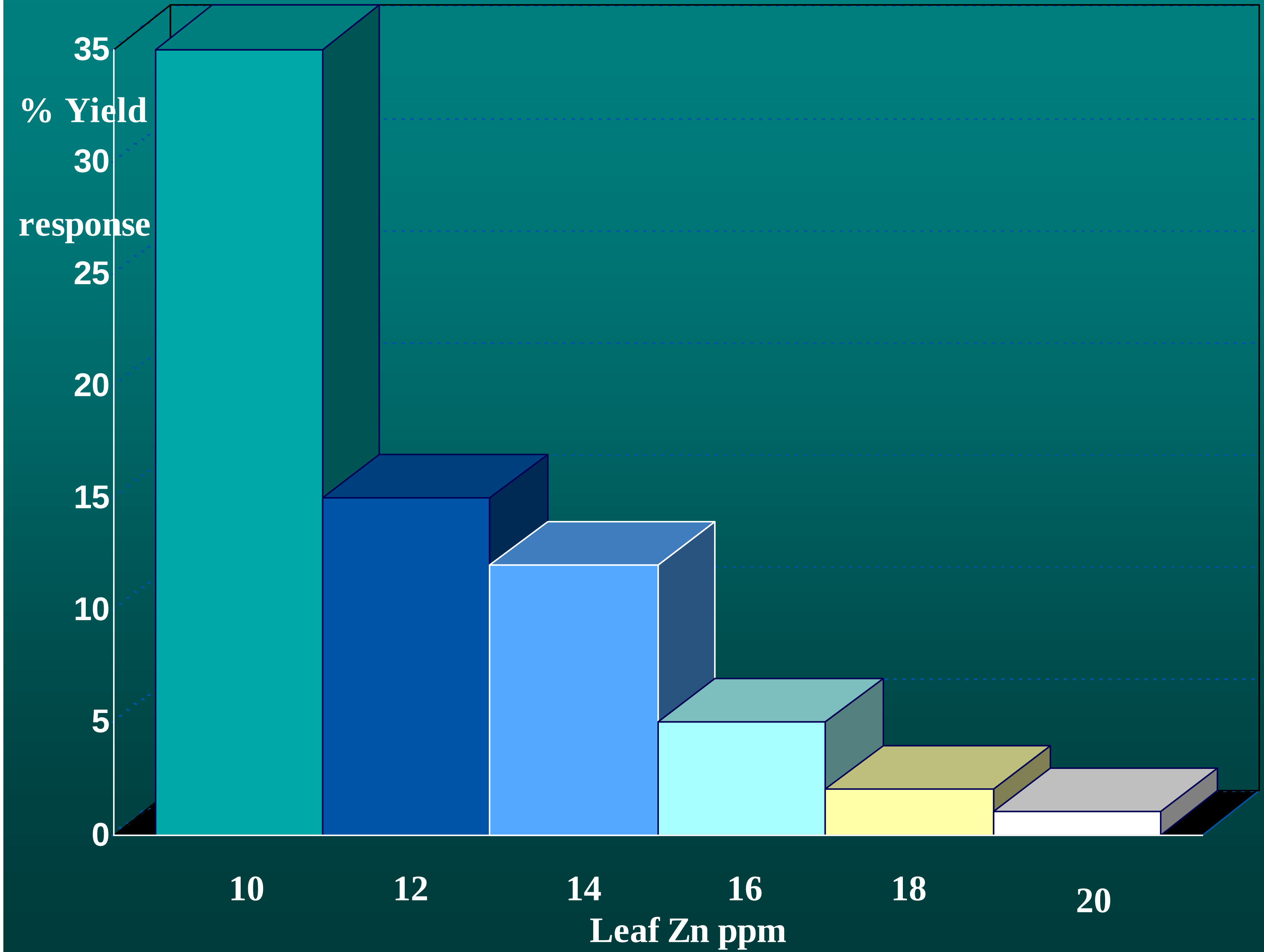
Summary of field responses to other micronutrients

Treatment	Soil form	Crop	Average yield	
			T cane/ha	% change
Control +B +Cu +Mn +Mo +Si +Zn	Cartref Doornkop	Plant	49.23 46.11 47.35 47.46 47.93 47.68 45.82	0 -6 -4 -4 -3 -3 -7
Control +Zn +Cu +Mo +B	Glenrosa Triangle	5R	182.7 164.5 175.6 171.4 181.2	0 -10 -4 -6 -1

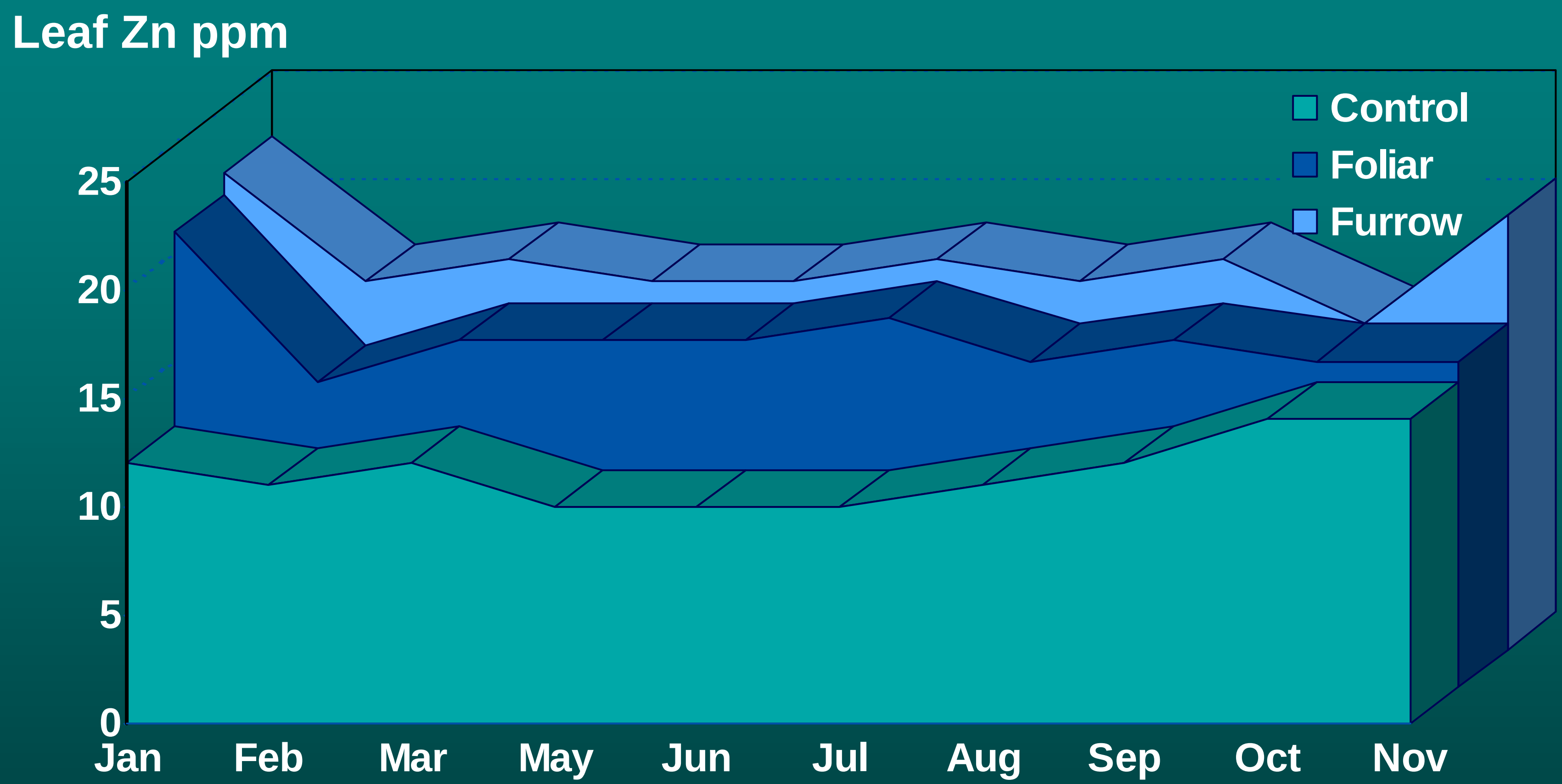
Calibrating leaf analysis



Response to Zn treatment vs leaf Zn content



Zn treatment vs leaf



Calibrating Soil test for Zn

- Five soil extractants evaluated in a pot trial
- 0.01M EDTA best correlation Zn uptake
- Validated 500 cane fields

Leaf Zn=17.32+1.92(EDTA-2.02)+

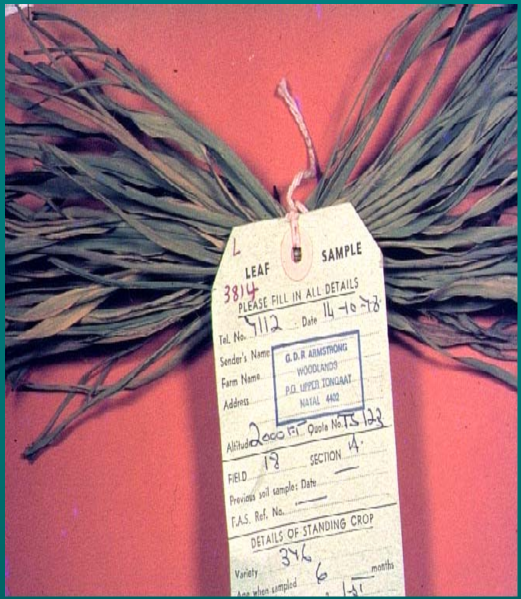
0.034(Clay%-30) (R^2=0.75)

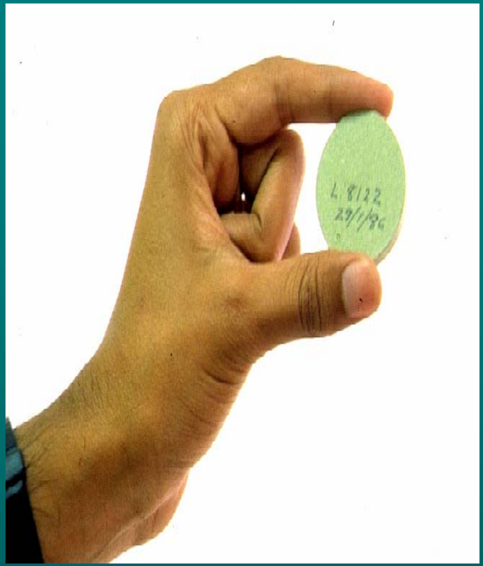
- Field soil thresholds
- 0.5ppm (<15%clay)

1.0ppm (>15%clay),1.5ppm

where lime needed

NUTRIENT SURVEYS BY LEAF ANALYSIS

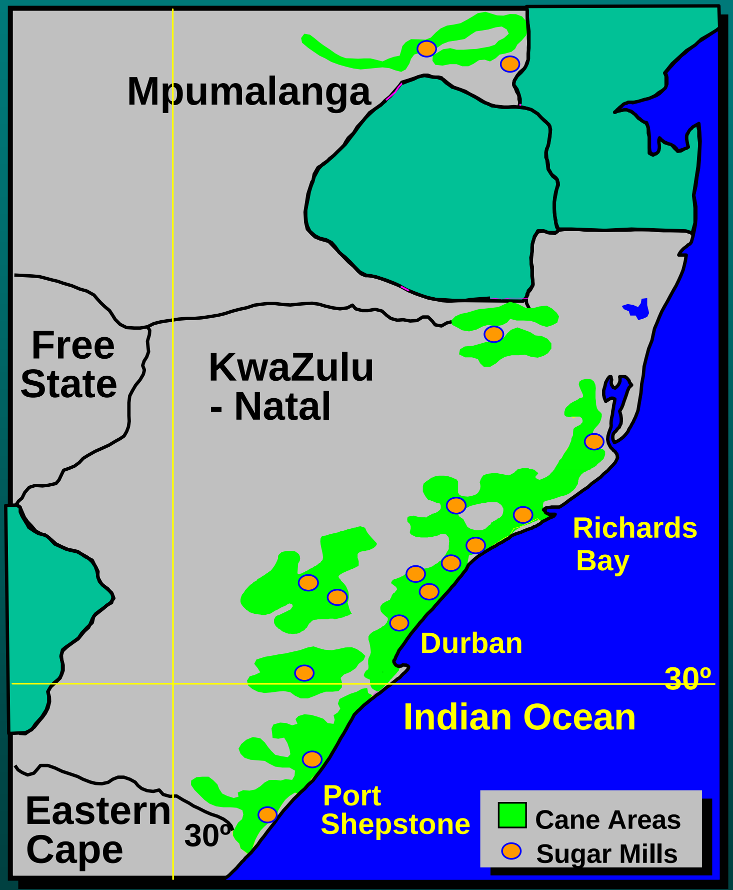




CRITERIA USED TO RATE LEAF MICRONUTRIENT STATUS (ppm)

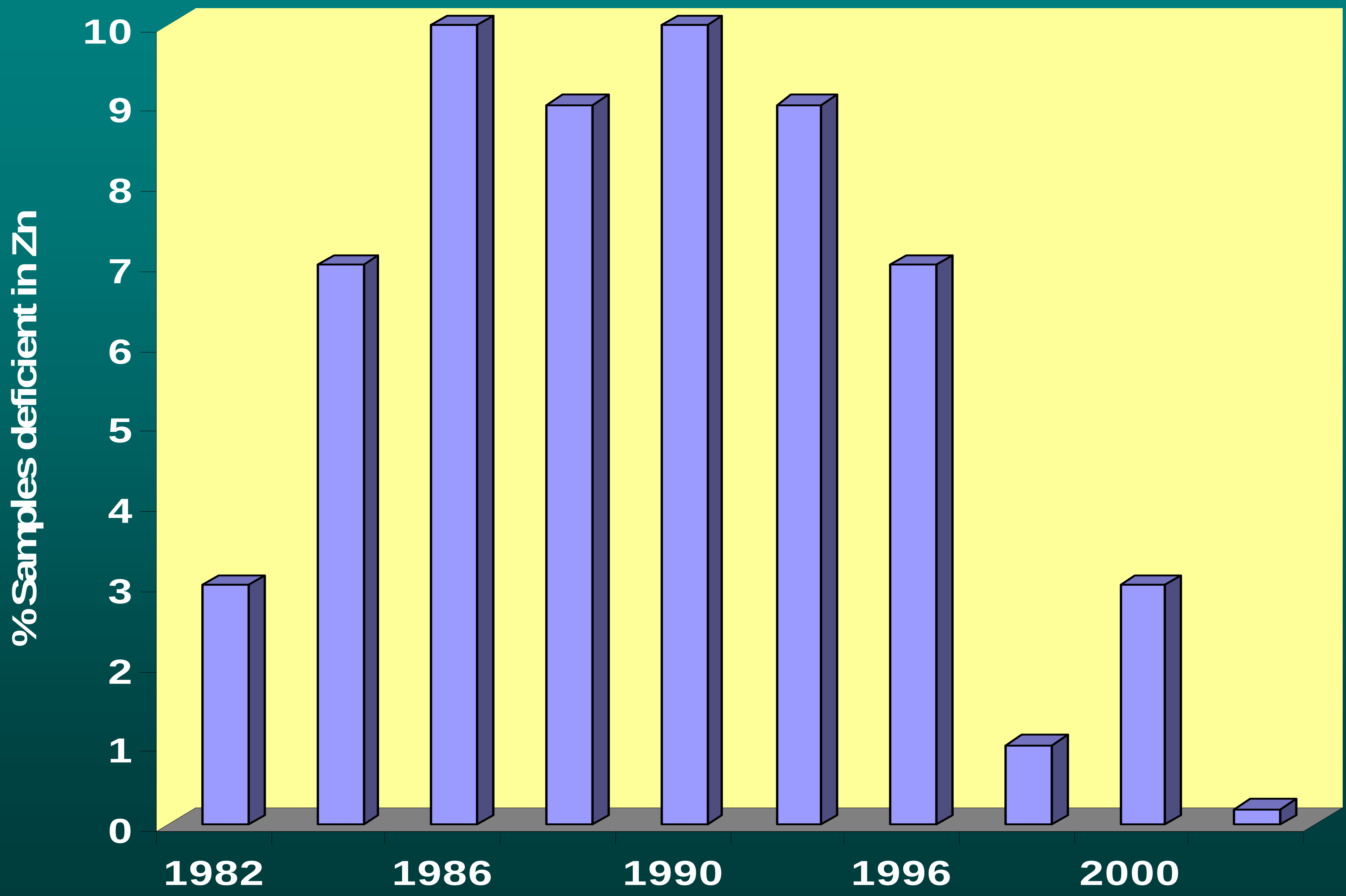
Nutrient	Deficient	Marginal	Adequate	High
Zn	12	15	25	>25
Mn	15	30	70	>70
Cu	3	5	10	>10
Fe	75	125	200	>200

NUTRIENT SURVEY OUTCOMES

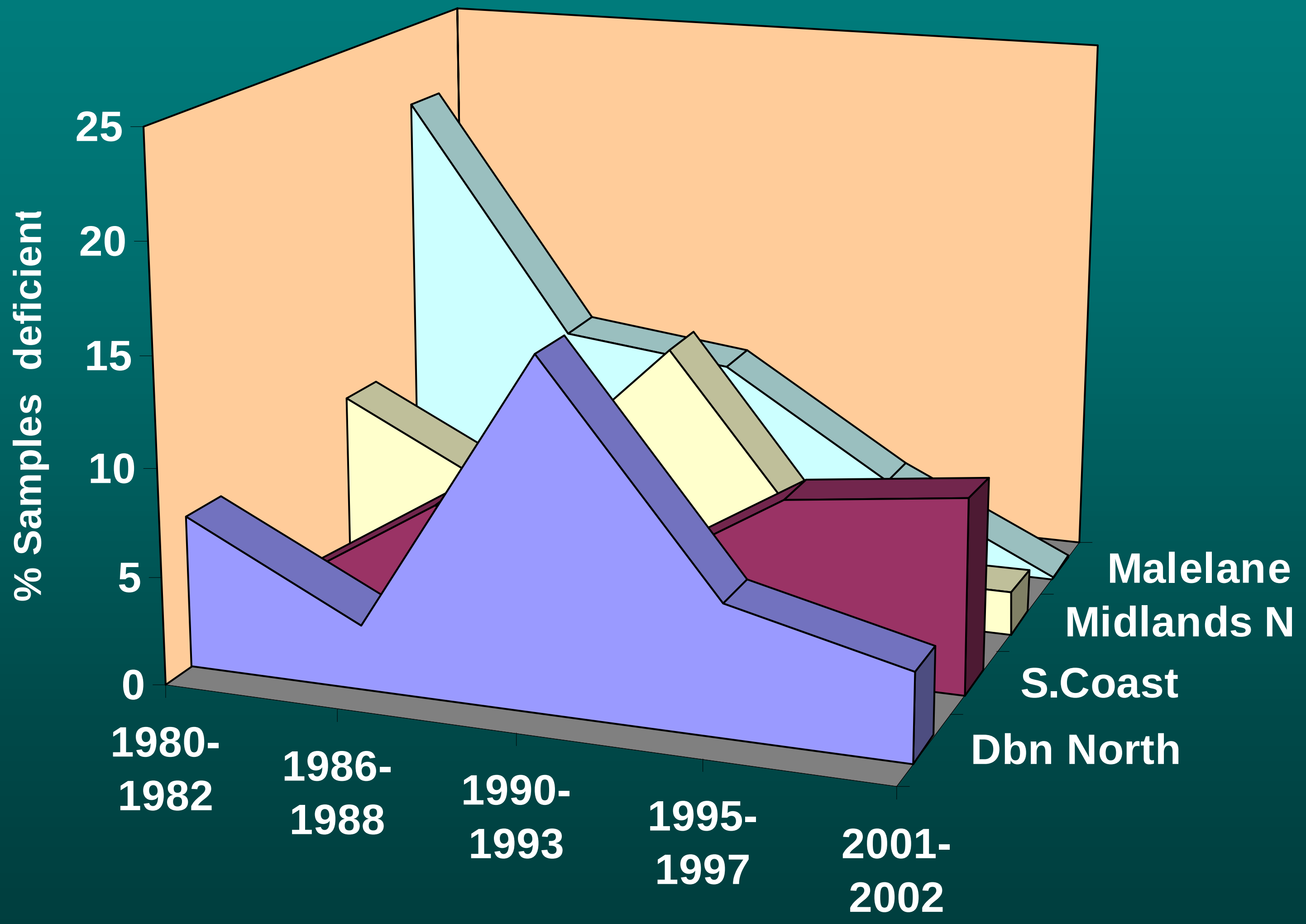


- 1967-190 fields, Zn deficiency TMS-mistbelt soils (40%)
- 1971-500 fields, Zn deficiency (12%) also found on coast & Pongola, toxic levels Mn identified
- 1989-FAS data base +/-100000 soil samples, 35000 leaf, 7% Zn deficiency, 22% marginal
- 1996 2000 fields
  - Fe deficiency 6%
  - Zn deficiency 4%
  - Cu deficiency 2%
- 2003 3000 fields
  - Fe deficiency 6%
  - Zn, Mn, Cu <1%

