

## FERTILISATION

Fertilisation is one of the biggest cost items faced by grain producers. It is also one of the most difficult inputs to handle, because the decision on the type and quantity of fertiliser can be influenced by many factors. A common practise is to relate fertiliser recommendations to expected yields or yield targets. Many other factors however, influence the reaction of the crop to the fertiliser. These include: clay percentage, clay mineral, organic matter, nutrient levels before fertilisation, rainfall and rainfall distribution, soil depth and acid saturation.

### SOIL SAMPLING METHODS

The main objective with a fertiliser/liming programme is to neutralise any kind of soil chemical restriction in the most economically viable manner, i.e. to maximise profit above input costs. This is only possible if the extent of all soil chemical limitations can be determined effectively by soil sampling and laboratory analyses for nutrients.

Fertiliser recommendations are based on soil analyses of these nutrients. Plant nutrients are usually not distributed evenly throughout the soil because of the band placing of fertiliser and because cultivation practices usually do not mix the fertiliser effectively with the soil. It is thus vital to take care that soil samples are taken correctly. The Fertiliser Handbook (MFSA, 2003) gives excellent guidelines on methods to take soil samples

and should therefore be used as a guide by every grain producer. Only a few important aspects are highlighted here:

- 1 If a field consists of more than one soil form, a soil sample should be taken from each soil form.
- 2 One representative sample for every 50 ha should be sufficient.
- 3 Each sample should consist of at least 20 sub-samples taken randomly throughout the land unit or soil form.
- 4 Sub-samples should be properly mixed before a representative sample is taken.
- 5 Topsoil samples are taken from 0 - 150 mm and sub soil samples from 150 - 600 mm.
- 6 It is not necessary to take more than five sub-samples per land unit when sub-soils are sampled.
- 7 In precision farming samples are taken in a predetermined grid, for example one sample per 5 ha, but usually one sample per one or two hectares is required.

Smart sampling is a process where specific locations are identified, up to three years in advance, to take soil samples. Satellite images, yield monitor data and physical inspections are used to identify the sites for sampling.

- 8 The reliability of a soil analysis depends on how representatively the soil samples were taken on a field.

METHOD 1

This method is recommended where residual nutrients and soil acidity are distributed homogeneously, for example in uncultivated soils or where residual bands have been removed by tillage. Twenty to forty topsoil (0 - 150 mm) sub-samples are taken, at random, per unit (<50 ha), preferably using a soil augers with a diameter of at least 75 mm. Five sub-samples for the deeper increments (150 - 300 mm and 300 - 600 mm) that are taken at random over the same area is suffice. If nitrogen analyses are required, separate but single samples taken from 0 - 600 mm depth, should be taken.

METHOD 2

This method is recommended under conditions where residual nutrients and soil acidity are not homogeneously distributed, for example after harvesting and before the first tillage operation of the coming season.

This method is applicable to most maize producing areas, since fertilisers for maize production in South Africa are banded at planting and are usually followed by a N fertiliser side-dressing. Orders for fertilisers and lime should be placed well in advance of the first tillage operation.

Representative samples of a 300 mm wide band over maize rows are analysed separately from between-row samples, as illustrated for a row width of 900 mm in the figure below.

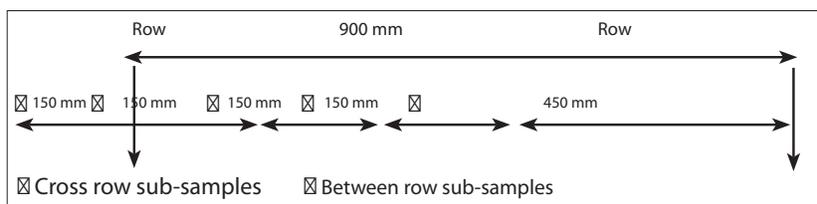
Cross row sub samples (■)

Three samples are taken across the row so that the fertiliser band can be sampled. The three samples represent a band of ±300 mm.

Between row sub-samples (●)

One soil sample is taken exactly in the middle of two rows (450 mm from the row for a row width of 900 mm). A second soil sample is taken exactly in the middle of the cross row sub-sample (■) and the between row sub-sample (●) (300 mm from the plant row for a row width of 900 mm).

All soil samples are taken either with Thompson, Edelman or soil augers with similar dimensions. Depth increments are the same as for the previous method, namely 0 - 150 mm, 150 - 300 mm and 300 - 600 mm. The sampling procedure is repeated five times per 50 ha soil unit. The five 0 - 150 mm samples are mixed thoroughly and one subsample taken from the mixture for analysis. The same procedure is followed for the 150 - 300 mm and 300 - 600 mm samples.



