

5.4. FERTILIZATION OF MAIZE

INTRODUCTION

Although maize originated in semi-arid regions, it is not a reliable crop under variable rainfall conditions and will usually be outperformed by crops such as sorghum. Maize is one of the most important crops in the milder subtropical and tropical regions of the world, under sufficient rainfall conditions. Maize does extremely well under irrigation in drier regions, and will produce higher yields than virtually all other grain crops. It is grown over a wider range of climatic conditions than other important grain crops such as wheat and rice, even though it is limited to the warmer areas (Arnon, 1975).

The choice of a suitable planting time for maize is extremely important. Both rainfall and temperature should be taken into account. Under most conditions, the planting process can commence once 25 mm of rain has fallen within five days, provided there is sufficient moisture in the subsoil.

Because the growth rate of maize is temperature dependent, general terms such as "140 or 150 days cultivars" are meaningless. For example, a cultivar planted at Ermelo in Mpumalanga may need 90 days from emergence to flowering, but it may begin flowering only 78 days after planting if it was planted on the same day at Lichtenburg in North West. The reason for this lies in the fact that higher average summer temperatures occur at Lichtenburg than at Ermelo.

A simple and practical method to overcome this problem is to use the concept of heat units (HU) or growing degree day (GDD), which takes into account daily maximum and minimum temperatures. However, HU does not account for data relating to soil moisture status, wind, humidity and day lengths, and consequently the HU concept may give only an indication of growth rate. The HU concept is also less successful under dry-land conditions than in irrigation situations, where soil moisture stress should not play any role.

The maize plant stops growing when the temperature drops below 8°C or rises above 34°C. The following formula is used to determine HU on a daily basis:

$$\text{Daily HU} = \left[\frac{\text{max. temp. (upper limit } 34^{\circ}\text{C)} + \text{min. temp.}}{2} \right] - 8^{\circ}\text{C}$$

The FSSA guidelines for the fertilization of maize is based on results gained from more than 15 years of calibration trials on the highveld. The guidelines provide an estimate of N-, P-, and K-requirements, based on experimental data, which will maximise the probability of obtaining a predetermined realistic yield target.

The fertilizer guidelines are linked to two variables, i.e. yield potential and soil status of P and K as determined by soil analysis. Other variables, such as climate, soil depth and soil type, also play an equally important role, and it is therefore the task of the expert fertilizer adviser to take such conditions into account in the final

recommendation. By implication, some of these factors are already integrated into the concept of yield potential. A deep soil in a high rainfall area will naturally have a higher yield potential than the same soil in a lower rainfall area. Similarly, a shallow soil in a low rainfall area will pose greater production risks (very low potential) compared to the same shallow soil in a higher rainfall area.

YIELD POTENTIAL

Yield potential in the context in which it is used in this publication, is that yield which can be realised on a given soil over several seasons, with optimum utilisation of all inputs. The principle that should always apply is that the yield potential should first be determined before deciding on a fertilizer programme.

The determination of yield potential is the first step in fertilizer planning. Decide on a realistic potential that can be achieved, by taking into consideration such factors as the production area, climate (rainfall and temperature), soil, planting date, cultivar and the availability of irrigation.

This definition of yield therefore relates to other popular terms such as yield target and planning yield. They all imply an attainable yield over the medium to long term. This is in contrast to the strict biological-genetical concept of potential, which can only be achieved under ideal conditions.

Various models exist which predict the yield potential on the basis of soil and climatological data. Some models are more sophisticated than others, and take factors such as wind strength, leaf area, and crop index into consideration.

An example of a relatively simple and empirical model that has gained a wide usage in the field with a fair amount of success appears in Table 5.4.1. Various adaptations of this model are used by different institutions.

