INFLUENCE OF NITROGEN AND POTASSIUM APPLICATIONS ON THE EARLY GROWTH AND DEVELOPMENT OF MAIZE (*Zea mays* L.)

by

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Dedicated to

My son, Willie Emmanuel jr., 'Boy', whom I was unable to stay with at the very early age of his life.

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ABSTRACT

Influence of nitrogen and potassium applications on the early growth and development of maize (*Zea mays* L.)

It is well known that appropriate band applications of N and/or K can result in optimum early growth and development of maize. Two pot experiments were conducted in a glasshouse at the University of the Orange Free State, Bloemfontein to determine the application levels at which the above mentioned phenomena occur. The first experiment was conducted to determine the influence of band placed N and/or K on the early growth and development of maize, while the second experiment was set up to determine the influence of K placement through banding, topdressing and a combination of banding and topdressing on the early growth and development of maize.

The first experiment was conducted from January to March 1999 with the cultivar PAN 6479. Two types of soil were used in the experiment, *viz.* a sandy loam soil collected from Ficksburg and a sandy soil collected from Boshof. The plant density was maintained at three plants per pot and the experiment was terminated four weeks after seedling emergence. A complete randomized design with a factorial combination consisting of two main factors, *viz.* four N and/or K band application levels which were replicated thrice, was used in this experiment. The application rates were the equivalent of 0, 20, 40 and 60 kg N or $K.ha^{-1}$ for a row spacing of 1.5 m.

The aerial and subsoil plant parameters, as well as, the nutrient uptake by maize were measured to determine the influence of different N and/or K applications on the early growth and development of maize. All the plant parameters measured showed that the interaction of N and K applications had no significant influence on the early growth and development of maize. The best results were obtained with an application of 20 to 40 kg $N.ha^{-1}$. An application of 20 kg $K.ha^{-1}$ provided the best results.

The second experiment was conducted from October to November 1999. With the exception of the fertilization procedure, all other aspects pertaining to the execution of this experiment were the same as those used in the first experiment. This experiment was terminated six weeks after seedling emergence. The experiment consisted of two main factors, *viz.* four levels and three methods of K application, arranged in a factorial combination in a complete randomized design with four replications. The application rates were the equivalent of 0, 20, 40 and 60 kg $K.ha^{-1}$ placed through banding, topdressing and a combination of banding and topdressing for a row spacing of 1.5 m. With regards to the combination application, half of K was banded and another half topdressed.

The aerial and subsoil plant parameters, as well as, the nutrient uptake by maize were studied to determine the effect of different levels of banded, topdressed and a combination of banded and topdressed K on the early growth and development of maize. All the plant parameters studied showed that the interaction of K application levels and methods had no significant influence on the early growth and development of maize. It seems the best results were attained with 0 to 20 kg $K.ha^{-1}$. A combination of banding and topdressing in the sandy loam soil and topdressing alone in the sandy soil provided the best results.

Finally, it is recommended that field trials should be conducted in order to verify these glasshouse results under field conditions.

Keywords: Maize, influence, banding, broadcasting, topdressing, nitrogen, potassium, early growth, development.

UITTREKSEL

Invloed van stikstof-en kaliumtoedienings op die vroeë groei en ontwikkeling van mielies (*Zea mays* L.)

Dit is bekend dat gepaste bandplasings van N en/of K die vroeë groei en ontwikkeling van mielies kan optimaliseer. Om hierdie rede is 'n glashuisondersoek by die Universiteit van die Oranje-Vrystaat, Bloemfontein uitgevoer. Die eerste eksperiment is uitgevoer om die invloed van bandgeplaaste N en/of K op die vroeë groei en ontwikkeling van mielies te bepaal. Die tweede eksperiment is uitgevoer om die invloed van K-plasings het sy deur bandplasing, topbemesting of 'n kombinasie van bandplasing en topbemesting op die vroeë groei en ontwikkeling van mielies te bepaal.

Ten einde bogenoemde te verwesenlik is die eerste stel proewe vanaf Januarie tot Maart 1999 met die kultivar PAN 6479 uitgevoer. Twee gronde naamlik 'n sandleemgrond vanaf Ficksburg en 'n sandgrond vanaf Boshof is vir die proewe gebruik. Die plantdigtheid was drie plante per pot en die proewe is vier weke na-opkoms beëindig. Beide proewe het uit 'n faktoriaalreëling met twee hoofbehandelings (bandplasing van N en K teen vier peile elk) met drie herhalings bestaan. Die toedieningspeile was ekwivalent aan 0, 20, 40 en 60 kg N of K.ha^{-1} vir 1.5 m rye.

Bogrondse en ondergrondse plantparameters sowel as voedingstofopname is gemeet om die vroeë groei en ontwikkeling van mielies by die verskillende N- en K-toedienings te evalueer. Vir al die plantparameters wat gemeet is, was die interaksie tussen N- en K-toedienings nie betekenisvol gewees nie. Die beste resultate is met'n N-toediening van 20 tot 40 kg.ha^{-1} verkry. 'n K-toediening van 20 kg.ha^{-1} in die band was in die meeste gevalle optimaal.

Die tweede stel proewe is gedurende Oktober tot November 1999 uitgevoer. Met die uitsondering van die bemestingspraktyke, is die uitvoering van dié proewe dieselfde as die van eersgenoemde proewe. Die proewe is ses weke na opkoms beëindig. Beide proewe het uit 'n faktoriaalreëling met twee hoofbehandelings (plasings van vier K-peile en drie

plasingsmetodes) met vier herhalings bestaan. Die toedieningspeile was ekwivalent aan 0, 20, 40 en 60 kg $K.ha^{-1}$ gebandplaas, topbemes of as 'n kombinasie van bandplasing en topbemesting vir 'n 1.5 m rywydte toegedien. Met betrekking tot die kombinasietoediening is die helfte van die K gebandplaas en die ander helfte is as 'n topbemesting toegedien.

Bogrondse- en ondergrondse plantparameters sowel as voedingstofopname is gemeet om die vroeë groei en ontwikkeling van mielies by die verskillende K-peile en K-toedieningsmetodes te evalueer. Vir al die plantparameters wat gemeet is, was die interaksie tussen K-peile en K-toedieningsmetodes nie betekenisvol gewees nie. Dit blyk dat die beste resultate met 'n K-toediening van 0 tot 20 $kg.ha^{-1}$ verkry is. 'n Kombinasie van bandplasing en topbemesting op die sandleemgrond en slegs topbemesting op die sandgrond met K het die beste resultate gelewer.

DECLARATION

I declare that the thesis hereby submitted by me for the Magister Scientiae Agriculturae degree at the University of the Orange Free State is my own independent work and has not previously been submitted by me at another university. I furthermore cede copyright of the thesis in favour of the University of the Orange Free State.

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CHAPTER 1

INTRODUCTION

Maize is a very important crop worldwide, but it's production is limited by, among other factors, low soil fertility. Soil fertility is also one of the major agronomic constraints of maize production in the southern and eastern Africa regions. The use of inorganic fertilizers has been widely promoted to boost maize yields as intensification of land use becomes the only route to increase productivity. Despite the advent and adoption of this technology the southern and eastern African region as a whole failed to achieve maize productivity growth rates in excess of population growth. In this region from 1951 to 1987 the annual population growth was 3 to 4%, while the average maize production only rose from 0.85 to 1.24 $t.ha^{-1}$ (Jones & Wendt, 1994).

The prevalent arid to semi-arid climatic conditions under which maize is predominantly produced in southern Africa also contribute to low maize productivity. Therefore, most farmers tend to use a wider row spacing when planting maize in an effort to compensate for the limited available water (Jones & Wendt, 1994). This wider row spacing has implications for fertilizer application to be efficient. Commercial farmers apply fertilizers through banding which is a beneficial method of fertilizer application as compared to broadcasting, especially under the mentioned conditions (Welch, Johnson, McKibben, Boone & Pendleton, 1966). Unfortunately, the few subsistence farmers who can afford to use fertilizers usually broadcast them, which is not always an efficient method of applying fertilizers since most of the fertilizer is applied in zones where it cannot be utilized efficiently by the crop.

In my own country, *viz*. Botswana the production of maize in low input cropping areas is also adversely affected by erratic rainfall and low soil fertility. Current yield levels are very low and it is often difficult to recommend the use of fertilizers as yield levels do not justify investment in such high cost seasonal inputs. The ever escalating cost of fertilizers has necessitated considerable research to improve the efficiency of fertilizers through better management practices and selection of alternative sources under these arid to semi-arid climatic conditions (Gakale, 1983).

As already mentioned one of the options to increase the efficiency of fertilization is band placing of fertilizers, especially with wider row spacing. According to Miller & Ohlrogge (1958) effective band fertilization must fulfill the following requirements:

- Placement in the soil should permit interception of nutrients by the extending root system of a crop.

- Nutrients should be able to move freely from the point of placement to absorption sites for uptake by the crop.

- Development of roots within the fertilized zone should be possible.

- During nutrient uptake soil conditions such as aeration, temperature and water content should be favourable in the vicinity of the placement.

In Botswana there exist no real guidelines regarding the maximum allowable amount of nitrogen (N) and/or potassium (K) band placement for maize production. Therefore, both commercial and subsistence farmers are to some extent dependent on the guidelines established by the Fertilizer Society of South Africa (FSSA), for N and/or K band placement (Bornman, Ranwell, Venter & Vosloo, 1989). These guidelines have been established just through several years of experience acquired in maize production and they are outlined in Table 1.1.

TABLE 1.1: Maximum recommended rates for banding of N alone or N plus K in combination when maize is produced in South Africa (Du Toit, 1997)

Row Spacing (m)	Maximum recommended rate (kg ha^{-1})	
	N alone	N plus K in combination
0.9	40	70
1.5	30	50
2.1	20	30

In South Africa there are claims that maize yield could be increased with as much as 25% when top-dressed with K, despite of sufficient K levels in soils. However, these allegations are not backed by scientific proof.

The guidelines of the FSSA for N and/or P band placement have been already verified by Ceronio (1997) in a previous investigation. Therefore, the present study was conducted to verify, firstly, the band placement guidelines of the FSSA regarding N and/or K, and secondly, the claims of yield increase by top-dressed K. Thus, the primary objectives of this study were to determine the:

- Influence of band placed N or K separately and in combination on the early growth and development of maize.

- Optimum band application rate of N and/or K which would not have adverse effects on the early growth and development of maize.

- Influence of K on the early growth and development of maize when applied through banding, top-dressing and a combination of banding and top-dressing.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Maize (*Zea mays* L.) ranks third, after wheat and rice, in the world production of cereals and it is widely grown in many parts of the world. The total area devoted to maize production is 110 million ha with a total yield of 230 million tons per annum. More than half of this world production, *viz.* 144 million tons is produced by the USA over only 25 million ha, with a gross value of 20 000 million dollars. The American economy, just like that of South Africa, is highly dependent on maize production (Van Rensberg, 1994).

In South Africa maize ranks first in production ahead of other cereal crops such as wheat, sorghum, barley and rye. It is produced throughout the whole of South Africa with the Free State, North West and Mpumalanga as the leading maize producing provinces (Table 2.1). On the other hand, the Western Cape has the lowest maize production compared to the rest of the other provinces. According to the Division of Planning and Statistics (1993), maize is the second most important crop after sorghum in terms of both production area and yield in Botswana.

TABLE 2.1: Maize production in accordance to the provinces of South Africa (South Africa, Department of Agriculture, 1999)

Produc-tion year	Western Cape	Eastern Cape	Northern Cape	Free State	KwaZulu-Natal	Northern Province	Mpuma-langa	Gau-teng	North West	Total
	1000 t									
1993/94	6	531	178	4346	659	168	2760	716	3878	13242
1994/95	20	220	160	1266	357	68	1192	281	1272	4836
1995/96	25	117	180	3291	328	64	1948	465	3275	9694
1996/97	24	44	182	3374	367	69	1755	375	3392	9582
1997/98	5	34	173	2494	264	48	1460	364	2240	7082
Average	16	189	175	2954	395	83	1823	441	2811	8887

Low maize yields, especially under subsistence agriculture are usually attributable to the inherent low fertility of most soils. Therefore, according to Tisdale, Nelson, Beaton & Havlin (1993), efficient fertilization programs supplying adequate plant nutrients needed to sustain maximum crop productivity and profitability, while minimizing environmental impact from nutrient use are essential. The major factors, listed by these authors, influencing the quantity of nutrients to apply are crop characteristics, soil properties, climatic conditions, fertilizer placement, yield goal and economics. In this literature review the emphasis will be, firstly, on fertilizer placement for crop production and secondly, on maize response to nutrient placement.

2.2 FERTILIZER PLACEMENT FOR CROP PRODUCTION

Tisdale *et al.* (1993) contended that determining the proper placement of fertilizers is just as important as choosing the correct amount of plant nutrients. Proper placement can result in more effective fertilizer use, reducing the quantity of fertilizers applied, lowering production cost and reducing pollution (Timmons, Burwell & Holt, 1973). Therefore, it is not surprising that numerous placement methods have been developed over many years. According to Tisdale *et al.* (1993) fertilizer placement options generally involve surface and subsurface applications before, at or after planting as illustrated in Figure 2.1 and these options can be summarized as follows:

- Before planting fertilizers are either broadcast (incorporated or unincorporated) or banded (surface or subsurface).

- At planting fertilizers are either surface banded, seed banded or subsurface banded.

- After planting fertilizers are either top-dressed or side-dressed.

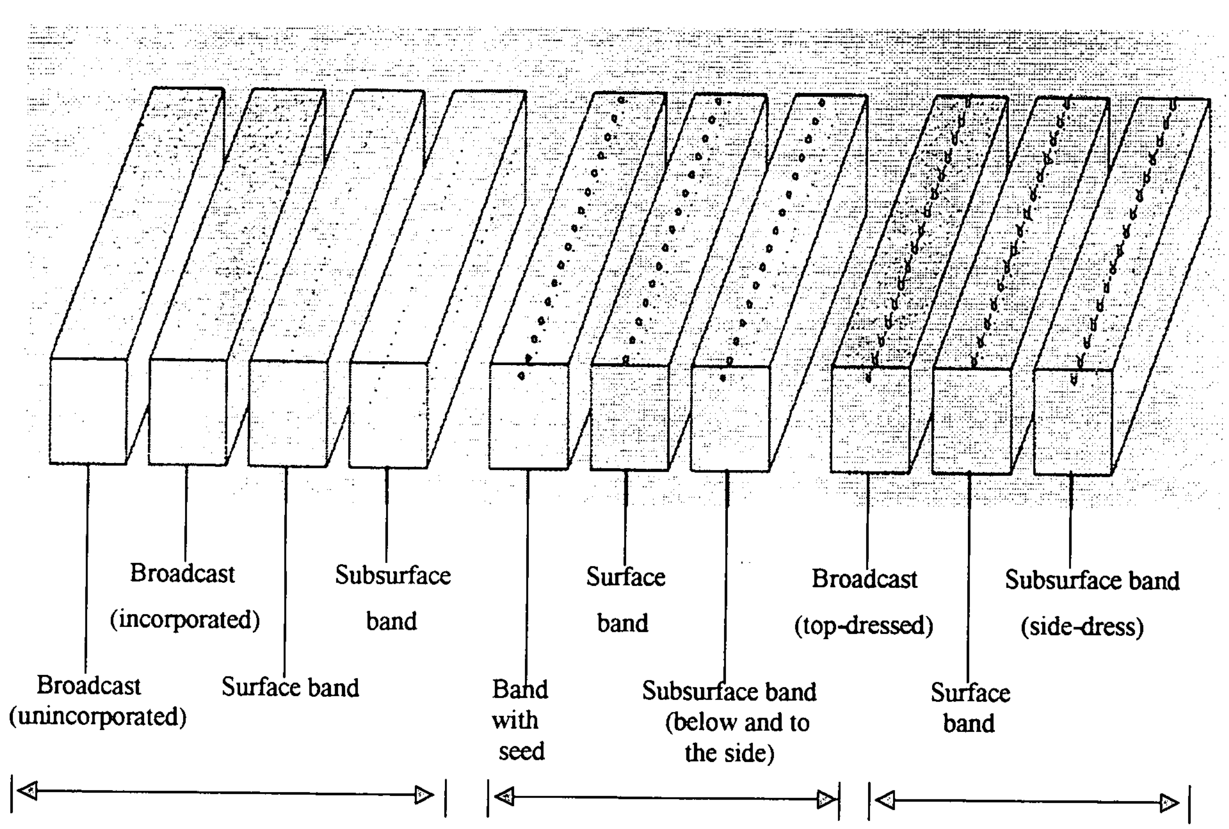


FIGURE 2.1: Cross section of soil showing fertilizer placement options (adapted from Tisdale *et al.*, 1993)

A more thorough discussion on these fertilizer placement options follows in sections 2.2.1 and 2.2.2.

Cummings (1943) as quoted by Miller & Ohlrogge (1958) indicated that the most proper placement of fertilizer is that which provides for an adequate supply of soluble nutrients in a well aerated zone of moist soil occupied by actively absorbing plant roots at intervals of growth when the demands for plant nutrients are most acute. It must be kept in mind that the choice of fertilizer placement depends, *inter alia,* on the crop characteristics, soil properties, climatic conditions, fertilizer characteristics, crop rotation, cultivation practices, nutrient mobilities, application times and equipment availability (Follet, Murphy & Donahue, 1981; Archer, 1988; Arnon, 1992; Tisdale *et al.*, 1993). Factors listed by Randall & Hoeft (1988), as well as, Tisdale *et al.* (1993) that should be considered with fertilizer placement decisions are:

- Efficient nutrient use is possible from plant emergence to maturity.
- Salt injury and ammonia toxicity are negligible.
- Convenience to the farmer is ensured.
- Minimization of environmental contamination.

2.2.1 Broadcast placement

Broadcasting refers to when fertilizers are applied uniformly over a field before or after planting. Preplant broadcasting followed by disking and ploughing leads to an even distribution of N, P and/or K containing fertilizers throughout the ploughed layer in which the plant roots are most active. This method may be of particular importance for the incorporation of P and K in soils that are deficient in these nutrients, as the first step in a build-up of sufficient reserves. It is also ideal when there is need for heavy rates of applications which may harm the crop if they were to be applied in a band (Arnon, 1992).

Where there is no opportunity for incorporation, such as in no-till cropping systems, N, P and/or K containing fertilizers may be broadcast on the surface. However, broadcast applications in no-till systems can greatly reduce N recovery by the crop due to immobilization, denitrification and volatilization losses. Crop recovery of N, P and K can be increased with subsurface band applications to no-till crops (Tisdale *et al.*, 1993).

Broadcasting of fertilizers after planting, *viz* topdressing of N is common with cereals and pastures. However, losses of N through immobilization and volatilization can reduce the efficiency of topdress N. Topdressed P and K are not nearly as effective as when these two nutrients are being broadcast before planting (Tisdale *et al.*, 1993).

Randall & Hoeft (1988) indicated that broadcasting will remain the most popular method (with narrow rows) of fertilizer application, because it is fast, easy and equipment is readily available. Especially, preplant broadcasting of fertilizers has grown rapidly due to the need to reduce the time involved in planting and handling of fertilizers (Follet *et al.*, 1981).