Samples should be air-dried or frozen if N analysis is required and samples cannot be delivered to the laboratory within 24 hours. Samples should in all instances not be exposed to direct sunlight. A soil mass of between 500 and 1000 g is required for each sample for analysis.

#### THE AMELIORATION OF SOIL ACIDITY

Maize production is limited by soil acidity only when toxic levels of elements such as aluminium (Al) and manganese (Mn) are present. A high concentration of hydrogen (H) ions, i.e. a low pH is not necessarily yield limiting. Al toxicity is predominantly associated with soil acidity, while Mn toxicity is rarely associated with soil acidity, although both forms of toxicity can sometimes occur simultaneously.

The danger of Al toxicity in maize only exists when the pH (KCl) <4.5, or the pH (H<sub>2</sub>O) <5.5. Even under these low pH levels, Al toxicity may not prevail. Al toxicity is characterised by short thick roots devoid of root hairs. Al toxicity is determined by the ratio of Al and H, to the total of potassium (K), calcium (Ca), magnesium (Mg), as well as Al and H. This ratio, expressed as a percentage, is known as acid saturation. Yield losses will increase as acid saturation increases above 20%, since water and nutrient uptake are then impaired. No grain yield is expected at 80% acid saturation. Under conditions where both Al and Mn toxicity occur, Mn toxicity will be sufficiently neutralised if soils are managed below 20% acid saturation.

Lime requirement is aimed at reaching acid saturation levels of between 0 and 15% in order to provide a buffer against re-acidification and Al toxicity. A large buffer against re-acidification (e.g. acid saturation of 0%) can be justified if: a) the rate of re-acidification is high; b) the variation in soil acidity in the field is high; c) more acid sensitive crops, e.g. wheat and dry beans are included in a rotation system, and d) the planning is such as to lime every three or more years. The cost implications of managing acid saturation at below 15%, should however be thoroughly considered. Lime application, more than what is necessary, to lower acid saturation to 0% for instance can usually not be justified.

Lime requirement calculation methods based on pH, such as the pH (KCl), texture and SMP buffer methods, can only be used to eliminate possible risks. Calculated lime requirements with pH based methods to increase the pH of an acid soil to a pH (KCl) of 5 for instance, are usually not economical. The use of pH based lime requirements calculations are therefore not recommended.

It is however important to determine up to what depth soil acidity prevails in the soil and to what depth it should be neutralised before the lime and gypsum rate is calculated.

#### LIME QUALITY

Laboratory determinations for lime quality, currently used, include: a) calcium carbonate equivalent (CCE) in hydro-

chloric acid (HCl); b) CCE in a resin (Rh method); c) particle size, and d) pH (KCl). These individual values cannot be directly related to soil acidity neutralisation under field conditions, but only through multidimensional mathematical equations. However, liming materials with the highest CCE (HCl), CCE (Rh), the largest portion of fine particles and the highest pH (KCl) should be the best to neutralise soil acidity under field conditions.



Acidification and the accompanying aluminium toxicity initially appear in small areas. Plant growth is poor with a pale green colour.

Act No. 36 of 1947 determine that 100% of the particles of a standard lime should be <math><1700\ \mu\text{m}</math> and 50% <math><250\ \mu\text{m}</math>. In case of microfine lime, 95% of particles should be <math><250\ \mu\text{m}</math> and 80% <math><106\ \mu\text{m}</math>. The minimum allowable calcium carbonate equivalent (CCE (KCl)) for both limes is 70%.

#### TYPE OF LIME

Dolomitic lime is recommended in favour of calcitic lime when the Mg status of the soil is low (<math><40\text{mg kg}^{-1}</math>) or relatively low in comparison with the Ca status, unless the Mg requirement can be met by the use of Mg containing fertilisers.

#### LIME REQUIREMENT

Lime recommendations at the ARC-GCI are based on the required change in acid saturation in the soil, lime quality criteria [5 particle sizes, CCE (HCl), pH (KCl)] and the cation exchange capacity (CEC summation) of the soil.

Liming recommendations, accounting for the quality of limes from some sources are presented in Table 1. The price of lime, transport costs, soil incorporation costs and moisture content of the lime should also be taken into consideration. These calculations were only done for the 0-150 mm soil layer and when liming needs to be done effectively to deeper soil layers, proportional adjustments should be made.

#### APPLICATION METHOD

Apart from quality, lime reaction in the soil is highly dependant on mixing the lime thoroughly with the soil. This is achieved by first disking, followed by ploughing. Lime should be applied at least two months prior to planting to ensure that lime reaction is complete at planting.

**SUBSOIL ACIDITY**

Liming in segments, using implements that deposit lime deeply (i.e. specially adapted rippers or deep ploughing) is effective but not always economically justifiable. A surface application of gypsum at a rate of 4 ton ha<sup>-1</sup> is an economically alternative method for ameliorating subsoils containing aluminium or iron oxides. Gypsum replaces Mg from the top to the subsoil and dolomitic lime should therefore be applied with gypsum to restore the topsoil Mg. Gypsum will need one or two seasons before it reaches the subsoil and therefore, deep incorporation of lime is often a quicker solution.