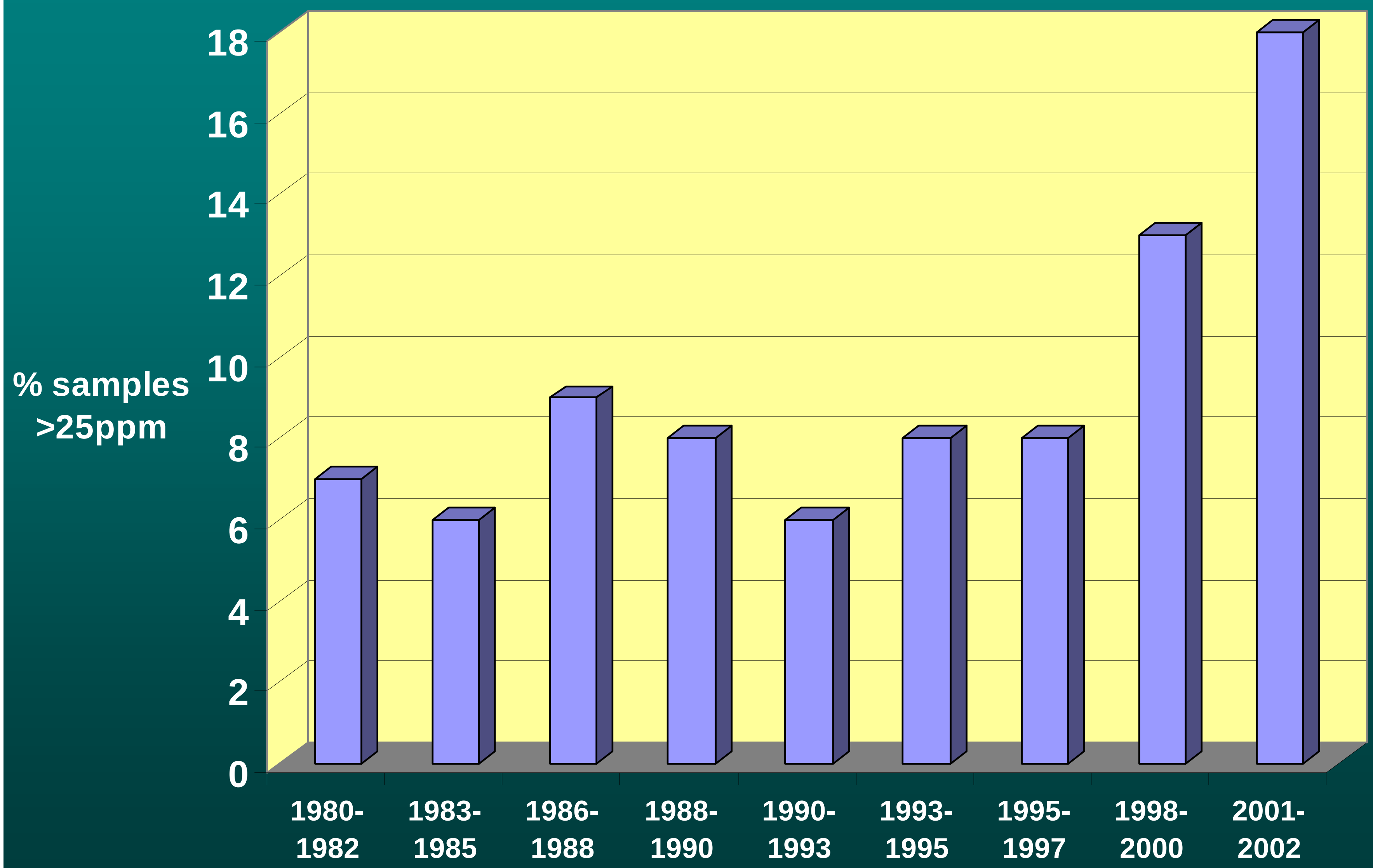
Industry wide percentage leaf samples deficient in Zn



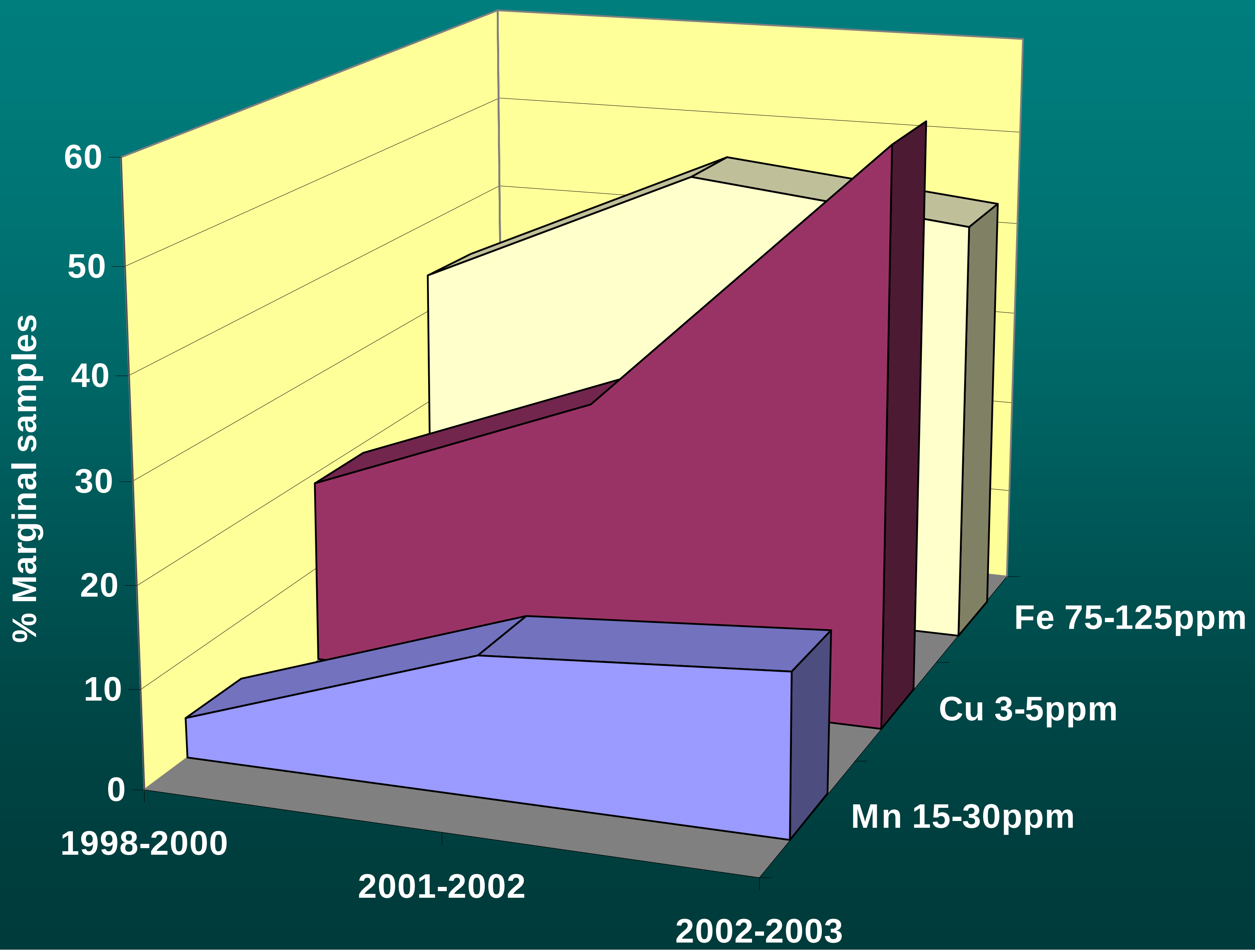
Trend in leaf Zn deficiency by region



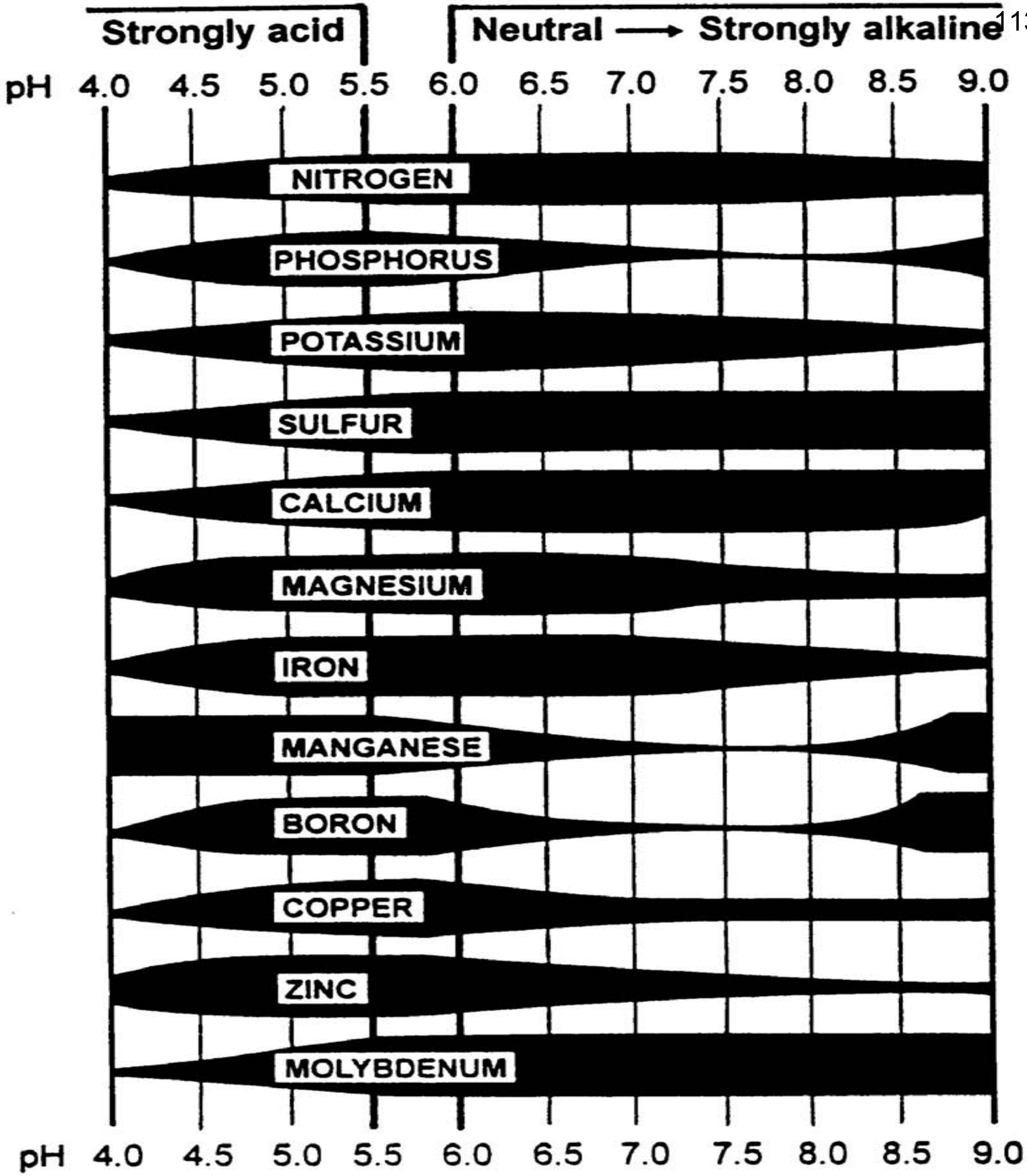
% Leaf samples showing high Zn levels > 25ppm



Industry trend in leaf samples showing marginal Fe, Cu and Mn levels



Nutrient availability and soil pH

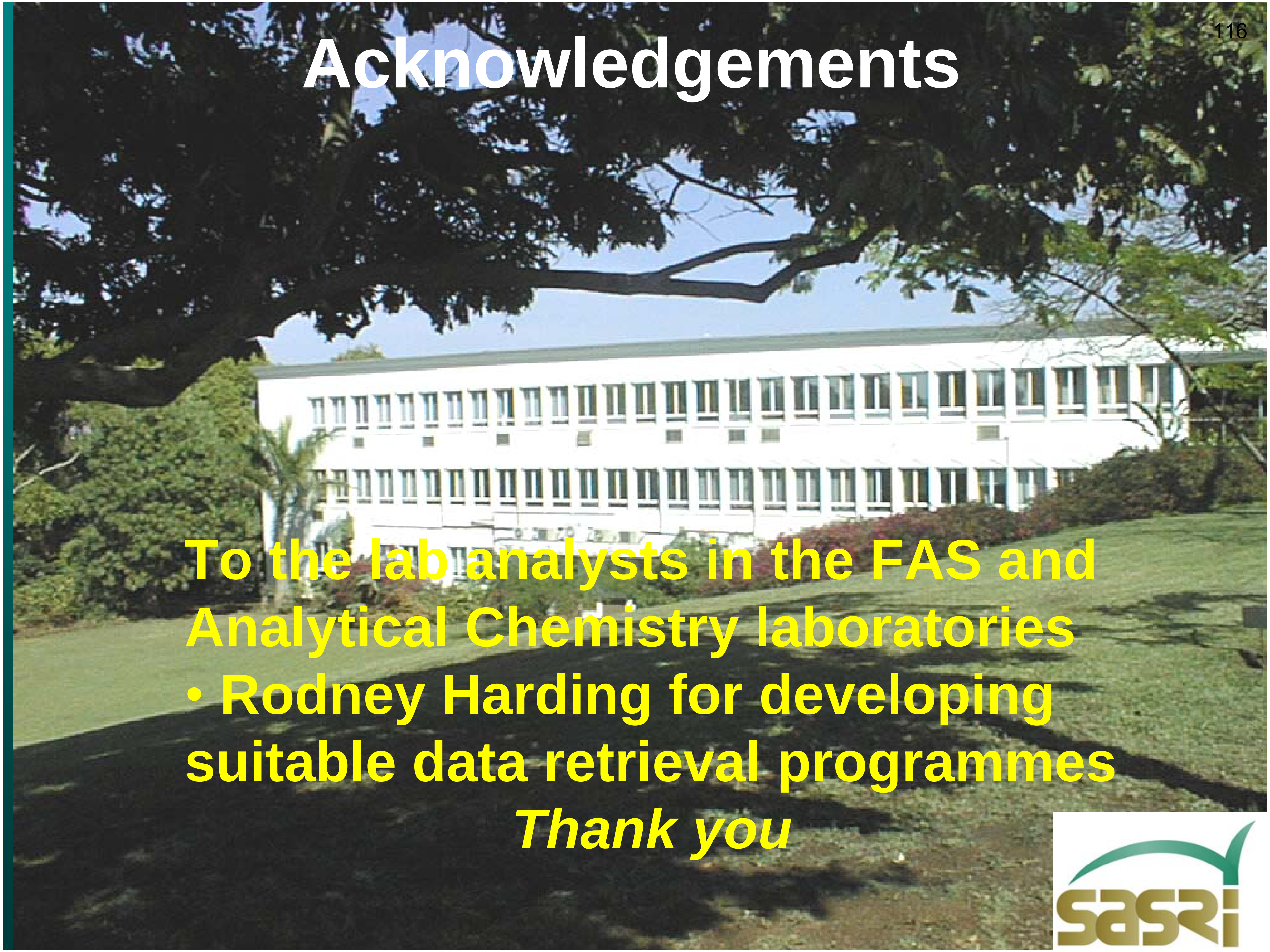


Conclusions

- Since 1980 large decline in Zn deficiency due to introduction of zincated fertilisers in early seventies
- Trial evidence shows substantial yield responses to Fe and Zn treatment
- Overall low incidence of Cu, Mn and Fe deficiency but frequency of samples with marginal levels increasing
- Evidence suggests that this may be linked to increasing acidification in coastal areas & alkalisation in irrigated areas
- Regular leaf and soil sample monitoring is justified

POTENTIAL RESEARCH NEEDS

- Micronutrient uptake curves for spring, summer, autumn and winter cycles
- Varietal correction factors for leaf analysis
- Improving the reliability of soil extraction procedures for Fe, Mn, Cu & B
- Establishing micronutrient toxicity levels
- Studying the Mo requirement in relation to nitrate reductase activity



Acknowledgements

To the lab analysts in the FAS and Analytical Chemistry laboratories

- **Rodney Harding for developing suitable data retrieval programmes**

Thank you

THE GLOBAL IMPACT OF ZINC MICRO NUTRIENT DEFICIENCIES

Michiel C. Laker

INTRODUCTION

Geomedical approach

ZINC IN HUMAN HEALTH

300 enzymes

Highest rated nutrient deficiency in the top 10 human health risk factors in developing countries (5th)

EXAMPLES OF ROLES OF ZINC IN HUMAN HEALTH

- Maintains immune system
- Essential for normal brain development and functioning
- Reduces vulnerability to malaria, pneumonia, diarrhoea
- Deficiency increases dwarfism

ZINC NUTRITION

- **Bio-availability and absorbability**
- **Effects of phytate, fibre, Vit. C**

REMEDIATION OF ZINC DEFICIENCIES IN DIET

- Supplementation
- Food fortification
- Changing diet or dietary habits
- “Field fortification” (Fertilization)

ZINC UPTAKE BY CROPS

Differences between crops

Differences between cultivars

ZINC IN SOILS

Two types of deficiencies:

- **Absolute deficiencies**
- **Induced deficiencies**

FACTORS ASSOCIATED WITH ABSOLUTE DEFICIENCIES OF ZINC IN SOILS

1. Parent materials like sandstone or granite
2. Sandy textures
3. Highly weathered and/or leached soils
4. High pH and calcareousness

FACTORS CAUSING INDUCED ZINC DEFICIENCIES IN SOILS

1. Injudicious liming
2. Injudicious phosphorus fertilization
3. Topsoil removal

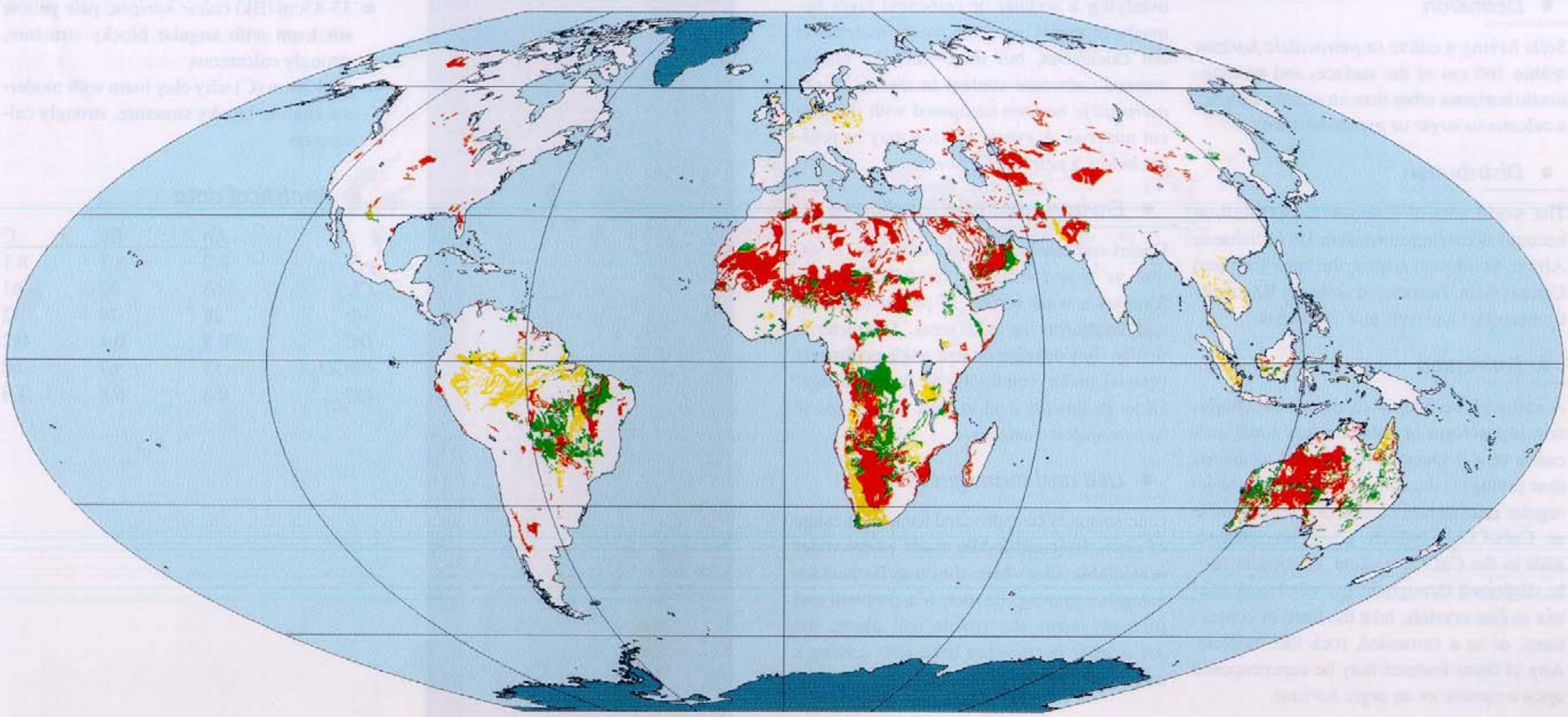
APPLICATION OF ZINC

1. Foliar sprays
2. Soil application of Zn compounds
3. Zn enrichment of NPK fertilizers

PROPOSED STRATEGY

1. Identify "zinc deficiency crisis areas" by means of systematic soil fertility surveys and the use of "pedological logic".
2. Use Zn-enriched NPK fertilizers – to improve both Zn content of diet and crop yields

• Distribution of Arenosols •

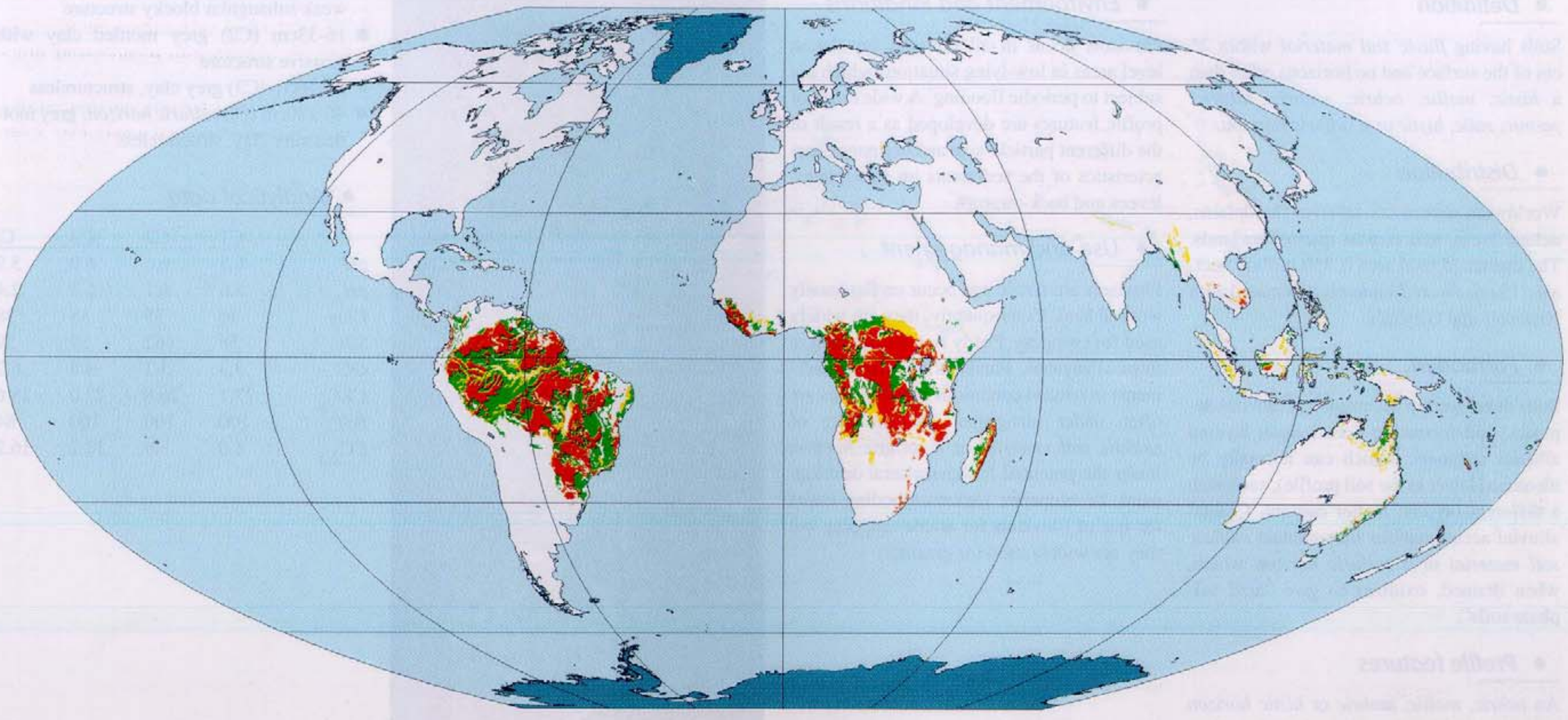


Dominant | Associated | Inclusions | Miscellaneous lands (Glaciers, No data)