2.2.2 Band placement

Banding refers to when fertilizers are surface or subsurface applied in a concentrated zone before, at or after planting (Tisdale *et al.*, 1993). Usually, subsurface banding of fertilizers is by far the most common practice compared to surface banding (Follet *et al.*, 1981).

Preplant subsurface band placement normally varies between 50 and 200 mm deep in the vicinity where the plant row will be, depending on the crop, soil and fertilizer characteristics. Especially, anhydrous ammonia is banded deep in sandy soils to prevent losses through volatilization. Subsurface banding at planting can occur at numerous locations, but usually it is between 25 and 50 mm to the side and below the seed in order to avoid salt injury and ammonia toxicity during germination. Therefore, with subsurface banding before and at planting the fertilizer is placed at a depth equal to or greater than that of the seed in order to separate the fertilizer from the drier surface soil and to allow interception of the nutrients in the band as the roots penetrate sideways and downward (Follet *et al.*, 1981; Smith, Demchak & Ferretti, 1990; Tisdale *et al.*, 1993; Bordoli & Mallarino, 1998).

Subsurface banding of N, P and K and some micronutrients before and at planting has received a great deal of attention as the most efficient method of fertilizer application. According to Welch, Mulvaney, Boone, McKibben & Pendleton (1966) with subsurface banding the fertilizer is placed in a smaller volume of soil than with broadcasting when the fertilizer is applied at the same rate per hectare. As a result, roots in contact with the banded fertilizer will be in zones of higher fertilizer concentration than roots with broadcast application, but broadcast application will result in a more homogenous contact between roots and fertilizer. Duncan & Ohlrogge (1958) reported that although the concentration of salts in subsurface bands may exceed the accepted limits beyond which the damage is normally caused to the plants, the fact that only a very small part of the root system is involved probably explains why seldom adverse effects are experienced from banding. Peck, MacDonald & Barnard (1988) stated that the subsurface fertilizer band should be close enough to the seed for early seedling response, but far away enough from the seed to avoid injury to the germinating seed and seedlings, especially from high salinity and potentially phytotoxic substances like ammonia.

The most extensive root systems develop through the soil in which plant nutrients are most abundant (Wilkinson & Ohlrogge, 1962). According to Arnon (1992), as a result of subsurface banding, fertilizers are confined to a small volume of soil and the levels of nutrients are relatively high and therefore remain available for a longer time. The rapid proliferation of roots in the fertilized band enables a high recovery rate of nutrients. This is especially important in soils with high fixation capacities for P and/or K. Subsurface banding is usually more efficient when low to moderate rates of P and/or K are applied, particularly to row crops. With higher application rates, differences in the efficiency of P and/or K absorption between band and broadcast applications diminish, especially at higher soil test levels (Randall & Hoeft, 1988).

Cooke (1954), as well as, Tisdale *et al.* (1993) contended that fertilizer placement with or near the seed is also regarded as a subsurface band, but it is commonly used as a starter application. This is used generally to enhance seedling vigour. Usually, low rates of fertilizer are applied to avoid germination or seedling damage. However, placing of fertilizers too close to the seed may delay germination or even reduce seedling growth markedly. This danger may be enhanced under conditions of water stress (Welch *et al.*, 1966a; Bremner & Krogmeier, 1989; Alkanani & MacKenzie, 1996).

Subsurface banding of fertilizers after planting, *viz*, sidedressing of N is common with maize, sorghum, cotton and other row crops. Sidedressing allows a farmer more flexibility in application time, but it can cause damage by either root pruning or ammonia toxicity. The sidedressing of immobile nutrients like P and K is not recommended because most crops require these nutrients early in the season (Follet *et al.*, 1981; Tisdale *et al.*, 1993).

Tisdale *et al.* (1993) reported that surface banding of fertilizers could also be a beneficial method of application before or at planting. However, if not incorporated, dry surface soil conditions can reduce nutrient uptake, especially with immobile nutrients like P and K. Surface band application can also promote N availability compared to broadcast application.

According to Follet *et al.* (1981) and Arnon (1992) the principal methods of fertilizer application that are predominantly used by farmers, are incorporated broadcasting before planting and subsurface banding before or at planting. Considerable research has been, therefore, conducted regarding the effect of N, P and K broadcast and band placements on crop production. Comparisons between broadcasting and banding of fertilizers have shown that appropriate band placement has increased yields when compared with the same rate of broadcast placement (Welch *et al.*, 1966a; Parks & Walker, 1969; Smith *et al.*, 1990). These researchers attributed the higher yields to more efficient fertilizer utilization by the immediate crop from banding than broadcasting which favours early growth and development of crops. Several studies (Jones & Warren, 1954; Locascio, Warren & Wilcox, 1960; Wilcox, 1967 and Hipp, 1970) revealed through leaf analysis that band placement compared to broadcast enhanced the uptake of P and K by crops. It is well known that an adequate supply of P and K early in the life of a crop is important for growth and development (Tisdale *et al.*, 1993). Welch *et al.* (1966a) suggested that a combination of broadcasting and banding might be even better for the early growth and development of a crop than either type of fertilizer placement alone.

In the next section the response of maize to N, P and K placement will be discussed in detail.

2.3 MAIZE RESPONSE TO NUTRIENT PLACEMENT

Soils vary greatly in their capacity for releasing nutrients in an available form for plant uptake. In most cases supplementation of nutrients through fertilization is, therefore, essential to ensure optimal maize production. Thus determining the precise quantities of nutrients needed for the production of maize is one of the major problems confronting farmers and their advisors (Follet *et al.*, 1981; Tisdale *et al.*, 1993).

Fertilization for maize production has critical implications from the economic, agronomic, and environmental viewpoints. Insufficient or excessive fertilization will result in an economic loss to the farmer. Low yields of poor quality can be expected as a result of insufficient fertilization. Excessive fertilization can adversely affect the yield by reaching toxic levels for certain nutrients or by inducing the deficiency of other nutrients. Fertilization in excess can also be detrimental to the environment by contaminating groundwater, particularly with nitrate (Olson & Sander 1988).

It is well known that the utilization of fertilizers by maize can be improved by proper placement, especially if the timing of application is appropriate (Follet *et al.*, 1981; Tisdale *et al.*, 1993).

2.3.1 Nitrogen

The wide usage of N fertilizer after 1945 has resulted in the quadrupling of average maize yields in the USA (Olson & Sander, 1988). Despite this increase in yield, Maddux, Raczkowski, Kissel & Barnes (1991) contended that the efficient use of N fertilizers by crops such as maize is still of major agronomic interest. The reason for this concern is that a review of earlier literature indicated that average crop recovery is only about 50% of the N applied.

Maize contains more N in its grain as compared to other soil-derived nutrients (Olson & Sander, 1988). The result is that a substantial amount of N fertilizer is used for maize production more than any other primary fertilizer nutrient. Therefore, efficient use of N fertilizers by maize is essential to maximize economic returns, minimize groundwater pollution and reduce energy requirements for the manufacturing of N (Herron, Dreier, Flowerday, Colville & Olson, 1971; Bigeriego, Hauck & Olson, 1979; Jokela & Randall, 1989; Arnon, 1992).

Unfortunately, N is by far the most mobile of all fertilizer nutrients and therefore being highly subject to losses from both leaching and volatilization. Losses of this nature can be minimized by proper placement of N fertilizers in combination with appropriate timing of application (Follet *et al.*, 1981). However, it should be kept in mind that small amounts of N are essential in early seedling vigour, but because of its mobility and potential toxic effects, high rates of N fertilizers should be applied before planting and at some distance from the seed or seedling. The quantity of fertilizer required could be reduced with banding rather than broadcasting over the entire area. Both downward and lateral movement of N from the fertilized zones, combined with root extension into the areas of high concentrations, compensate for lower rates applied in a band (Tisdale *et al.*, 1993).

Usually, in the case of maize production a portion of N is applied in a mixed fertilizer before or at planting, and the rest of N as topdressing or sidedressing 3 to 6 weeks after emergence of the seedlings (Martin, Leonard & Stamp, 1976). Such split or delayed application of N is desirable for enhancing efficiency in its use (Welch, Mulvaney, Oldham, Boone, McKibben & Pendleton, 1971; Miller, Kavanaugh & Thomas, 1975; Russelle, Deibert, Hauck, Stevanovic & Olson, 1981; Olson & Sander, 1988). Thereby an active root system is established for taking up N as it is applied, and the time for losses to leaching and volatilization are minimized. The delayed supply of N also results in smaller plants with greater grain-to-stover ratio, thus less vegetative growth and more N for grain formation (Bigeriego *et al.*, 1979; Olson & Sander, 1988).

Some discrepancies in this regard are reported in the literature. Field studies under both irrigated and nonirrigated conditions by Welch *et al.* (1971) have shown increased grain yields and more efficient use of N fertilizer by maize when N application was delayed until several weeks after emergence rather than applied before planting. However, Miller *et al.* (1975), as well as, Bigeriego *et. al.* (1979) have shown no difference in grain yield between N applications at planting and after planting of maize. In this particular investigation, excessive delays or unusually dry conditions have reduced yields from late applications of N. Russelle *et al.* (1981) reported that the efficiency of N fertilizers when applied at optimum rates to maize could be increased with delayed sidedressing as compared with applications made before or at planting. Likewise, in this investigation, appropriate water management has also been proved essential for minimized losses of applied N.

Nitrogen may be lost through ammonia volatilization to the atmosphere when ammonium containing or forming fertilizers are surface applied, especially to alkaline and/or calcareous soils. For instance, field losses of N from agricultural soils of eastern Quebec, Canada may reach 15% if urea is surface-applied without incorporation (Alkanani & MacKenzie, 1996). Urea fertilizers have been found to be more efficient in maize production when incorporated, presumably because of decreased volatilization of ammonia (Maddux *et al.*, 1991).

Losses of NH_3 from urea fertilizer can be minimized if it is banded or injected into the soil (Alkanani & MacKenzie, 1996). Banding urea fertilizer with maize has usually resulted in greater N use efficiencies than broadcast incorporated applications. However, banding urea at high levels may have negative effects on seed germination, seedling growth and early plant growth. Bremner & Krogmeier (1989) reported that the adverse effect of urea on germination of maize seed in the soil was directly due to NH_3 formed following urea hydrolysis.

Duncan & Ohlrogge (1958), as well as, Miller & Ohlrogge (1958) contended that N increased the uptake of P from a band placement when the two nutrients were mixed together. It was assumed that this effect was due to the more extensive development of roots within the band. Field experiments conducted by Robertson, Smith, Ohlrogge & Kinch (1954), using the tracer techniques, demonstrated that the interaction between N and P to be an extremely significant one in efficient fertilizer use. Subsequently, other workers (Olson & Dreier, 1956; Olson, Dreier, Lowery & Flowerday, 1956) also confirmed the significance of the relationship.

2.3.2 Phosphorus

Olson & Sander (1988) reported that the quantity of P required for maize production is less than one-quarter the quantity of N, but a substantially greater proportion of that taken up is harvested in the grain. The native P in soils or that added as fertilizer has very limited mobility in soils because of surface adsorption and chemical reactions into low solubility forms. Its movement to plant roots is almost entirely by diffusion through short distances of less than 1 mm. Consequently, placement in a favourable position for root uptake before or at planting is essential for efficient utilization of P fertilizer (Anghinoni & Barber, 1980).

Many studies have revealed that banding of P fertilizer in the vicinity of the seed promoted early growth and development of maize (Follet *et al.*, 1981). This vigorous early growth and development of maize, particularly on soils of low P availability, generally results in maximum yield response compared with other fertilizer placements (Stanford & Nelson, 1949; Welch *et al.*, 1966b). This effect can only be realized if the soil remains moist in the root zone for most of the growing season, allowing continuous root activity. With optimum water content, a substantial proliferation of roots occurs in the fertilized zone, which further facilitates fertilizer use by the crop (Olson & Dreier, 1956; Duncan & Ohlrogge, 1958).

Under unfavourable water conditions, broadcasting of P fertilizer followed by ploughing may give better results than banding because a fraction of P is located in continuously moist soil (Olson & Sander, 1988). Such applications are essential where higher rates of P are employed in an effort to build up soil P levels for future crops. Band placement of P reduces the surface area of fertilizer in contact with soil, thereby limiting reversion reactions (Shear & Moschler, 1969; Singh, Thomas, Moschler & Martens, 1966). However, such applications leave the P exposed to runoff losses which consequently lead to water pollution (Olson & Sander, 1988).

Olsen, Watanabe & Danielson (1961) reported that P uptake by maize seedlings is inversely related to soil water tension. The decrease in P uptake with increased soil water tension may play an important role when comparing banded and broadcast applications. Banded P would be closer to the maize plant and the soil water in this vicinity will develop high tension, due to water uptake by the plant, sooner than an area further away from the plant. During dry periods broadcast incorporated P might be more readily absorbed than banded P.

Studies conducted by Robinson, Sprague & Gross (1959) revealed that the superiority of band placement over P mixed with the soil was greater at low than at higher temperatures. This was not due to the banded P being less effective at higher temperatures, but it was due to the mixed P being more effective at higher temperatures. These authors then concluded that band placement of P was apparently more effective because of increased concentration of P in a portion of the root zone. They further concluded that band application would be particularly important for plantings made during periods of low temperature, especially for crops that make most of their growth during cold weather and on soils low in available phosphate, particularly if they have high fixing capacity.

According to Welch *et al.* (1966) the effect of placement on availability of P for plant uptake is dependent on the water solubility of the applied P. Lawton, Apostolakis, Cook & Hill (1956) found in greenhouse studies that the percentage P uptake was greater from mixed than from band placement if less than 40 to 45% of the added P was water soluble. At higher water solubilities, band placement gave a greater percentage P uptake than did mixed placement. Webb & Pesek (1958) reported that, with P broadcast and ploughed under, water solubility was not an important factor in determining the effectiveness of P fertilizers for maize grown on acid soils. However, with calcareous soils, increasing the water solubility of P fertilizers appeared to have some slight advantage.

In general, it is argued that the recommended broadcast application rate of P for maize can be reduced when band placed due to greater efficiency, but sometimes this may result in lower yields as indicated by the following example. The P fertilizer recommendations for maize produced on Histosols in Florida are for broadcast applications based on preplant soil tests (Sanchez, Porter & Ulloa, 1991). These authors contended that a 25% reduction in the P rate is suggested for band application, but this reduction is based on field experience rather than controlled experiments. However, in cases where P use has been limited with band placement, yield and quality of maize were reduced and the profitability of maize production compromised.

Therefore it is clear that the effects of banded versus broadcast P on plant uptake depends *inter alia* on soil, crop and fertilizer characteristics. It is not surprising that despite the best P fertilizer management practices, rarely is 20% of the P utilized by the crop in the year of application because of P reversion reactions and the slow diffusion rate of P ions in the soil (Olson & Sander, 1988).

2.3.3 Potassium

Olson & Sander (1988) stated that K, which is the third primary nutrient, is used by maize in almost the same magnitude as P for grain production. However, a much greater quantity is contained in the stover, usually in the order of four times as much as in the grain. Consequently, the total K requirement of maize is substantially higher than that for P and about the same as that for N. Accordingly, soil depletion of K is much more rapid when maize is harvested for silage than for grain.

These authors contended that the major portion of root absorption of K results from diffusion of the nutrient in soil to the root surface. The diffusion rate of K is more rapid than that of P, resulting in generally greater crop utilization of applied K fertilizer than is achieved with P fertilizer. Although K is more mobile than P in the soil, the rate of K diffusion is so slow that placement would still be expected to be an important consideration. Band placement may be more important for K than for P because of the faster uptake rate of K than P prior to silking. Normally the absorption of K by the plant is completed several weeks before crop maturity, tending to peak with the onset of ear formation (Welch *et al.*, 1966).

Therefore, according to Olson & Sander (1988) the principles involved in proper placement and timing of K are basically similar as for P. Since the uptake of K by crops is mostly through diffusion to the root surface, it is important that K fertilizer be placed in soil that will be moist during the major portion of the crop season and in a zone of high root concentration. This can be accomplished by appropriate placement, as close and below the seed row or ploughed down during or before planting. Placement after the crop is established will cause excessive root pruning.

In the case of maize production broadcast incorporated K may not be as efficient as banded K because of a difference in chemical and/or positional availability between the two placement methods. Mixing the K fertilizer with soil enhances fixation and therefore the chemical unavailability for uptake by maize, as it occurs with broadcast application. Broadcast application may also result in K being placed in soil zones that are not permeated by maize roots. This would result in decreased uptake of K fertilizer by maize since some of the added K would be positionally unavailable (Welch *et al.*, 1966).

Therefore, it is not surprising that Prummel (1957) demonstrated that band placed K_2SO_4 was twice as effective as broadcast applications. In accordance, Welch *et al.* (1966) found that the relative efficiency for maize of broadcast K compared to banded K ranged from 0.33 to 0.88 and was affected by the rate at which K is applied and soil type. Although the placement of K in a band near the seed has generally exceeded the benefit derived from broadcast application, a few researchers like Barber (1959) reported no difference in maize yields between banded and broadcast K. According to Welch *et al.* (1966) similar yields are only possible with significantly higher rates of broadcast K compared to banded K. Thus, Randall & Hoeft (1988) concluded that in most situations band placement of K fertilizer could improve fertilizer efficiency and economic returns thereof.

However, it should be noticed that tillage practices might affect the utilization of K fertilizers by maize. According to Welch *et al.* (1966) maize produced under conventional tillage practices utilized banded K far more efficient than broadcast K. This is not necessarily the case when maize is produced under minimum tillage practices. The high root activity of maize in the soil under minimum tillage allows effective utilization of surface broadcast K fertilizer at least in humid cropping regions (Shear & Moschler, 1969; Moschler, Shear, Martens, Jones & Wilmouth, 1972; Fink & Wesley, 1974).

The proper band placement of K is important from the standpoint of maize germination, because reduced germination may result if comparatively large amounts of K are placed too close to the seed (Welch *et al.*, 1966). According to the results of Cummings & Parks (1961) placement with regard to maize germination is more critical for K than for P.

It is clear from the foregoing discussion that banded K is in most cases more beneficial to the early growth and development of maize than broadcast K. According to Parks & Walker

(1969) this is especially the case when maize is produced in high K fixing soils with low K levels, resulting in large savings of K fertilizer applications.

2.4 CONCLUSION

Although maize is one of the main cereal crops worldwide, its production is limited by among other factors low soil fertility of most soils. Fertilization of maize is, therefore, one of the major agronomic practices which should be adopted by farmers if they are to attain the expected yield potential. The yield potential of maize can only be achieved if an appropriate fertilizer application method is used. The two main methods which are widely used by farmers are broadcast incorporated before planting and subsurface banding before or at planting. Of these two methods, banding has always been proven to be the most efficient compared to broadcasting at equivalent fertilizer application rates. Appropriate band placement can result in efficient fertilizer use by the immediate crop, while minimizing environmental pollution from nutrients. With banding the fertilizer is placed in a restricted soil zone, hence the fertilizer level in this zone increases and remains more available for a longer period of time. Nevertheless, some investigations have demonstrated that a combination of banding and broadcasting could be better than applying either method alone.