**STRIP LIMING**

Strip liming is recommended when strip acidification has been identified by Soil Sampling Method 2, or when the whole field is acidic and under controlled traffic practices. Strip acidification usually occurs under controlled traffic practices where N is applied in a band at planting, but also as a side-dressing during the season. Lime should be applied at least two months prior to planting in a strip of 300 mm over the row and incorporated into the soil.

**SALINE SOILS**

Saline soils are alkaline soils that usually contain high concentrations of sodium (Na), calcium (Ca) and magnesium (Mg). If soil conductivity is higher than 500 mS m<sup>-1</sup>, or the Na concentration is

more than 15% of the sum of all cations, maize production may be impaired.

A prerequisite for reclaiming saline soils is proper drainage. Soils that have a high conductivity, but not a high Na concentration, can successfully be reclaimed by over-irrigation. This only applies if the irrigation water is of acceptable quality.

Application of gypsum at 2.9 ton ha<sup>-1</sup> or an application of sulphur at 0.54 ton ha<sup>-1</sup> for every 230 mg Na kg<sup>-1</sup> will displace sodium to the subsoil, from where it can be leached by over irrigation. The application of gypsum is, however, not recommended if the calcium concentration is already very high, in which case sulphur should be applied.

**NUTRIENT REQUIREMENTS**

Various approaches for the fertilisation of crops are followed. Two approaches that receive a lot of attention are the so-called sufficiency approach where nutrient levels of the soil are brought to a level to achieve any expected yield in a relative short period, and the target yield approach where sufficient fertiliser is applied to obtain a certain economic target yield. The basic cation saturation ratio concept (or soil balancing system), a third approach to fertilisation, is not supported by the ARC-GCI.

The target yield approach is the most widely used as it is commonly believed that the required fertiliser depends on the grain yield. This implies that only the nutrients removed by the crop are applied. If

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Table 1 Lime recommendations (ton ha<sup>-1</sup>) according to required change in acid saturation ( $\Delta$ AS), the cation exchange capacity (CEC summation) of the soil and quality of some lime sources as determined in 2002

$\Delta$ AS (%)	CEC (cmolc kg <sup>-1</sup> )	Hiqua (Witbank)	Marico (Zeerust)	Bühmanskdrif* (Zeerust)	Meyerton (Vereeniging)	Sappi* (Germiston)	Immerpan (Pietersburg)	Calmasil (Middelburg)	Vaalbrug (Orkney)	Britten (Christiana)	Mooiplaas (Pretoria)
10	1	0.3	0.6	0.5	0.4	0.2	0.4	0.4	0.4	0.5	0.4
	2	0.6	1.2	1.1	0.8	0.5	0.7	0.7	0.7	1.1	0.9
	3	0.8	1.8	1.7	1.3	0.7	1.1	1.1	1.1	1.7	1.3
	4	1.1	2.5	2.3	1.7	0.9	1.5	1.5	1.5	2.3	1.8
20	1	0.6	1.3	1.2	0.9	0.5	0.8	0.8	0.8	1.2	1.0
	2	1.3	2.8	2.6	2.0	1.0	1.7	1.7	1.7	2.6	2.0
	3	2.0	4.4	4.0	3.1	1.6	2.6	2.7	2.7	4.1	3.2
	4	2.7	6.1	5.5	4.2	2.2	3.6	3.6	3.7	5.6	4.3
30	1	1.0	2.2	2.0	1.5	0.8	1.3	1.3	1.4	2.1	1.6
	2	2.2	4.8	4.3	3.3	1.7	2.8	2.9	2.9	4.4	3.4
	3	3.4	7.5	6.8	5.2	2.7	4.4	4.5	4.5	6.9	5.3
	4	4.6	10.3	9.3	7.1	3.7	6.0	6.1	6.2	9.5	7.3
40	1	1.5	3.2	2.9	2.2	1.2	1.9	1.9	1.9	3.0	2.3
	2	3.1	6.9	6.3	4.8	2.5	4.1	4.1	4.2	6.4	4.9
	3	4.9	10.8	9.8	7.5	3.9	6.4	6.5	6.5	10.0	7.7
	4	6.7	14.9	13.5	10.3	5.3	8.8	8.9	8.9	13.8	10.6
50	1	1.9	4.3	3.9	3.0	1.6	2.5	2.6	2.6	4.0	3.1
	2	4.1	9.2	8.3	6.4	3.3	5.4	5.5	5.5	8.5	6.6
	3	6.5	14.4	13.1	10.0	5.2	8.5	8.6	8.7	13.4	10.3
	4	8.9	19.9	18.0	13.7	7.1	11.7	11.9	11.9	18.4	14.2

\* Calcitic limes. All other limes are dolomitic.

a build-up of nutrients takes place, it will happen gradually over years. The advantage of this approach is that optimum economic levels can easily be reached. However, a disadvantage of this approach in the case of nitrogen, is that the plant available N, before fertilisation, is not taken into account.