Flat Polar Quartic Projection

FAO-GIS, February 1998

• Distribution of Ferralsols •



Dominant | Associated | Inclusions | Miscellaneous lands (Glaciers, No data)

Flat Polar Quartic Projection

FAO-GIS, February 1998

Zinc in Forages for Dairy Cows

Acknowledgements:

Mart Farina
Joanne Mann
Nicky Findlay

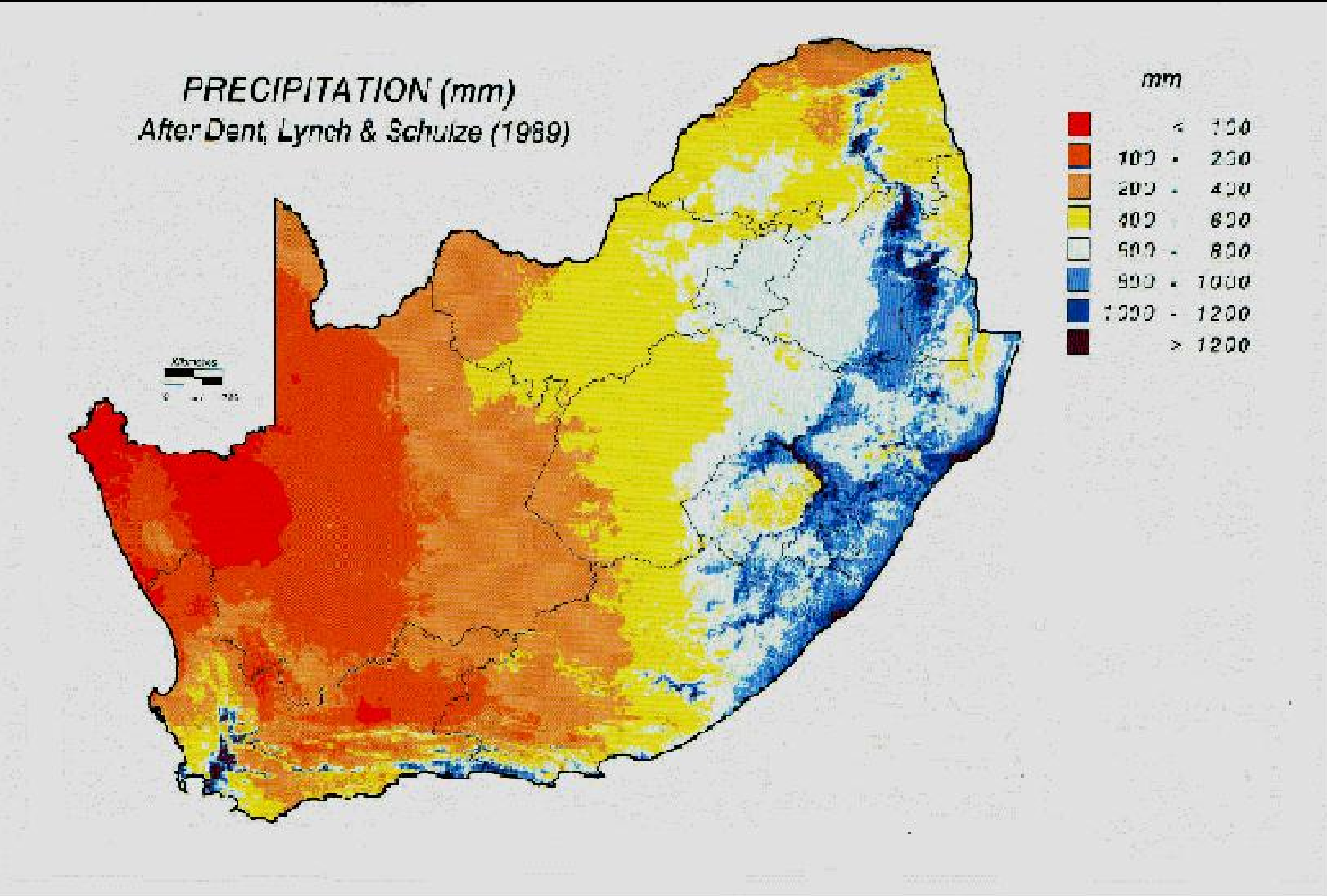

PRECIPITATION (mm)
After Dent, Lynch & Schulze (1989)
Kilometres
mm
< 100
100 - 200
200 - 400
400 - 600
600 - 800
800 - 1000
1000 - 1200
> 1200

Photo: Alan Manson


TRAIL BOSS


SILAGE
SYSTEMS
20

Major forages:

- Kikuyu
- Annual ryegrass
- Perennial ryegrass
- White clover
- Maize silage

Zinc in forages for dairy cows

- Essential for plant growth and high yields
- Essential for animal health and productivity

In the higher rainfall areas of SA, Zn deficiency frequently encountered in crops


Photo: Mart Farina


Photo: Mart Farina

Soil P = 1.5 ppm, Zn = 0.3 ppm. MAP(0.75% Zn) applied to soil surface @ 600 kg/ha after planting.

Correction of Zn deficiency

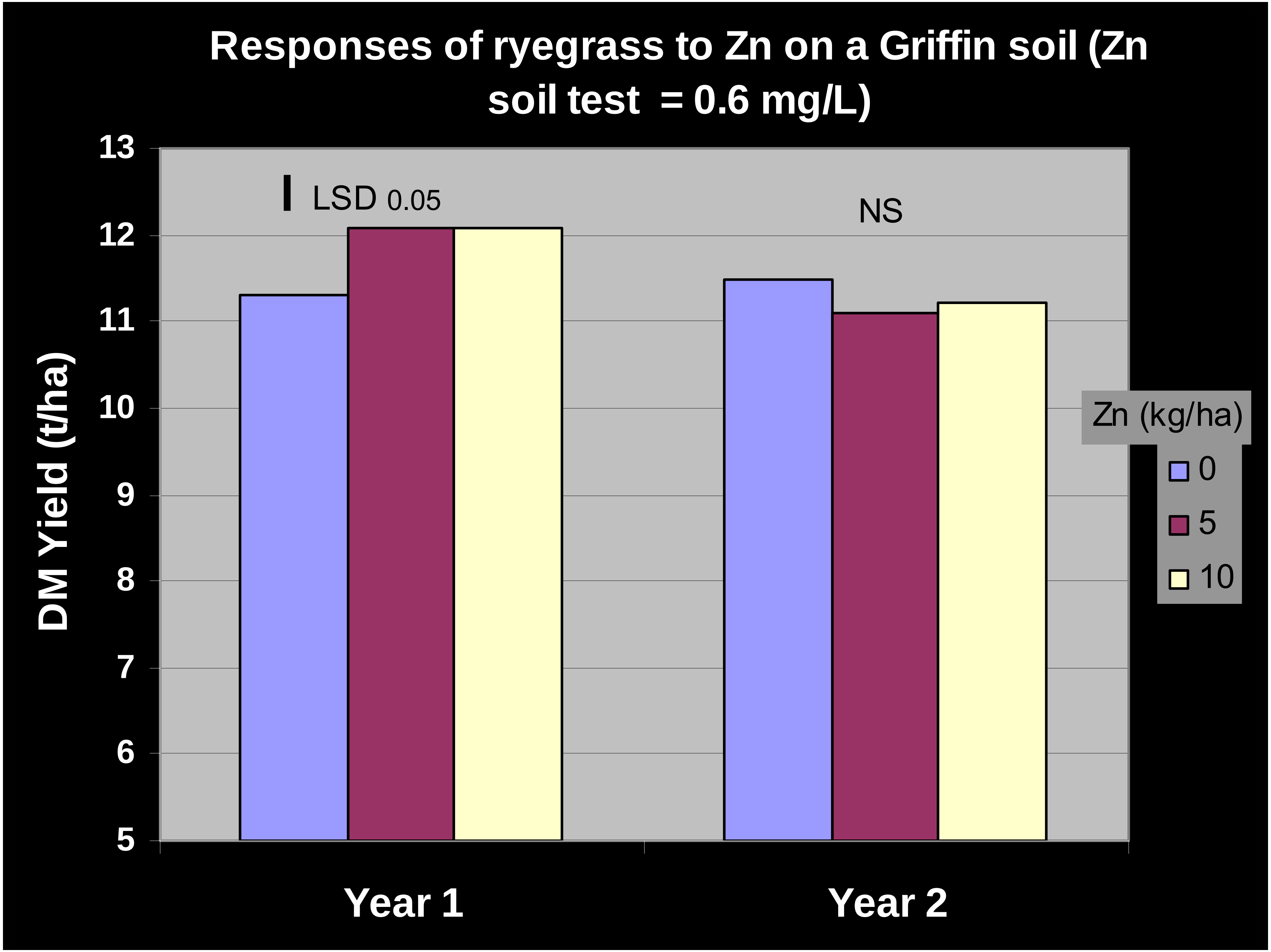
- Zinc oxide – low solubility

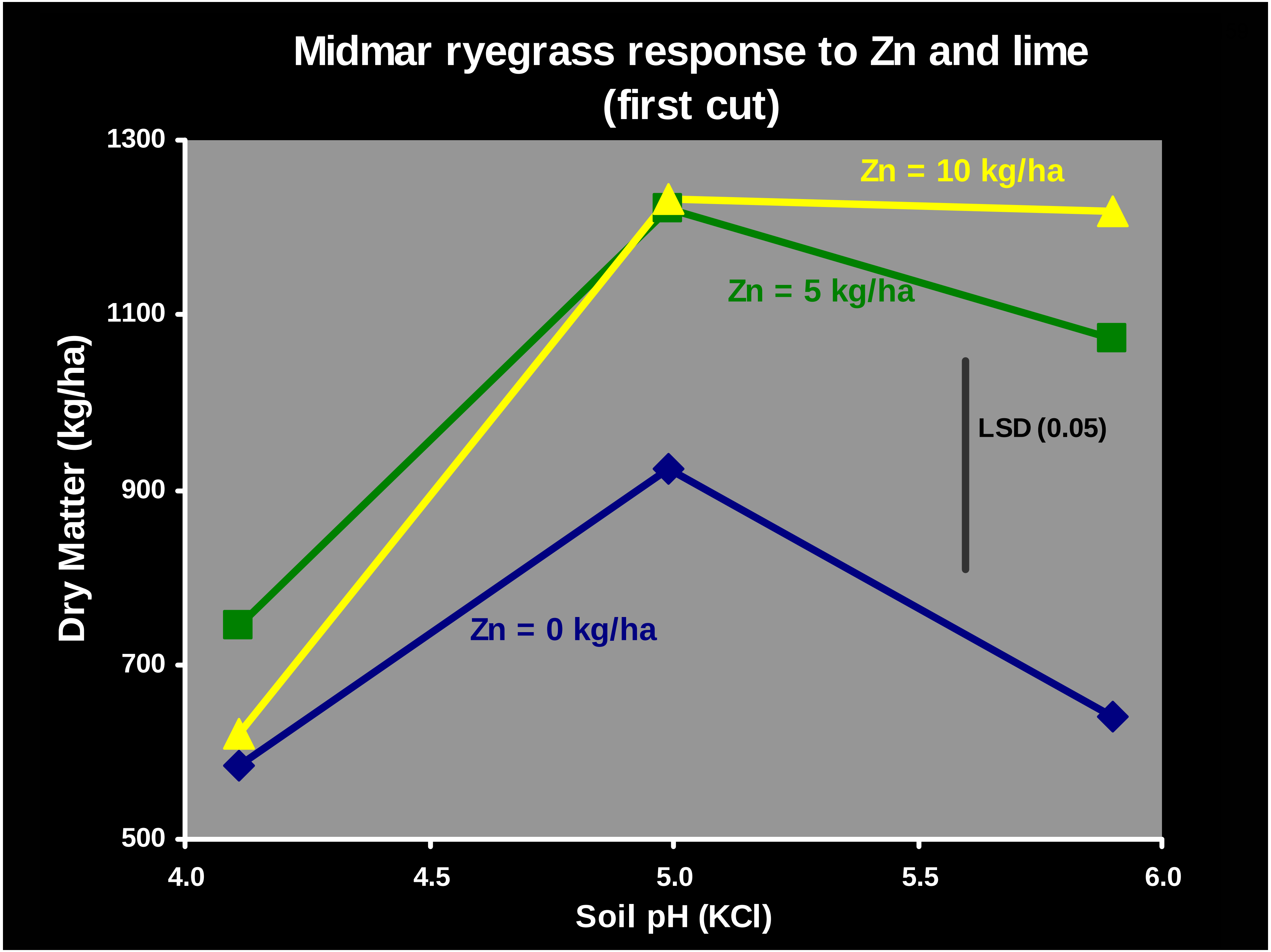
- Zinc oxide granules in fertilizer bulk blends of limited value (poor spread, low solubility)

- In DAP and MAP, zinc incorporated in granules - acidity generated improves Zn availability

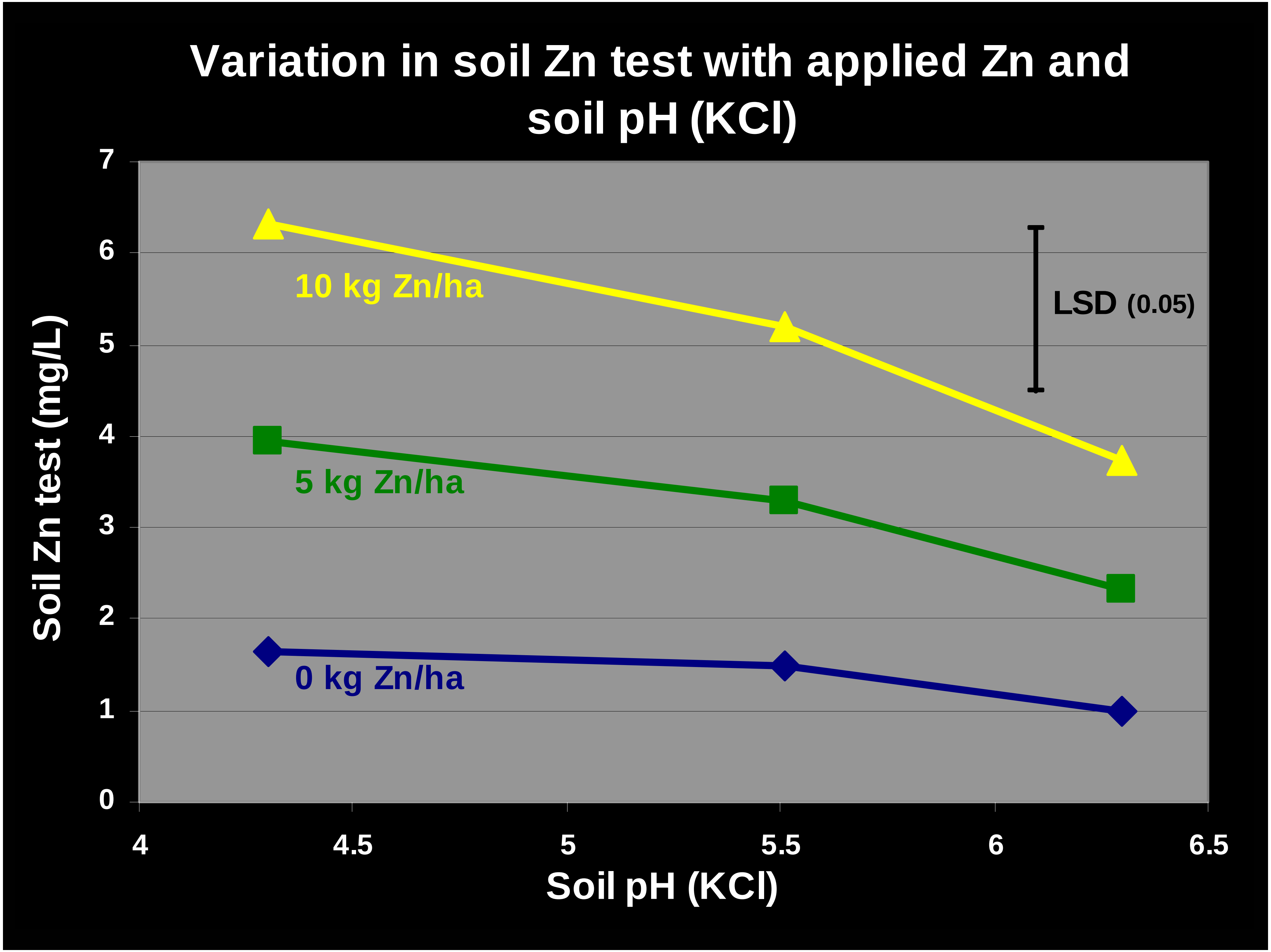
Pasture field trials with Zn as a factor

Species	Number of trials	Trial design	Zn effects on yield
kikuyu	5	Multi-nutrient (randomized blocks)	nil
ryegrass	1	Factorial with lime	positive
white clover	1	Factorial with lime	nil

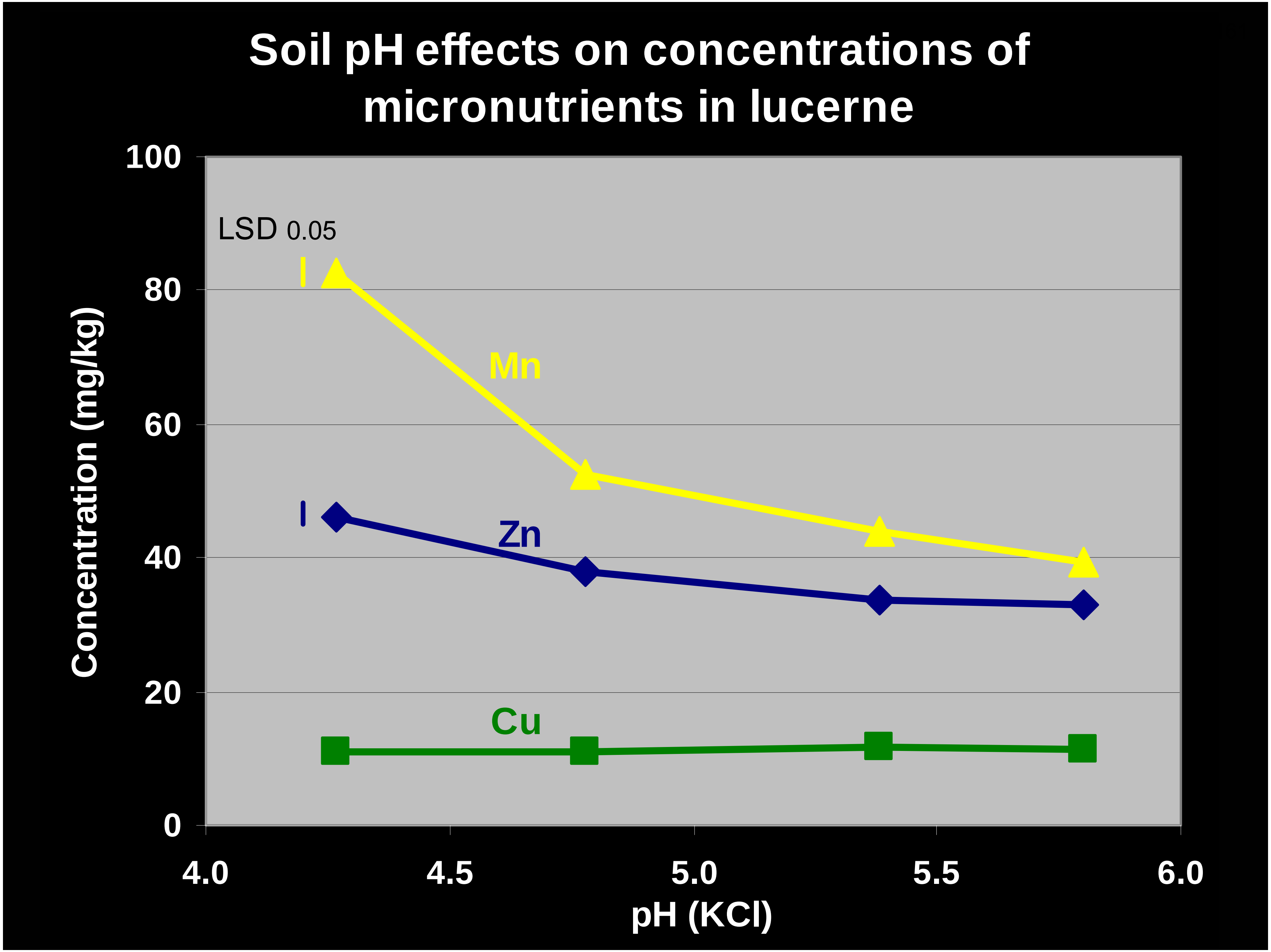

Responses of ryegrass to Zn on a Griffin soil (Zn soil test = 0.6 mg/L)
13
12
11
10
9
8
7
6
5
DM Yield (t/ha)
LSD 0.05
NS
Zn (kg/ha)
0
5
10
Year 1
Year 2