When applying N fertilizers the major concern is usually how to minimize losses, particularly through leaching and volatilization. As a result, proper band placement of N fertilizers coupled with appropriate timing are vital to minimize these losses and derive maximum benefits from N fertilization. Generally, the nearer the time of application to peak N demand, the more efficient the utilization. Since P is immobile in the soil, band placement in the zone of root development is usually beneficial. However, in order to achieve high yields of most crops it is essential to build up the P soil level first through broadcasting. Extreme care should be exercised when banding K since it can adversely affect germination if placed too close to the seed. Similarly, band placement of P and K has been noticed to be more efficient compared to broadcast application. Broadcasting enhances fixation of both P and K, thereby rendering both nutrients unavailable to plants.

CHAPTER 3

INFLUENCE OF BAND PLACED NITROGEN AND POTASSIUM ON THE EARLY GROWTH AND DEVELOPMENT OF MAIZE (*Zea mays* L.)

3.1 INTRODUCTION

Tisdale *et al.* (1993) indicated that low maize yields, particularly under small scale farming are usually caused by the inherent low fertility of most soils. Consequently, adequate fertilization programmes are needed to sustain maximum crop productivity, while minimizing environmental pollution from the nutrients.

The proper placement of fertilizer often improves the efficiency of nutrient uptake by plants and in turn promotes maximum yields of intensively managed agronomic crops such as maize (Mahler, Lutcher & Everson, 1989). Banding fertilizer below and/or to the side of the seed at planting is, therefore, extensively used to improve nutrient use efficiency provided the seeds and/or seedlings are not damaged by the fertilizer.

It is not surprising that extensive research has been geared towards the comparison of banding and broadcasting, which has revealed that proper band placement has significantly increased maize yields compared to the same dose of broadcast (Welch *et al.*, 1966; Parks & Walker, 1969; Eckert & Johnson, 1985; Randall & Hoeft, 1988; Smith *et al.*, 1990). The benefit of banding is that the fertilizer is placed in a restricted zone of soil and the nutrients remain available for plant uptake over a longer period of time. This effect is of particular importance with lower application rates on soils that have a high fixation capacity for nutrients like P and K.

In Southern Africa band placement of fertilizer with maize production is commonly practised in order to improve the efficient use of fertilizers thereof. Therefore, a glasshouse experiment was conducted to determine the effects of band placed N and K separately or in combination on the early growth and development of maize with an ultimate goal of establishing optimum band application rates.

3.2 MATERIALS AND METHODS

3.2.1 Execution of experiment

A pot experiment on banding of N and/or K with maize was conducted during the 1998/99 growing season in the glasshouse at the University of the Orange Free State, Bloemfontein.

In this experiment the maize cultivar, PAN 6479, was planted. It is a white hybrid with high production potential and wide adaptability, hence it is grown in all the important maize producing areas of Southern Africa. This cultivar has a good standability and tends to produce more than one cob per plant. It also has a high resistance against diseases, including grey leaf spot. The cultivar PAN 6479 takes 71-79 and 140-150 days to reach 50% flowering and physiological maturity, respectively.

Two types of soil were used in the experiment, *viz.* a sandy loam soil collected from Ficksburg and a sandy soil collected from Boshof (Table 3.1). Each topsoil was air-dried, sieved through a 5 mm opening sieve and then thoroughly mixed before the relevant pots were filled with it.

TABLE 3.1: Some chemical properties of the two topsoils used in this experiment

Property*	Sandy Loam Soil	Sandy Soil
pH (H_2O)	6.42	6.92
Electrical resistance (Ohms)	1620.00	4350.00
Exchangeable cations (mg.kg^{-1})		
Ca (NH_4 OAc)	488.00	288.00
Mg (NH_4 OAc)	114.00	146.00
K (NH_4 OAc)	112.00	110.00
Na (NH_4 OAc)	7.00	6.00
Extractable nutrients (mg.kg^{-1})		
P (Olsen)	28.80	1.20
Zn (HC*l*)	6.50	1.50

*Determined according to standard methods (The Non-affiliated Soil Analysis Work Committee, 1990)

N as limestone ammonium nitrate (28% N) and K as potassium chloride (50% K) were banded in a factorial combination to each soil at rates equivalent to 0, 20, 40 and 60 kg.ha^{-1} N and/or K for a row spacing of 1.5 m (Table 3.2). A uniform basal application of 0.96 g.pot^{-1} P, banded as superphosphate (10.5% P) was also furnished to all pots at the equivalent rate of 20 kg.ha^{-1} P. Every treatment combination of N and K was replicated thrice, therefore, 96 pots were prepared.

TABLE 3.2: The amount of nitrogen and potassium band placed as limestone ammonium nitrate (28% N) and potassium chloride (50% K) for a row spacing of 1.5 m

Nitrogen and/or potassium rate (kg.ha^{-1})	Nitrogen and/or potassium application (g.pot^{-1})
0	0
20	0.96
40	1.91
60	2.87

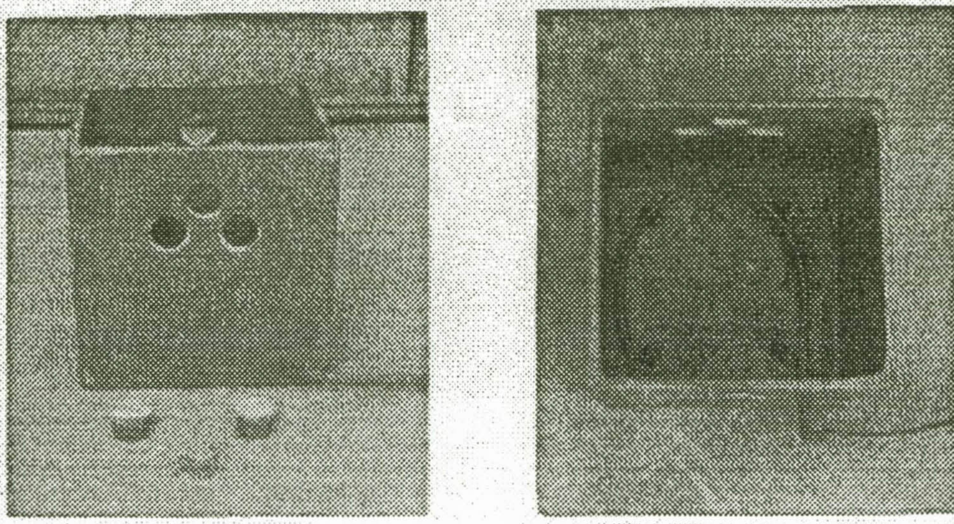
Asbestos pots (Figure 3.1a) measuring 0.34m x 0.34 x 0.35m (40.5 *l*) were used in the experiment. A flexible plastic pipe (0.5 m long with a diametre of 16 mm) in which 2 mm holes were punched 25 mm apart on either side of the pipe was placed at the bottom of each pot to drain excess water (through a suction force of 20 kPa) after the plants have been watered. Excess water was drained to keep the soil water content at field capacity. The drained water was returned to its respective pots in order to avoid loss of nutrients through leaching. The release pipe was located 15 mm from the bottom and 20 mm from the corner of the pot.

In each pot, two sets of openings (each set with three openings) were made on either side of the pot through which subsoil plant samples were obtained. These three openings, each measuring 51 mm in diameter were spaced as follows: The centre of the first opening measured 80 mm from the top of the pot, while the centre points of the two remaining openings, respectively, measured 50 mm below and 50 mm away from the centre of the first opening (Figure 3.1a). These openings were made so that samples of roots in the fertilized band and those in the area opposite the fertilized band could be taken with a stainless steel soil sampling probe (Figure 3.1b). During the experimentation period these openings were sealed with corks.

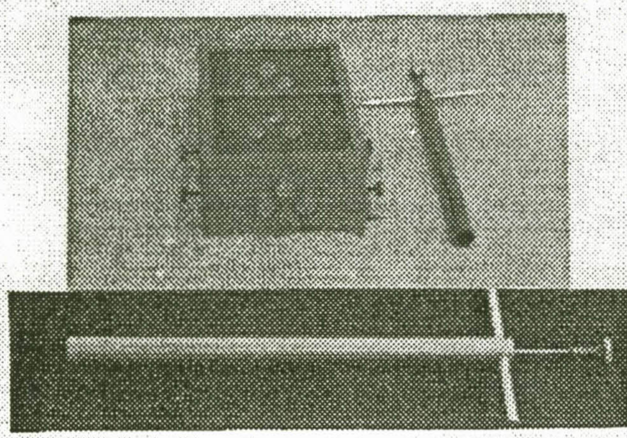
A gravel layer approximately 30 mm thick (5 kg) was placed at the bottom of every pot. This gravel layer covered the drainage pipe, thus holding it in position. A gauze was placed on top of the gravel layer to prevent the soil from penetrating the gravel layer and block the drainage pipe holes. Thereafter, each pot was filled with soil up to the level of fertilization (110 mm from the top of the pot). The fertilizer band was then applied by filling a hard plastic pipe (12 mm in diametre) with the correct amount of fertilizer after which it was stuck through one of the bottom openings of the pot (51 mm opening) and inverted to release the fertilizer. After the fertilizer was placed 50 mm of soil was added up to the planting depth. The correct amount of maize seed (nine seeds per pot) was planted along the top 51 mm opening of the pot. Another 50 mm of soil was added so that the final level of the soil was 30 mm from the top of the pot. The nine seeds planted were thinned to three seedlings per pot ten days after planting. The pots were then sprinkled with water in an effort to create a soil crust after planting. During the experimentation period the pots were randomly rotated once per week in an attempt to expose plants to similar environmental conditions within the glasshouse. This would be expected to significantly minimize the plants variation due to environmental influence and enhance their performance to be due to the different levels of fertilizer.

The plants were watered with distilled water and the water content of the soil was maintained at field capacity throughout the experimentation period. Distilled water was preferred instead of ordinary tap water because tap water has nutrients which would have influenced the results of the experiment. In order to maintain soil water content at field capacity, excess water was extracted with a vacuum pump through a suction force of 20 kPa. The extracted water was returned into each respective pot to avoid loss of nitrate through leaching. Care was exercised not to water pots beyond the drip point to avoid nitrate leaching. The glasshouse temperature was maintained at 25 ± 5°C during the day and at 15 ± 5°C during the night with a natural light regime.

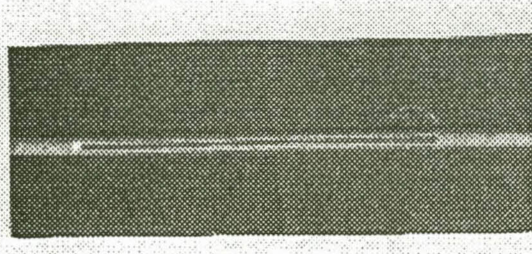
Throughout the experimentation duration the plants grew free of diseases and/or pests, hence no control measures were necessary.



(a) Front and top view of the trial pot



(b) Stainless steel sampling probe with guiding frame for taking soil samples in and directly opposite the fertilizer band



(c) The apparatus for placing of fertilizer in a band (12 mm pipe with incision)

FIGURE 3.1: Presentation of the trial pots and its associated apparatus

3.2.2 Observations during experiment

Leaf count, stem thickness and plant height were measured on a weekly basis starting from the first until the fourth week after emergence when the experiment was terminated. At termination of the experiment, *viz.* four weeks after planting leaf area, biomass and all the subsoil plant parameters were also measured.

3.2.2.1 Aerial plant parameters

*1. **Leaf count:*** Only the completely developed leaves were counted during the period of plant growth.

*2. **Stem thickness:*** Stem thickness was measured with a verniar calliper perpendicular to the main vein of the leaf sheath, 10 mm from the soil level.

*3. **Plant height:*** Plant height was measured with a tape from the soil level to the highest natural point of the maize plant.

*4. **Leaf area:*** The leaf area of each plant was determined with a LICOR leaf area meter, after cutting off the leaves from the stem.

*5. **Shoot mass:*** The shoots of all three plants from each pot were chopped into small pieces, dried at 60°C for 48 hours in an oven, whereafter the dry mass was determined.

*6. **Plant analysis:*** The dried aerial plant samples were milled and thoroughly mixed for the determination of the concentration of N, P, K, Ca, Mg, Na, Fe, Zn, Mn and Cu in the biomass. N was determined with steam distillation after the plant material was digested with sulphuric acid. In the case of other nutrients the plant material was dry ashed with nitric acid. Thereafter, P was determined colorimetrical while K, Ca, Mg, Na, Fe, Zn, Mn and Cu were determined atomic absorptiometrical (Hesse, 1971). These nutrient concentrations were used to calculate the accumulation of N, P, K, Ca, Mg, Na, Fe, Zn, Mn and Cu in the biomass.

3.2.2.2 Subsoil plant parameters

1. ***Root length:*** Soil cores were obtained with a stainless steel sampling probe (Figure 3.1b) from the fertilized band and the area opposite the fertilized band through the two bottom 51 mm openings of the pots (Figure 3.1a). Each core was divided into two halves longitudinally. One half was used for the extraction of roots, while the other half was retained for the measurement of electrical resistance (The Non-affiliated Work Committee, 1990) to determine if the fertilizer band remained intact or some fertilizer leached during the trial period. The roots were separated by washing each core half with a stream of water over a 0.5 mm sieve. A modified infrared root line intersection counter (Rowse & Phillips, 1974) was used to determine the length of the roots from the fertilized band and from the area opposite the fertilized band.

2. ***Root volume:*** The root volume was measured by submerging the roots in a volumetric cylinder containing some water and the difference in water volume before and after submerging the roots was considered as the root volume.

3. ***Root area:*** The root area was calculated by means of the root volume and the root length.

4. ***Root mass:*** The root mass was determined after drying the roots at 60°C for 48 hours in an oven.

3.2.3 Experimental design and data processing

As already described a complete randomized experimental design with a factorial combination consisting of two main factors, *viz.* four N or K band application levels which were replicated thrice, was used for each soil. Therefore, statistical analysis were performed for each soil regarding its parameters, using analysis of variance at a 5% level of probability (SAS Institute, Inc., 1985). The procedure of Tukey was used to compare the treatments means, also at 5% probability level (Gomez & Gomez, 1984).

3.3 RESULTS AND DISCUSSION

The influence of band placed N and K on the early growth and development of maize can only be estimated to its true value if it is known that the fertilizers remained largely intact in the application zone despite of repeated waterings. Therefore, the primary purpose of measuring electrical resistance at the termination of the experiment was to confirm this aspect. Unfortunately, the decline of electrical resistance in the fertilized zones with increased application levels of N and/or K was somewhat disguised by the uniform basal application of P (Appendices 3.1 and 3.3). The application of N had no significant influence on the electrical resistance of the fertilized zone in the sandy loam soil, but it significantly influenced the electrical resistance of the fertilized zone in the sandy soil. On the other hand, the application of K significantly influenced the electrical resistance of the fertilized zone in the sandy loam soil, but had no marked effect on the electrical resistance of the fertilized zone in the sandy soil. However, in both soils the electrical resistance of the fertilized zone decreased slightly as the application level of either N and/or K increased. The large difference in the mean electrical resistance of the fertilized and unfertilized zones confirms that the fertilizers were to a large extent intact in both soils (Figure 3.2a, 3.2b, 3.3a and 3.3b), which is in agreement with the findings of Ceronio (1997), who used exactly the same methodology.

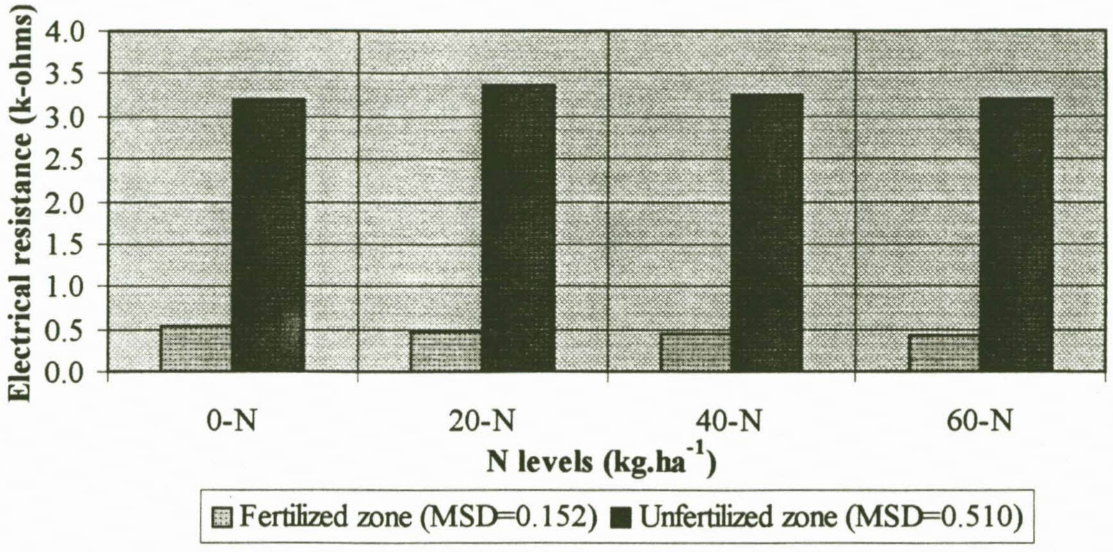


FIGURE 3.2a: Mean electrical resistance in the fertilized and unfertilized zones of the sandy loam soil as a result of nitrogen application

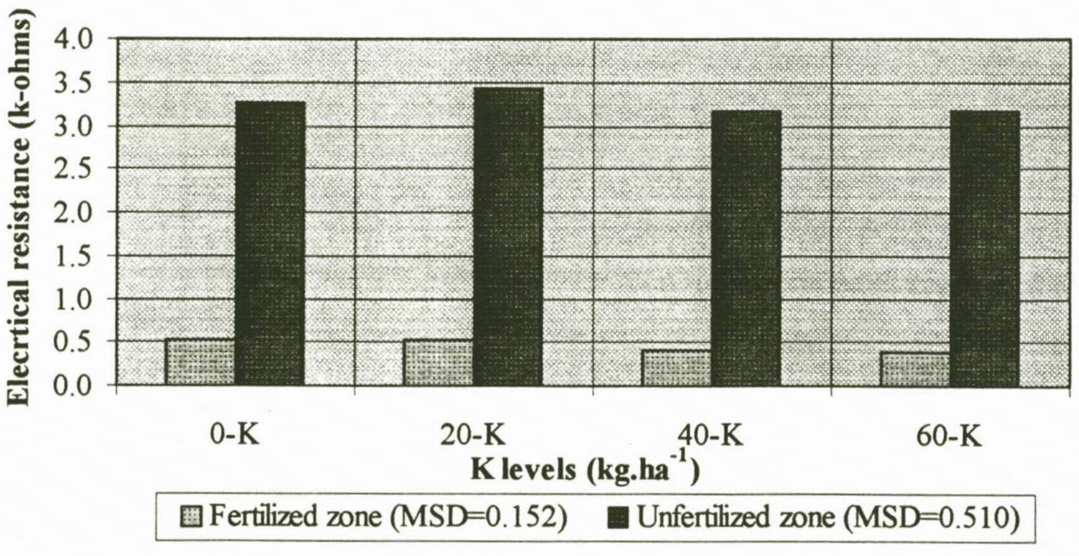


FIGURE 3.2b: Mean electrical resistance in the fertilized and unfertilized zones of the sandy loam soil as a result of potassium application