The sufficiency approach is based on the relationship between nutrient element concentrations or quantities in the soil and relative yield. Nutrient levels in the soil should be managed to obtain a certain percentage of the expected yield. Soil Sampling Method 1 should be used when the residual nutrients are homogeneously distributed. Should it not be the case, Soil Sampling Method 2 is applicable. According to this method, soil volumes of which the expected concentration differs substantially will be analysed separately, expressed as quantities rather than concentrations summed, and then expressed in terms of kg nutrient elements  $\text{ha}^{-1}$  in the soil at a specific depth.

A benefit of this approach is to ensure that plant nutrients should never be yield restricting, as is the case during certain seasons when yields are very high. A further benefit is that available N in the soil is accounted for, because nitrogen analysis is needed for this approach. A disadvantage is that the recommended amount is not always economically justifiable.

A database of soil analyses accumulated for each production unit over a period of seasons is an excellent aid for producers. Soils have the ability to continuously supply plant nutrients. Soil analysis

can be regarded as the net result of the supply from the soil, plus the amount applied through fertilisation, less the amount removed by the crop. Soil analyses can thus be used to determine whether a certain nutrient is over or under supplied through fertilisation. The ideal would be that all nutrients are gradually increased to a level where, beyond doubt, sufficient amounts of specific nutrients are present in the soil. When this point has been reached, fertilisation of this nutrient can be lowered to maintain the level.

This principle is real for most nutrients, but especially for P, as most soils in South Africa are low in phosphorus. Phosphorus is immobilised by many soils and therefore the availability of P is restricted in such soils. It is recommended that soils which have not reached the optimum P level, should gradually be built-up with P over time. Since this is an expensive operation, producers should decide on an affordable time schedule to fit in with their cash flow.

## MACRO NUTRIENT ELEMENTS

### NITROGEN (N)

#### Target yield approach

The most common approach to determine the amount of nitrogen to be applied, is to link it to the expected yield. According to this method,  $15 \text{ kg ha}^{-1}$  N is applied for each  $1 \text{ t ha}^{-1}$  yield expected. This method overestimates the application rate for yields lower than  $3 \text{ t ha}^{-1}$  and probably underestimates the

application rate for yields higher than 4 t ha<sup>-1</sup>. It is also commonly known that texture influences the nitrogen supply rate of the soil. Soils with a high clay content supply more N than sandy soils. Guidelines for nitrogen fertilisation, adapted to compensate for it, are presented in Table 2 (Bloem, 2004). The guidelines presented in Table 2 are for use when no soil N analyses are available and take into consideration the ability of the soil to supply nitrogen.

#### Sufficiency approach

Where inorganic N analyses are available, the following approach can be followed. According to this approach, the inorganic N in the soil to a depth of 600 mm should be managed at 100 ± 20 kg ha<sup>-1</sup> over all localities to obtain 100% yield. Under similar conditions, optimum N in the soil was, e.g. 80 kg N ha<sup>-1</sup> at 11% clay, but 120 kg N ha<sup>-1</sup> at

3% clay. More relationships are however required nationally before soil criteria can be related to soil N optima within specific production practices. Yield suppression due to too much N has thus far occurred when these measurements exceeded 170 kg N ha<sup>-1</sup>. Under irrigation, inorganic N should be managed at levels approaching 170 kg N ha<sup>-1</sup> during the growing period until flowering, but should not exceed that level.

General expected soil responses to N applications are presented in Table 3. More N is required on a sandy soil, compared with a clayey soil, to increase the soil N by one unit (Table 3). Although these guidelines are used, the demarcation of soils according to clay content (Table 3) using a sliding scale of N requirement, factors according to clay content will have to be redefined when more data of more locations are available. Furthermore, the guidelines in Table 3 are only valid when most

Table 2 Nitrogen application levels (kg N ha<sup>-1</sup>) at various yield levels and clay contents

Clay content (%)	Yield (ton ha <sup>-1</sup> )									
	2,0	2,5	3,0	3,5	4,0	4,5	5,0	5,5	6,0	
5	23	41	58	75	92	109	126	143	160	
10	17	35	52	69	86	103	120	137	154	
15	10	28	45	62	79	96	113	133	147	
20	4	22	39	56	73	90	107	124	141	
25	0	16	33	50	67	84	101	118	135	
30	0	9	26	43	60	77	94	111	128	
40	0	0	14	31	48	65	82	99	116	
50	0	0	0	18	35	52	69	86	103	

plant material is removed. Incorporation of large amounts of organic fertilisers or organic material will have a major effect on N requirement factors. Liming will also enhance the conversion of organic N to inorganic N. Since most organic N will be mineralised shortly after planting, it is more accurate to measure inorganic N during the season.