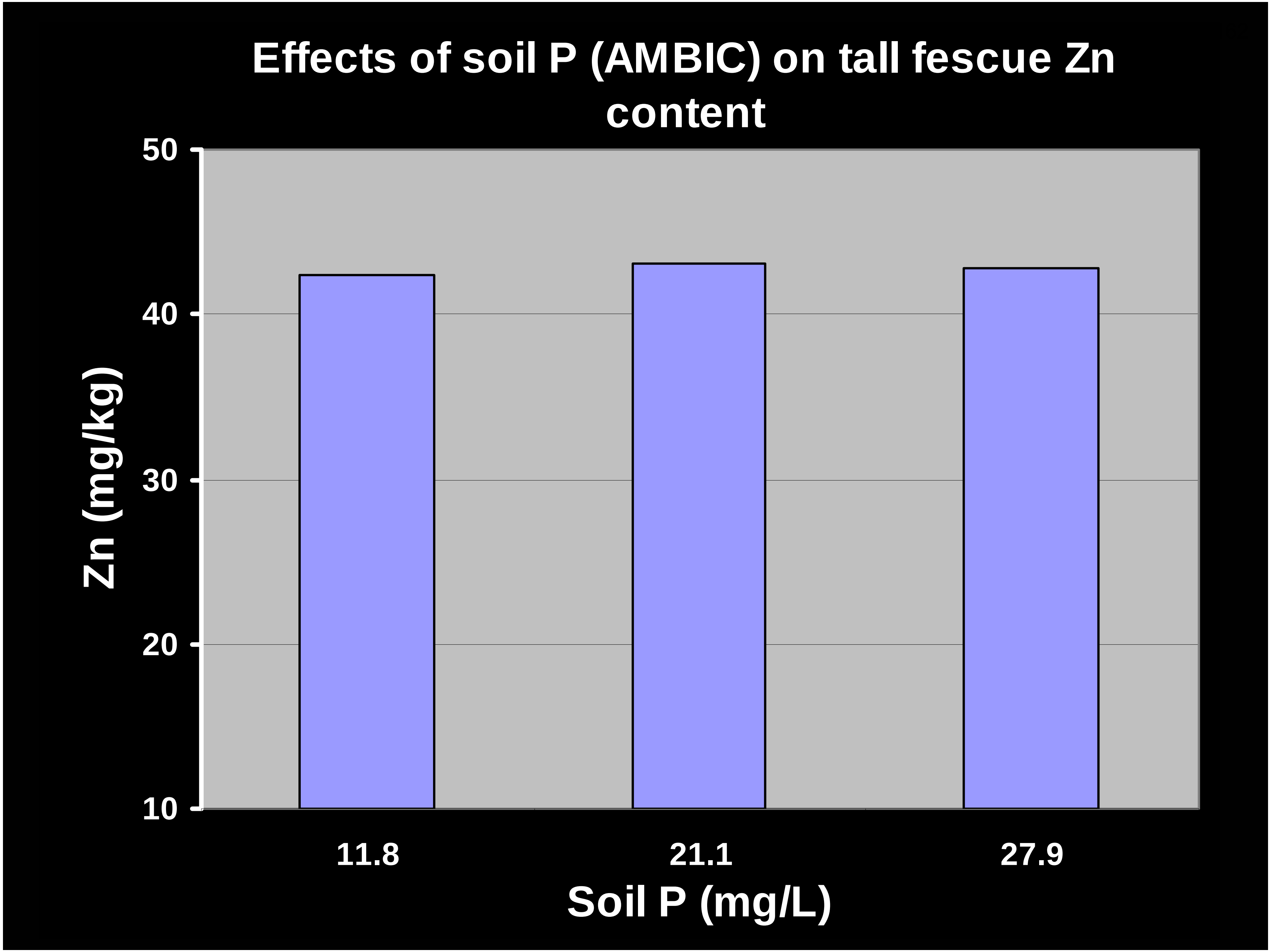


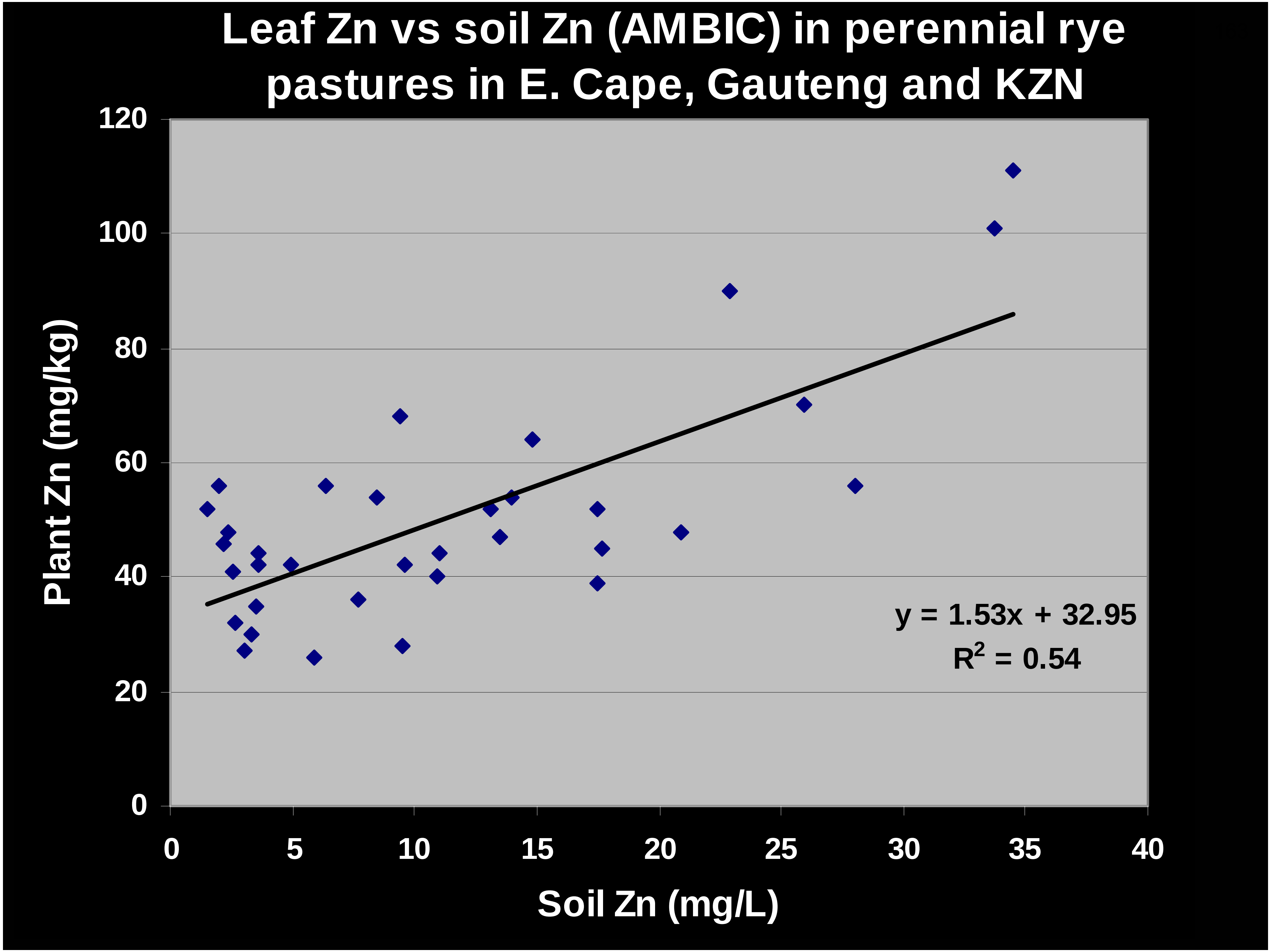
Midmar ryegrass response to Zn and lime
(first cut)
Zn = 10 kg/ha
Zn = 5 kg/ha
Zn = 0 kg/ha
LSD (0.05)
1300
1100
900
700
500
Dry Matter (kg/ha)
4.0
4.5
5.0
5.5
6.0
Soil pH (KCl)



Variation in soil Zn test with applied Zn and soil pH (KCl)
Soil Zn test (mg/L)
7
6
5
4
3
2
1
0
4
4.5
5
5.5
6
6.5
Soil pH (KCl)
10 kg Zn/ha
5 kg Zn/ha
0 kg Zn/ha
LSD (0.05)


Soil pH effects on concentrations of micronutrients in lucerne
100
80
60
40
20
0
Concentration (mg/kg)
LSD 0.05
Mn
Zn
Cu
4.0
4.5
5.0
5.5
6.0
pH (KCl)


Effects of soil P (AMBIC) on tall fescue Zn content
50
40
30
20
10
Zn (mg/kg)
11.8
21.1
27.9
Soil P (mg/L)


Leaf Zn vs soil Zn (AMBIC) in perennial rye pastures in E. Cape, Gauteng and KZN
120
100
80
60
40
20
0
Plant Zn (mg/kg)
0
5
10
15
20
25
30
35
40
Soil Zn (mg/L)
y = 1.53x + 32.95
R2 = 0.54

Zinc in dairy cows

- Role in many *body functions*
- Very important for healthy *immune system* (along with Cu and Se)
- Critical for *keratin* synthesis
  - keratin main constituent of hoof tissue
  - keratin lines teat canals (cows in milk) and plugs canal in dry cows

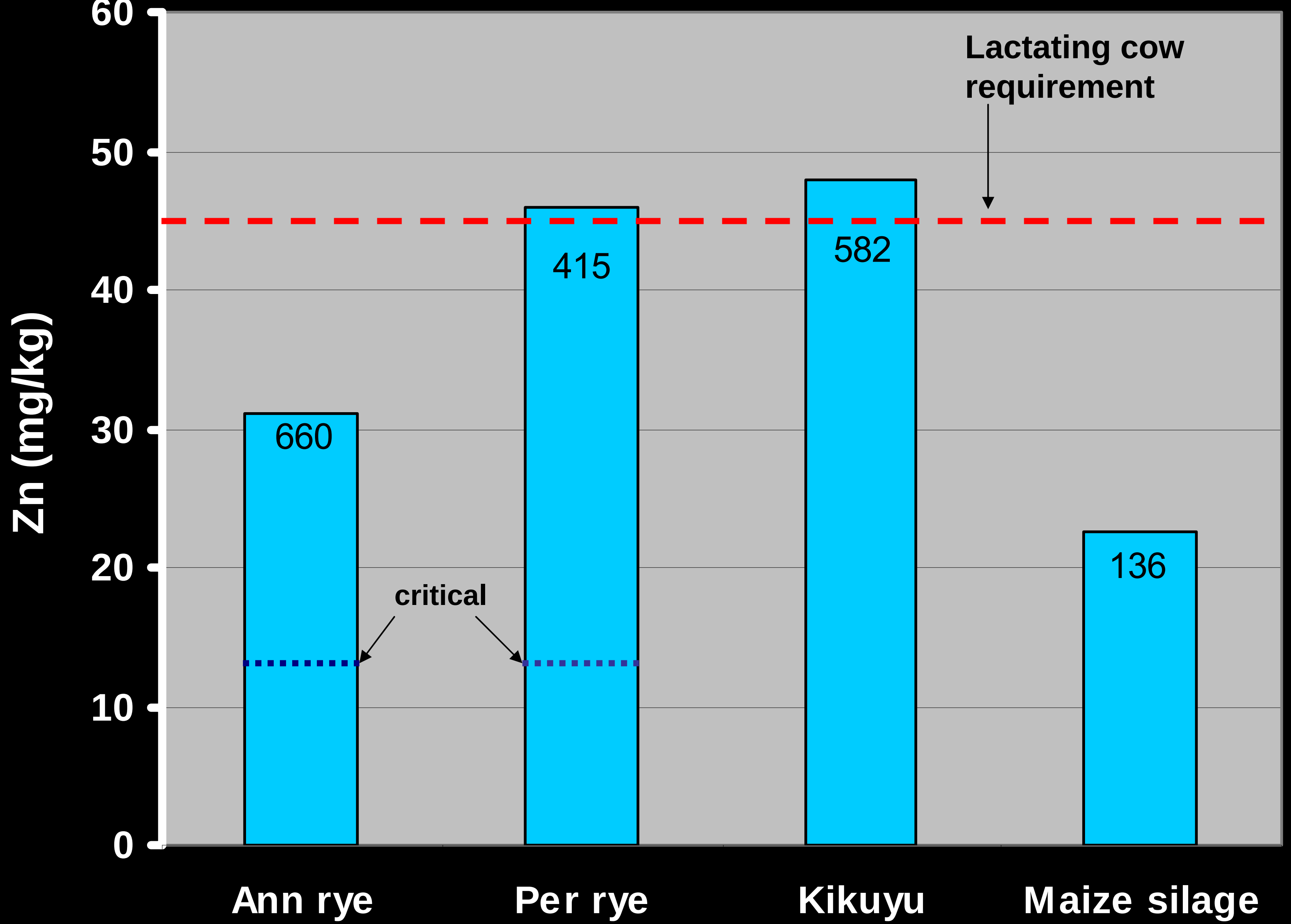
Major reasons for enforced culling:

- Poor fertility
- Mastitis
- Lameness

Adequate supplies of Zn essential for counteracting:

- Lameness
- Udder infections

Median Zn concentrations in fodder species



Zinc in forage species

Species	---------- Zn (mg/kg) ----------		
	median	min	max
Ann. ryegrass	31	6	77
Per. ryegrass	46	21	192
Kikuyu	48	21	154
Maize silage	22	12	50

Advantages of improved forage Zn concentrations:

- **Regular supply to animals**
- **Cost effective**
- **Organic Zn not antagonistic to Cu in absorption process**

CONCLUSIONS

- Crops such as maize frequently impacted by Zn deficiency.
- Physical and chemical forms of Zn fertilizers need attention.
- Zn deficiencies less common in pastures.

- **Adequate Zn supplies of major importance to the health and productivity of dairy cows.**
- **Forages – an excellent source of Zn for cows.**
- **Potential to supply much of cow’s Zn requirement through forages.**


FSR
9535

Molybdenum Relationships in Soils and Plants

Guy Thibaud

KwaZulu-Natal Department of Agriculture and Environmental Affairs.

Introduction

- Essentiality of Mo for growth of higher plants firmly established by Arnon and Stout (1939).
- Had serious doubts that field cases of Mo deficiency in plants would ever occur due to extremely low requirement.
- “Probably destined to remain forever a laboratory curiosity”

- A. J. Anderson (1942): Identified Mo as the limiting factor to clover production in some South Australian pastures.

    Observed remarkable increases in pasture production from the use of 5g/ha Mo as a fertilizer.

- In the ensuing years, Mo found to be limiting for plant growth on millions of hectares of land.

South Africa

► Mo deficiency recorded in a number of crops:

Lucerne	:	(Graven,1962; Roach & Beyers,1962; Beyers,1969).
Fruit / vegetable	:	(Roach & Beyers,1962; Pienaar & Bartel,1968).
Maize	:	(Du Toit,1962; Burrell, Roach & Shadwell,1966).

- Continued reports of Mo deficiency in maize in SA during the 1970's and 1980's (Blamey,1972; Farwell, 1984)

- Mo re-enforcement of seed has long been a standard practice in the SA maize industry.

Mo deficiency in seed maize near Rietvlei during the 2002/03 season

Soyabean yield responses to Mo in excess of 170% recorded at Greytown in 1991/92.

Source: M. Farina

Mo in Soils

- Average total Mo content of soils = 1-3 mg kg^{-1}.
  - Mo fixed within crystal lattice of primary & secondary minerals.
  - Mo retained by clay minerals, especially sequioxides, as the MoO_4^{2-} anion.
  - Organically-bound Mo.
  - Water-soluble Mo.

Extractable Mo content of Soils

Distribution of oxalate extractable Mo in 200 topsoils (0-20 cm)

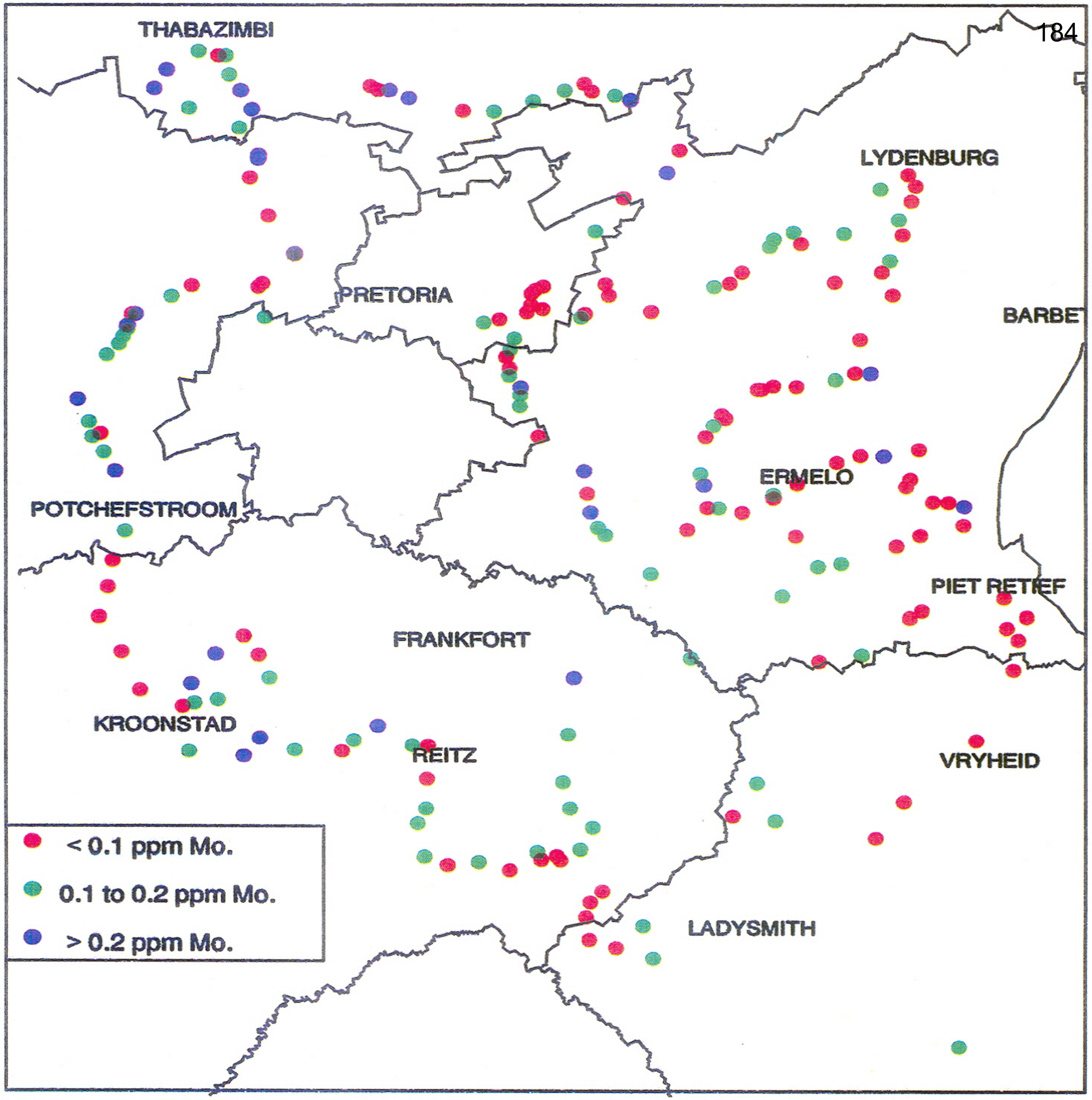


Figure 2 Geographical distribution of sampling points and class intervals for oxalate extractable Mo.

Effect of soil type and depth on oxalate extractable Mo.

Soil type	No. of profiles	Sampling depth (m)			
		0-0.2	0.2-0.4	0.4-0.6	0.6-0.8
Hutton	65	0.14	0.16	0.21	0.25
Clovelly	28	0.08	0.10	0.16	0.18
Avalon	24	0.09	0.12	0.31	0.39
Shortlands	11	0.22	0.23	0.18	0.20
Rensburg	9	0.08	0.07	0.05	0.04
Oakleaf	7	0.21	0.19	0.25	0.13
Glenrosa	7	0.12	0.14	0.23	0.27
Kroonstad	6	0.11	0.13	0.19	0.06
Valsrivier	6	0.15	0.13	0.12	0.10

Effect of soil type and depth on oxalate extractable Mo.

Soil type	No. of profiles	Sampling depth (m)			
		0-0.2	0.2-0.4	0.4-0.6	0.6-0.8
Pinedene	6	0.16	0.17	0.23	0.19
Longlands	5	0.07	0.06	0.05	0.28
Arcadia	4	0.10	0.06	0.04	0.04
Griffin	4	0.08	0.08	0.27	0.36
Cartref	3	0.07	0.04	0.17	0.14
Westleigh	3	0.08	0.14	0.16	0.22
Bonheim	2	0.21	0.12	0.12	0.04
Willowbrook	2	0.12	0.05	0.05	0.04
Estcourt	1	0.15	0.20	0.16	0.13

Effect of lithology on average topsoil Mo content of soils in north-eastern RSA

Lithology	Oxalate Extr. Mo (mg kg^{-1})
Sandstone Quartzite Granite	0.07
Dolerite Diabase	0.10
Shale	0.10 - 0.14
Basalt Andesite Hornfels Ferrogabro	0.17 -0.19
Dolomite	0.53

Mo in Plants

Molybdenum: - Physiological Functions

- ► Nitrate assimilation (nitrate reductase: $NO_3^- \xrightarrow{Mo} NO_2^-$)
- ► Biological nitrogen fixation by rhizobia (nitrogenase: $N_2 \xrightarrow{Mo} NH_3$)
- ► Formation of ureides (zanthine dehydrogenase: purines eg. xanthine $\xrightarrow{Mo}$ uric acid)
- ► Catabolism of S-containing amino acids (sulfite oxidase: $SO_3 \xrightarrow{Mo} SO_4$)

Molybdenum in Plants

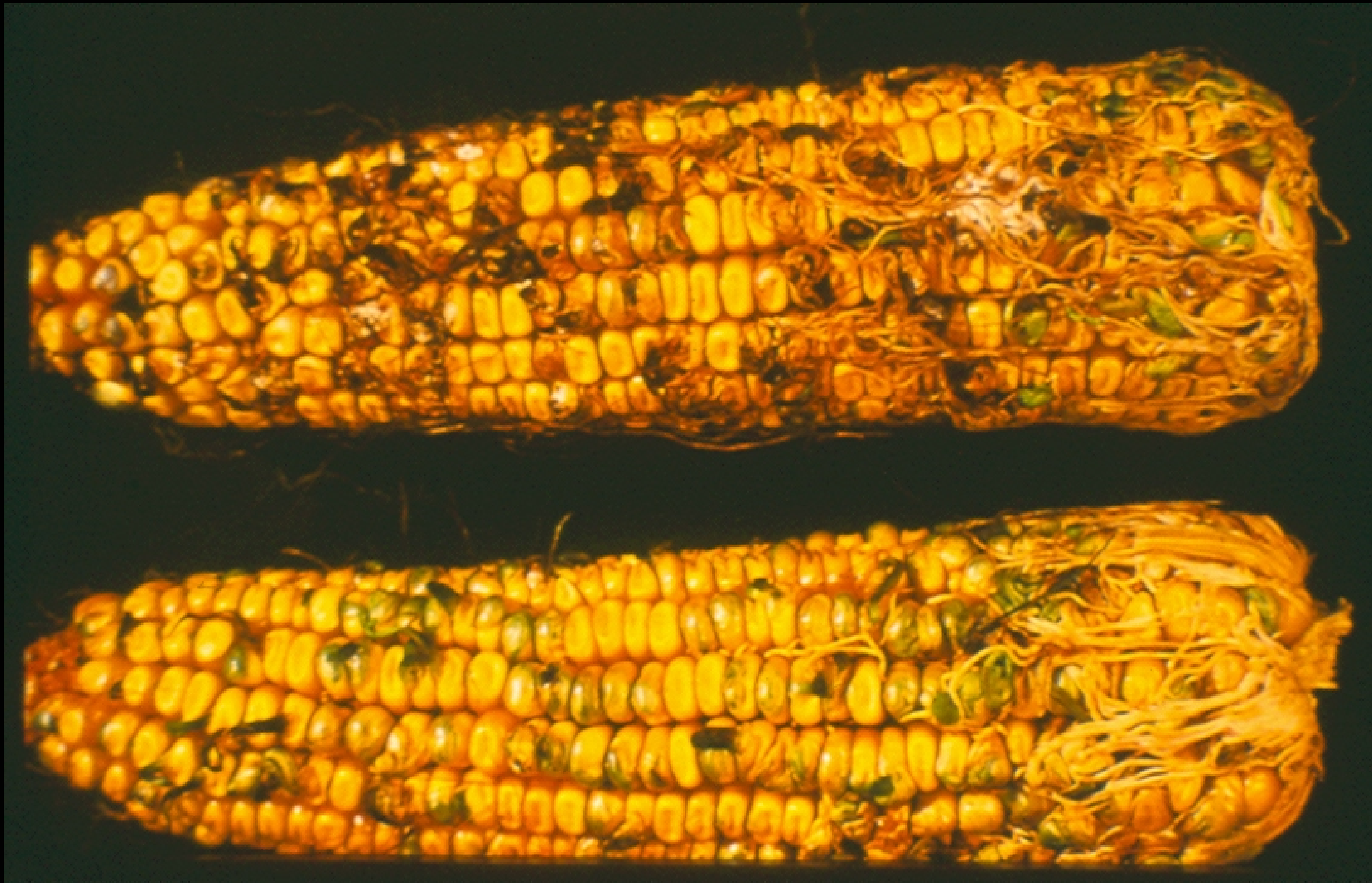
- Of all the essential micronutrients needed for the growth of higher plants, Mo required in the least.
- Typically, 0.1 – 0.5 mg kg^{-1} in leaves considered adequate for most crops.
- Symbiotic bacteria require about 10 times more Mo for N_2-fixation than does the host plant for NO_3^- assimilation.