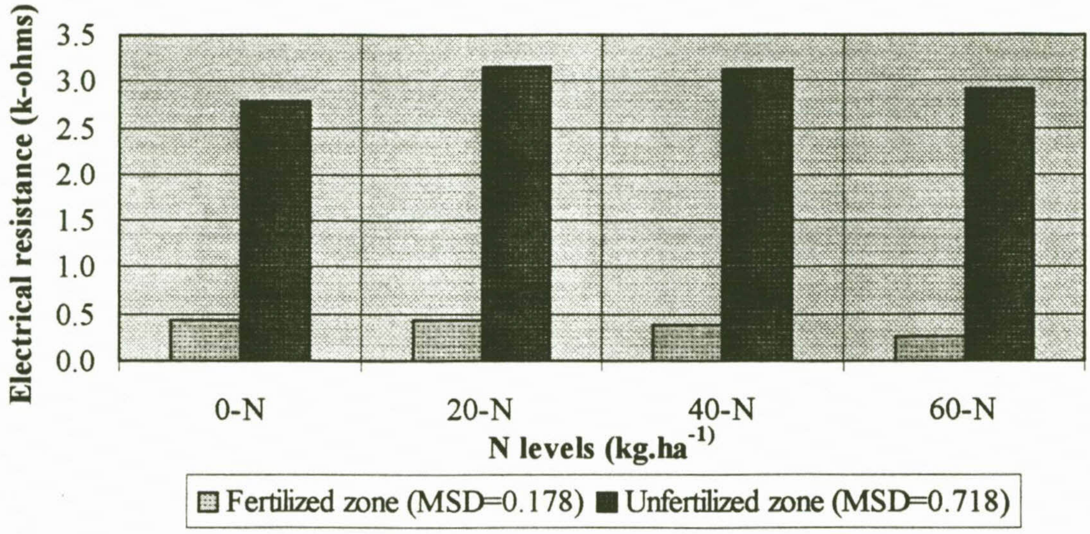


FIGURE 3.3a: Mean electrical resistance in the fertilized and unfertilized zones of the sandy soil as a result of nitrogen application

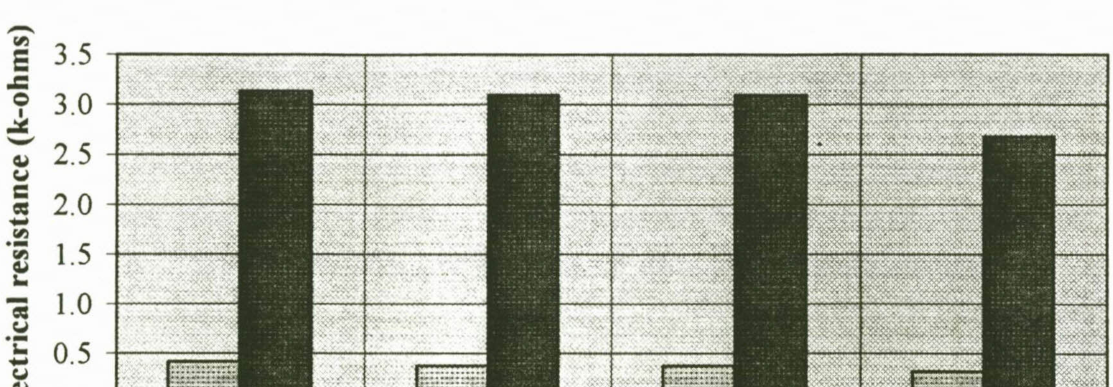


FIGURE 3.3b: Mean electrical resistance in the fertilized and unfertilized zones of the sandy soil as a result of potassium application

3.3.1 Growth analysis on the aerial plant parameters

The interaction of N and K application levels did not significantly influence any of the aerial plant parameters for both soils (Appendices 3.5-3.32). However, the application of N and K separately had significant effects on some of the aerial plant parameters. As a result, the discussion on aerial plant parameters will be focused on these two main factors.

3.3.1.1 Leaf count

Sandy loam soil:

The application of N had no significant influence on leaf count during the first and second weeks of plant growth, but it significantly influenced leaf count during the third and fourth weeks of plant growth (Appendices 3.5-3.8). During weeks three and four of plant growth, leaf count was significantly lower at 0 kg $N.ha^{-1}$ than at 20, 40 and 60 kg $N.ha^{-1}$ application levels, with no marked differences between the three higher levels (Figure 3.4a).

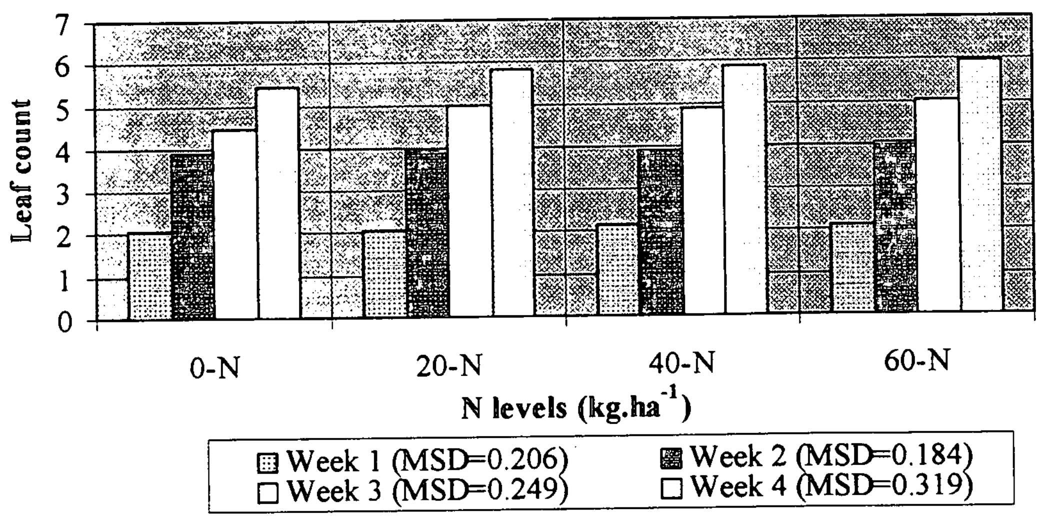


FIGURE 3.4a: Leaf count as a result of nitrogen application to the sandy loam soil

During the first four weeks of plant growth, K showed no significant influence on leaf count (Appendices 3.5-3.8), as it is also illustrated very clearly in Figure 3.4b.

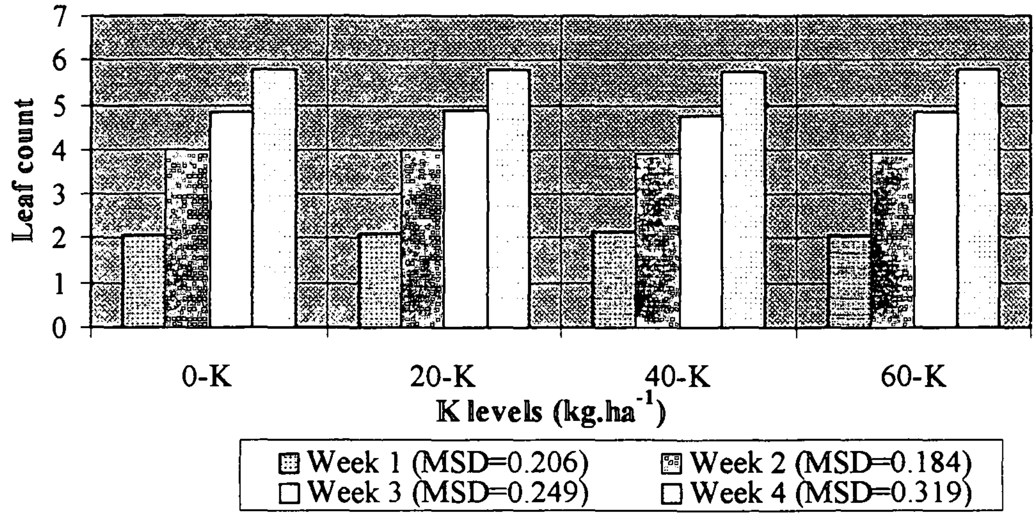


FIGURE 3.4b: Leaf count as a result of potassium application to the sandy loam soil

Sandy soil:

With the exception of the first week, the application of N significantly influenced leaf count during the second, third and fourth weeks of plant growth (Appendices 3.9-3.12). As it is illustrated in Figure 3.5a, the 40 and 60 kg $N.ha^{-1}$ application levels significantly increased leaf count compared to the 0 kg $N.ha^{-1}$ application level during the second week of plant growth. Furthermore, during the third and fourth weeks of plant growth, the N application levels 20, 40 and 60 $kg.ha^{-1}$ resulted in a markedly higher leaf count than 0 kg $N.ha^{-1}$.

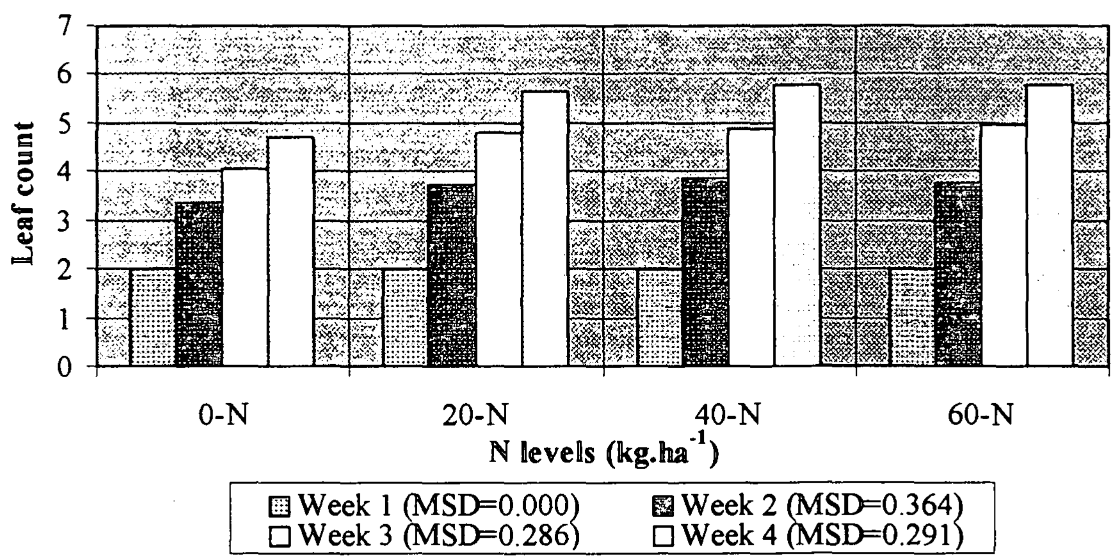


FIGURE 3.5a: Leaf count as a result of nitrogen application to the sandy soil

No significant differences were observed in leaf count as a result of the application of K during the first and third weeks of plant growth, but K significantly influenced leaf count during the second and fourth weeks of plant growth (Appendices 3.9-3.12). Although not always significant, Figure 3.5b clearly indicates for weeks two, three and four a decrease in leaf count when K is applied. In comparison with the 0 kg $K.ha^{-1}$ application level, a significant decline in leaf count resulted from 60 and 20 kg $K.ha^{-1}$ application levels, during the second and fourth weeks of plant growth, respectively.

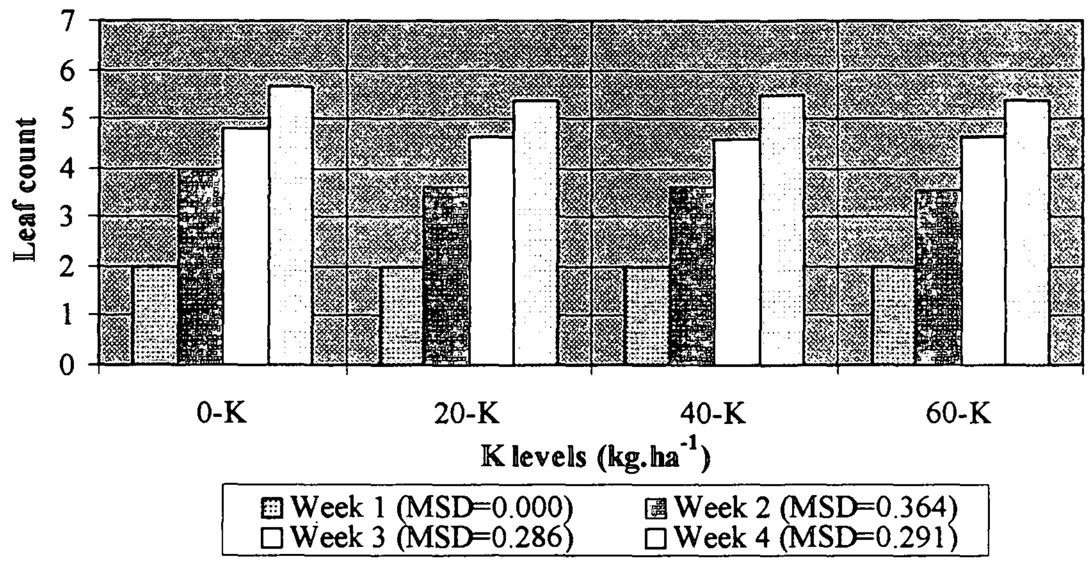


FIGURE 3.5b: Leaf count as a result of potassium application to the sandy soil

Considering that leaf count can be used as a guideline to monitor the growth and development of the maize plant, this parameter can be used to determine if the growth and development has been either stimulated or inhibited by the application of N and/or K. The results on leaf count revealed that an application of 20 kg $N.ha^{-1}$ resulted in optimum growth and development of the maize plant in both soils. The application of K showed no significant increase in leaf count, hence fertilization of K to both soils is not required for improving the growth and development of the maize plant during the first four weeks of plant growth.

3.3.1.2 Stem thickness

Sandy loam soil:

With the exception of the first week, the application of N significantly influenced stem thickness during the second, third and fourth weeks of plant growth (Appendices 3.13-3.16). Figure 3.6a shows an almost linear increase in stem thickness as the N application level increases during the second, third and fourth weeks of plant growth. There were no marked differences between N application levels 20 and 40 kg.ha^{-1}, but 60 kg N.ha^{-1} significantly increased stem thickness compared to 0 and 20 kg N.ha^{-1} during the second week of plant growth. During the third and fourth weeks of plant growth, no differences were observed between 40 and 60 kg N.ha^{-1}, but 60 kg N.ha^{-1} resulted in a significantly greater stem thickness than 0 and 20 kg N.ha^{-1}.

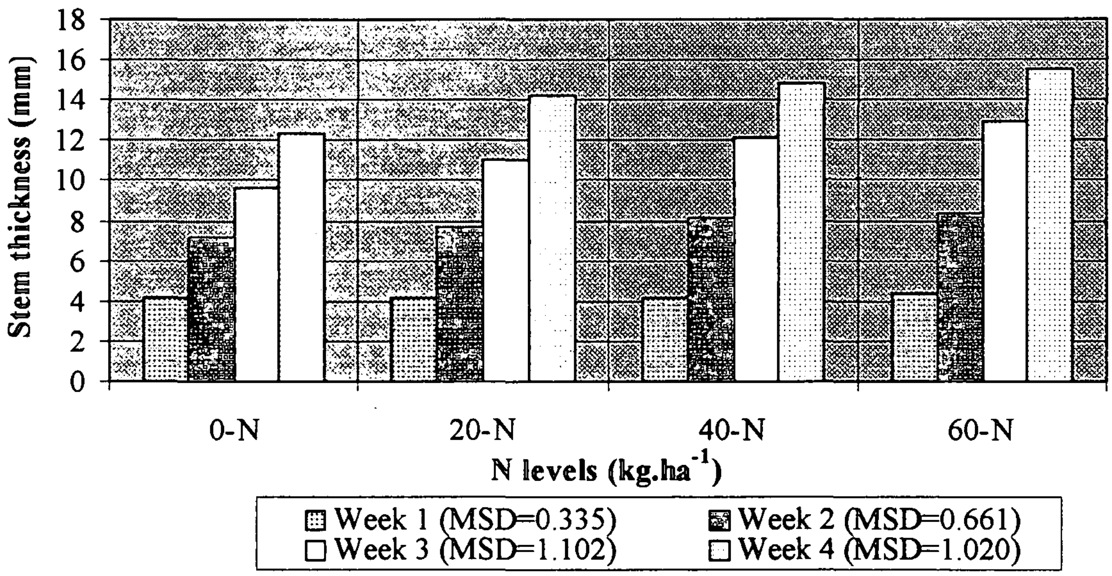


FIGURE 3.6a: Stem thickness as a result of nitrogen application to the sandy loam soil

The application of K showed no significant influence on stem thickness during the four weeks of plant growth (Appendices 3.13-3.16), as it is also evident from Figure 3.6b.

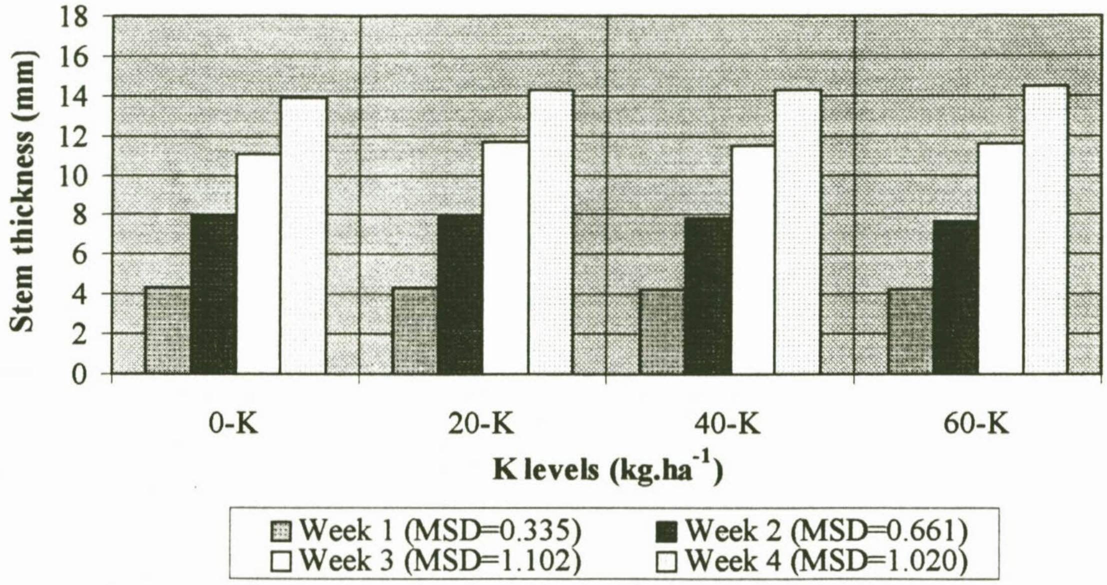


FIGURE 3.6b: Stem thickness as a result of potassium application to the sandy loam soil

Sandy soil:

The application of N significantly influenced stem thickness during the four weeks of plant growth (Appendices 3.17-3.20). As it is illustrated in Figure 3.7a there were no marked differences in stem thickness between N application levels 20, 40 and 60 kg.ha^{-1} for any week. However, the application of 40 kg N.ha^{-1} had a significant increase on stem thickness compared to 0 kg N.ha^{-1} during the first week of plant growth. During the second, third and fourth weeks of plant growth the N application levels 20, 40 and 60 kg.ha^{-1} resulted in a significantly greater stem thickness than 0 kg N.ha^{-1}.