Table 5.4.1. Maize yield potential of a field

(Adapted from: "Mielieproduksie en die Mielierekenaar", P.J. Möhr, 1977; FSSA Publication No. 61)

	Potential for restricting layer							
	Solid rock/ hard plinthite		Broken rock/gravel		Soft plinthite	Soft plinthite/clay		
Rainfall	Depth (m):							
	0.6	1.2	0.3	0.9	0.3	0.6	1.2	
mm jr ⁻¹	t ha ⁻¹							
500	1.8	2.5	-	2.3	1.9	2.6	3.5	
600	2.7	4.1	1.8	3.8	2.6	3.7	5.5	
700	3.4	6.4	2.5	5.4	3.1	4.6	7.4	
800	3.9	8.7	3.1	6.8	3.3	5.1	8.9	
900	4.1	10.4	3.6	8.1	3.0	5.4	10.1	

PLANT NUTRIENT REQUIREMENTS

The **rate of N- and K-uptake** by the maize plant reaches a peak approximately two weeks prior to flowering, whilst the peak for **P-uptake** coincides with flowering and maximum water uptake. This is illustrated in Figure 5.4.1. These are typical curves and do not necessarily apply to a specific cultivar.

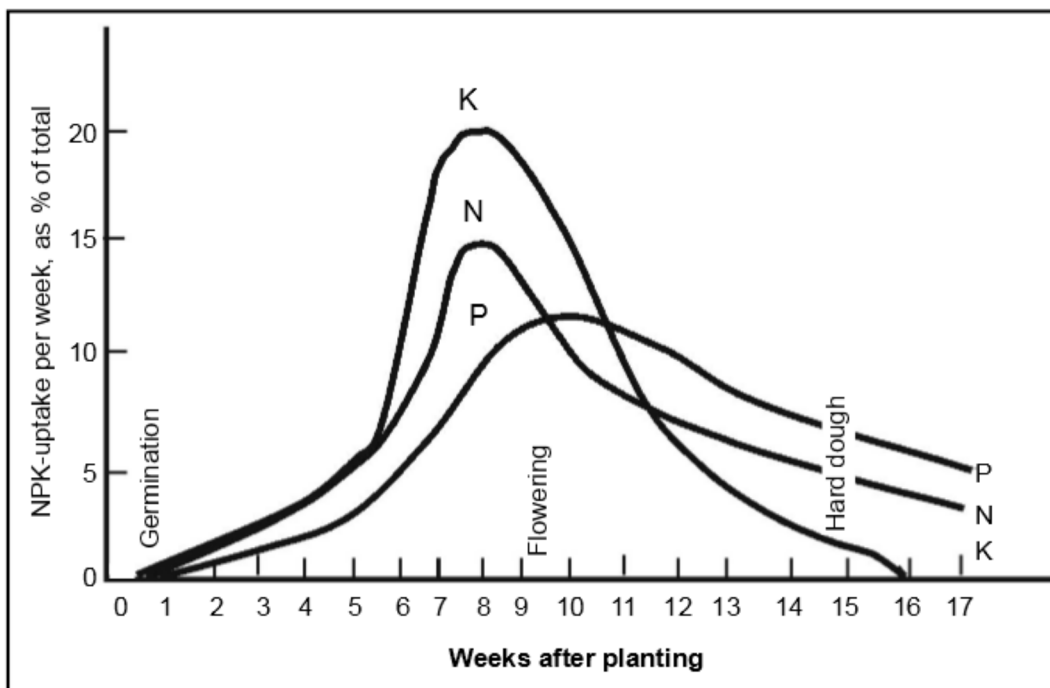


Figure 5.4.1. Rate of nutrient uptake by maize. (From Aldrich & Leng, 1965)

The cumulative uptake of N, P and K by the maize plant, expressed as a percentage of the total uptake, is reflected in Figure 5.4.2. The number of days from emergence to flowering in Figure 5.4.2 applies to a medium growing cultivar. Depending on the climate and cultivar, this may vary from 48 to 85 days.

The average removal of plant nutrients by maize is shown in Table 5.4.2.

SCHEDULING OF APPLICATION

The following guideline may be used when scheduling application.