Consequences & Symptoms of Mo Deficiency

Symptoms of Mo deficiency in maize near Rietvlei.

Source: M. Farina

Excess nitrate accumulation owing to Mo deficiency predisposes maize to pre-germination



Source: M Farina

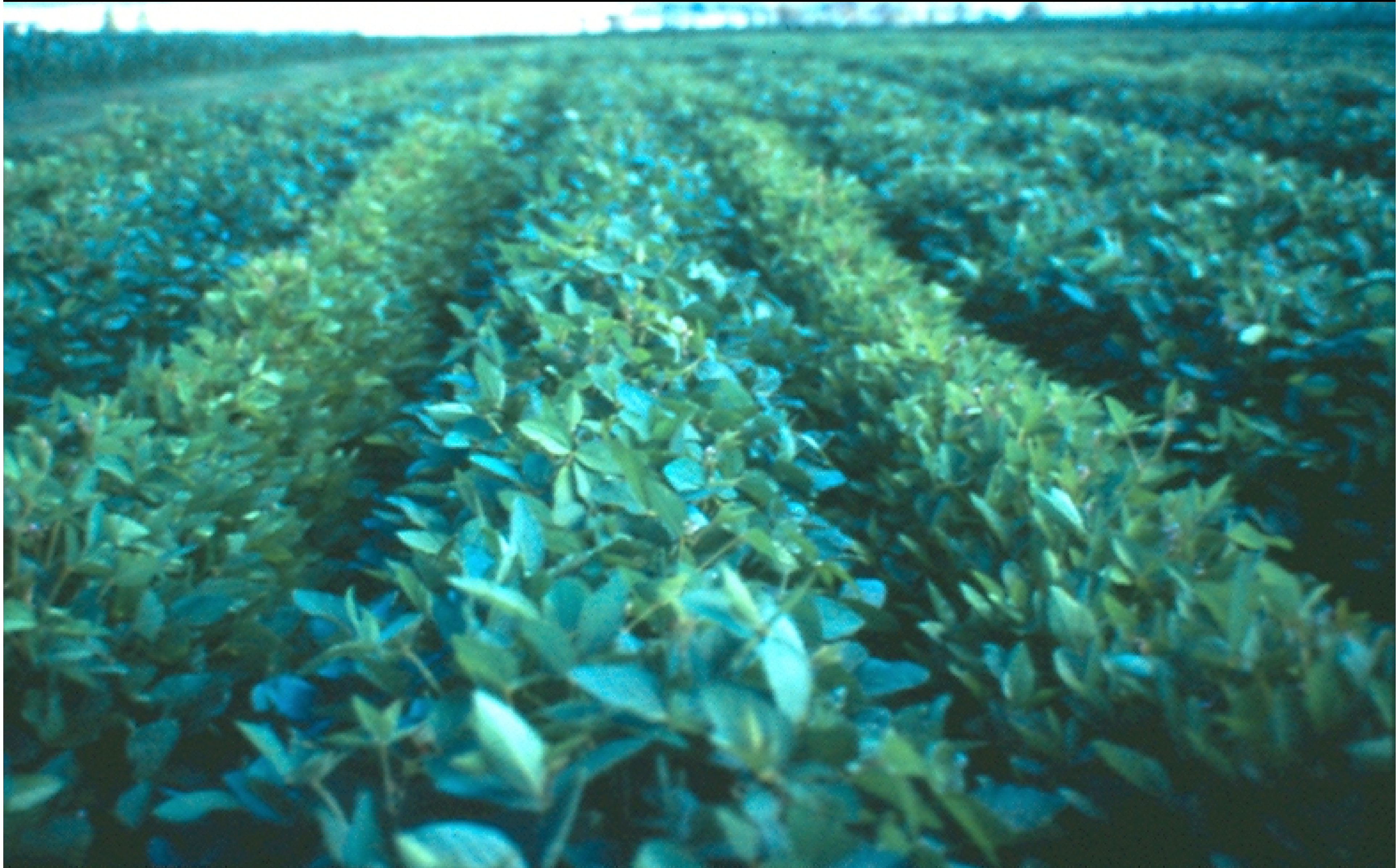
Mo deficiency in soyabean on a Balmoral clay soil at Greytown

Source: M. Farina

Effect of Mo seed treatment on soyabean in an acid Balmoral clay soil at Greytown.

Source M.Farina

Soyabean response to Mo on a sandy Avalon at Dundee.



Source M. Farina

Mo Toxicity

- Mo toxicity in plants not observed under field conditions. Has been induced in hydroponics and sand culture studies.

- Molybdenosis " peat scours". Consumption of feed matter containing > 5 mg kg^{-1} Mo by ruminants is considered hazardous if Cu intake is low (feed < 4 mg kg^{-1}Cu).

Factors Affecting Mo availability and Crop Response to Mo

Soil Factors

- pH.
- Mineralogy.
- Redox potential.
- Organic matter.
- Availability of other nutrients (N, P & S).

Soil pH

- Mo solubility usually increases rapidly with an increase in pH.
- Ligand exchange mechanism involving MoO_4^{2-} and OH^-.
- Liming acid soils is known to increase plant available Mo.

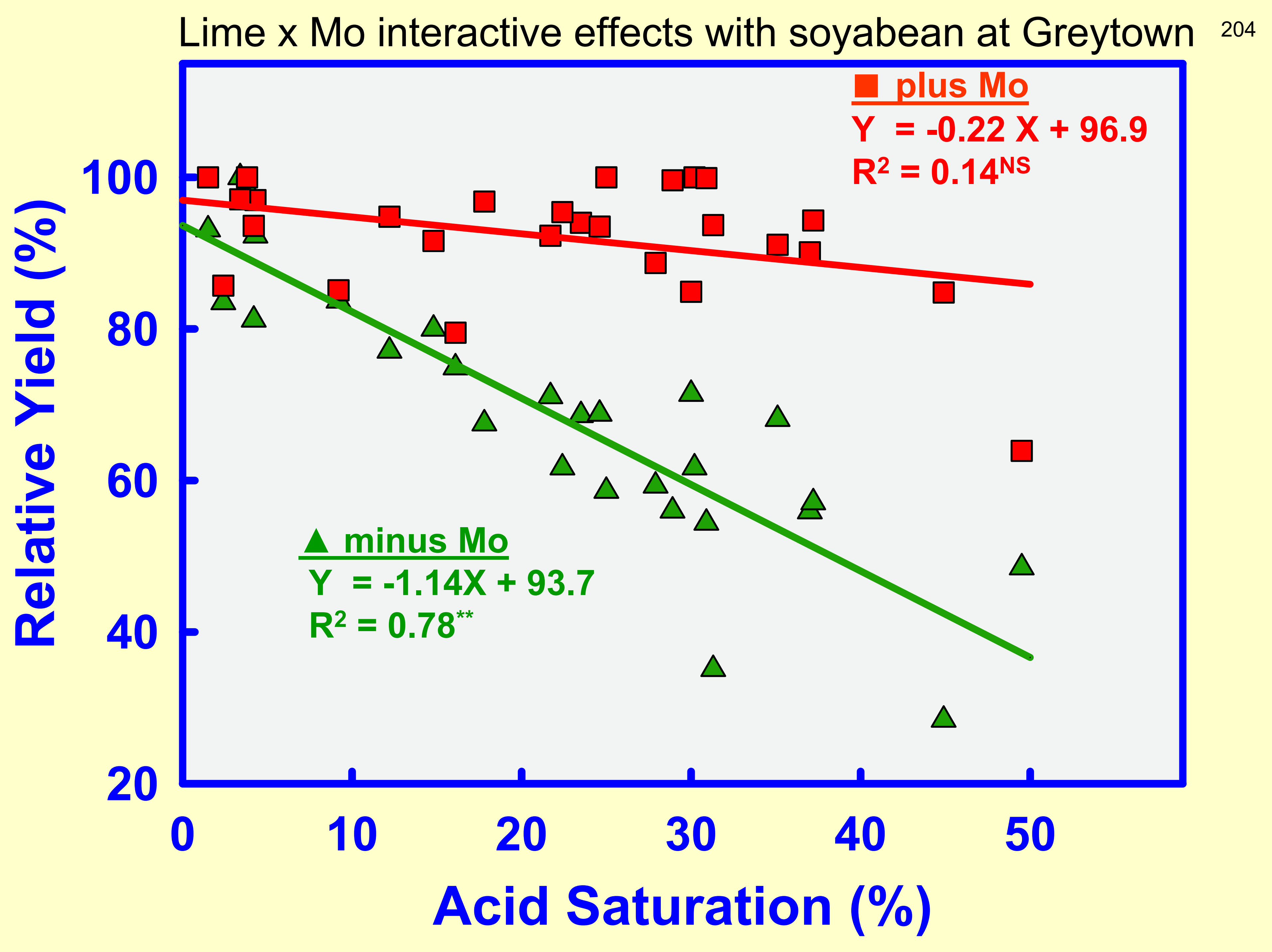
Effect of soil pH on Mo availability to maize near Rietvlei

Effect of soil pH on the Mo content of dry bean seed produced at two locations in KwaZulu-Natal.

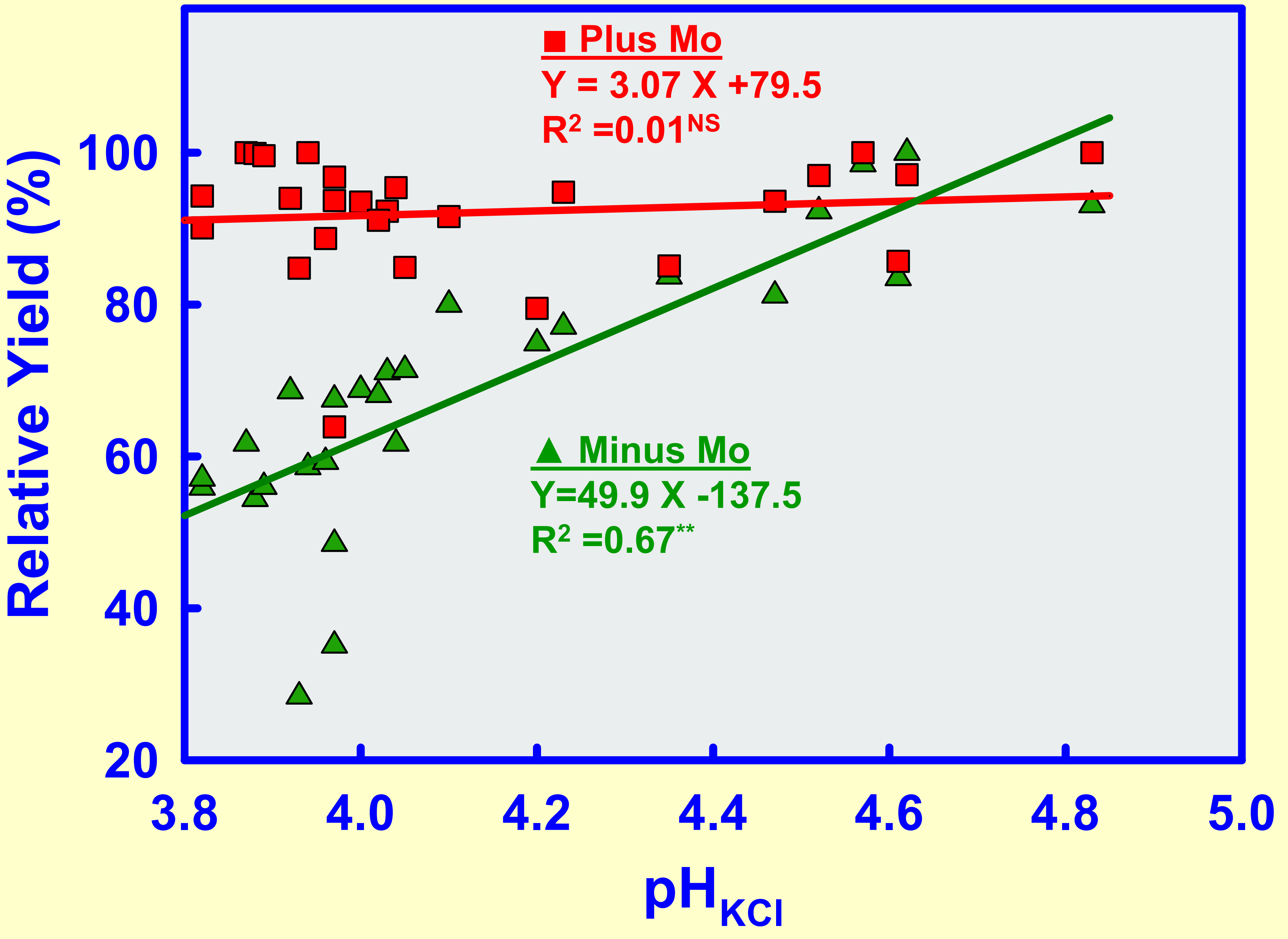
pH_{KCl}	Seed Mo (mg kg^{-1})	pH_{KCl}	Seed Mo (mg kg^{-1})
Cedara		Obonjaneni	
4.08	0.06	4.02	0.09
4.11	0.07	4.16	0.38
4.22	0.10	4.19	0.59
4.44	0.16	4.42	0.67

Lime x Mo interactive effects with soyabean on a Balmoral clay at Greytown.

Source: M. Farina


Lime x Mo interactive effects with soyabean at Greytown
plus Mo
Y = -0.22 X + 96.9
R2 = 0.14NS
minus Mo
Y = -1.14X + 93.7
R2 = 0.78**
Relative Yield (%)
100
80
60
40
20
0
10
20
30
40
50
Acid Saturation (%)

Lime x Mo interactive effects with soyabean at Greytown



Mineralogy

- Adsorption or precipitation of MoO_4^{2-} ions by hydrous oxides of Fe & Al are major processes in formation of unavailable Mo in soils.

- Fe oxide content of soil found to be negatively correlated with Mo uptake by plants.

Redox Potential and Organic Matter

- Poorly drained soils are frequently associated with excess Mo in herbage, especially where impeded drainage is accompanied by organic matter accumulation.

- Increases in pH and reduction of Fe oxides at low redox values may increase solubility of ferric molybdate compounds or complexes.

Nutrient Interactions involving Mo

Phosphorus x Mo interactions

► Occurrence and interpretation of P x Mo interactive effects are less well documented and clear cut than for lime.

► Several references made to the fact that P enhances Mo uptake.

→ Formation of phosphomolybdate complexes

→ $H_2PO_4^-$ exchange for MoO_4^{2-}

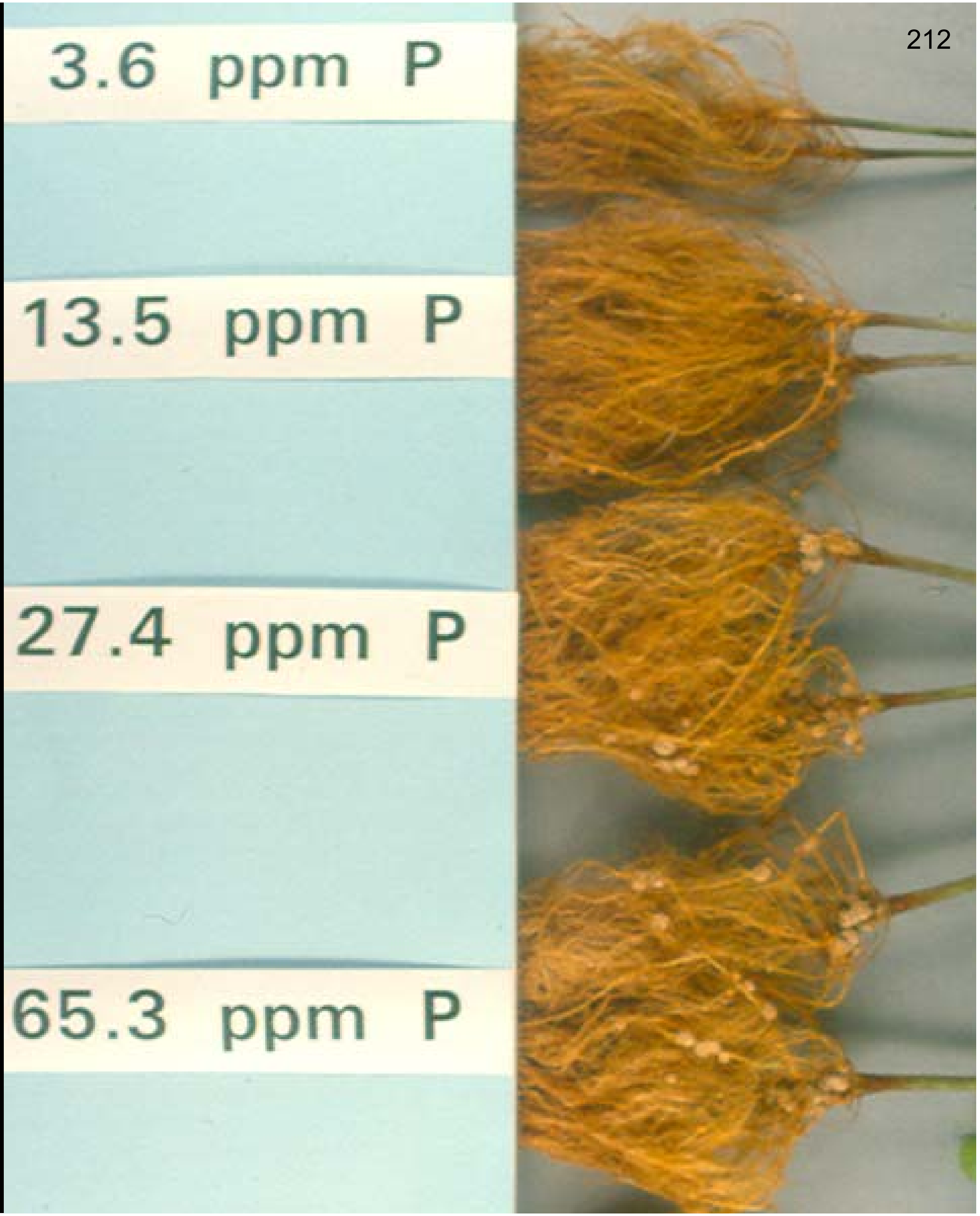
Phosphorus effects on soyabean yield and leaf Mo content on a Normandien clay loam at Geluksburg.