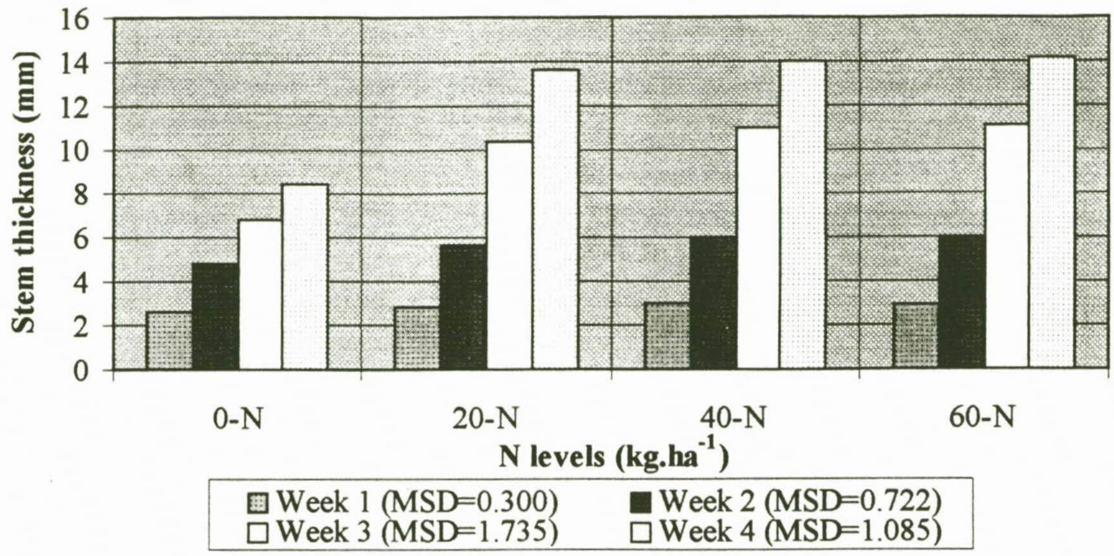


FIGURE 3.7a: Stem thickness as a result of nitrogen application to the sandy soil

Like in the sandy loam soil, the application of K showed no significant influence on stem thickness during the four weeks of plant growth in the sandy soil (Appendices 3.17-3.20). It is also evident from Figure 3.7b that with the exception of week one, 60 kg K.ha^{-1} had a negative effect on stem thickness.

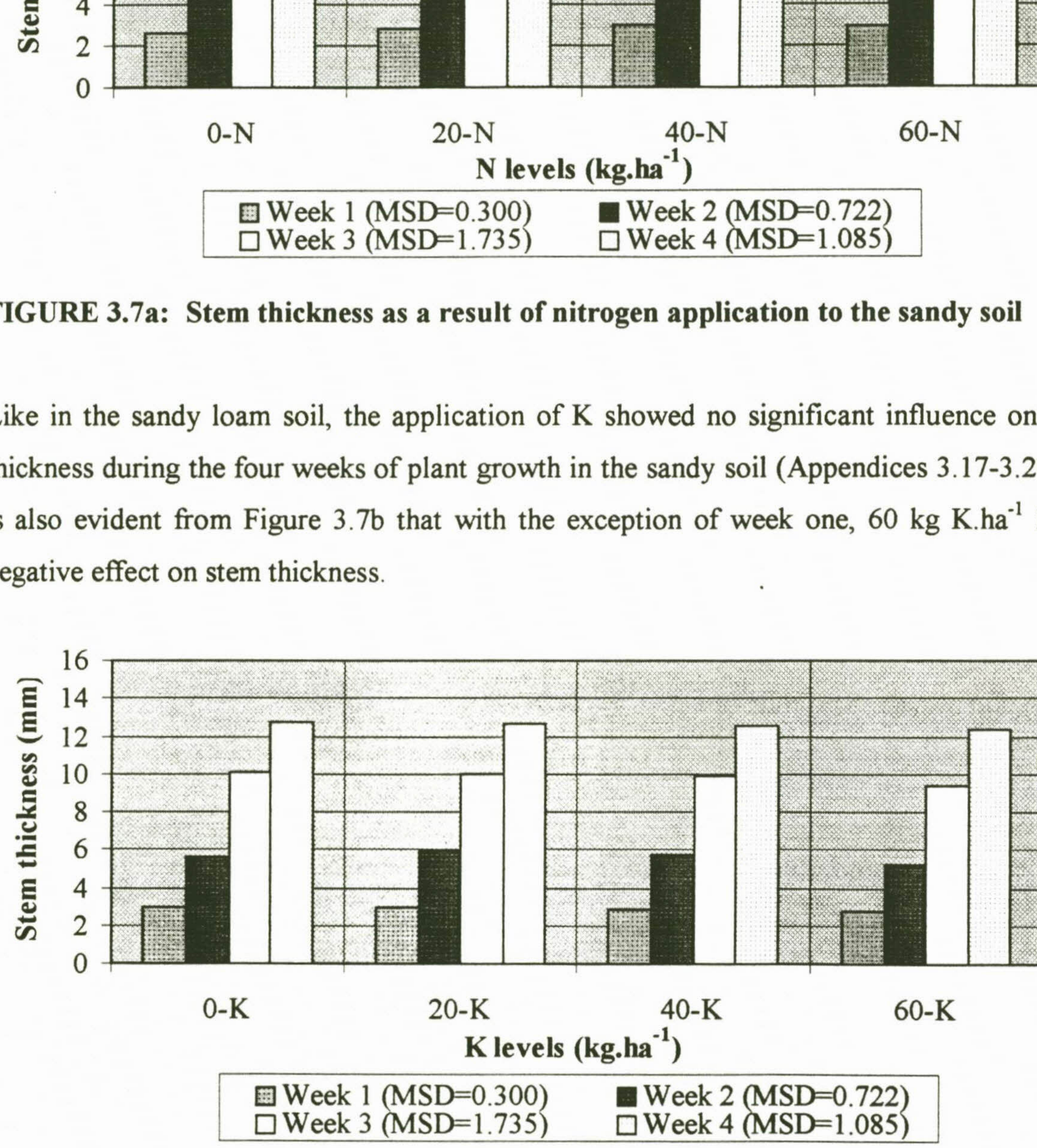


FIGURE 3.7b: Stem thickness as a result of potassium application to the sandy soil

The results revealed that 40 to 60 kg $N.ha^{-1}$ resulted in optimum stem thickness of the maize plant in the sandy loam soil, while 20 kg $N.ha^{-1}$ was found to be suitable for the sandy soil. In contrast, stem thickness was not affected at all by the application of K.

3.3.1.3 Plant height

Sandy loam soil:

The application of N showed no significant effects on plant height during the first and second weeks of plant growth, but significantly influenced plant height during the third and fourth weeks of plant growth (Appendices 3.21-3.24). It is evident from Figure 3.8a that for weeks three and four there were no marked differences in plant height between N application levels 20, 40 and 60 $kg.ha^{-1}$. However, the 60 kg $N.ha^{-1}$ application level significantly increased plant height compared to 0 kg $N.ha^{-1}$ application level during the third week of plant growth. During the fourth week of plant growth, N application levels 20, 40 and 60 $kg.ha^{-1}$ resulted in a significantly greater plant height than 0 kg $N.ha^{-1}$.

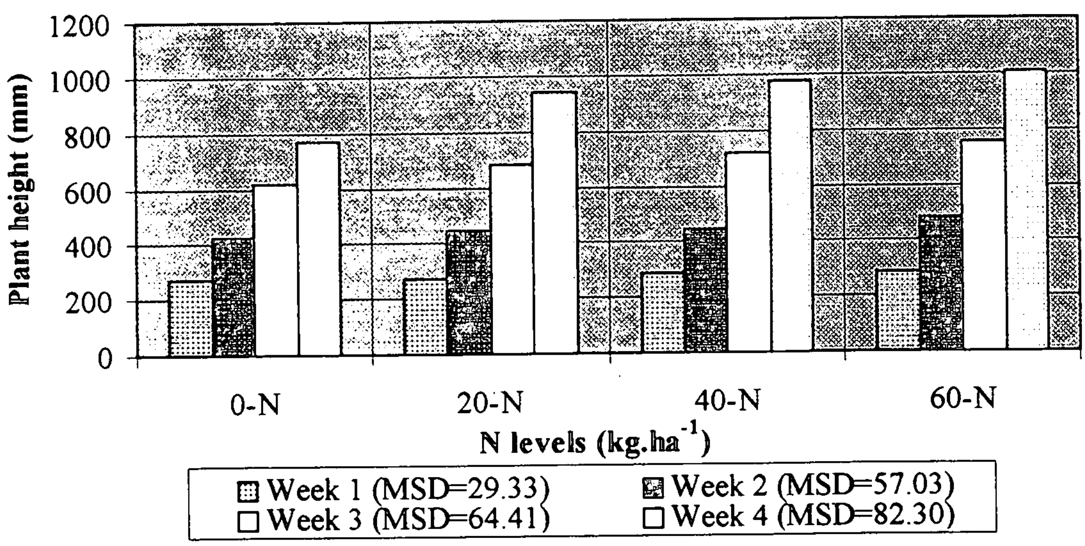


FIGURE 3.8a: Plant height as a result of nitrogen application to the sandy loam soil

The application of K showed no significant influence on plant height during the four weeks of plant growth (Appendices 3.21-3.24). Although there were no significant differences between the K application levels 0, 20, 40 and 60 $kg.ha^{-1}$, Figure 3.8b clearly indicates that an application level of 20 kg K.ha^{-1} had a marginal influence on plant height compared to the other three application levels during the four weeks of plant growth.

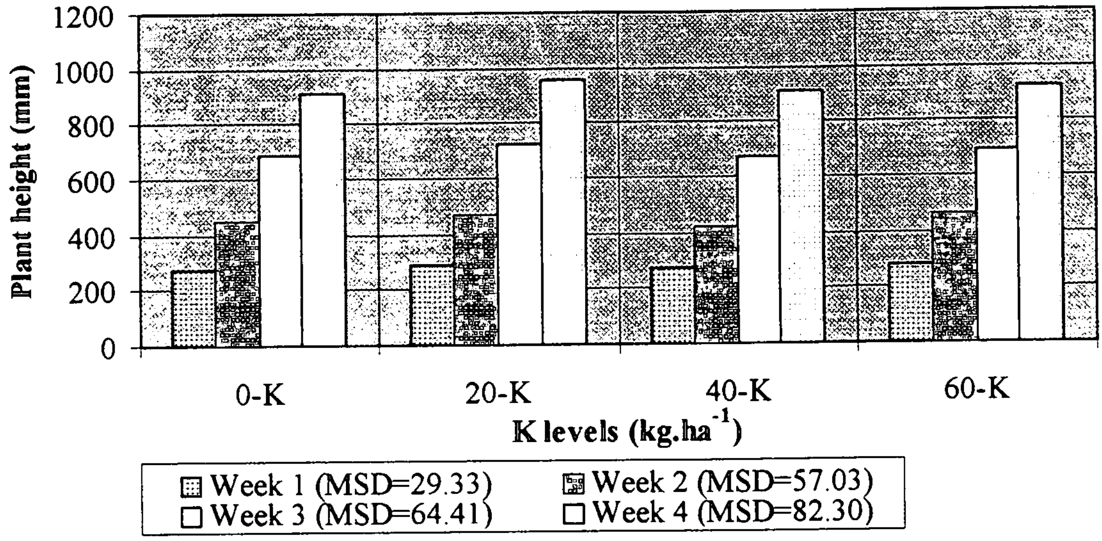


FIGURE 3.8b: Plant height as a result of potassium application to the sandy loam soil

Sandy soil:

With the exception of the first week, N application levels significantly influenced plant height during the second, third and fourth weeks of plant growth (Appendices 3.25-3.28). As it is illustrated in Figure 3.9a for weeks two, three and four there were no marked differences in plant height between N application levels 20, 40 and 60 kg.ha^{-1}. However, 40 and 60 kg N.ha^{-1} significantly increased plant height compared to 0 kg N.ha^{-1} during the second week of plant growth. During the third and fourth weeks of plant growth, N application levels 20, 40 and 60 kg.ha^{-1} resulted in a significant increase in plant height compared to 0 kg N.ha^{-1}. A thorough inspection of Figure 3.9a shows that an application of 40 kg N.ha^{-1} resulted in the greatest plant height from the first to the fourth week of plant growth.

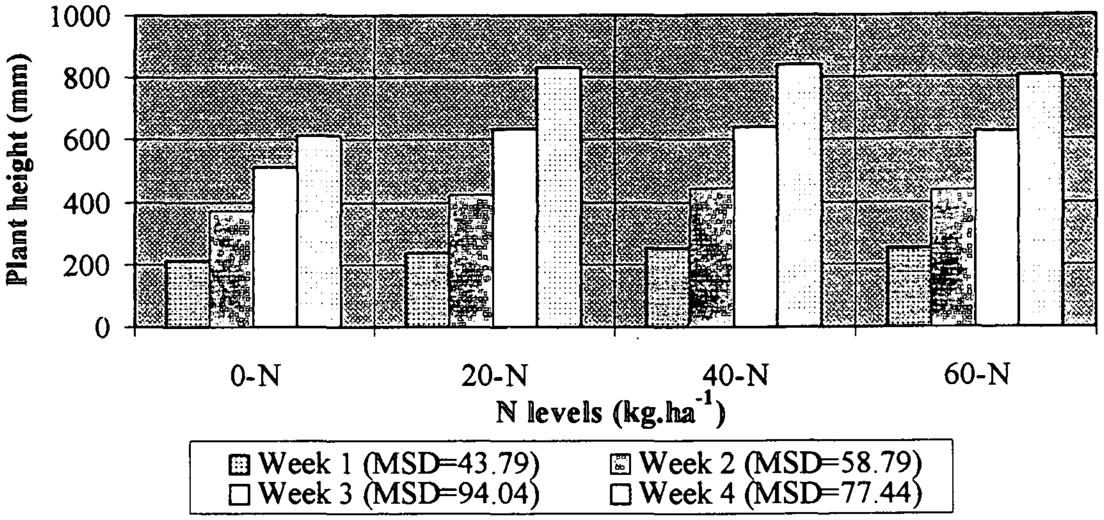


FIGURE 3.9a: Plant height as a result of nitrogen application to the sandy soil

The application of K had no significant effects on plant height during the first, third and fourth weeks of plant growth, but it significantly influenced plant height during the second week of plant growth (Appendices 3.25-3.28). The 60 kg $K.ha^{-1}$ application level significantly decreased plant height compared to 0 kg $K.ha^{-1}$ application level during the second week of plant growth. However, Figure 3.9b clearly illustrates that for weeks two, three and four plant height was inhibited by the application of K.

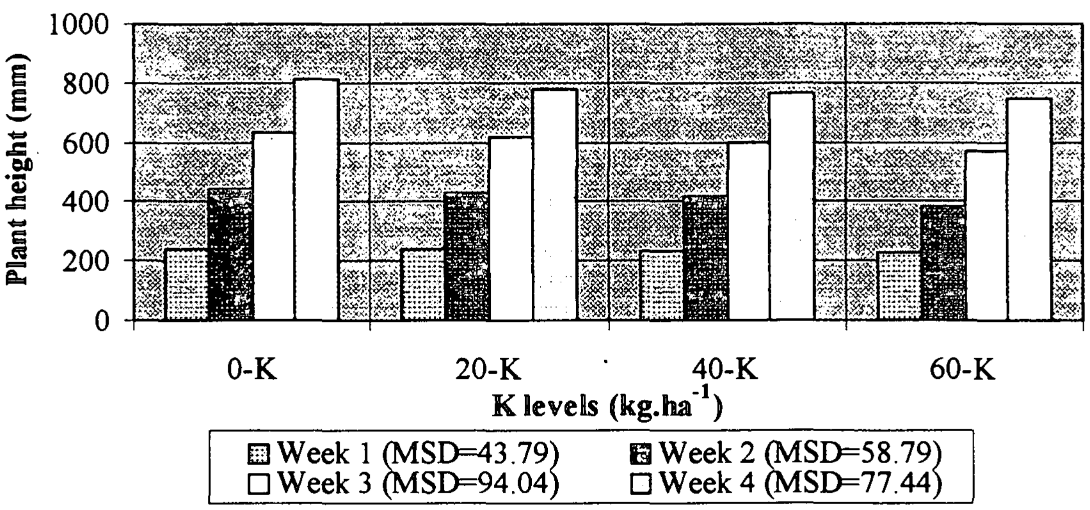


FIGURE 3.9b: Plant height as a result of potassium application to the sandy soil

The results revealed that 20 to 40 kg N.ha^{-1} accounted for optimum plant height of the maize plant in the sandy loam soil, while 40 kg N.ha^{-1} was suitable for the sandy soil. An application of 20 kg K.ha^{-1} was noticed to be optimum for plant height of the maize plant in the sandy loam soil, but for the sandy soil an application of 0 kg K.ha^{-1} was optimum.

3.3.1.4 Leaf area

Sandy loam soil:

The application of N had a significant influence on leaf area (Appendix 3.29). It is evident from Figure 3.10a that leaf area increases as the N application level increases. However, there were no significant differences in leaf area between the N application levels 40 and 60 kg.ha^{-1}, but both of these levels resulted in a significantly greater leaf area than N application levels 0 and 20 kg.ha^{-1}. Furthermore, 20 kg N.ha^{-1} application level also accounted for a marked increase in leaf area compared to 0 kg N.ha^{-1} application level.

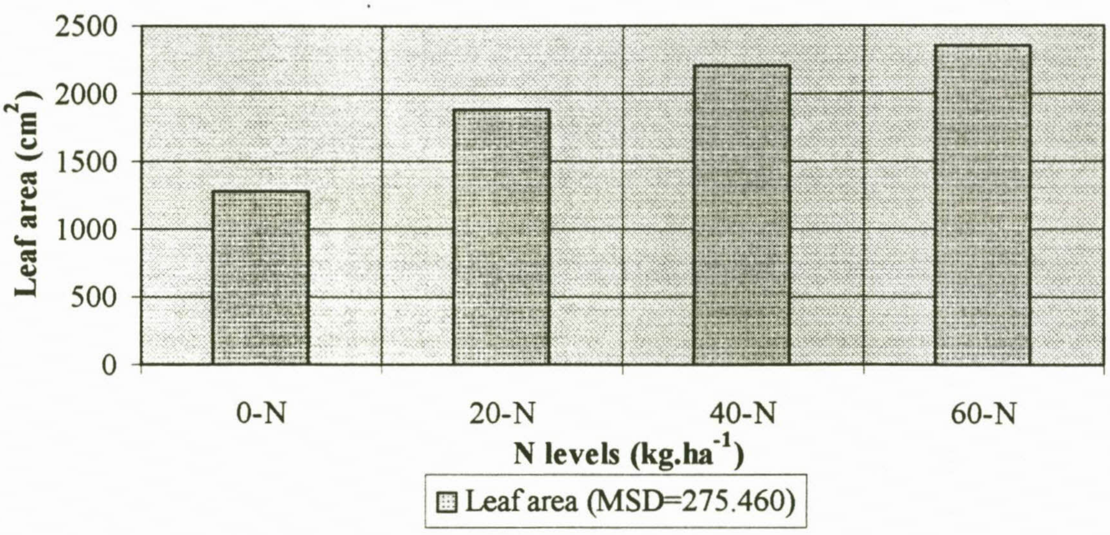


FIGURE 3.10a: Leaf area as a result of nitrogen application to the sandy loam soil

In contrast, the application of K had no significant influence on leaf area (Appendix 3.29). Despite the fact that there were no significant differences, Figure 3.10b clearly shows that an application of 20 kg K.ha^{-1} was marginally better than the other application levels with regard to leaf area.