#### Delta yield approach

An alternative method to determine the requirement of N fertiliser, is the delta yield method. Delta yield measures the difference between the optimum economic yield and the yield of an adjacent control that did not receive any N fertiliser. Delta yield correlates well with optimal N fertiliser requirement, regardless of location, soil type or whether it is dry land or irrigated maize. The consequence is that only one formula (or table) is needed for the South African maize production area, without the need of considering

soil texture or any other factors. In fact, it seems that only one universal formula is needed, since the South African derived formula is in agreement with that of the USA.

#### Delta yield method

The delta yield method is simple and requires some control plots of strips in a maize field. It is recommended that approximately 1.6% of the area of the maize field should not receive any N fertiliser, but only the recommended amount of P, K and other nutrients. This control unit (zero N) may be a single row, or a few adjacent rows of a predetermined length, for example 4 rows of 20 m. The control plots should be evenly distributed over the whole field. These control plots/rows should be rotated every year. The rest of the field should be fertilised to reach the economic optimum yield. At harvesting time, the yields of the control plots and

Table 3 The relationship between clay content and N soil response when most of the plant material is removed

Clay (%)	NRF*
	(kg N per ha <sup>-1</sup> application/kg N ha <sup>-1</sup> analysed; 0-600 mm)
<15	2.0
15-20	1.5
>20	1.0

\* N requirement factor, i.e. the amount of N that should be applied per ha to increase the nitrate N plus ammonium N analyses in the top 600 mm soil by 1 kg per ha<sup>-1</sup>

fertilised field are determined independently. The difference in yield between the N fertilised and zero N plot is the delta yield. In precision farming, these practices are followed almost automatically and it is recommended that every four ha should contain a control plot.

The fertiliser requirement for maize in the following season, can be determined from Table 4. The mean delta yield for every specific crop system over seasons per soil type, or per field (if the soil is homogeneous) should be calculated. In

this way, the nitrogen fertiliser requirement can be refined over time.

Advantages

Except for the promising accuracy of the delta yield approach, other advantages are:

- The yield of the control plot is a measurement of the plant available nitrogen or soil supply in terms of yield.
- It is thus not necessary to take soil samples for N analyses eliminating the probability of errors in doing so.

Table 4 Nitrogen fertiliser requirements for maize according to the delta yield approach

Delta yield	N requirement	Delta yield	N requirement
(kg ha <sup>-1</sup> )			
250	28	4250	153
500	42	4500	158
750	54	4750	163
1000	64	5000	169
1250	73	5250	174
1500	82	5500	179
1750	90	5750	183
2000	97	6000	188
2250	104	6250	193
2500	111	6500	197
2750	118	6750	202
3000	124	7000	206
3250	130	7250	211
3500	136	7500	215
3750	142	7750	219
4000	147	8000	224

The farmer is now fully in control of determining the nitrogen fertiliser need of his maize. Yield loss due to the control plots will be lower than 0.5% of the yield when 1.6% of the surface area is used for trial purposes. The advantages of more efficient N fertilisation will most likely exceed the yield loss as a result of the control plots, hence both under and over fertilisation can be limited to a minimum.

#### APPLICATION METHODS

##### Placement

The following rates of N application, in a band at planting 50 mm away from the seed and 50 mm below the seed, should not be exceeded:

0.9 m rows: not more than 40 kg N ha<sup>-1</sup>

1.5 m rows: not more than 30 kg N ha<sup>-1</sup>



Deficient plants next to plants with a sufficient supply of nitrogen.

##### Leaf analysis

Analysis of leaves below and opposite the uppermost ears at flowering should be between 2.4 and 2.9% N. N deficiency is characterised in young plants as a pale green or yellow green appearance. At later stages the older leaves turn yellow with a distinctive reversed V form lesion. No kernels develop at the tip of the maize ear and is stubbed.



Nitrogen deficiency on older leaves.