All the phosphate (P) is applied at planting (or prior to planting where the soil-P reserves are very low). A portion of the nitrogen is applied at planting. The balance is applied mechanically before 5 to 6 weeks have lapsed since emergence as a side-dressing under dry-land cultivation. With irrigation, a portion of the nitrogen may be applied in the form of fertigation up to the last vegetative stage.

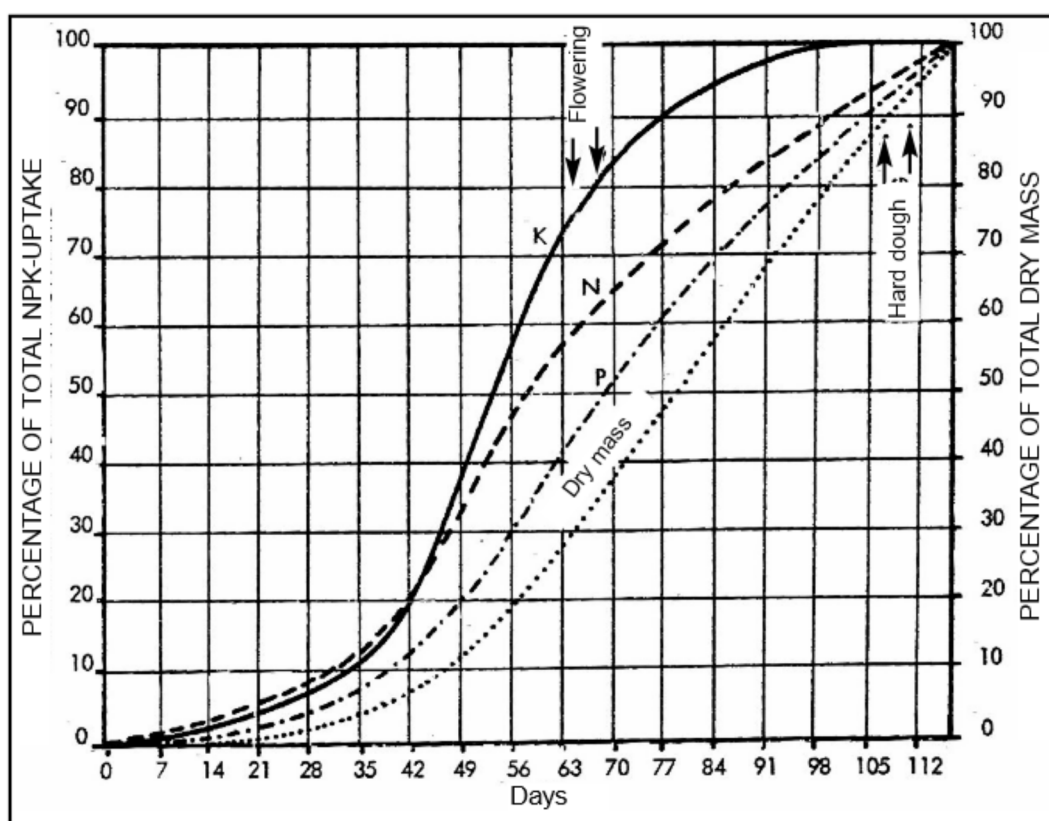


Figure 5.4.2. Cumulative uptake of nitrogen, phosphorus and potassium by a maize plant as a percentage of total uptake by the plant (Aldrich & Leng, 1966)

Table 5.4.2. NPK-removal by maize per 1 ton of marketable product

	N	P	K
Grain only	15	3	3.5
Whole plant ⁽¹⁾	27	4.5	20

(1) Excluding roots.

Usually all the potassium will be applied prior to or at planting, depending on the amount to be applied. In cases where potassium supply under high yield conditions is suspect, good results may be obtained with a side-dressing, or fertigation, up to the last vegetative stage, as with nitrogen.