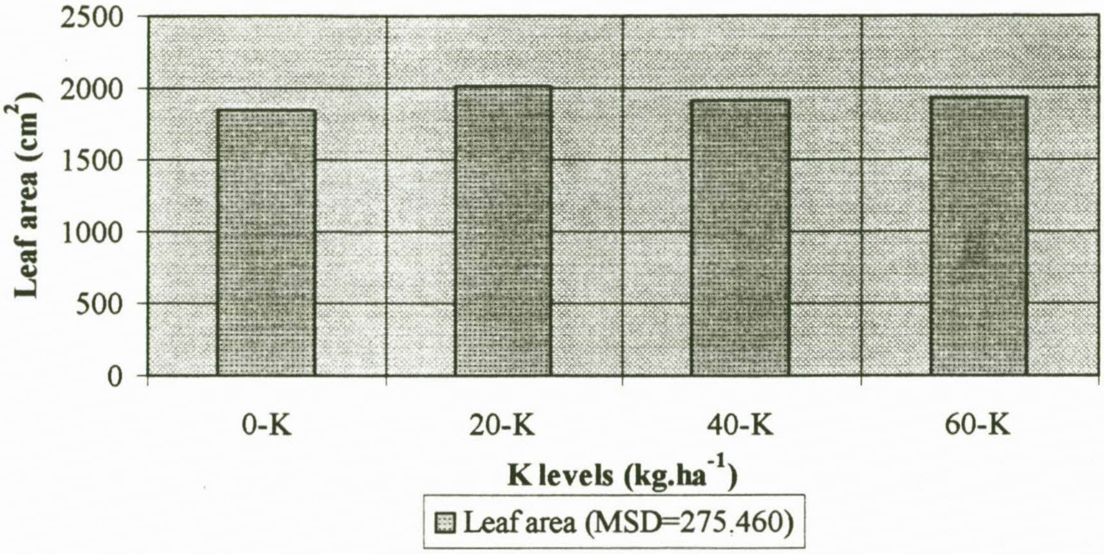


FIGURE 3.10b: Leaf area as a result of potassium application to the sandy loam soil

Sandy soil:

The application of N had a significant influence on leaf area (Appendix 3.30). As it is illustrated in Figure 3.11a there were no significant differences between N application levels 20, 40 and 60 kg.ha^{-1}, but all these three levels resulted in a significantly greater leaf area than the 0 kg N.ha^{-1} level.

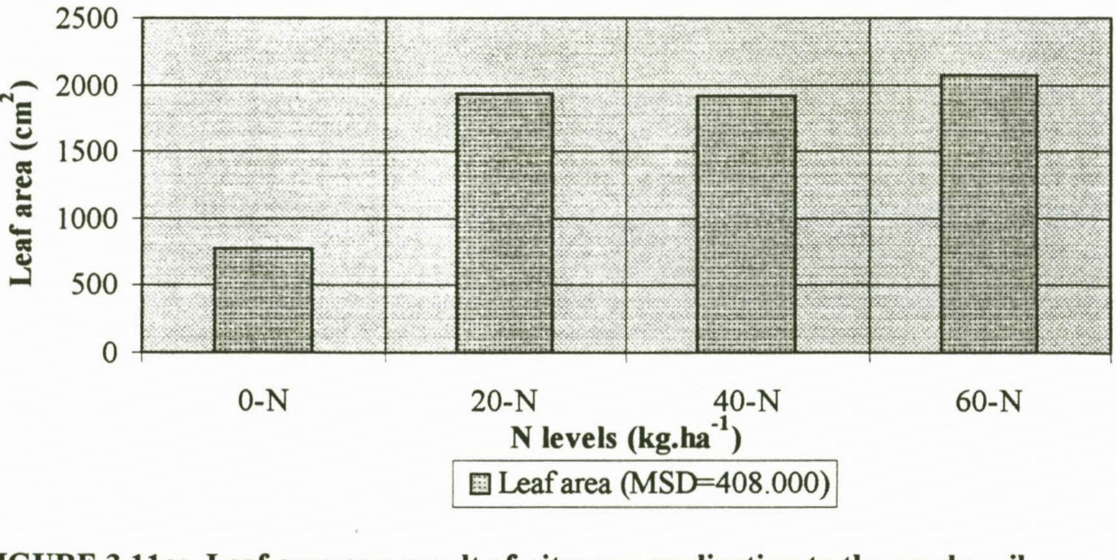


FIGURE 3.11a: Leaf area as a result of nitrogen application to the sandy soil

On the other hand, the application of K showed no significant differences in leaf area (Appendix 3.30). However, Figure 3.11b clearly shows that K application levels of 20, 40 and 60 kg.ha^{-1} inhibited leaf area.

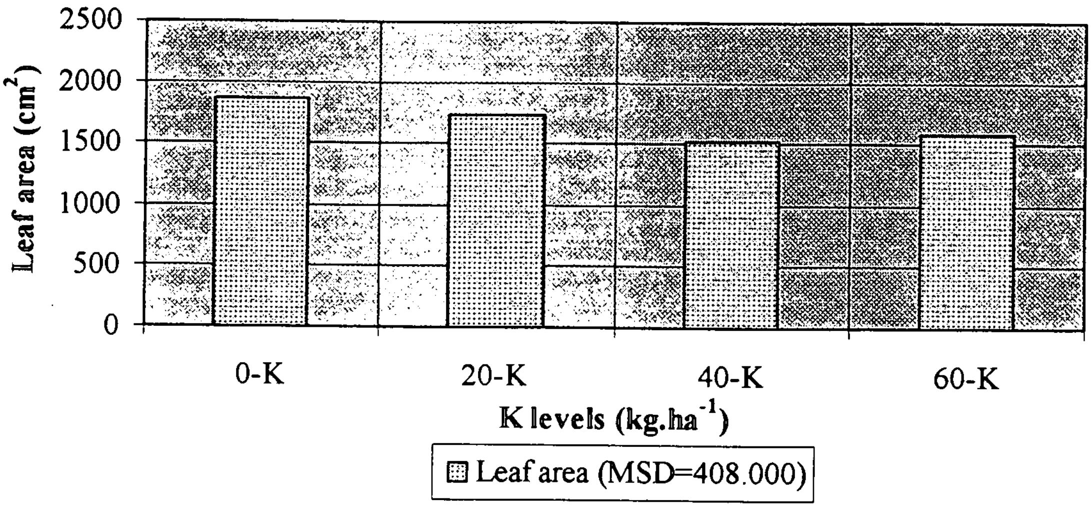


FIGURE 3.11b: Leaf area as a result of potassium application to the sandy soil

The results showed that 40 to 60 kg N.ha^{-1} resulted in optimum leaf area of the maize plant in the sandy loam soil, while 20 kg N.ha^{-1} was found to be suitable for the sandy soil. An application level of 20 kg K.ha^{-1} was noticed to be suitable for the optimum leaf area of the maize plant in the sandy loam soil, whereas 0 kg K.ha^{-1} would seem to be ideal in the sandy soil.

3.3.1.5 Biomass

Sandy loam soil:

The application of N had a significant influence on biomass (Appendix 3.31). Figure 3.12a clearly indicates an increase in biomass as the level of N increases. No marked differences were observed between the N application levels 40 and 60 kg N.ha^{-1}, but 60 kg N.ha^{-1} had a significant increase in biomass compared to 0 and 20 kg N.ha^{-1}. Furthermore, 20 and 40 kg N.ha^{-1} also resulted in a significantly higher biomass than 0 kg N.ha^{-1}.

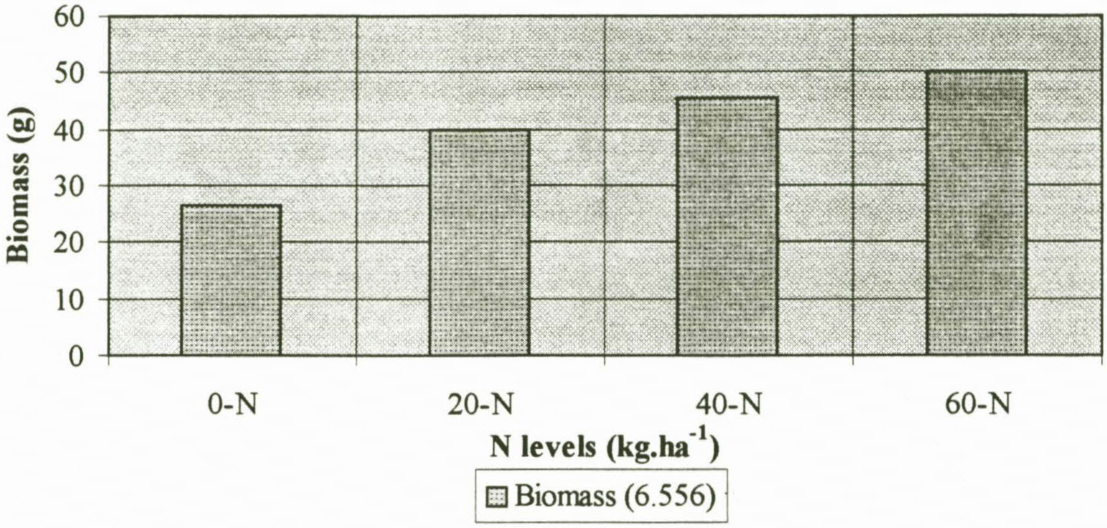


FIGURE 3.12a: Biomass as a result of nitrogen fertilization to the sandy loam soil

The application of K had no significant effect on biomass (Appendix 3.31), which is also clearly evident from Figure 3.12b.

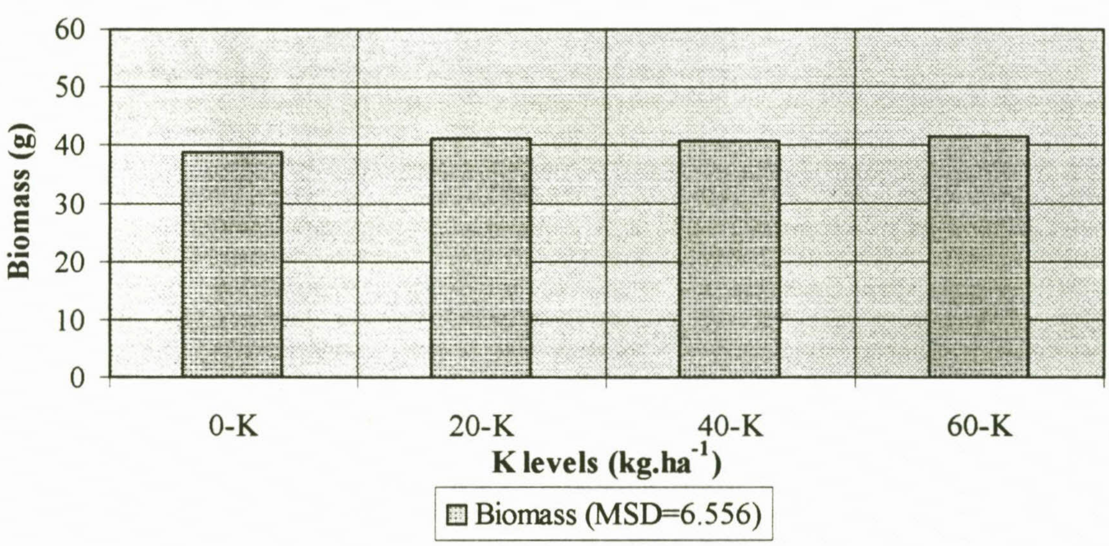


FIGURE 3.12b: Biomass as a result of potassium fertilization to the sandy loam soil

Sandy soil:

The application of N had a significant effect on biomass (Appendix 3.32). As it is illustrated in Figure 3.13a no significant differences were noticed in biomass between N application levels 20, 40 and 60 kg.ha^{-1}, but all these three levels significantly increased biomass compared to 0 kg N.ha^{-1}. However, 20 kg N.ha^{-1} resulted in a slightly inferior biomass compared to 40 and 60 kg.ha^{-1}.

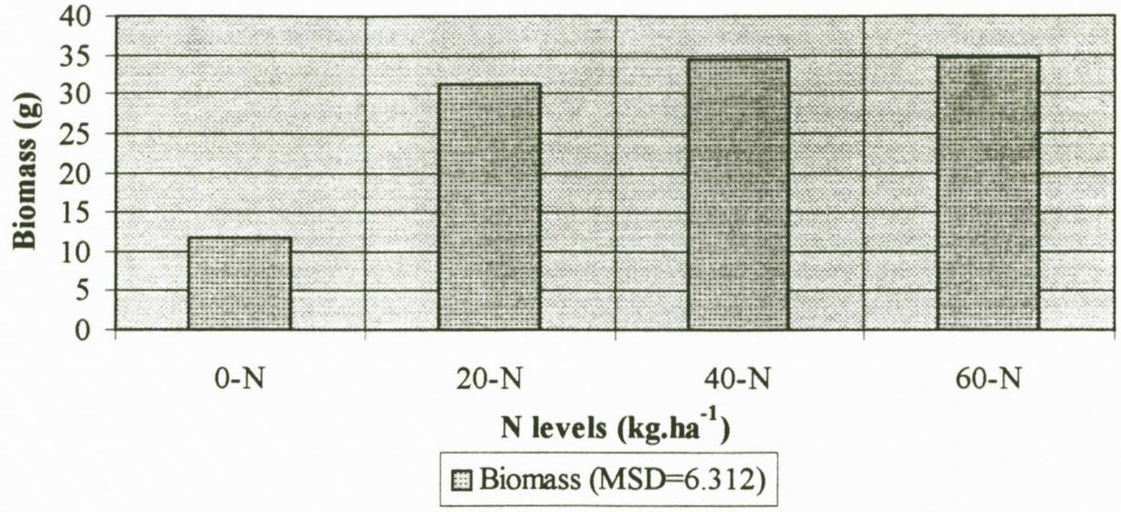


FIGURE 3.13a: Biomass as a result of nitrogen fertilization to the sandy soil

Like in the sandy loam soil, the application of K showed no significant influence on biomass in the sandy soil (Appendix 3.32). Despite the fact that no significant differences were detected due to the application of K, Figure 3.13b clearly shows a linear decrease in biomass as the application level of K increases from 0 to 60 kg.ha^{-1}.

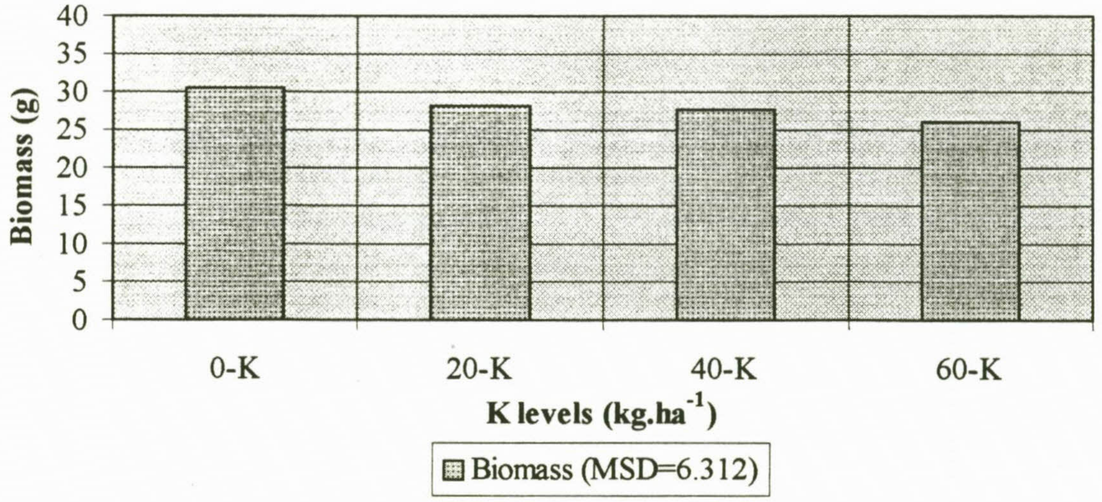


FIGURE 3.13b: Biomass as a result of potassium fertilization to the sandy soil

The results revealed that 40 to 60 kg N.ha^{-1} resulted in optimum biomass of the maize plant in the sandy loam soil, while 20 to 40 kg N.ha^{-1} was suitable for the sandy soil. An application level of 20 kg K.ha^{-1} accounted for optimum biomass of the maize plant in the sandy loam soil, while 0 kg K.ha^{-1} was ideal for the sandy soil.

The N and K application levels which were noticed to be appropriate for the optimum early growth and development of the maize plant with respect to the aerial plant parameters are outlined in Table 3.3. These N and K application rates were found to be suitable for the early growth and development of the maize plant without causing any adverse effects. It seems that in most cases an application level of 40 kg N.ha^{-1} for the sandy loam soil and an application level of 20 kg N.ha^{-1} for the sandy soil will be sufficient to ensure optimum growth and development of maize during the first four weeks of plant growth. In most cases additional K inhibited the growth and development parameters of maize during the first four weeks of plant growth, therefore, application should not exceed 20 kg.ha^{-1} in the sandy loam soil and 0 kg.ha^{-1} in the sandy soil.

TABLE 3.3: Nitrogen and potassium levels (kg.ha^{-1}) appropriate for the optimum growth and development of the aerial parameters of maize during the first four weeks of plant growth

Parameter	Sandy loam soil		Sandy soil	
	N	K	N	K
Leaf count	20	-	20	-
Stem thickness	40-60	-	20	-
Plant height	20-40	20	40	-
Leaf area	40-60	20	20	-
Biomass	40-60	-	20-40	-

3.3.2 Growth analysis on the subsoil plant parameters

The interaction of N and K application levels did not significantly influence any of the subsoil plant parameters for both soils (Appendices 3.33 to 3.48). However, the application of N and K separately had significant effects on some of the subsoil plant parameters. As a result, the discussion on subsoil plant parameters will be focussed on these two main factors.

*3.3.2.1 **Root length***

Sandy loam soil:

The application of N did not significantly influence the length of the roots in the fertilized and unfertilized zones (Appendices 3.33 and 3.34). However, Figure 3.14a clearly shows that N application increased the root length in the fertilized zone and that 20 kg $N.ha^{-1}$ was the most beneficial level in this regard. In the unfertilized zone, the application of N had a negative influence on the root length.