Soil P (mg L^{-1})	Yield (kg ha^{-1})	Leaf Mo (mg kg^{-1})
2.5	1099	0.11
4.2	1366	0.10
10.7	1777	0.12
32.9	2051	0.13
Lsd (0.05)	108	0.2

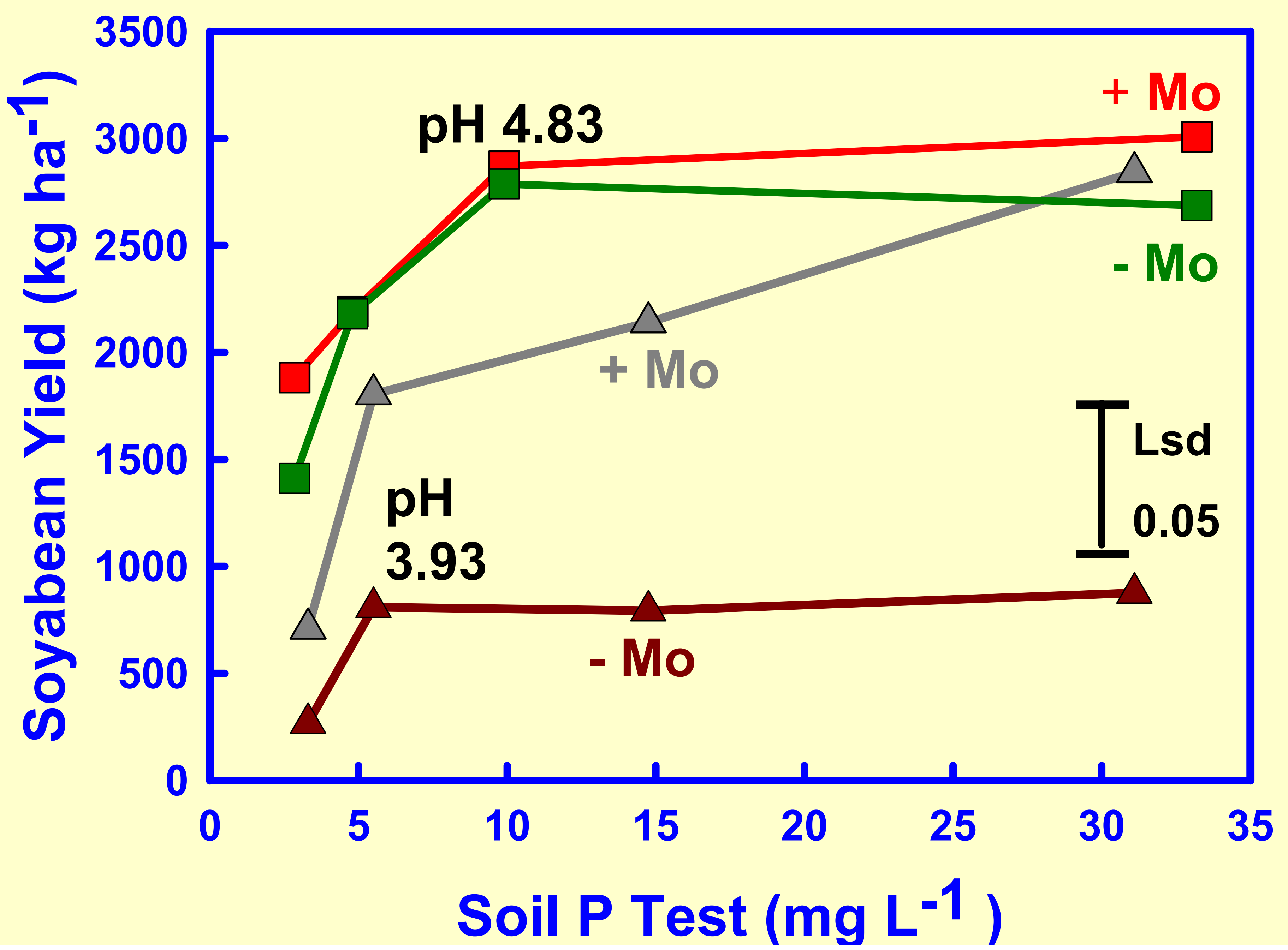
P effects on soyabean yield, seed Mo content and Mo uptake on a Balmoral clay at Greytown.

Soil P	Yield	Seed Mo	Mo uptake
mg L^{-1}	kg ha^{-1}	mg kg^{-1}	g ha-1
3.3	1263	0.31	0.45
5.5	1596	0.21	0.38
11.5	2233	0.19	0.49
32.0	2366	0.14	0.39
		Lsd (0.05)	
2.0	227	0.07	NS

Effect of increasing soil P test on soyabean nodulation in a Balmoral clay



Mo x P x lime interactive effects on soyabean yield at Greytown



Sulphur x Mo Interactions

- Numerous reports of S depressing Mo uptake.
- Similar size of SO_4^{2-} and MoO_4^{2-} leads to antagonism at absorption sites on roots.

Gypsum effects on soyabean yield and leaf Mo content at two sites in KwaZulu-Natal.

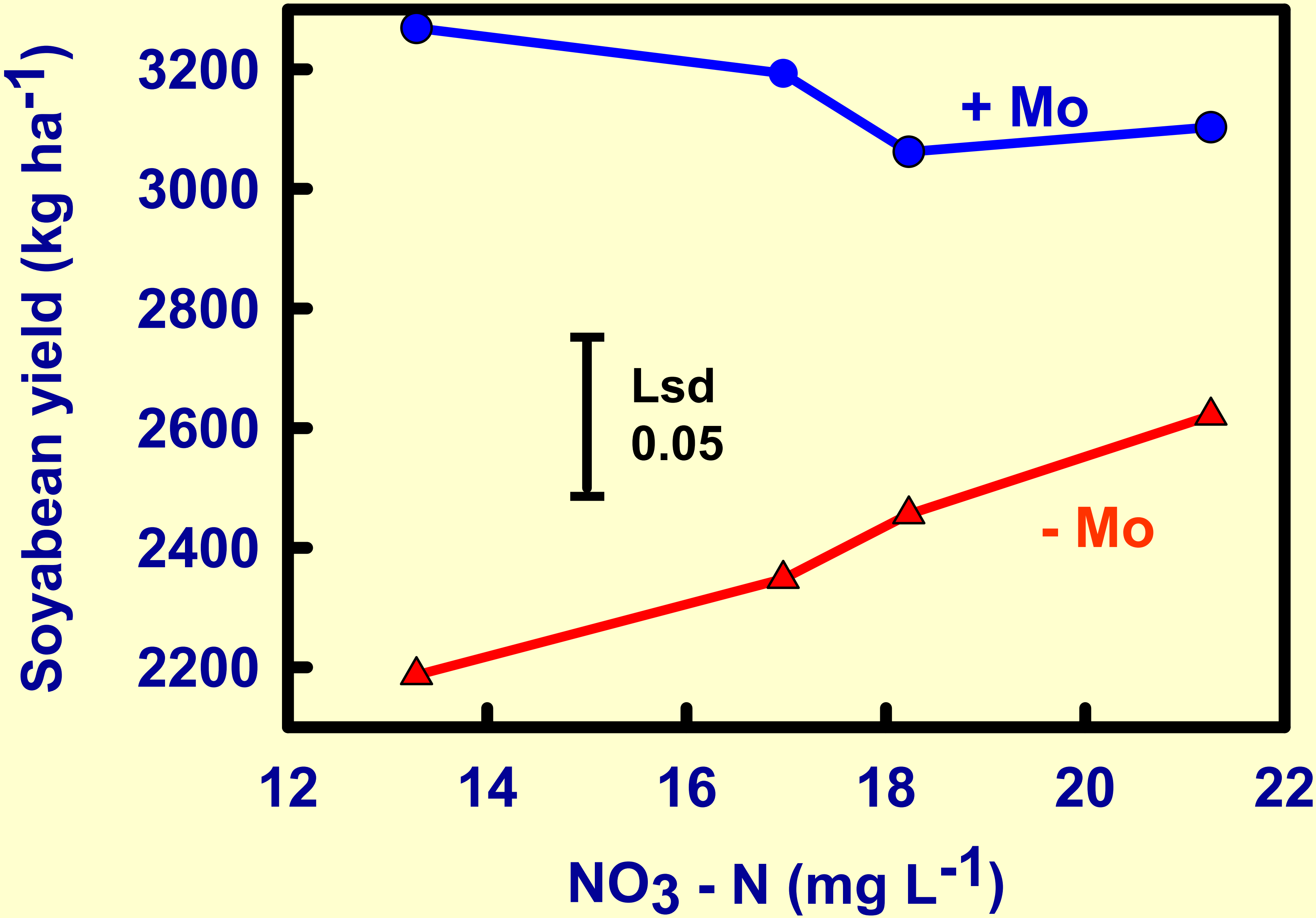
Gypsum ($Mg\ ha^{-1}$)	Yield ($Mg\ ha^{-1}$)	Leaf Mo ($mg\ kg^{-1}$)
	Gelukgsburg	
0.0	2.79	0.17
2.5	2.64	0.16
5.0	2.78	0.17
	Greytown	
0.0	1.89	0.22
1.0	1.95	0.22
2.0	1.97	0.23
3.0	2.10	0.23
4.0	2.02	0.20

Nitrogen x Mo Interactions

- Crops utilizing NH_4 – N as their main form of nitrogen have little or no requirement for Mo.

- In nodulated soyabean with impaired N_2-fixation & / or N-transport, negative Mo x residual soil N interactions sometimes occur.

Mo x residual soil N interaction at Bergville



Plant Factors Influencing Mo Needs

Plant species

Mo requirement

legumes > cruciferous crops and cucurbits > grasses

Mo = 4.6 $\mu g\ g^{-1}$

= 2.0 $\mu g\ seed^{-1}$

Mo = 9.9 $\mu g\ g^{-1}$

= 1.6 $\mu g\ seed^{-1}$

Mo x genotype interaction for dry bean on an acid, Hutton type soil, at Cedara.

Cultivar	Seed Mo	- Mo	+ Mo
	-- mg kg^{-1} --	---- yield (kg ha^{-1}) ----	
Star	0.10	2076	1828
PAN 159	0.05	2094	2102
Cerillos	0.06	2444	2769
PAN 181	0.06	2119	2353
PAN 146	0.07	2052	2316
PAN 150	0.07	2577	3289

Lsd (0.05): Mo = 163, Mo x cultivar = 500

Estimating Plant Available Mo in Soils

- ► Most widely employed method has been that of Grigg (1953): Over night extraction of the soil with 0.275 M oxalate (pH 3.3) using 1:10 soil:solution ratio.
- ► Oxalate method has several limitations.

Effect of pH on oxalate extractable Mo, seed Mo content and Mo uptake by soyabean on a heavy Hutton soil at Greytown.

pH_{KCl}	Oxalate extr. Mo	Seed Mo content	Mo uptake
	--------------- ($mg\ kg^{-1}$)	---------------	-- ($g\ ha^{-1}$) --
3.82	0.16	0.17	0.52
3.82	0.16	0.19	0.58
3.87	0.16	0.18	0.59
3.92	0.17	0.20	0.64
4.52	0.15	0.24	0.82
Lsd (0.05)	NS	0.04	0.15

Failure of oxalate extractable Mo to reflect the positive effect of increasing pH on plant available Mo led to the use of the term:

pH + 10 x ppm Mo

Interpretation Guide

Sedberry *et al* (1973)

critical pH + 10 x ppm Mo = 7.5 for soya

Mueller *et al* (1964)

critical pH + 10 x ppm Mo = 6.2 for lucerne

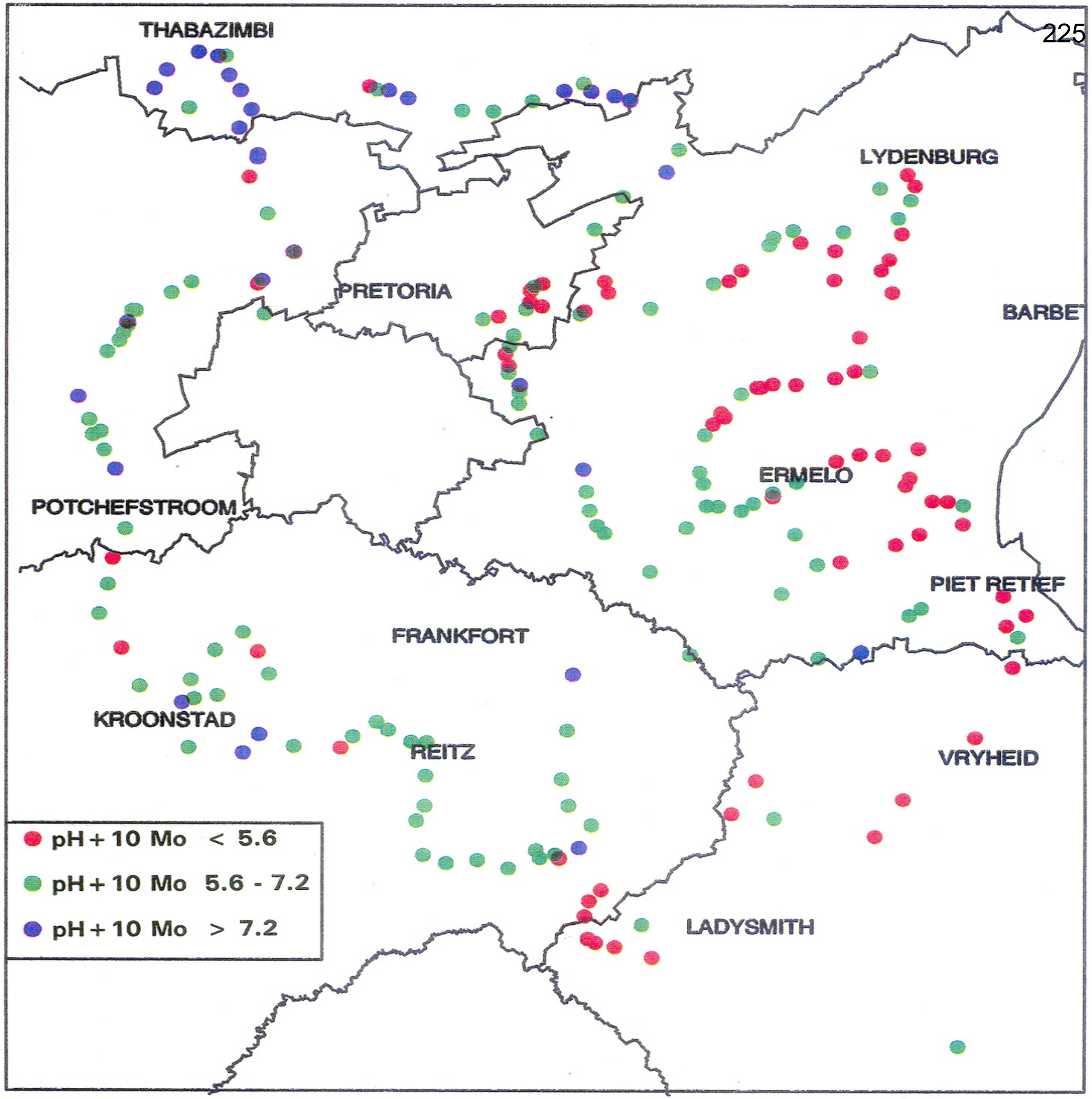


Figure 3 Geographical distribution of class intervals for the relationship (pH + 10 x ppm Mo).

Summary of selected soil properties and extent of soyabean response to Mo seed treatment on acid soils in KZN.

Soil type	Oxalate extractable Mo	Fe	Al	Mn	Maximum response
	$mg\ kg^{-1}$	---------- $g\ kg^{-1}$	----------		%
Normandien	0.138	2.28	2.52	0.026	10
Leksand	0.062	1.17	1.32	0.022	30
Bergville	0.114	1.94	1.32	0.093	49
Balmoral	0.158	7.70	4.43	0.179	84
Balmoral	0.141	8.03	5.07	0.190	173

Ratio of oxalate extractable Al, Fe & Mn (%) to oxalate extractable Mo (ppm) on acid soils in KZN.

Al/Mo	Fe/Mo	Mn/Mo
1.8	1.7	0.2
0.8	1.9	0.4
1.1	1.7	0.7
2.8	4.9	1.1
3.6	5.7	1.4

Increasing soya response to Mo

Mo as a Fertilizer

- **Sources**
  - sodium molybdate (39% Mo)
  - ammonium molybdate (54% Mo)
  - molybdenum trioxide (66% Mo)

- Amount of Mo required to correct deficiency varies with soil type, plant species, source and method of application.

Conclusions

- Mo deficiency enhances the apparent need for lime.
- pH elevation through massive inputs of lime on acid heavy-textured kaolinitic soils will not ensure adequate Mo reserves in seed produced.
- Legume (eg soyabean) response to P is reduced under Mo-deficient conditions.
- Owing to numerous interactive effects, soil testing for Mo is too ambiguous & unreliable for making on-farm Mo recommendations.

wes-kaap landbou
agriculture western cape
ezolimo entshona koloni

Micronutrient and heavy metal excess and toxicity in Southern African soils

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INTRODUCTION

- There is a fine balance between sufficiency and excess for micro-nutrients like boron and copper. Natural or applied excesses of these and most micronutrients lead to antagonism, or worse, toxicity.

- For copper, examples ranging from deficiency, to excess, to toxicity are described and clear antagonisms are revealed.

- Boron excess in soil is well known, but less well known is the effect of excess B sprayed on crops and the toxicity or imbalance it causes.

- Zinc excess is rare in field soils but rising levels in manured soils may constitute a human toxicity hazard in vegetables for instance.

- High nickel is toxic and chromium potentially so in ultramafic soils, which are significant in area in parts of Southern Africa. Mechanisms of toxicity are discussed, as these are important in knowing how to treat affected soils and crops.

COPPER EXCESS AND TOXICITY

Antagonism of Cu with other elements

- Cereals especially wheat are sensitive to copper deficiency which is manifested by drooping, purplish ears devoid of grain.
- Deficiency is mostly associated with sandier soils low in organic matter in Southern Africa.
- For instance, granite sands in Zimbabwe have had to have copper application where irrigated wheat is grown in rotation with maize and tobacco. High zinc and P applications for these preceding crops were at first thought to aggravate copper deficiency.
- Pot trials showed that this was not the case (Fig 1); the photograph shows grain response to Cu despite Zn and P additions in some treatments [1].

Fig. 1. Wheat response to Cu in a Cu deficient soil. Despite Zn & P additions in factorial design, no interference with Cu occurred (I only of 6 reps. shown for clarity).

COPPER EXCESS AND TOXICITY

Excess Copper application

- Low soil copper was the problem at responsive field trial sites (Fig. 2); the chart shows however, that yield was repressed at double the recommended rate of soil Cu application.

- At another site soil copper was adequate and yield was repressed by copper application to soil and in most cases to leaves (Fig. 3) [2].

- It was also observed in the field, that soil applied copper sulphate inadvertently applied at twice the intended rate (20 kg $CuSO_4$/ha instead of 10 kg $CuSO_4$/ha), induced what appeared to be Fe-chlorosis in a strip where an overlap during application occurred (Fig 4).

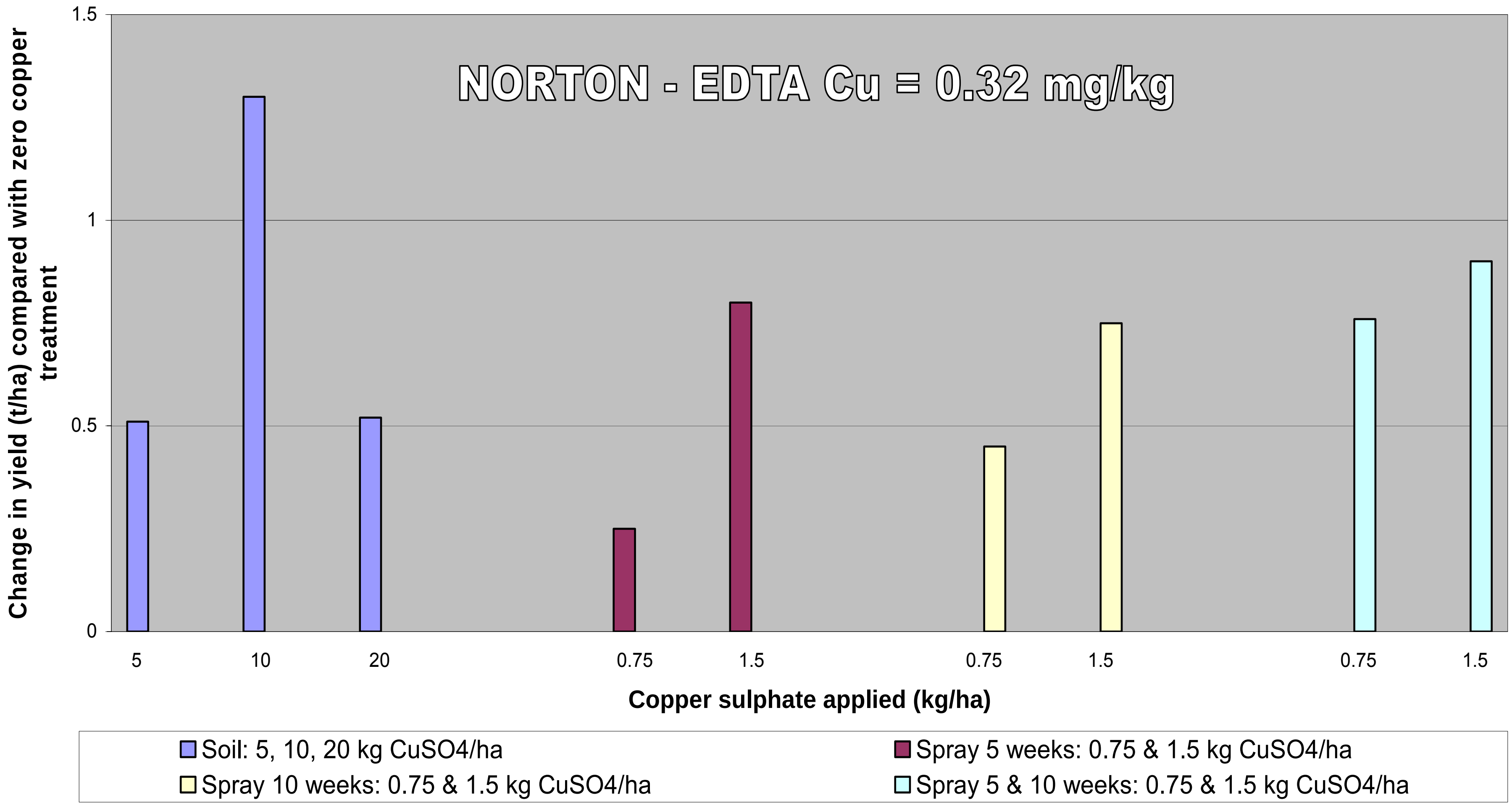

Fig. 2. Effect of rate and method of copper sulphate application on wheat yield: Norton site.