MACRONUTRIENTS

Nitrogen (N)

The FSSA guideline for N-fertilization assumes that the relationship between yield and N-requirement is strong enough to serve as a basis for a guideline. This is a debatable point, and one that may well be changed in the future. Research is currently being conducted in finding methods to determine the mineral-N content of the soil, and to take this into consideration when making recommendations. Figure 5.4.3 indicates the relationship found in four FSSA trials between N-rate and yield. This serves as an illustration of the type of relationships that can be achieved.

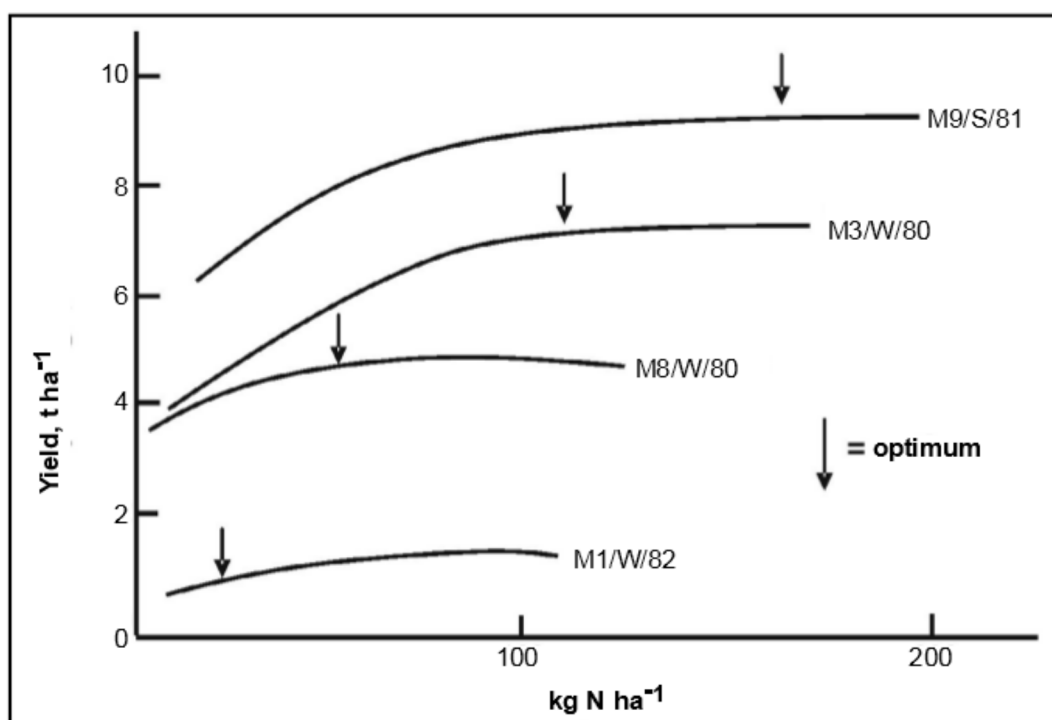


Figure 5.4.3. Yield graphs to illustrate optimum N-levels in several FSSA trials.

Figure 5.4.4 illustrates the relationship between optimum N-rates and the corresponding yields obtained in all FSSA trials since 1978. It shows a good correlation between the FSSA N-guideline (broken line) and the experimental regression line (solid line).

The broken line in Figure 5.4.4 can also be represented in table form (Table 5.4.3), and this is the actual N-guideline for fertilization of maize.

When using the guideline, sound judgement should always prevail. Several factors that could influence the nitrogen requirement must be considered when making a final recommendation from the relationship in Table 5.4.3. These factors can be divided into primary and secondary or management factors.