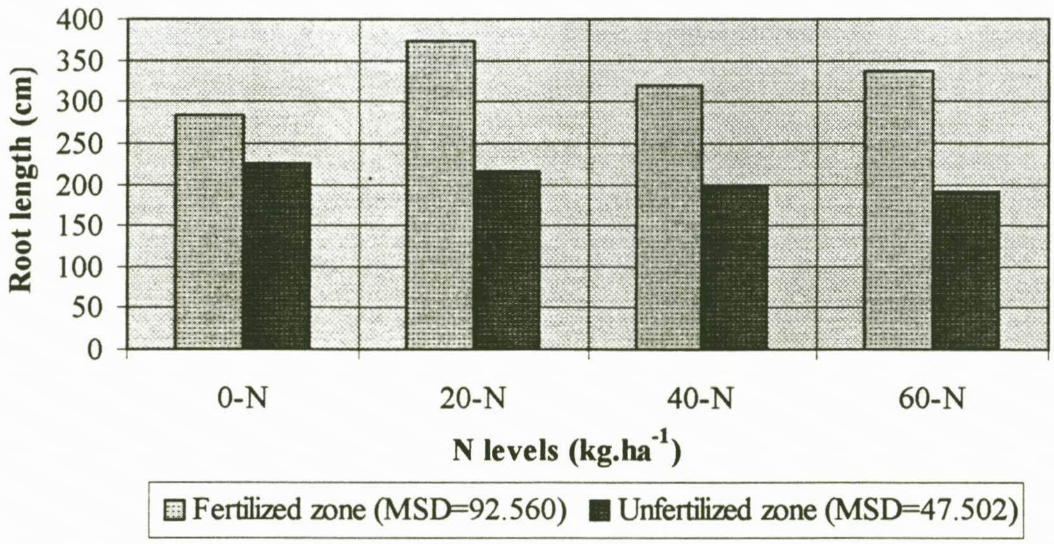


FIGURE 3.14a: Root length as a result of nitrogen application to the sandy loam soil

Similarly, the application of K had no significant effects on the length of the roots in the fertilized and unfertilized zones (Appendices 3.33 and 3.34). In fact Figure 3.14b clearly shows that the application of K slightly inhibited root elongation.

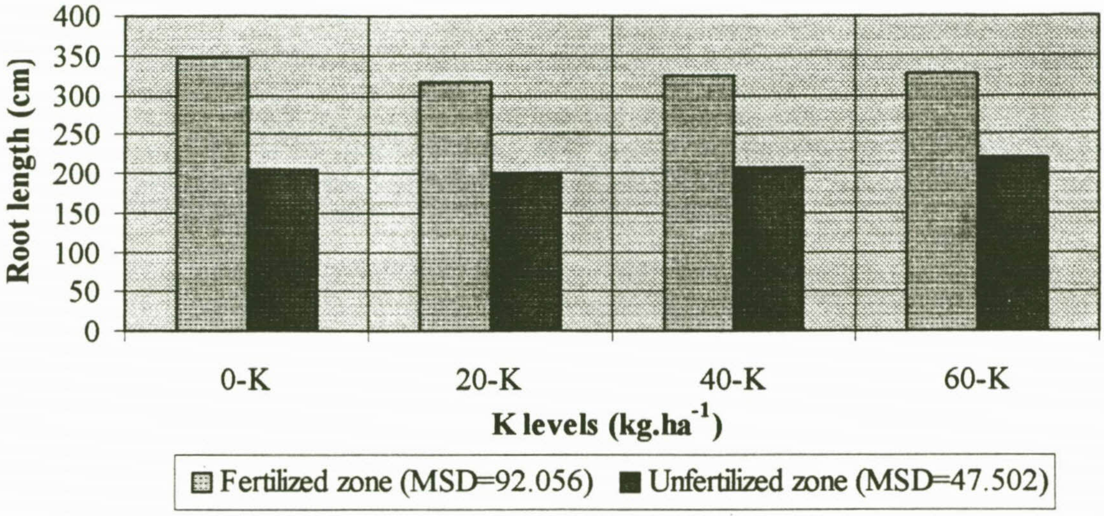


FIGURE 3.14b: Root length as a result of potassium application to the sandy loam soil

Sandy soil:

The length of the roots in the fertilized and unfertilized zones was significantly influenced by the application of N (Appendices 3.35 and 3.36). It is evident from Figure 3.15a that in the case of the fertilized zone there was a corresponding increase in root length as the level of N increases. Despite this phenomenon, no significant differences were obtained in the root lengths of the 20, 40 and 60 kg $N.ha^{-1}$ applications levels. However, the root lengths of the 40 and 60 kg $N.ha^{-1}$ applications were significantly longer than that of 0 kg $N.ha^{-1}$ application. In the case of the unfertilized zone, the root lengths of the 20, 40 and 60 kg $N.ha^{-1}$ applications were significantly longer than that of 0 kg $N.ha^{-1}$ application, but they did not significantly differ from each other.

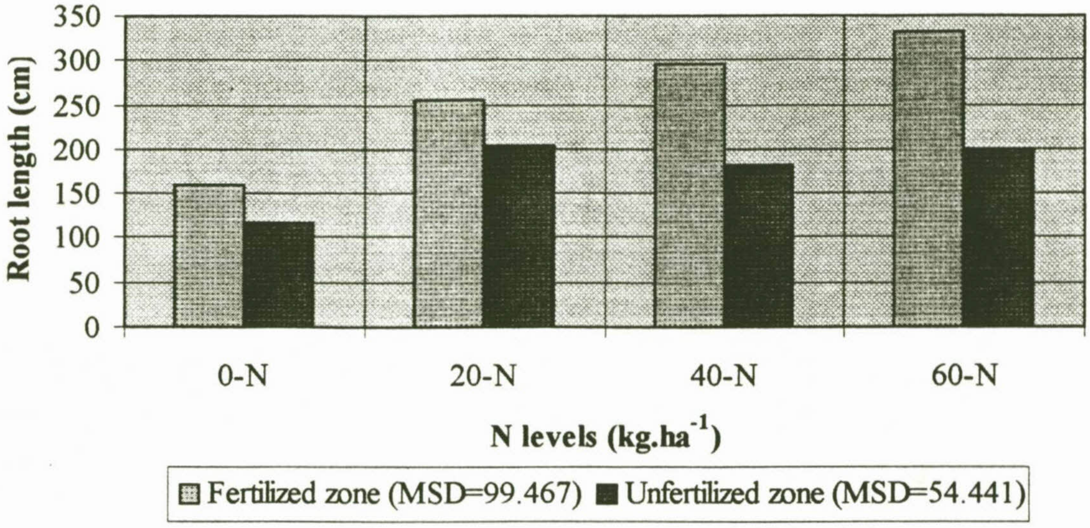


FIGURE 3.15a: Root length as a result of nitrogen application to the sandy soil

Like in the sandy loam soil, K had no significant effects on the length of the roots in the fertilized and unfertilized zones in the sandy soil (Appendices 3.35 and 3.36). However, Figure 3.15b indicates that K had a negative influence on root length in the fertilized zone, where applications of 20, 40 and 60 kg $K.ha^{-1}$ slightly inhibited root elongation.

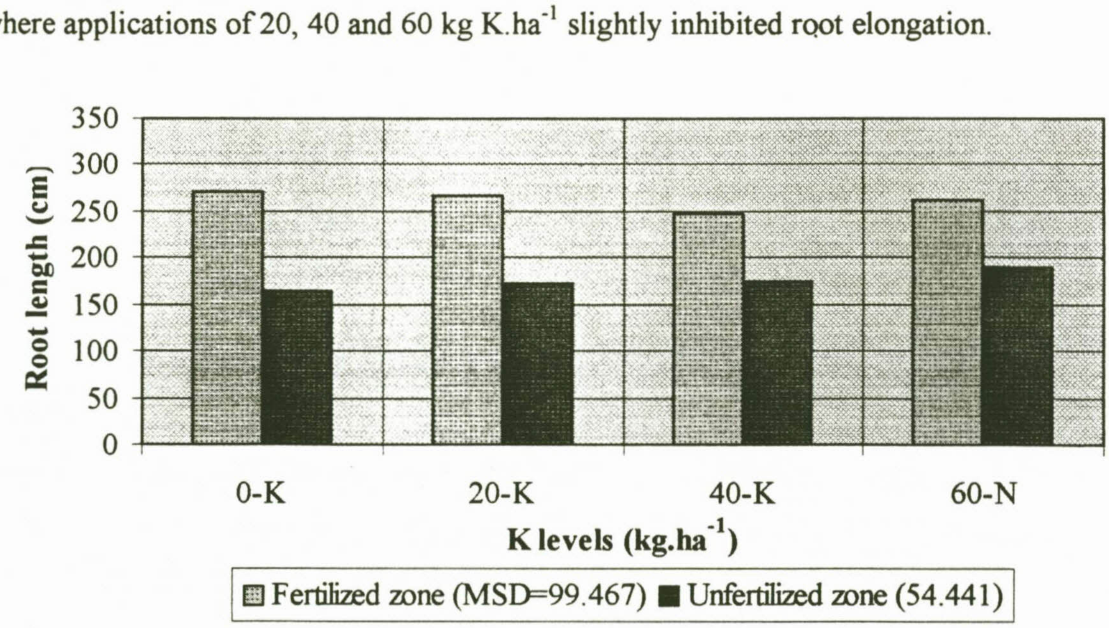


FIGURE 3.15b: Root length as a result of potassium application to the sandy soil

The results showed that an application of 20 kg $N.ha^{-1}$ in the sandy loam soil and 20 to 40 kg $N.ha^{-1}$ in the sandy soil was ideal for root length. However, the application of K had a negative influence on root length, therefore, fertilization of K to both soils to enhance the growth and development of maize during the first four weeks of plant growth was deemed unnecessary.

3.3.2.2 Root volume

Sandy loam soil:

The application of N significantly influenced the volume of the roots in the fertilized zone, but showed no marked effect on the volume of the roots in the unfertilized zone (Appendices 3.37 and 3.38). In the fertilized zone, no differences were obtained between the root volumes of 20, 40 and 60 kg $N.ha^{-1}$, but 60 kg $N.ha^{-1}$ resulted in a significantly greater root volume than 0 kg $N.ha^{-1}$ (Figure 3.16a).

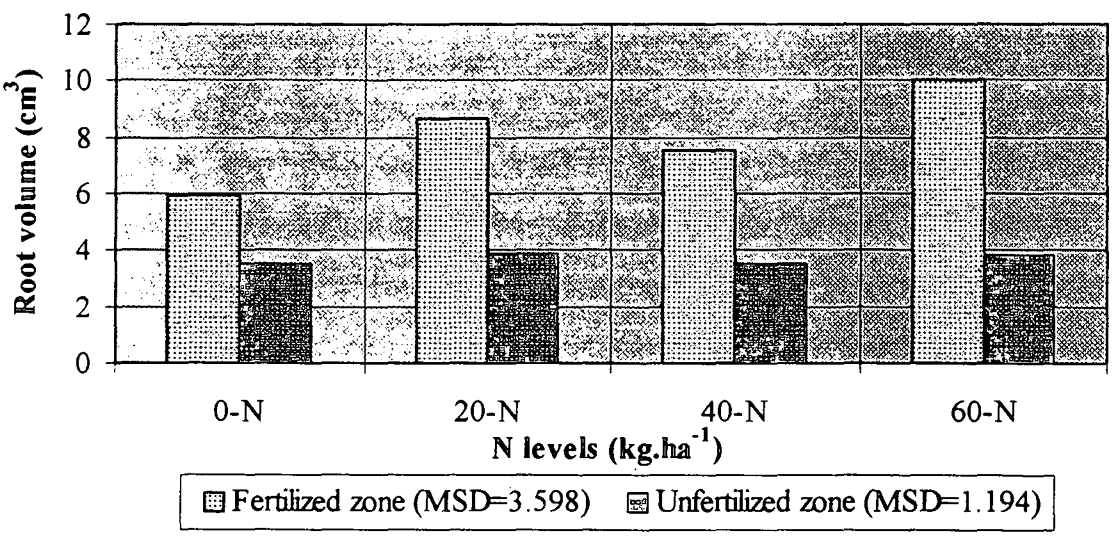


FIGURE 3.16a: Root volume as a result of nitrogen application to the sandy loam soil

The application of K did not significantly influence the volume of the roots in the fertilized and unfertilized zones (Appendices 3.37 and 3.38). Although there were no significant differences in the volume of the roots in the fertilized zone, Figure 3.16b clearly shows that 20 and 40 kg $K.ha^{-1}$ had a slightly positive influence on root volume, while 60 kg $K.ha^{-1}$ contributed to a decline in root volume compared to the root volume at 0 kg $K.ha^{-1}$.

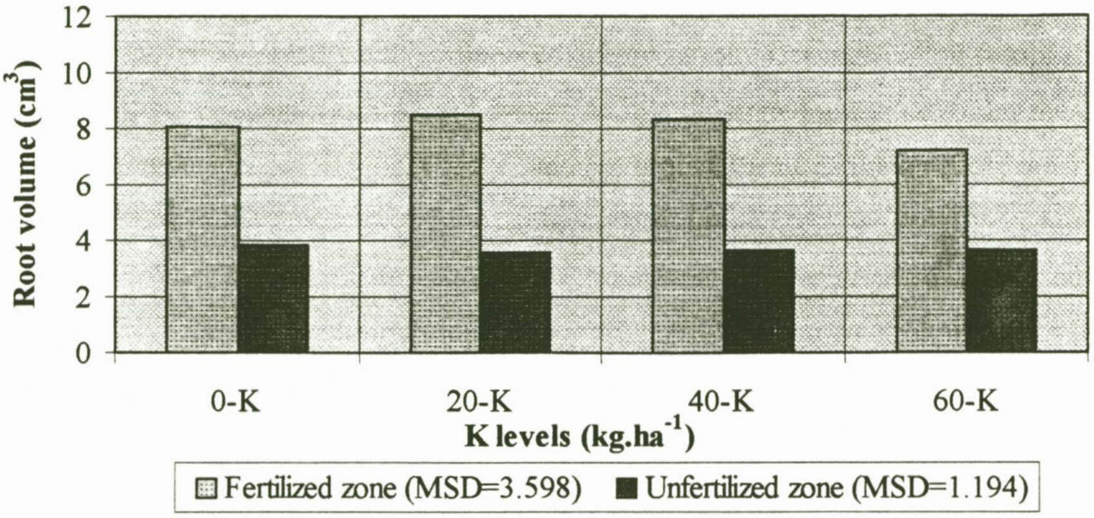


FIGURE 3.16b: Root volume as a result of potassium application to the sandy loam soil

Sandy soil:

The application of N significantly influenced the volume of the roots in the fertilized and unfertilized zones (Appendices 3.39 and 3.40). In the case of the fertilized zone, the root volume increased linearly as the level of N increases from 0 to 40 kg N.ha^{-1} (Figure 3.17a). The root volumes of 40 and 60 kg N.ha^{-1} were almost the same, but significantly higher than that of 0 kg N.ha^{-1}. No significant differences were observed in the root volumes of 20, 40 and 60 kg N.ha^{-1} in the fertilized zone. In the case of the unfertilized zone, the root volumes of 20, 40 and 60 kg N.ha^{-1} were significantly higher than that of 0 kg N.ha^{-1}, but they did not differ from each other.

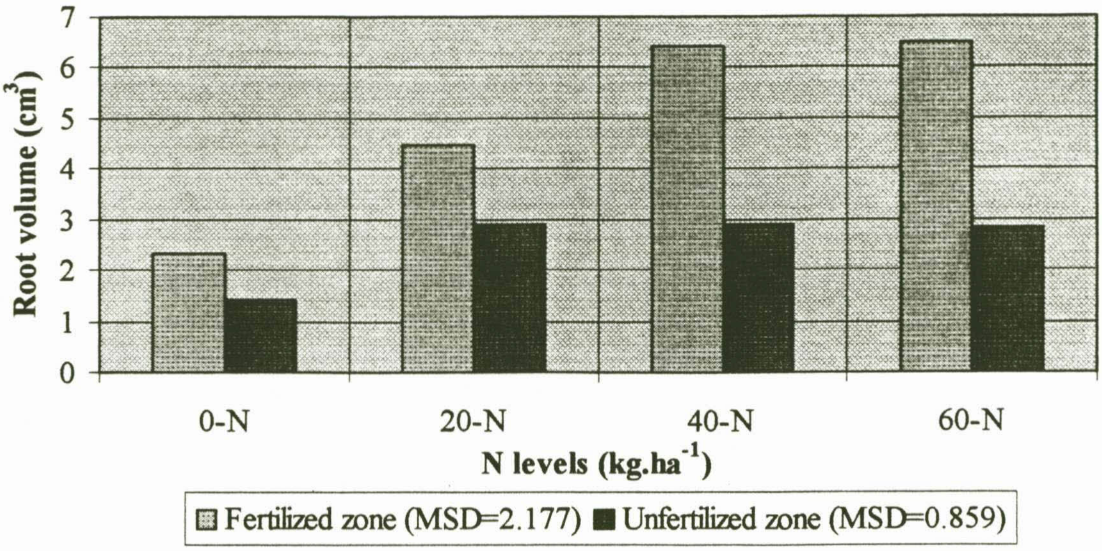


FIGURE 3.17a: Root volume as a result of nitrogen application to the sandy soil

Like in the sandy loam soil, the application of K showed no significant influence on the volume of the roots in the fertilized and unfertilized zones in the sandy soil (Appendices 3.39 and 3.40). Although there were no significant differences between the volumes of the roots in the fertilized band, Figure 3.17b clearly indicates that an application of 20 kg $K.ha^{-1}$ resulted in the highest root volume, whereas applications of 0, 40 and 60 kg $K.ha^{-1}$ resulted in almost the same root volumes.

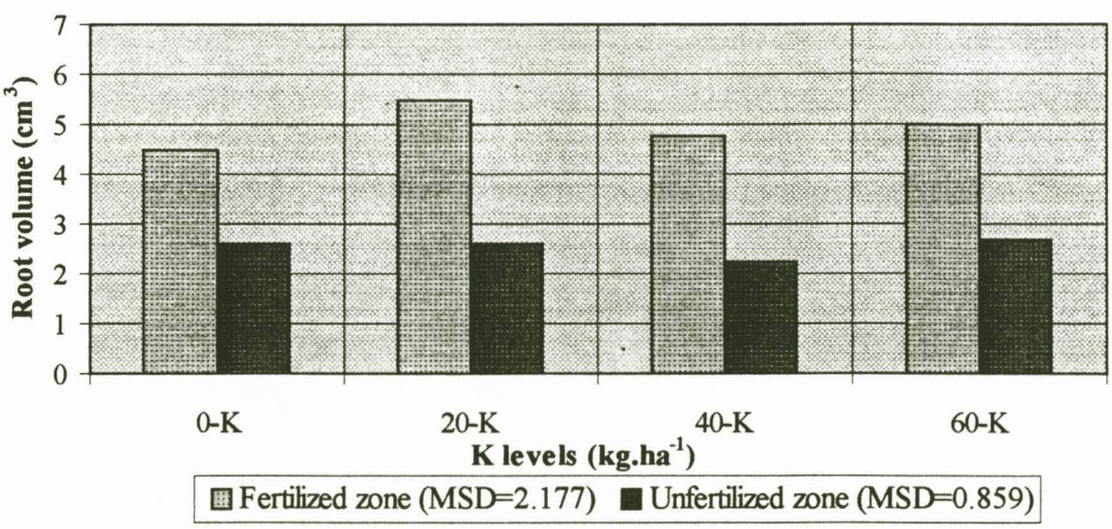


FIGURE 3.17b: Root volume as a result of potassium application to the sandy soil

The results showed that 20 kg N.ha^{-1} for the sandy loam soil and 40 to 60 kg N.ha^{-1} for the sandy soil was ideal for root volume. Although K showed no significant influence on root volume, an application level of 20 to 40 kg K.ha^{-1} was found to be suitable for the optimum growth of the maize plant in the sandy loam soil, while 20 kg K.ha^{-1} was ideal for the sandy soil.