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2.1 m rows: not more than 20 kg N ha<sup>-1</sup> | 70 to 100 mm away from and below  
 N plus K applications should not exceed | the seed. Top-dressings of all N sources  
 70, 50 and 30 kg ha<sup>-1</sup> for the respective | are usually applied as a side-dressing,  
 row widths. Larger quantities can how- | 100 to 150 mm from the rows. These  
 ever be banded, provided they are placed | applications should be incorporated into

Table 5 Optimum extractable P according to Ambic 1 and Bray 1 in the top 150 mm soil for different clay+silt contents, aimed at achieving 90% of the yield target

Clay+Silt %	Ambic 1 mg kg <sup>-1</sup>	Bray 1 mg kg <sup>-1</sup>	Clay+Silt %	Ambic 1 mg kg <sup>-1</sup>	Bray 1 mg kg <sup>-1</sup>
13	25.3	33.5	37	9.9	17.9
14	23.6	31.8	38	9.7	17.6
15	22.1	30.3	39	9.5	17.4
16	20.8	29.0	40	9.3	17.2
17	19.7	27.8	41	9.1	17.0
18	18.7	26.8	42	8.9	16.9
19	17.8	25.9	43	8.7	16.7
20	17.0	25.1	44	8.6	16.5
21	16.2	24.3	45	8.4	16.4
22	15.6	23.6	46	8.3	16.2
23	15.0	23.0	47	8.1	16.1
24	14.4	22.4	48	8.0	15.9
25	13.9	21.9	49	7.8	15.8
26	13.4	21.4	50	7.7	15.7
27	13.0	21.0	51	7.6	15.5
28	12.6	20.6	52	7.5	15.4
29	12.2	20.2	53	7.4	15.3
30	11.8	19.8	54	7.3	15.2
31	11.5	19.5	55	7.2	15.1
32	11.2	19.2	56	7.1	15.0
33	10.9	18.9	57	7.0	14.9
34	10.6	18.6	58	6.9	14.8
35	10.4	18.3	59	6.8	14.7
36	10.1	18.1	60	6.7	14.6

the soil to reduce or eliminate potential N losses.

#### Time of application

N should always be included in fertiliser mixtures, but climatic conditions and residual N in the soil will dictate when the most N should be applied. The largest quantity of N should be applied early in the season where the seasonal rainfall is less than 700 mm and the N supply capacity of the soil is low (as on sandy soils). If the seasonal rainfall is more than 700 mm and the soil N supply capacity is high (as in clayey soils), most of the N should be applied later (not later than eight weeks after planting) during the season .

An equal division between early and late applications should be made if the seasonal rainfall is more than 700 mm and the N supply capacity of the soil is low. Three to five equal applications are recommended for sandy soils under irrigation, but should preferably be completed two weeks prior to flowering.

#### PHOSPHORUS (P)

P recommendations are based on the analysis of extractable P, as well as the clay plus silt content in the top 150 mm soil. Optimum extractable P in the soil either according to Bray 1 or Ambic 1, which is generally used for maize production, is presented in Table 5. According to current price ratios and risks involved, soil P management to achieve

90% relative yield and no higher is recommended. If the clay plus silt content is less than 13%, optimum soil P values at 13% clay plus silt should be used. Similarly, the optimum soil P values at 60% clay plus silt, is to be used for clay plus silt values of more than 60%.

When soil P levels are lower than the optimum, a programme aimed at increasing soil P levels over a number of years, can for financial reasons, be followed. The amount of P that should be applied to increase the soil P by 1 mg kg<sup>-1</sup> (Bray 1) is 5, 7 and 9 kg P ha<sup>-1</sup> for soil textures of <10%, 10-20% and 21-35% clay respectively. P applications required for maintaining P levels are calculated at 4 kg P ton<sup>-1</sup> grain produced.

#### Leaf analysis

An analysis of leaves below and opposite the uppermost ears during flowering should be between 0.22 and 0.30% P. Deficiency symptoms are normally exhi-



Phosphorus deficiency limits growth and symptoms are reddish to purple leaf tips and edges.

bited by young plants, especially under cool, wet conditions. Leaves are dark green with reddish-purple tips and edges. Plants with a phosphorus deficiency grow slower and are therefore stunted.

#### Application methods

The general practice is to band-place P at 50 mm away and 50 mm below the seed. If for practical reasons the quantity cannot be band-placed, a second application can be done shortly after planting, but further away from the plant row. This can be done in combination with additional N and K. Broadcasted applications of P will be more dependent on fixing than band-placed applications, especially on clayey soils.

#### POTASSIUM (K)

Yield response to K fertilisation, in the larger maize producing areas, i.e. under acidic soils with relatively low Ca content, can only be expected if the exchangeable K content in the top 600 mm soil is less than 300 kg ha<sup>-1</sup> that is, 29 mg kg<sup>-1</sup> at 3% clay or 38 mg kg<sup>-1</sup> at 56% clay. The K requirement factor for this depth (0 to 600 mm) is 1.5 kg K ha<sup>-1</sup> for an increase in exchangeable K of 1 kg ha<sup>-1</sup>. The optimum topsoil (0-150 mm) K content for kaolinitic clay soils (53% clay) in KwaZulu-Natal, was established at 125 mg kg<sup>-1</sup> where the subsoil up to a depth of 600 mm, was 20 mg kg<sup>-1</sup> at commencement of the trial. Applications of 3 kg K ha<sup>-1</sup> should increase the topsoil

content with 1 mg kg<sup>-1</sup>. Under alkaline conditions where the topsoil Ca content was in excess of 3000 mg kg<sup>-1</sup> and the K content as high as 200 mg kg<sup>-1</sup> and higher, K deficiency symptoms have been reported. Research in this respect is lacking, but the band-placement of K is currently recommended under such conditions at a rate of 4 kg K ton<sup>-1</sup> of expected grain yield.