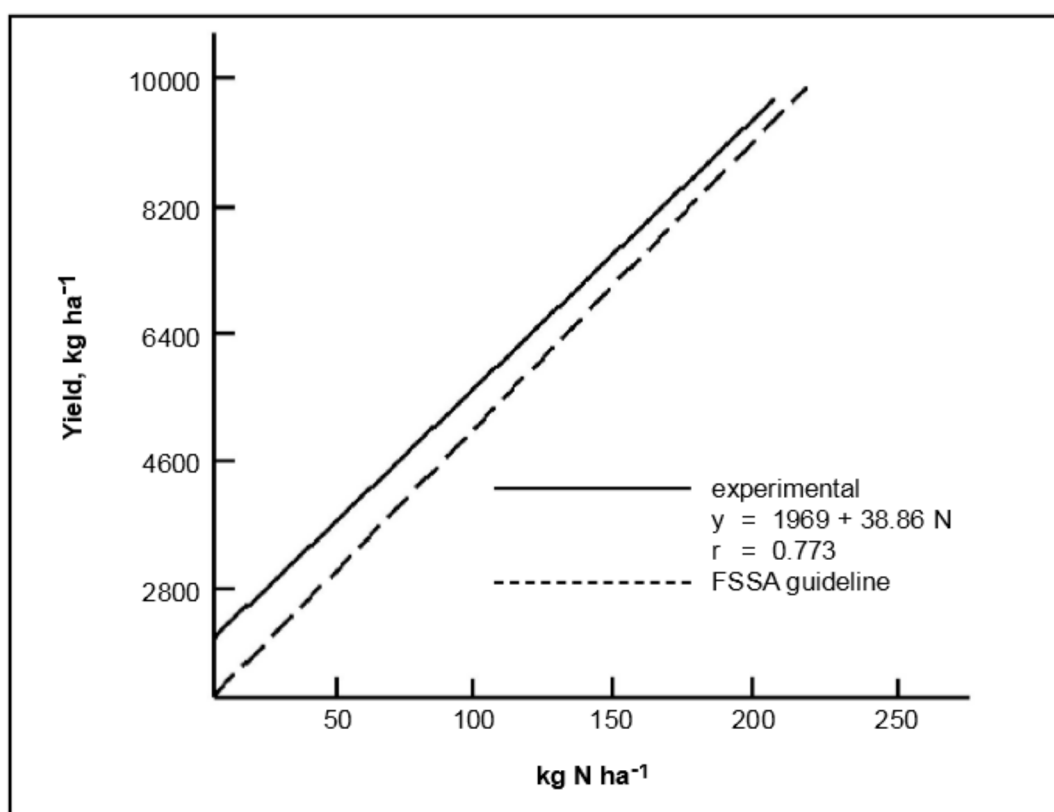


Figure 5.4.4. Relationship between optimal N-levels and yields obtained in all FSSA trials since 1978/79

Table 5.4.3. Guideline for N-fertilization of maize⁽¹⁾

	t ha ⁻¹								
Yield potential	2	3	4	5	6	7	8	9	10
	kg ha ⁻¹								
N-application	20	45	70	95	120	145	170	195	220

⁽¹⁾ Where yields in excess of 10 ton ha⁻¹ are obtained (e.g. under irrigation), 20 to 30 kg N per additional ton may be applied.

Primary factors

- ♦ **Leaching.** The leaching of nitrates out of the root zone can occur in well-drained soils after excessive rainfall. This can be partially overcome by timing nitrogen applications to coincide with the active growth of the plant.

- ♦ **Denitrification.** This occurs when the soil oxygen supply is limited, i.e. under very wet conditions with temperatures above 20°C. If these conditions persist for a reasonably long period, additional applications of nitrogen would be warranted.
- ♦ **Negative N-period.** If large amounts of organic matter with a wide C:N ratio are incorporated into the soil (i.e. wheat straw), the mineral-N in the soil is temporarily "fixed" by micro-organisms, causing the nitrogen to become temporarily unavailable. When such conditions prevail, the solution would be to apply part of the total-N earlier.
- ♦ **Symbiotic N-fixation.** Legumes are capable of converting atmospheric nitrogen into a usable form through the symbiotic action of micro-organisms and roots. Legumes can fix between 25 and 250 kg N ha⁻¹ in this manner, and most of this will become available to the next crop in the rotation system. This will necessitate a lowering of that crop's N-fertilizer requirement.