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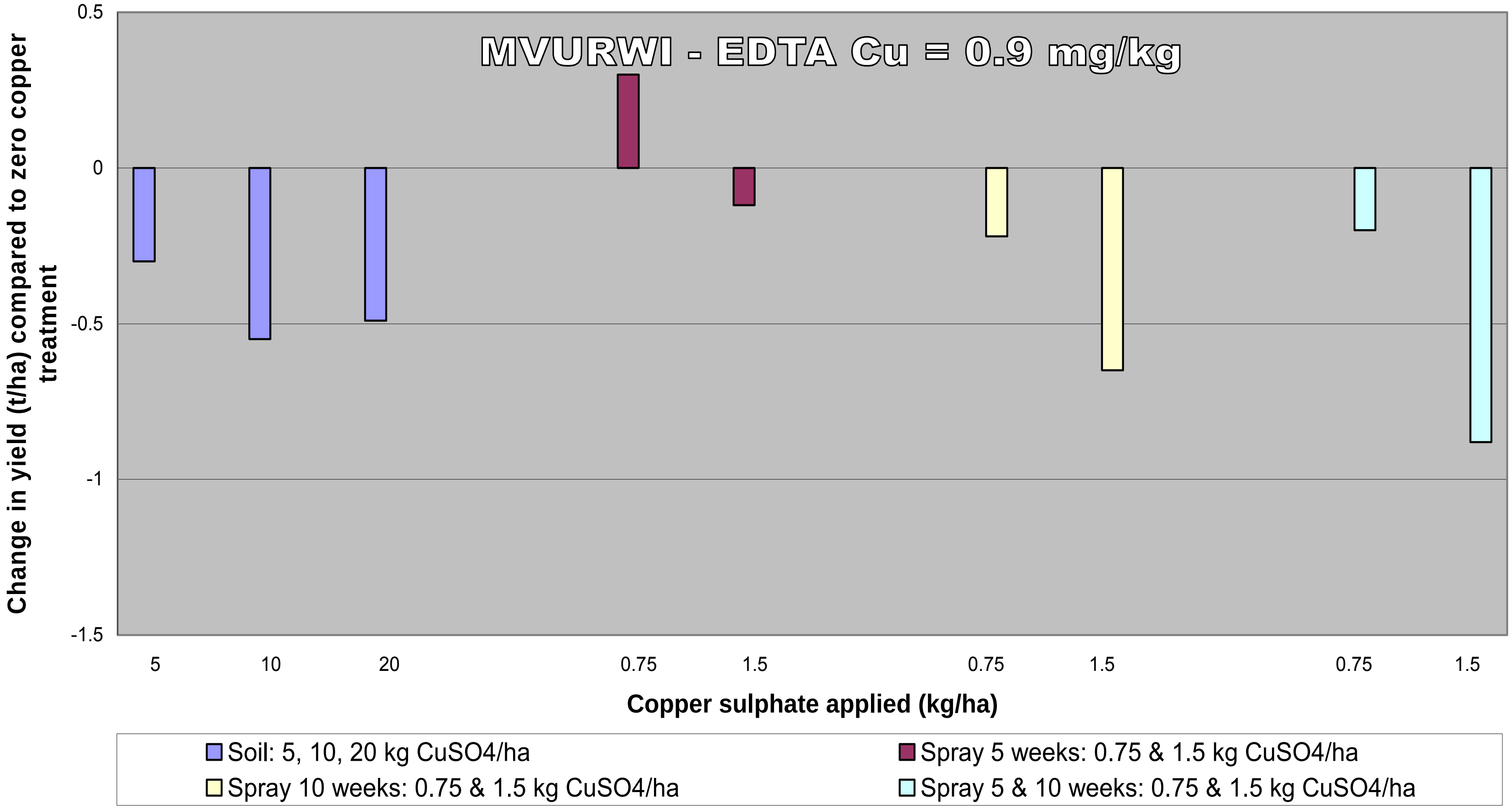

Fig. 3. Effect of rate and method of copper sulphate application on wheat yield: Mvurwi site

COPPER EXCESS AND TOXICITY

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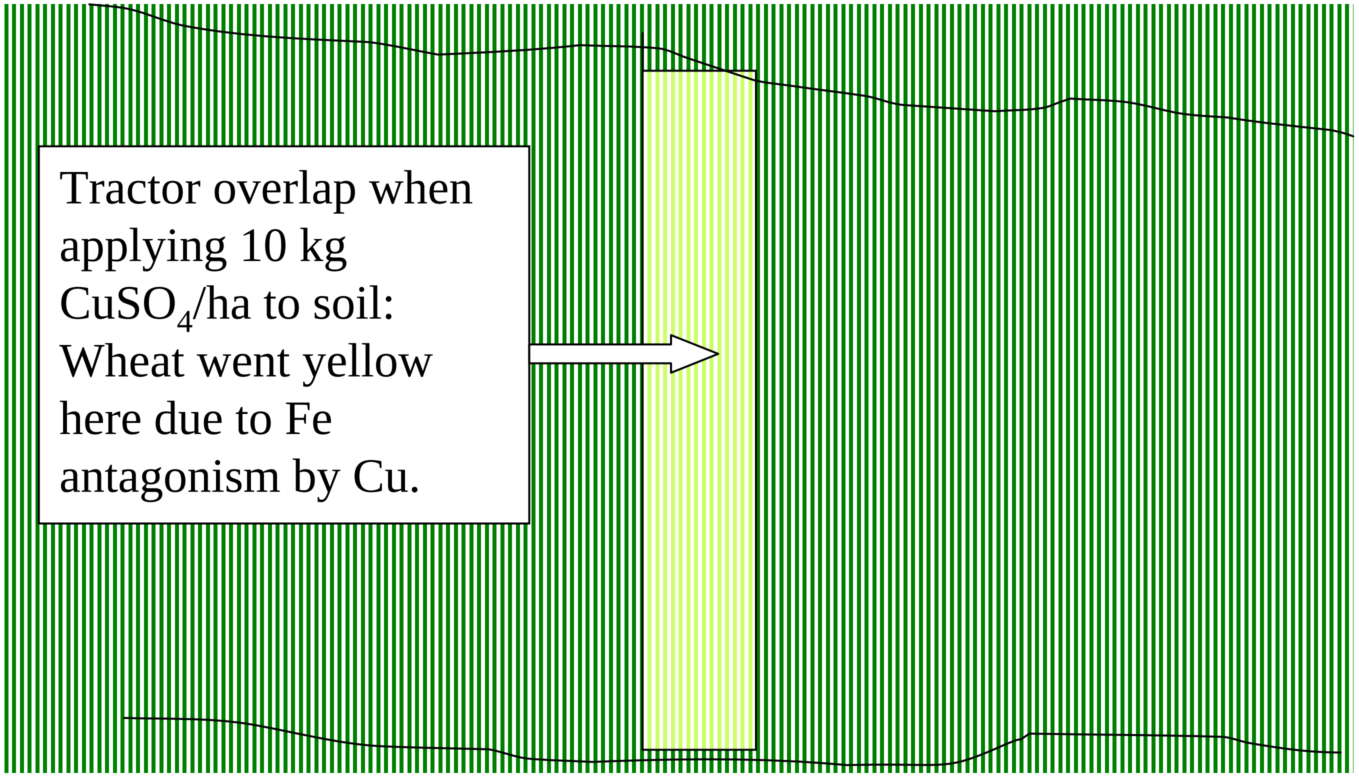


Fig. 4. Chlorotic strip that developed in wheat land after overlap of $CuSO_4$ application at 10 kg/ha.

Table 1. Crops and organisms affected by high levels of applied copper.

CROP	PREVIOUS HISTORY	SYMPTOM	COPPER STATUS	SOLVED BY
Proteas, Leucodendron Fynbos [3]	Old Apple Orchard; years of copper sprays (Bordeaux mixture). SaL	Leaves yellowing, browning, poor development	10 mg/kg EDTA-Cu in top soil	Deep ploughing of profile to be tried.
Medics and clover pasture [3]	30 year old apple orchard; years of copper sprays (Bordeaux) Sandy soil	Yellowing; poor establishment	Depth EDTA Cu (cm) (mg/kg) 0-10 cm 20 10-20 cm 5-6 20-30 cm < 0.5	Deep ploughing to 1 metre rectified.
Wheat [1]	Wheat/maize rotation; possibly high zinc in soil. SaL	Purpling of heads ; poor grain set Chlorosis similar to Fe-deficiency	Low soil Cu; 10 kg $CuSO_4$/ha ↓ (Spray overlap) 20 kg $CuSO_4$/ha applied to soil	Cu deficiency rectified. ↓(overlap) Temporary (?) Cu/Fe antagonism

Table 1. Crops and organisms affected by high levels of applied copper.

CROP	PREVIOUS HISTORY	SYMPTOM	COPPER STATUS	SOLVED BY
Citrus France Florida RSA [4]	Many years of Bordeaux sprays Areas of lighter soils → low pH from N fertilizer.	Reduction in tree vigour, chlorosis, die back of twigs. Fe chlorosis	50-100+ mg/kg EDTA-Cu	150-250 g EDTA-Fe chelate/tree + lime. Deeper roots get iron and surface roots gradually grow back.
Bowling greens Cynodon [5]	Many years of copper sprays e.g. copper oxy-chloride. On old greens. Sandy.	Reduction in vigour, pale growth (chlorosis) when soil Cu is very high.	EDTA-Cu > 10 mg/kg for 55% of greens (n=66); 30% were in range 55-355 mg Cu/kg	Cease applying Cu (and Zn) fungicide sprays; keep pH neutral.

Table 1. Crops and organisms affected by high levels of applied copper.

CROP	PREVIOUS HISTORY	SYMPTOM	COPPER STATUS	SOLVED BY
Earthworms [6]	Cu sprayed on field plots as for vineyards & soil Cu & earthworms measured.	Reduction in earth-worm biomass of ±70% and earth-worm numbers of ± 56% .	Soil Cu increased by ± 385 % to 22 mg/kg and earth-worm body Cu by ± 163%.	Illustrates harm done to earthworms after 1 year of spraying Cu

COPPER EXCESS AND TOXICITY

Naturally occurring copper toxicity

- Naturally occurring copper toxicity occurs near copper ore outcrops in areas where copper is mined.
- Plant and soil levels associated with two such anomalies are given for maize and the mechanism of toxicity appears to be suppression of manganese uptake without significant accumulation of copper in leaves (Figs. 4 & 5 and Table 2).
- Soil EDTA-Cu levels above 300 mg/kg caused severe chlorosis and reduction in leaf and node size (compared to Fe or Mn deficiency) and suppressed leaf Mn below the sufficiency level of 20 mg Mn/kg [5].

Fig. 4. Copper toxicity symptoms on maize growing in high copper soil in Cu mining area.

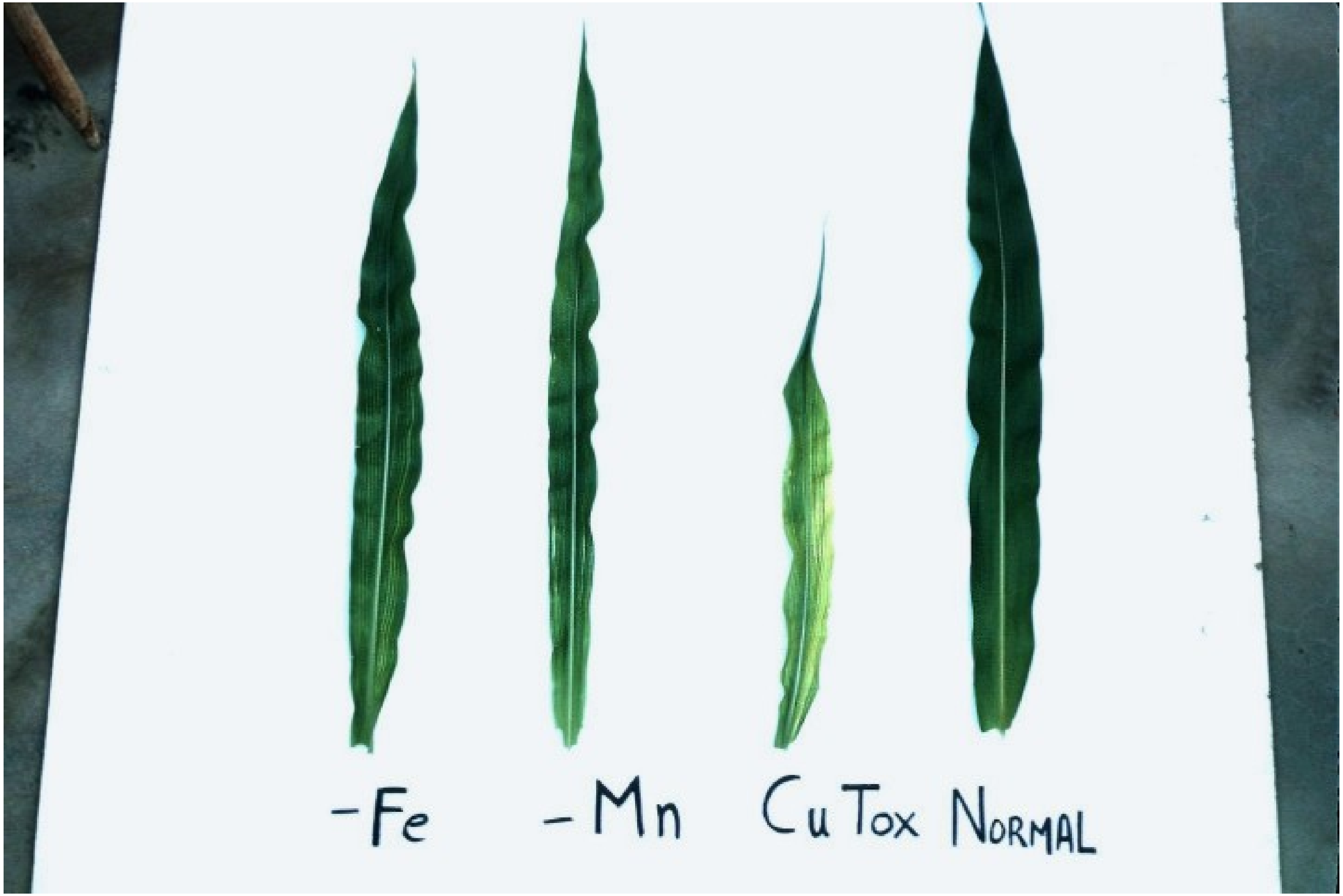


Fig. 5. Cu toxicity in maize compared to iron and manganese deficient and normal leaves.

Table 2. Soil and leaf analyses for maize grown at two sites naturally high in soil copper, showing low leaf Mn in chlorotic leaves [5].

Alaska Soil	mg SaL pH = 5.6 Resin P = 42 mg/kg Exch K = 0.22 Ca = 2.9 Mg = 1.33 cmol+/kg EDTA-Cu = 300						
Alaska Leaves	**Mg %**	**S %**	**Fe mg/kg**	**Mn mg/kg**	**Cu mg/kg**	**Zn mg/kg**	**B mg/kg**
Normal	0.33	0.22	103	**36**	31	31	11
Chlorotic	0.55	0.28	165	**19**	26	25	11
Angwa Soil:Good	mg LS pH = 5.1 Resin P = 408 mg/kg Exch K = 0.36 Ca = 8.3 Mg = 1.3 cmol+/kg EDTA-Cu = 260						
Good Leaves	0.18	0.14	60	**24**	18	22	7
Angwa Soil: Chlorotic	mg LS pH = 5.4 Resin P = 240 mg/kg Exch K = 0.40 Ca = 7.6 Mg = 1.40 cmol+/kg EDTA-Cu = 530						
Chlorotic cob leaves	0.22	0.21	48	**14**	19	24	9

BORON EXCESS AND TOXICITY

- Boron toxicity occurs where B weathered from parent materials of marine origin e.g. argillaceous shale, accumulates in dry climates.

- Leaf edge yellowing/browning symptoms are well known even though boron toxicity is not common in cropping areas of Southern Africa.

- Deficiency is more widespread and is often associated with sandy or calcareous soils. Inadvertent over-application of boron to soil will give classic symptoms of toxicity.

- Over-application via leaf sprays can just as easily occur. Figs. 6-9 show distortion of sweet corn resulting from 3-4 leaf sprays of boron at approximately 4 times the recommended rate of application (1 kg Solubor/ha), applied up to 6 weeks after emergence.

Fig. 6. “Gooseneck” caused by excess boron leaf sprays

Fig. 7. Stunting caused by excess boron leaf sprays

Fig. 8. Distortion caused by excess boron leaf sprays

Fig. 9. Distortion and “crinkled” leaves caused by excess boron leaf sprays

Table 3. Analysis of sweet corn leaves over-dosed with boron (planting date 7/10/04).

Date sampled	Leaf description	P %	K %	Ca%	Mg%	Fe mg/kg	Cu mg/kg	Zn mg/kg	Mn mg/kg	B mg/kg
19/11/04	Growing point tissue	0.63	3.91	0.25	0.13	166	8	48	61	371
9/12/04	Upper	0.44	2.59	0.48	0.13	156	10	60	84	88
9/12/04	Lower	0.49	2.45	0.59	0.15	185	10	69	120	81
9/12/04	Crinkled	0.48	3.52	0.19	0.11	136	8	74	43	56
	Normal leaves 7-8 weeks	0.4 - 0.7	2.5 - 3.5	0.5 - 0.9	0.2 - 0.6	60 - 200	6-20	20-70	30 - 300	8-25 > 100 toxic

BORON EXCESS AND TOXICITY

- Table 3 shows a toxic boron level (> 100 mg/kg) in “growing point tissue” (maize ± 6 weeks old) and very high B in leaves (maize ± 9 weeks old).
- High B absorbed by leaves was accompanied by lower Ca but higher K in “growing point tissue” and “crinkled” leaves. The mutual antagonism between Ca and B is well known; high Ca suppressing B uptake and vice versa. K uptake is apparently enhanced because of reduced Ca uptake.
- These phenomena are usually related to soil-root uptake mechanisms, but in this case excess B also appeared to antagonise Ca in the leaf tissue, preventing or hindering Ca from performing its normal role in cell and cell wall development (e.g. in “crinkled leaves”).
- As growth continued (“upper” and “lower” leaves), boron concentration was diluted along with its inhibitory effect on Ca utilization and Ca concentrations increased and leaf development normalized. Other metabolic activities may well have been upset by high B, and had Ca been sprayed with the boron, less distortion may have occurred.

ZINC EXCESS AND TOXICITY

- Excess soluble zinc (500-1500 mg/kg in soil) is taken up almost linearly by wheat, grasses and potato plants (100-200 mg/kg in tissues) without apparent harm. Thus zinc although quite mobile within plants, is not considered to be highly phytotoxic.

- Despite tolerance of most plants to high levels of zinc, there is concern because of prolonged use of Zn fertilizers and in areas of industrial pollution [7].

- Soil Zn levels in South African cultivated lands are not considered excessive; a survey of metals in soils in the Loskop dam catchment area showed levels in cultivated maize soils (0.2-9.2 mg EDTA-Zn/kg and mean = 2.88) did not differ significantly from virgin soils (0.2-11.3 mg EDTA-Zn/kg and mean = 1.88) [8].

ZINC EXCESS AND TOXICITY

- Chicken manure and composted sewage sludge are generally high in Zn and therefore of concern, not only as potential sources of toxicity to plants, but also to humans where these materials are used for instance for vegetable production.

- An overseas study showed potential dietary toxicity Zn levels in soil (when the threshold of 20 mg/kg in edible plant material was exceeded), varied from 19-176 mg DTPA-Zn/kg for different parts of 3 vegetables.

Shoot dry matter yield reduction thresholds in soil (threshold of 10% yield reduction) were from 56-103 mg DTPA-Zn/kg. In one case yield reduction threshold was not reached when the potential dietary toxicity threshold was exceeded [9].

- The lower levels of these thresholds are exceeded not infrequently in South African vegetable producing soils.

ZINC TOXICITY
(Glasshouse)

Growth is restricted and becomes spindly.
Leaf analysis 280 mg Zn/kg

From "Diagnosis of mineral Disorders in Plants" Vol. 3, 1987, ADAS, AFRC,. HM Stationery Office, U.K.

Interveinal cholrosis; small partly unopened leaves; purplish undersides

NICKEL EXCESS AND TOXICITY

- Ni along with Fe, Mn, Cr and sometimes Co is concentrated in ultramafic or serpentine rocks and its toxicity is well known in soils derived from such parent materials.
- Ni in soil is associated with oxides of Fe and Mn and with organic matter in surface horizons is mobile and easily assimilable by plants.
- Serpentine rocks and soils associated with the Bushveld Igneous Complex in North West Province and Mpumalanga have significant amounts of extractable Ni and Cr; ammonium acetate extractable amounts were found to vary from 17-65 mg Ni/kg (n= 6) [10].
- The Great Dyke in Zimbabwe has significant areas of potentially arable soil but for high Mg, Ni and Cr. The red (kaolinitic) soils of the Dyke are high in NH_4 acetate exchangeable Ni particularly in surface horizons (3-101 mg Ni/ha, n=108). Black vertisols (smectitic) are devoid of Ni. Red alluvial soils along the banks of streams are highest in Ni, indicative of transport and accumulation with clay (and perhaps organic matter) [11].

NICKEL EXCESS AND TOXICITY

- The symptoms of Ni toxicity in maize are an interveinal chlorosis (see Fig. 9a) and stunting with inhibited root growth at higher levels.

- Amendments were applied to a high Ni soil (90 mg/kg exchangeable Ni); sewage sludge gave the best response compared to lime, gypsum and Fe-spray (responses were 38, 11, 9 and 21 percent respectively (p=0,05). Lime reduced uptake and toxicity of Ni as did Fe-spray which also synergised Zn uptake. Sludge supplied Fe, Zn and other nutrients and reduced Ni uptake, presumably by chelation and bulk soil dilution [11,12].

- Because Ni toxicity resembles Fe deficiency and a response to Fe sprays was obtained, leaves of Ni-chlorotic, Fe-deficient and normal plants were analysed in order to elucidate the mechanism of Ni toxicity (Table 4). Physiologically active iron or Fe (II) as well as total Fe was measured [13].

Fig. 6a. Interveinal chlorosis due to Ni in a high Ni soil (90 mg Ni/kg)

NICKEL EXCESS AND TOXICITY

Table 4. Iron status of normal, Fe deficient and Ni-chlorotic maize leaves (means of 3 replicates; sand culture).

	Total Fe (mg/kg)	Fe (II) (mg/kg)	Ni (mg/kg)
Green leaves	24	79	2
Fe-chlorotic	154	61	40
Ni-chlorotic	149	39	70
S.E.	5.9	2.5	2.8
L.S.D. (p=0.05)	16.2	7.8	8.1

- Total Fe content of Ni-chlorotic leaves remained high which indicates little or no interference by Ni with Fe chelation during translocation of Fe in the root or during uptake via xylem to the leaves. However, Fe (II) content of Ni-chlorotic leaves was reduced, and biochemical reactions involving Fe (II) are apparently inhibited by Ni in leaves; up to six biosynthetic pathways during chlorophyll production may be affected [11,12].

CHROMIUM EXCESS AND TOXICITY

- Small amounts of Cr either as soluble Cr (III) or Cr (VI) are extremely toxic to plants especially roots as shown by sand culture experiments.

- Total Cr is often high in ultramafic rocks but as Cr (III) in the refractory mineral chromite is very insoluble, toxicity is rare and difficult to demonstrate; total Cr in Great Dyke soils varies from 15-5400 mg Cr/kg [11].

- Chromium distorts roots in a similar way to aluminium and only small amounts are translocated to leaves of maize making confirmation of toxicity difficult by leaf analysis. However, in field ultramafic soil and in high Cr treatments in sand culture, abnormal flowering (tasseling) of maize (Fig. 10) was seen, confirming this as a symptom of chromium toxicity [11].