#### Leaf analyses

An analysis of leaves below and opposite the uppermost ears during flowering should show between 1.5 and 1.9% K. Potassium deficiencies initially appear as yellow or necrotic leaf edges beginning at the lower leaves followed by a spreading to the upper leaves. Mature plants lodge more easily, if the potassium supply is insufficient, due to disease infection of the stems. Kernels towards the tip of the ear are small and have a shrunken appearance.

#### Application methods

The accepted method is to band-place K, 50 mm away and 50 mm below the seed in a fertiliser mixture at planting. The following rates of application should not be exceeded:

0.9 m rows: not more than 40 kg K ha<sup>-1</sup>

1.5 m rows: not more than 30 kg K ha<sup>-1</sup>

2.1 m rows: not more than 20 kg K ha<sup>-1</sup>

K plus N applications should not exceed

70, 50 en 30 kg ha<sup>-1</sup> for the respective row widths.

Larger quantities can however be banded, provided they are placed 70 to 100 mm away and below the seed.

#### MAGNESIUM (Mg)

An analysis of the topsoil should record at least 40 mg Mg kg<sup>-1</sup>. Mg deficiencies are usually associated with soil acidity and are therefore rectified when soil acidity is ameliorated by dolomitic lime applications. If soil acidity is not a problem, Mg can be replenished using fertiliser mixtures containing Mg or alternatively, by products such as Mg oxide or Mg sulphate. On sandy soils Mg deficiencies are induced by large applications of K or high levels of K in the soil.

An analysis of leaves below and opposite the uppermost ears during flowering should be between 0.15 and 0.25% Mg. The first indication of a Mg deficiency is interveinal chlorosis on the lower leaves. This is followed by the develop-



Typical interveinal chloroses due to a magnesium deficiency on older leaves.

ment of necrotic spots in the chlorotic area and a distinctly beaded appearance.

#### CALCIUM (Ca)

Ca deficiencies have thus far not been observed under field conditions. Soils with a Ca content of 100 mg kg<sup>-1</sup> have not shown any response to Ca applications. Low Ca levels are usually associated with soil acidity and are therefore rectified when lime is applied to ameliorate soil acidity.

An analysis of leaves below and opposite the uppermost ears at flowering should be between 0.2 and 0.25% Ca. Calcium deficiency prevents the emergence and unfolding of new leaves, the tips of which are almost colourless and are covered with a sticky gelatinous material that causes them to adhere to one another.

#### SULPHUR (S)

Sulphur deficiencies usually occur as a result of the prolonged use of fertilisers containing no S, e.g. clear solutions and other products containing high P concentrations. A response to S can be expected if the inorganic S concentration in the topsoil is less than 3 mg S kg<sup>-1</sup>, while it is reasonably sure that a S response will not occur at concentrations higher than 10 mg kg<sup>-1</sup>. Reaction on the application of S on soil with a S content between 3 and 10 mg kg<sup>-1</sup> will depend on the contribution of S from the atmosphere to the soil

reserve and the S content of the subsoil.

An analysis of leaves below and opposite the uppermost ears during flowering should be approximately 0.2% S. Overall light yellowing of leaves without a definite pattern is typical of S deficiencies in young plants. However, in older plants yellowing of younger leaves is more pronounced. The base of these younger leaves is the first to show yellowing. The reintroduction of fertiliser mixtures containing S is usually sufficient to augment shortages.

#### MICRO NUTRIENT ELEMENTS

##### ZINC (Zn)

Zn is the micronutrient element that is applied the most, because it is included in many fertiliser mixtures. Deficiencies can be expected if an analysis of the topsoil shows less than 1.5 mg Zn kg<sup>-1</sup> or if an analysis of the leaves below and opposite the uppermost ear at flowering shows less than 20 mg kg<sup>-1</sup>.

Zinc deficiency appear as light interveinal chlorosis which join together to form bands which can stretch from the base to the tip of the leaves. The edges, mid-ribs and leaf tips, usually remain green. As a rule plants are stunted and a transverse section through the stems, indicate a dark-purpling of the lower nodes. Under cool, overcast conditions deficiency symptoms suddenly appear, but disappear just as quickly once the sun is shining. High levels of P in the soil, inhibit Zn uptake, while high levels of N, enhances Zn uptake. Alkaline conditions [pH (H<sub>2</sub>O)

> 7.5] also induce Zn deficiencies.