Secondary and management factors

There are many secondary or management factors that may have an effect on the level of nitrogen fertilization in a given season:

- ♦ **Carry over:** The yield attained in the previous season, compared to the N applied. A simple balance sheet of enrichment/depletion can be drawn up, and this will serve as an indication of the net status of the soil-N.
- ♦ **Removal:** Take into account the removal by the preceding crop (grain and/or rest of the plant).
- ♦ **Soil nutrient status.** The efficiency of N-uptake is decreased if the status of P and K, and also other macro- and micronutrients, is very low.
- ♦ **Weed control.** Poor weed control suppresses yield potential and the availability of soil moisture, and therefore also the chances of optimum utilisation of applied nitrogen.
- ♦ **Insect control.** Poor insect control has the same effect as poor weed control.
- ♦ **Plant population.** An uneven stand or a too low plant population for specific conditions may also lead to under-utilisation of the applied nitrogen.
- ♦ **Available soil moisture.** Knowledge of the status of available soil moisture in the profile during the growing season, especially when the crop can still benefit from applied-N, will allow for informed decisions to be made whether additional N should be applied as a side-dressing.
- ♦ **Planting date.** Planting dates that deviate from the ideal can also suppress yield potential.

The fertilizer adviser should take as many of these factors as is possible into consideration before making a final recommendation.

Research conducted by the North West Department of Agriculture (Bloem, 2002) has indicated a link between nitrogen supply and the clay content of soils. The higher nitrogen supply of a soil with higher clay content can be ascribed to the release of nitrogen from organic matter. (Organic matter is positively correlated with clay content.) A summary of the research results in a nitrogen fertilizer guideline appears in Table 5.4.4.

Table 5.4.4. N-guideline (kg N ha⁻¹) adjusted for texture according to North West Department of Agriculture

Clay content (%)	Yield (ton ha ⁻¹)				
	2.0	3.0	4.0	5.0	6.0
5	23	58	92	126	160
15	10	45	79	113	147
25	0	33	67	101	135
40	0	14	48	82	116

Source: Andries Bloem: "Databasis- en navorsingsresultate dui stikstoflewering van gronde aan". SA Graan/Grain, July 2002 (table abbreviated).

Phosphorus (P)

The uptake of phosphorus by plant roots is almost exclusively through the process of diffusion. The contribution made by direct contact and mass flow uptake is negligible.

When soluble forms of phosphorus (such as in compounds, MAP and super-phosphates) are applied to the soil, they will invariably tend to be converted to less soluble forms. These factors make it necessary for soil-P reserves to be available in sufficient quantities to ensure optimum P-uptake. Calibration work done by the FSSA over more than 15 years has given rise to a P-fertilizer approach that may be summarised as follows:

- ♦ The reaction to applied-P is equally dependent on both seasonal and soil differences. This is true for a wide range of soils. Therefore, no effort is made to differentiate between soil forms and families concerning P-requirements.
- ♦ Soil analysis is not infallible in predicting yield response to applied-P. It does, however, explain sufficient variation to be used as a useful tool in determining P-requirements.
- ♦ By indirect method it was established that, within limits, low yield potentials had lower P-optima, and conversely that higher yield potentials had higher P-optima.

- ♦ Probability of response to applied-P decreases from 100% in the 0 to 6 mg kg⁻¹ (Bray 1) soil-P range to 42% in the 15 to 25 mg kg⁻¹ (Bray 1) soil-P range.
- ♦ Soil-P reserves need to be built up quicker on high potential soils and slower on low potential soils.