Fig. 10. Abnormal tasseling in maize due to Cr toxicity; sand culture.

CHROMIUM EXCESS AND TOXICITY

- Several ultramafic soil samples high in total Cr developed extreme toxicity after years in storage; maize was extremely stunted with choloritic and purplish leaves (Fig 11 shows one of the soils; soil 39). Cr (VI) was identified in extracts of these soils which also contained Fe-Mn concretions and high readily reducible Mn i.e. higher oxides, which are theoretically capable of oxidizing Cr (III) to Cr (VI) in solution (Table 5) [11,14].

Fig.11. Extreme stunting due to Cr toxicity in Soil 39 and no response to lime, gypsum or super phosphate treatment.

Table 5. Soil analysis data for three toxic ultramafic sub soils (after growth of maize in them).

Soil Reference	Exchangeable cmol+/kg Ca	Mg	mg/kg Ni	Cr	Total Cr mg/kg	Reducible Mn mg/kg	Dry matter maize yield g
39-0	5.5	11.6	26	23.4	305	305	0.9
33-0	5.0	15.0	42	10.7	1013	530	2.6
94-0	1.0	5.6	28	3.0	8600	102	5.7
Mean (n=96)	4.1	11.2	37.8	0.57	970	312	20.5
S.E.	0.04	0.2	0.9	0.17	11	214	0.5

CHROMIUM EXCESS AND TOXICITY

• To elucidate the mechanism of Cr toxicity, Mn compounds were added to other high Cr soils from storage. Potassium permanganate ($KMnO_4$) induced identical Cr toxicity in a few well aerated sub soils but not in top soils. Manganese dioxde (MnO_2) addition did not induce toxicity. These sub soils were somehow predisposed to oxidation, which suggests an intermediate form of Cr (III) capable of oxidation, weathered from chromite. Table 5 shows results of 5 soils treated with $KMnO_4$ which oxidized Cr (III) to Cr (VI) in some of them, inducing toxicity (yield reduction and leaf purpling) in maize [11].

Table 6. Soil and maize analytical data for high total Cr-containing soils treated with $KMnO_4$

Soil Reference and sampling depth	Texture	Total Cr mg/kg	Extractable Cr mg/kg	Dry matter maize yield g	Purpling of leaves and stunting
22 (0-15 cm)	SaL	600	0.48 (0.12)	20.6 (13.8)	No
80 (40-60 cm)	Sa	887	0.8 (0.04)	24.4 (19.9)	No
44 (30-40 cm)	SaCL	450	7.92 (0.36)	7.9 (17.0)	Yes
65 (30-50 cm)	SaCl	925	5.36 (0.04)	12.4 (21.3)	Yes
90 (20-40 cm)	SaCL	3500	4.68 (0.44)	12.0 (15.8)	Yes

Values for extractable Cr and yield in parenthesis are for control soils i.e. not receiving $KMnO_4$.

CHROMIUM EXCESS AND TOXICITY

• A two stage mechanism was proposed: Firstly a slow hydrolysis of Cr (III) in chromite to $Cr(OH)_3$ which becomes adsorbed on the surfaces of Mn oxides. Secondly, oxidation of adsorbed Cr (III) by the reduction of higher Mn oxides to Cr (VI) [11,14].

• The first stage may occur in any soil containing high total Cr when moist and slightly acid, neutral or alkaline conditions prevail. The second stage requires in addition, the presence of lower Mn oxides such as hausmannite (Mn_3O_4) and manganite (MnOOH), most likely to exist under mildly oxidizing conditions such as may occur in the concretionary subsoils. Well aerated subsoils and topsoils containing high total Cr that are not toxic, are likely to contain only forms of MnO_2 such as birnessite that are theor-etically less capable of oxidizing Cr (III).

• For anthropogenic sources of Cr (III) such as slag from steel works or tannery wastes, a similar oxidation process to Cr (VI) is likely in poorly drained soils where water table fluctuations occur. Such oxidized Cr could become hazardous locally and in drainage water.

SUMMARY & CONCLUSIONS

EXCESS COPPER:

- **Response of wheat grain to 10 kg $CuSO_4$/ha (2.5 kg Cu/ha) applied to soil with low EDTA-Cu= 0.32 mg/kg was positive; but where soil EDTA-Cu=0.92 mg/kg, negative response was obtained. The gap between sufficiency and toxicity/imbalance is narrow on unbuffered soils**

- **Proteas show sensitivty to soil EDTA-Cu at 5 mg/kg and medics and clover at 20 mg/kg. Bordeaux mixture has raised EDTA-Cu to 50-100+ mg/kg in orhards, which is toxic in acid soils; rectified with Fe-EDTA plus lime. Soil EDTA-Cu raised to 22 mg/kg from CuOCl sprays reduced earthworm biomass by 78% and numbers by 56%.**

CONCLUSION:

- **Leaf Fe is reduced by excess copper in most of the above crops; unbufferd soils, sandy, low organic matter and aggravated by low pH. Possible solution is to supply Fe to soil or leaves after liming.**

SUMMARY & CONCLUSIONS

COPPER TOXICITY:

- **For maize, natural soil EDTA-Cu levels above 300 mg/kg caused severe chlorosis and reduction in leaf and node size (compared to Fe or Mn deficiency) and suppressed leaf Mn below the sufficiency level of 20 mg Mn/kg.**

CONCLUSION:

- **Leaf Mn is reduced by excess copper in the case of maize in light and medium textured soils crops. Possible solution is to supply Mn to soil or leaves and maintain pH and high P and nutrient levels.**

SUMMARY & CONCLUSIONS

BORON TOXICITY:

• Inadvertant excess boron (4 x normal) applied to maize leaves caused distortions and stunting. Leaf Ca reduced in some tissue and leaves. Potassium uptake increased in affected leaves by way of compensation.

CONCLUSION:

• Avoid excess boron application!

• If boron applied with calcium – as is done for some crops susceptible to Ca shortages e.g. tunnel cucumbers, higher tolerance to excess boron may have resulted.

SUMMARY & CONCLUSIONS

ZINC TOXICITY:

- **Soil available Zn in the range 500-1500 mg/kg leads to uptake of 100-200 mg Zn/kg in leaves by grasses and potatoes without harm. Thus tolerance is generally high and Zn is not regarded as very phytotoxic. Some S.A. maize soils contained up to 10 mg/kg.**

- **Glasshouse crops are more likely to encounter Zn toxicity from errors of application or from zincated rooves etc. Toxicity in tomato occurred at levels of 280 mg Zn/kg in leaves.**

- **Vegetable or market garden soils that receive chicken manure (which is high in Zn) or other manures may lead to levels in vegetables that actually suppress yield and are dangerous to human health.**

CONCLUSION:

- **Use of zincated fertilizer when it is not needed is wasteful and expensive if not generally harmful. Monitor Zn in soils, manures and plants especailly leafy vegetables, regularly.**

SUMMARY & CONCLUSIONS

NICKEL TOXICITY:

- **South African and Zimbabwean ultramafic soils have from 65-100+ mg/kg exchangeable Ni which is easily taken up and toxic to crops like maize, causing chlorosis and stunting. Toxicity is aggravated in low Ca:Mg ratio soils.**

- **The chlorosis resembles Fe-deficiency and was shown in fact to be a deficiency of Fe (II) iron in leaves, usually masked by normal or higher than normal total iron levels. Ni appears to interfere with biochemical reactions involving Fe (II) in leaves and not during uptake from soil by roots.**

CONCLUSION:

- **Fe sprays rectify the shortage of Fe(II) in leaves and toxicity is reduced when calcium deficiency is corrected in low Ca:Mg ratio soils by lime or gypsum application.**

SUMMARY & CONCLUSIONS

CHROMIUM TOXICITY:

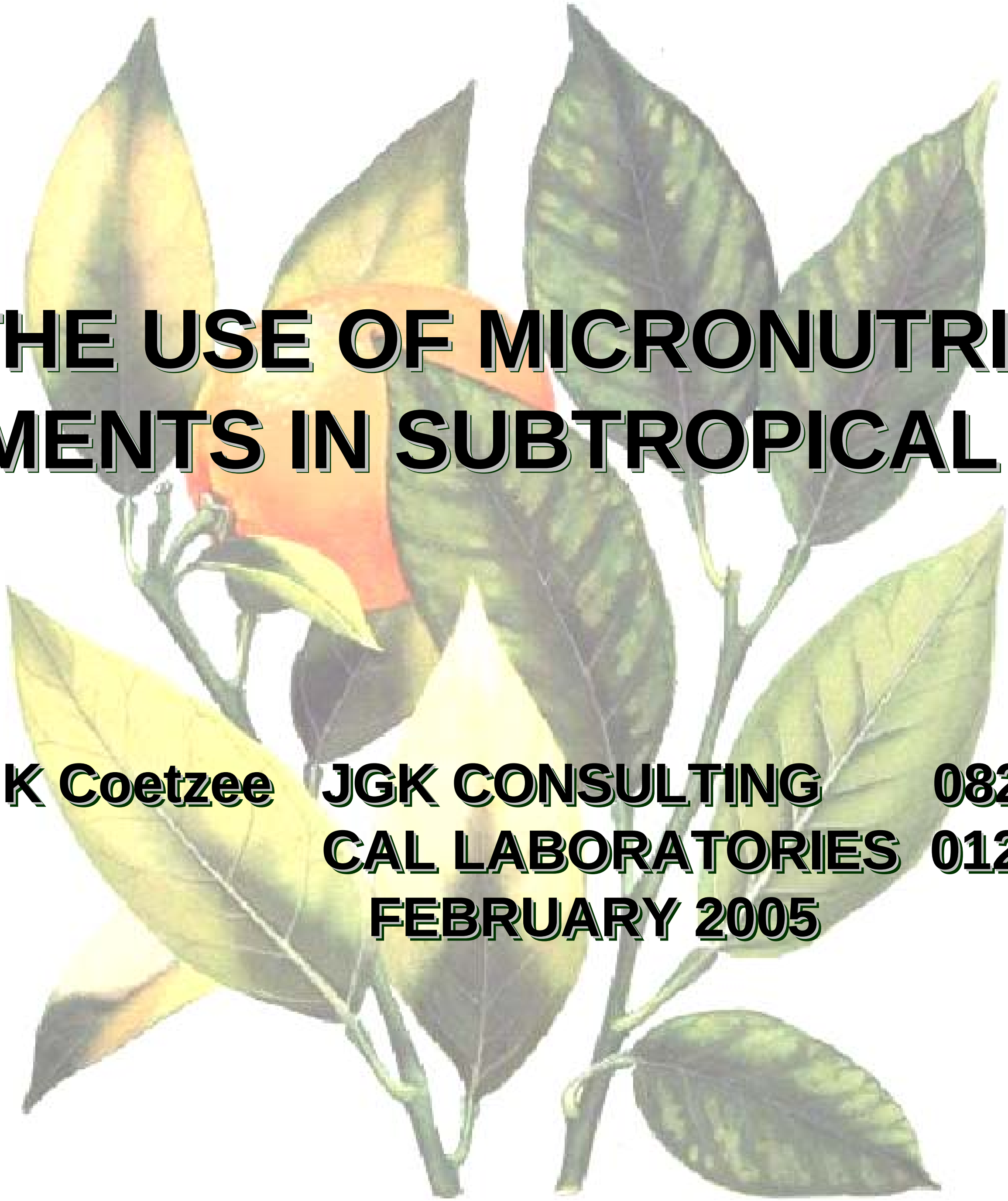
- Ultramafic soils often have very high total Cr levels (up to 8600 mg/kg) but low extractable levels.

- A few sub soils became very toxic to maize after years in dry storage and some Cr had become extractable (from 3-23 mg/kg), identified as Cr(VI) (from 3-23 mg/kg). These soils had high levels of easily reducible Mn. Other soils became toxic after addition of an oxidizing agent and released rom 4-8 mg extractable Cr/kg.

- Slow hydrolysis of chromite containing Cr(III), seems to have occurred in situ which was adsorbed on the surfaces or in the proximity of Mn oxides. Some of the Mn-oxides were capable of slow oxidation of Cr(II) to Cr(VI) in dry storage.

CONCLUSION:

- The toxic soils were all subsoils associated with fluctuating water tables. Hence natural Cr toxicity can be expected under these conditions; also Cr wastes disposed of in wet soils have the potential to become oxidized to mobile and toxic forms of Cr.



THE USE OF MICRONUTRIENT ELEMENTS IN SUBTROPICAL CROPS

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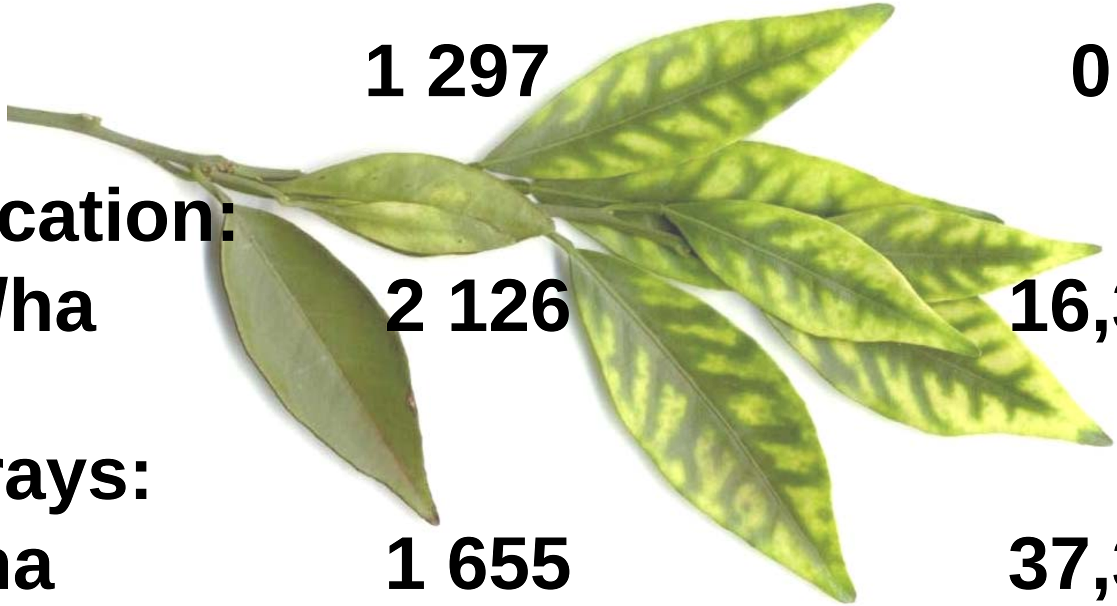
CAL LABORATORIES 012 305 5003

FEBRUARY 2005

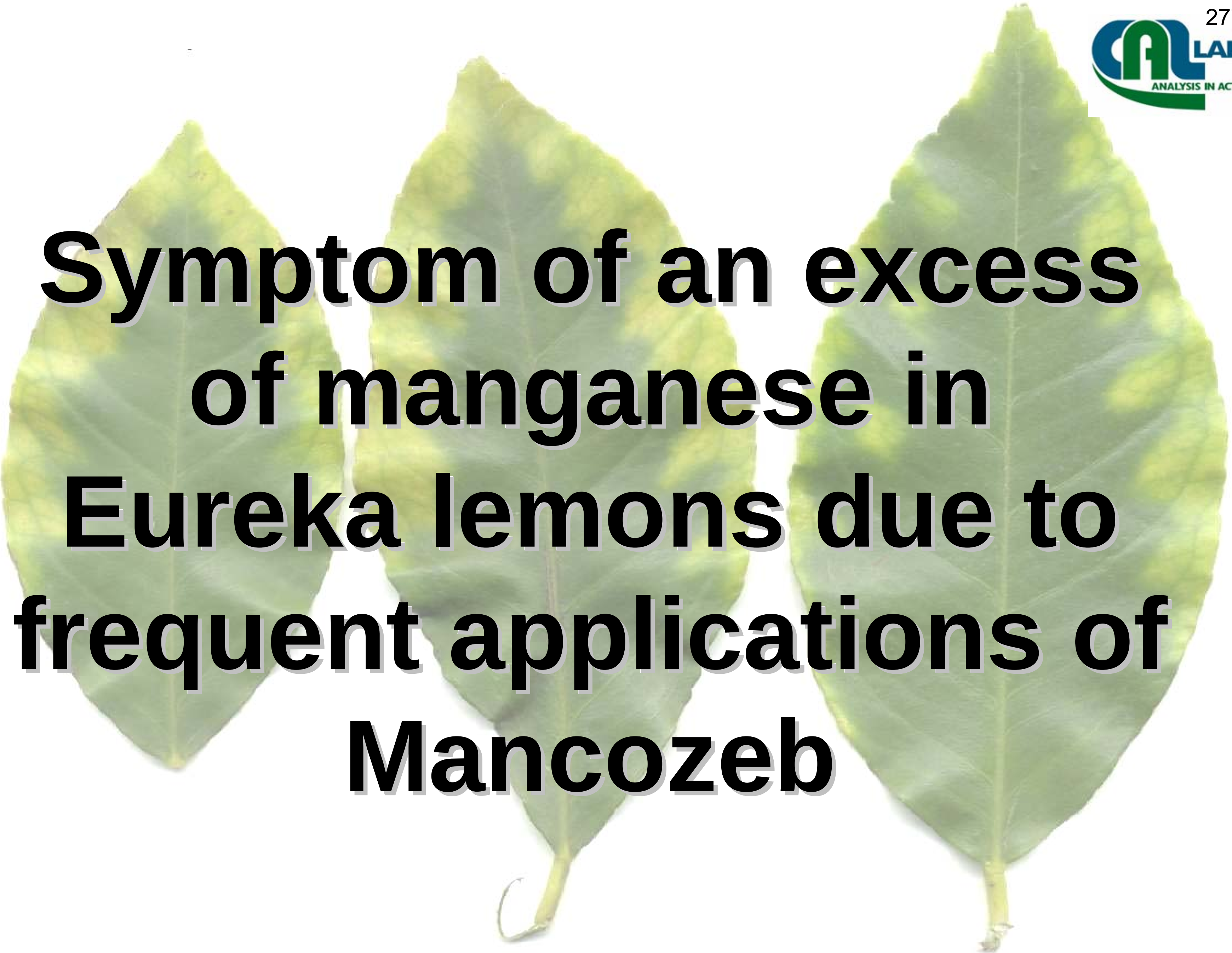
The effect of Zn applications on the production of coffee

Treatment	kg/ha	kg beans/kg Zn applied
Control	1 297	0
Soil application:		
150kg Zn/ha	2 126	16,30
Foliar sprays:		
45kg Zn/ha	1 655	37,30



The response (kg fruit per tree) of Palmer navels in Kirkwood on treatments with FeEDDHA

Treatment (gram per tree)	Yield	Income/cost(03)
Control 1 (72% of canopy is chlorotic)	34	-
Control 2 (50% of canopy is chlorotic)	42	-
300g FeEDDHA to Control 1	89	11
300g FeEDDHA to Control 2	171	26



Symptom of an excess of manganese in Eureka lemons due to frequent applications of Mancozeb

DIAGNOSTIC METHODS-1

- Experience
- Observations

Zn deficiency

Fe deficiency

DIAGNOSTIC METHODS-2

- Leaf analysis
  1. Sample
  2. Contamination
     - ✓ Spray deposits of nutrients and pesticides
  3. Bio-activity
     - ✓ Any level >30mg Fe/kg leaf material means nothing

DIAGNOSTIC METHODS-3

The effect of a low rate of Cu supply on the development of leaves on a new twig of an orange tree

Leaf nr.	Leaf mass g/leaf	Cu content in mg/kg of different age 30 days	60 days	7 months
1 Basal	10,26*	2	6	11
2	11,53*	2	6	12
3	4,12	5	7	14
4	2,55	6	7	15
5	2,11	6	8	14
6 Tip	1,73	7	8	14

* These leaves expressed symptoms of a copper deficiency

APPLICATION METHODS

- Soil applications
- Fertigation
- Foliar sprays

SOIL APPLICATIONS

Soil condition	Effect on efficiency
> pH	< Cu, Fe, Mn and Zn
< pH	< Mo and B
> HCO_3	< Fe and Mn
< Aeration	< Fe > Mn
> PO_4	< Zn
> Leaching + < pH	< Cu, B, Mn and Zn
> Organic matter	< Cu

FERTIGATION

Volumes of soil per tree treated

System	Litres of soil treated
Micro jets	11 375
Double line drippers	1 550
Daily daylight fertigation	150

FOLIAR SPRAYS - 1

Mechanism of absorption

- ✓ Stomata
- ✓ Large
- ✓ Abundant 20 to 800 per mm^2
- ✓ Filled with gasses
- ✓ Inter fibril pores
- ✓ Small 1nm diameter
- ✓ Abundant 108 per mm2
- ✓ Permeable to water

FOLIAR SPRAYS - 2

Substances effectively absorbed

Substance	Molecular mass
➢ Water	18
➢ Urea	60
➢ Glucose	180
➢ Fructose	180
➢ Glyphosate	169
➢ Dimiton-S-methyl	230
➢ EDTA	292
➢ Proteïns	?
➢ Fosetyl-aluminium	354

FOLIAR SPRAYS - 3

Factors determining efficiency

- Concentration
  - Volume applied
    - Formulation

FOLIAR SPRAYS - 4

Concentration

- In the product
  - In the spray solution
    - Calculation

      To > from 20 to 40mg/kg

      - Apply 20mg/kg

FOLIAR SPRAYS - 5

Bench marking

- Solubor^{R}
  - 150g/100 litres water
    - 300mg B/litre spray solution
      - Much less dicey

FOLIAR SPRAYS - 6

Volume to be applied

- Keep nutrient in solution
- Increase the absorption time
- The % absorption of Fe^{55}, Mn^{52} and Zn^{65}

Element	6	48	192 hours
Fe	3	8	15
Mn	11	22	40
Zn	30	60	70

(after Tukey)

FOLIAR SPRAYS - 7

- 2 500 to 3 000 litres per ha

- Climatic conditions

RH %	Temperature ^0C	Droplet size microns	ECT seconds
70	20	100	20
		50	5
40	20	100	9
45	17	500	840

FOLIAR SPRAYS - 8

Formulation

- Carrier

NO_3, SO_4, Cl

- pH buffers
- Surfactants
- Magic

FOLIAR SPRAYS - 9

Evaluation of products

Bench mark		Concentration of various products
Solubor[R]	300mg/litre	82,50 to 310
$Zn(NO_3)_2$	82	2,62 to 106
Cytokinins	1 to 5	0,000014 to 10

CONCLUSIONS

- Optimal supply of micronutrients contributes to better yield and quality

- Standard practice to evaluate, correct and maintain adequate levels

- Develop new products responsibly

- Try new products in a comparative way