The use of fertiliser mixtures containing Zn is usually sufficient to augment shortages in soils. The continuous use of Zn containing fertilisers is unnecessary once the soil concentration has reached acceptable levels.

##### MOLYBDENUM (Mo)

Mo deficiencies seldom occur, because seed is treated with Mo and seed producers increase the Mo content of the seed by leaf spraying with Mo.

An analysis of leaves below and opposite the uppermost ears during flowering should be approximately 0.2 mg Mo kg<sup>-1</sup>. Deficient plants are light green, while the youngest leaf tips and edges wither. Mo shortage is exacerbated by acid soils and is associated with premature germination of seed on the ear.

##### BORON (B)

Boron is subjected to leaching under high rainfall conditions, but can accumulate to toxic levels in soils under semi-arid conditions. Over-liming can also induce B deficiencies due to the unavailability of B at high pH. Optimum warm water extractable B in the topsoil is between 1 and 2 mg kg<sup>-1</sup>, but toxic effects may occur from 5 mg kg<sup>-1</sup>.

Boron deficiency is characterised by malformed ears with an uneven distribution of kernels due to poor pollination. Deficiencies are expected when analyses of

leaves below and opposite the uppermost ears at flowering shows less than 5 mg kg<sup>-1</sup>. Deficiencies can be rectified by applications of 0.5 - 2.0 kg B ha<sup>-1</sup> before planting.

Boron toxicity is characterised by yellowing of leaf tips followed by progressive necroses, beginning at the leaf tips and edges and then to the interveinal areas and the midrib. Leaves may take on a scorched appearance and may drop prematurely.

#### MANGANESE (Mn)

Most soils contain sufficient Mn to support crop growth, but Mn is unavailable under alkaline conditions or when there are high levels of organic matter in the soil. Broadcast applications of Mn are not recommended but band placement at 6 kg Mn ha<sup>-1</sup> should be sufficient to rectify deficiencies. Foliar applications at 1 to 5 kg Mn ha<sup>-1</sup> should also be effective.

Manganese deficiencies, as with Mg deficiencies, are associated with interveinal yellowing which may also be light-green in appearance. Mn deficiencies differ from Mg deficiencies in that symptoms are first shown by the younger leaves. Mn deficiencies are expected when analysis of leaves below and opposite the uppermost ears at flowering is less than 15 mg Mn kg<sup>-1</sup>.

Manganese toxicities occur under acidic conditions on Mn rich soils. Symptoms are characterised by silver-bleak to brown spots, especially on the older leaves. Manganese toxicities will be suffi-

ciently neutralised if soils containing both high levels of Mn and Al are limed to below 20% acid saturation.

#### COPPER (Cu)

Soil threshold values of 4 mg Cu kg<sup>-1</sup> for HNO<sub>3</sub> extractions and 0.2 mg Cu kg<sup>-1</sup> for DTPA extractions were reported for grain crops. Most soils contain sufficient Cu but highly weathered sandy soils may be depleted. The availability of Cu may however be very low under alkaline conditions.

Deficiency symptoms are characterised by bleak yellow to white colouring of younger leaves that may result in necrotic leaf tips and edges. Cu deficiencies are expected when leaf analysis of leaves beneath and opposite the uppermost ears is less than 5 mg kg<sup>-1</sup> during flowering.

Soil applications of Cu are preferred to leaf applications. Since band placement of Cu can be toxic, soil incorporation in most of the rhizosphere is preferred. Recommendations are generally between 1 and 10 kg Cu ha<sup>-1</sup> but can be as high as 22 kg Cu ha<sup>-1</sup>. Organic fertilisers usually contain sufficient Cu and will therefore eliminate the need for additional Cu applications.

#### IRON (Fe)

Most acid soils have adequate available Fe for crop production. Highly weathered sandy soils may however be an

exception. Fe becomes unavailable at pH (H<sub>2</sub>O) of between 6.5 and 8.0 and the higher the pH, the greater the restriction.

Deficiency symptoms are characterised by distinct interveinal chlorosis of whole leaves that begin on the younger leaves. The entire plant can show these symptoms and yellow strips may even turn white. Plants will generally be stunted.

Iron deficiencies that result from Fe unavailability are best rectified by foliar applications of a 2% iron sulphate solution.



Typical interveinal chloroses due to an iron deficiency on younger leaves.

Several applications, two weeks apart, may be necessary. An increase in the use of acidifying fertilisers, such as ammonium sulphate, is recommended under alkaline conditions, to increase the availability of Fe.

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