These findings have been included in the fertilization model (Table 5.4.5), with the following reference values and interpolations between these values:

- A maximum of 130 kg ha⁻¹ P for yields of 8 tons ha⁻¹ and higher. This is a low risk situation with quick replenishment of soil-P reserves.
- A maximum P-application of 45 kg ha⁻¹ for yield potentials of 3 ton ha⁻¹, with extrapolation to 20 kg ha⁻¹ for 2 t ha⁻¹. There is higher risk and therefore slower build-up of soil-P reserves.
- Build-up of soil-P to 14 mg ha⁻¹ (Bray 1) for yield potentials of 2 to 4 t ha⁻¹, 20 mg kg⁻¹ for potentials of 4 to 6 t ha⁻¹ and 20 to 25 mg kg⁻¹ for yield levels of 8 to 10 t ha⁻¹. It is assumed that soil-P can still be built up with maintenance applications in excess of 3 kg ha⁻¹ P. Based on other data, this figure is somewhat conservative.

Interpolation between these reference values was rounded off to the nearest 1 kg ha⁻¹ (Table 5.4.5) for the sake of convenience. The model is not meant to imply accuracy to the nearest 1 kg ha⁻¹.

Table 5.4.5. Guideline for P-fertilization of maize

Soil-P (Bray 1)	P-recommendation for yield potentials of (t ha ⁻¹):									Comments
	2	3	4	5	6	7	8	9	10	
mg kg ⁻¹	kg ha ⁻¹									
0 - 4	20	42	65	88	109	130	130	130	130	Suboptimal-P: P-build-up + maintenance
5 - 7	17	31	47	63	67	90	93	95	97	
8 - 14	13	19	30	42	50	59	64	67	68	
15 - 20	10	13	21	29	36	42	47	50	53	
21 - 27	7	10	15	19	26	31	34	38	41	Optimal soil-P
28 - 34	6	9	12	15	18	22	24	27	30	Above optimal soil-P: maintenance

Potassium (K)

K-deficiencies seldom occur in the maize producing areas of South Africa. There are two main reasons for this. Firstly, the export of K from the soil with relatively low yield levels is rather low, and secondly, most of the arable soils in South Africa have higher K-levels than the generally accepted sufficiency limits of 80 to 120 mg kg⁻¹ K.

There are well-documented positive responses to K-fertilization, especially in the higher rainfall areas and on soils with an inherently low K-status (i.e. less than 50 mg kg⁻¹). In such instances it has been found that large yield losses can occur if insufficient K is applied. A low K-status in the topsoil will also not necessarily guarantee a positive response with K-fertilization as higher levels of K in the sub-soil will provide adequate potassium in many instances.

Table 5.4.6. Guideline for K-fertilization of maize on soils with low clay content (< 25%)

Soil-K at start of season (NH ₄ OAc)	K-recommendation for yield potentials (t ha ⁻¹):								
	2	3	4	5	6	7	8	9	10
mg kg ⁻¹	kg ha ⁻¹								
10	10	19	28	37	46	55	64	73	82
20	0	11	20	29	38	47	56	64	73
40	0	5	13	22	30	39	47	56	64
60	0	0	8	16	24	32	40	48	56
80	0	0	5	12	20	27	35	42	50
100	0	0	0	10	17	24	31	38	45
120	0	0	0	8	15	21	28	34	41

The supply of potassium to the maize plant is determined to a large extent by the total potassium reserves in the root zone, but especially in the topsoil, the clay content, the type of clay mineral present and the water content of the soil. The occurrence of compaction with certain tillage practices can also reduce the K-supply to the plant.

Yield responses are very variable due to these factors, and therefore the FSSA guideline for potassium must be considered to be a compromise of all the variable experimental results.

Table 5.4.7. K-fertilization of maize on soils with high clay (> 25%)

Soil-K at start of season (NH ₄ OAc)	K-recommendation for yield potentials of (t ha ⁻¹):								
	2	3	4	5	6	7	8	9	10
mg kg ⁻¹	kg ha ⁻¹								
< 40	16	30	44	58	72	86	100	114	128
40	5	16	27	38	49	60	71	81	93
60	0	9	19	30	40	49	59	67	78
80	0	5	13	22	31	40	49	57	67
100	0	0	9	17	25	33	41	48	57
120	0	0	6	13	20	27	34	41	48
140	0	0	5	11	17	23	29	35	41
160	0	0	5	10	15	20	25	30	35

Potassium deficiencies are indicated by yellow or necrotic leaf margins that first appear on older leaves and may spread fairly rapidly to the younger leaves, depending on the degree of deficiency. Leaf analysis of the leaves opposite the top ears during flowering may confirm a deficiency if potassium concentrations are considerably lower than 1.9% (ARC-Grain Crops Institute, 2002).

Calcium (Ca) and magnesium (Mg)

Liming of acid soils is an essential practice for the maintenance of soil fertility and soil productivity. Soils under cultivation are inclined to become more acid, and the rate of acidification is accelerated by fertilization, especially with ammonium-containing nitrogenous fertilizers. Research conducted by the FSSA on sandy loam soils of the Avalon and Hutton families on the highveld indicates a minimum acceptable pH (KCl) level of 4.5, and a maximum acceptable acid saturation percentage of 10 to 15.

In trials on the Mpumalanga highveld it was found that an application of at least 1 ton of agricultural lime per hectare per annum is required to maintain the optimum pH and acid saturation levels. Magnesium levels in the soil should preferably not drop to lower than 50 mg kg⁻¹. Should the magnesium content drop below this level, dolomitic lime should be applied.

Sulphur (S)

Sulphur is an essential micronutrient and is therefore just as important as the other macronutrients in plant nutrition. Deficiency symptoms are a yellow colouration of the entire plant which is often first observed on the new growth. Plants with a sulphur deficiency often also have thinner stems and smaller plants.

The application of sulphur by means of fertilizer has decreased considerably in recent years, especially with the increasing use of higher-grade fertilizer compounds containing little or no sulphur. In addition, South African maize producing soils generally have a low capacity of sulphur supply. This can be ascribed to, among other things, low organic matter content, low pH and low clay percentage. The statutory limitation on industrial SO₂ emissions also contribute to a total decrease in indirect sulphur supply to crops. It is, however, not possible to exactly quantify this decrease. A 1993 study conducted by the Water Research Commission revealed that sulphate dioxide deposition in the Vaal Dam catchment area was in the range of 10 to 23 kg S ha⁻¹ yr⁻¹.

The application of sulphur (4 kg S ha⁻¹ maintenance per ton of grain) may be considered where deficiencies are indicated by leaf and/or soil analyses.

MICRONUTRIENTS

Zinc (Zn)

Zinc came to the forefront during the sixties when widespread zinc deficiencies were identified on young maize plants. These deficiencies were prominent where high concentrations of fertilizer were placed close to the seed, where the soil was recently limed, and when cool, cloudy conditions persisted. Zinc deficiencies have largely disappeared with the advent of Zn-containing compounds, and in some instances unnecessarily high reserves of Zn have been built up in soils.

As a general rule, zinc fertilization is indicated where soil analyses are less than 1.5 to 2 mg kg⁻¹ Zn.

Boron (B)

Positive yield responses have been obtained in trials where the leaf content of B at flowering was lower than 8 to 10 mg kg⁻¹ (G.C.J. Kruger, Sasol Fertilizers, personal communication). These reactions were mainly on light textured soils of the eastern Free State and the highveld region of Mpumalanga, where leaf analyses during the previous season indicated a possible B-deficiency. An application of 0.5 to 2 kg ha⁻¹ B will suffice to correct identified boron deficiencies. It should preferably be applied as a water soluble product prior to planting.

Molybdenum (Mo)

Molybdenum deficiencies on soils with a low pH were a common occurrence during the sixties. The introduction of Mo treated seed has all but eliminated this problem. Mo-deficiencies are associated with very acid soils, and liming will make Mo more available in the soil.

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