3.3.2.3 Root area

Sandy loam soil:

The application of N significantly influenced the area of the roots in the fertilized zone, but showed no significant effects on the area of the roots in the unfertilized zone (Appendices 3.41 and 3.42). In the fertilized zone, the 20, 40 and 60 kg N.ha^{-1} application levels resulted in larger root areas than the 0 kg N.ha^{-1} application (Figure 3.18a). However, it was only the root area of the 60 kg N.ha^{-1} application level that differed significantly from the root area of the 0 kg N.ha^{-1} application. There were no significant differences in the root areas of the 20, 40 and 60 kg N.ha^{-1} applications.

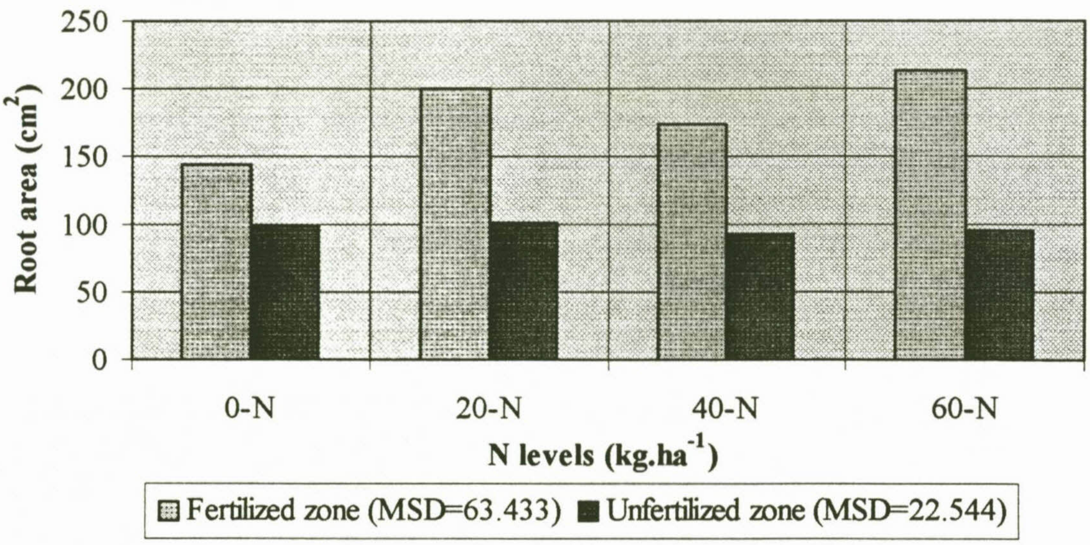


FIGURE 3.18a: Root area as a result of nitrogen application to the sandy loam soil

The application of K showed no significant influence on the area of the roots in the fertilized and unfertilized zones (Appendices 3.41 and 3.42), as it is also illustrated in Figure 3.18b.

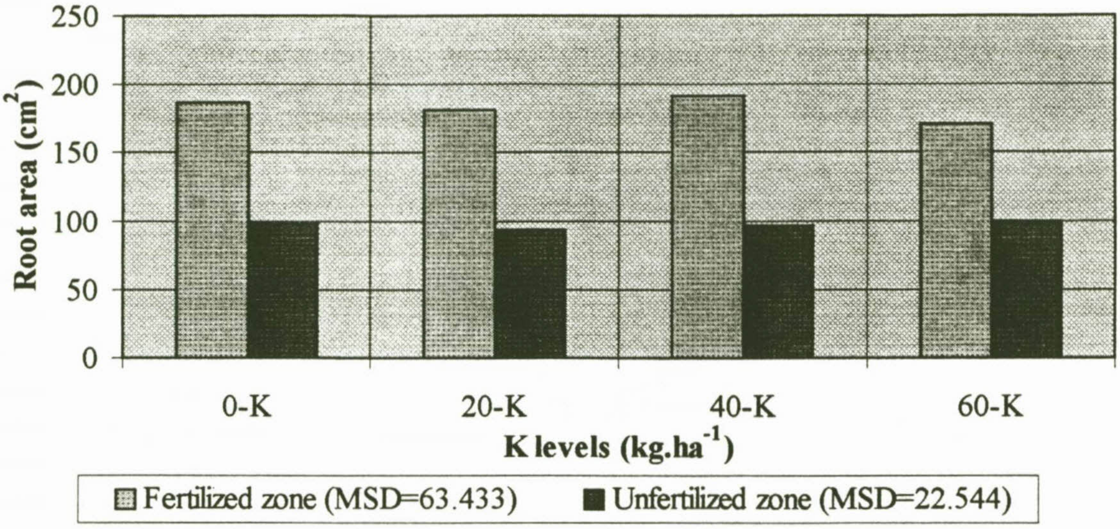


FIGURE 3.18b: Root area as a result of potassium application to the sandy loam soil

Sandy soil:

The application of N significantly influenced the area of the roots in the fertilized and unfertilized zones (Appendices 3.43 and 3.44). As indicated in Figure 3.19a there was a corresponding increase in the root area of the fertilized zone as the level of N increases to 60 kg N.ha^{-1} and in the unfertilized zone as the level of N increases to 20 kg N.ha^{-1}. For both zones, the root areas of 20, 40 and 60 kg N.ha^{-1} were significantly greater than that of 0 kg N.ha^{-1}, but these three levels did not significantly differ from each other.

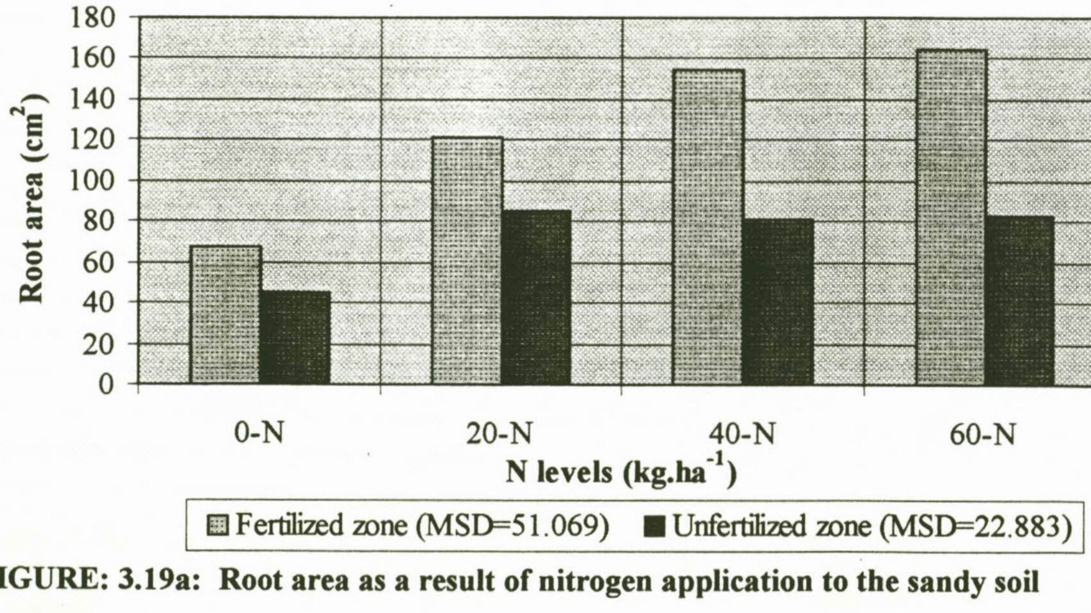


FIGURE: 3.19a: Root area as a result of nitrogen application to the sandy soil

Like in the sandy loam soil, K showed no significant influence on the area of the roots in the fertilized and unfertilized zones in the sandy soil (Appendices 3.43 and 3.44). Although there were no significant differences between the K application levels, Figure 3.19b clearly shows that 20 kg K.ha^{-1} had a slight beneficial influence on the area of the roots in the fertilized zone.

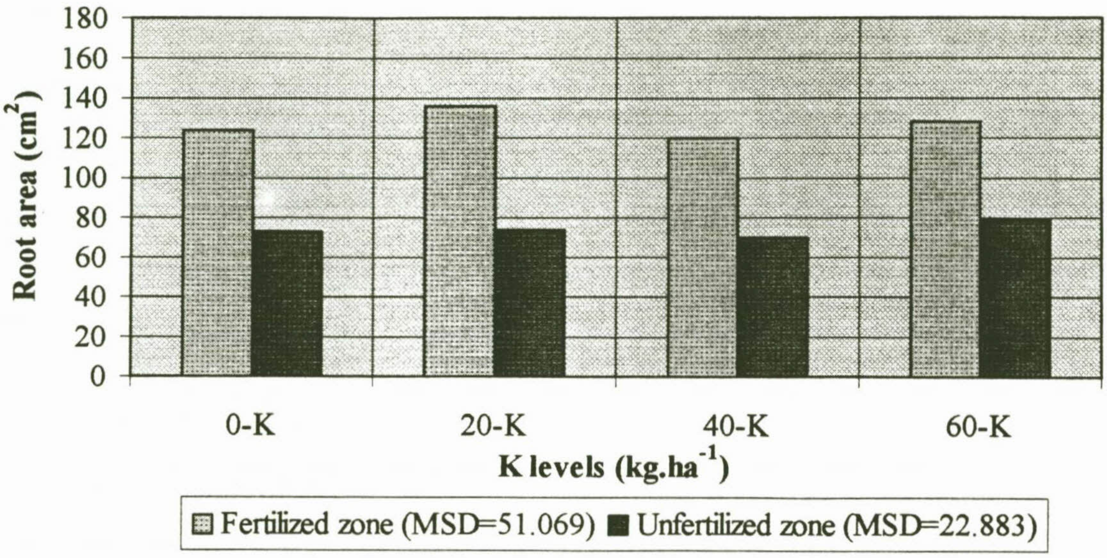


FIGURE 3.19b: Root area as a result of potassium application to the sandy soil

The results indicated that 20 kg N.ha^{-1} was sufficient for optimum root area in the sandy loam soil, while 40 to 60 kg N.ha^{-1} was suitable for the sandy soil. K had no significant effects on root area in the sandy loam soil, while 20 kg K.ha^{-1} was favourable for the sandy soil.

3.3.2.4 Root mass

Sandy loam soil:

The application of N significantly influenced the mass of the roots in the fertilized zone, but had no significant effects on the mass of the roots in the unfertilized zone (Appendices 3.45 and 3.46). In the fertilized zone, the application of N at levels of 20, 40 and 60 kg.ha^{-1} resulted in greater root masses than 0 kg N.ha^{-1} level (Figure 3.20a). However, only the root masses of the 20 and 60 kg N.ha^{-1} application levels were significantly greater than that of the 0 kg N.ha^{-1} level. No significant differences were detected in the root masses of the 20, 40 and 60 kg N.ha^{-1} application levels.

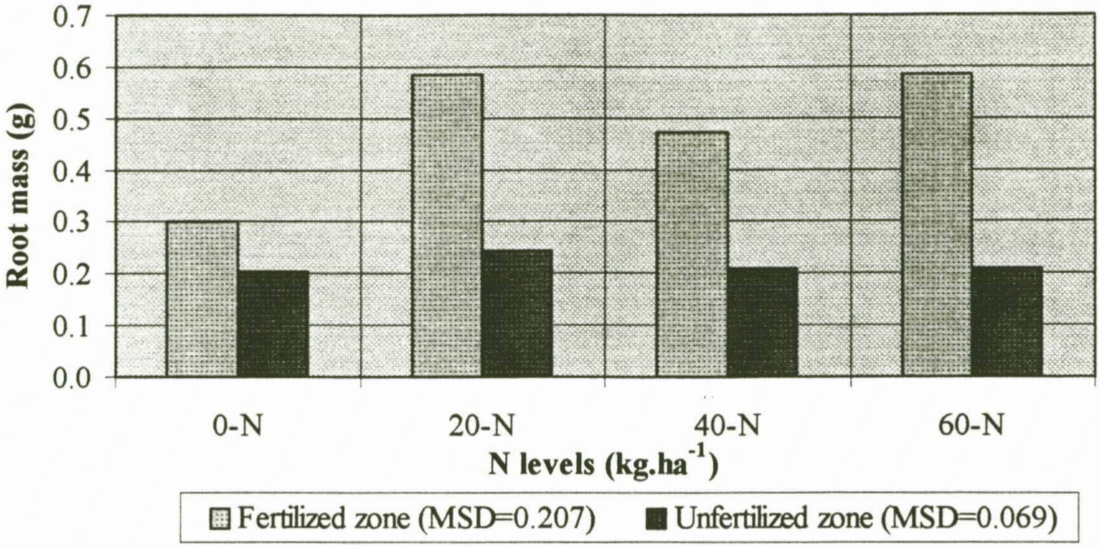


FIGURE 3.20a: Root mass as a result of nitrogen application to the sandy loam soil

The application of K showed no significant influence on the mass of the roots in the fertilized and unfertilized zones (Appendices 3.45 and 3.46). In the fertilized zone, K had a negative influence on root mass where applications of 20, 40 and 60 kg K.ha^{-1} clearly inhibited root mass (Figure 3.20b).

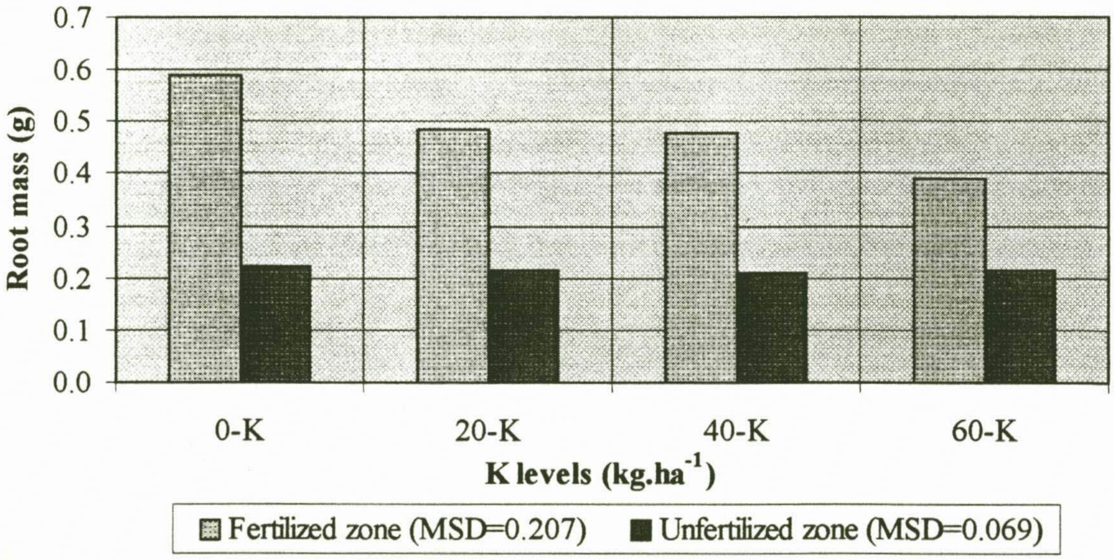


FIGURE 3.20b: Root mass as a result of potassium application to the sandy loam soil

Sandy soil:

The application of N significantly influenced the mass of the roots in the fertilized and unfertilized zones (Appendices 3.47 and 3.48). As it is illustrated in Figure 3.21a, there was a corresponding increase in the mass of the roots in fertilized zone as the level of N increases to 60 $kg.ha^{-1}$ and in the unfertilized zone as the level of N increases to 20 $kg.ha^{-1}$. For both zones the root masses of 20, 40 and 60 kg $N.ha^{-1}$ applications were significantly greater than that of the 0 kg $N.ha^{-1}$ application. In the case of the fertilized zone the root masses of the 40 and 60 kg $N.ha^{-1}$ applications significantly exceeded that of the 20 kg $N.ha^{-1}$ application. However, in the case of the unfertilized zone there were no significant differences in root mass between the 20, 40 and 60 kg $N.ha^{-1}$ applications.

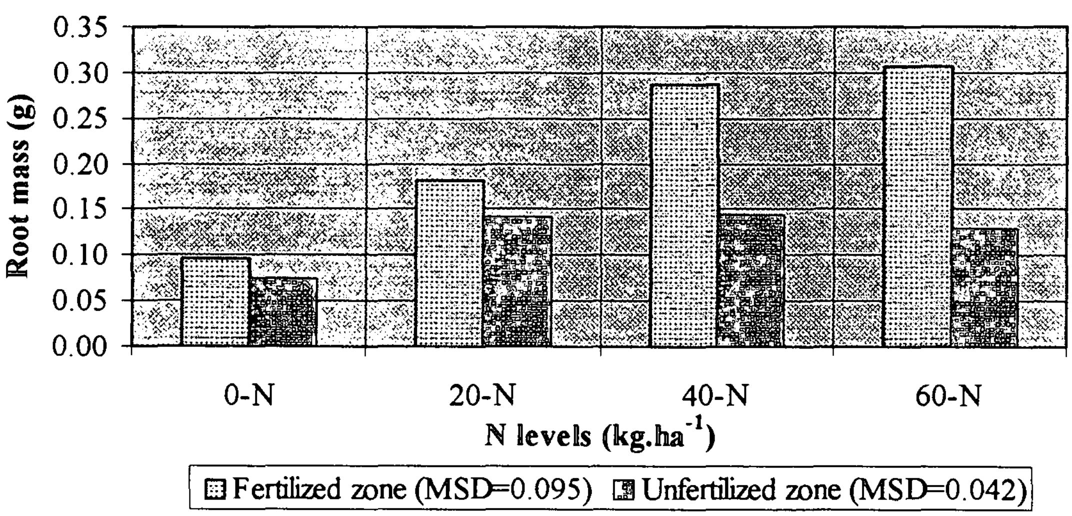


FIGURE 3.21a: Root mass as a result of nitrogen application to the sandy soil

Like in the sandy loam soil, the application of K had no significant effects on the mass of the roots in the fertilized and unfertilized zones in the sandy soil (Appendices 3.47 and 3.48). Although there were no significant differences in root mass between the K application levels, Figure 3.21b shows that in the fertilized zone an application of 20 kg $K.ha^{-1}$ resulted in the highest root mass. However, in the unfertilized zone the root mass shows no general trend with regard to K application.

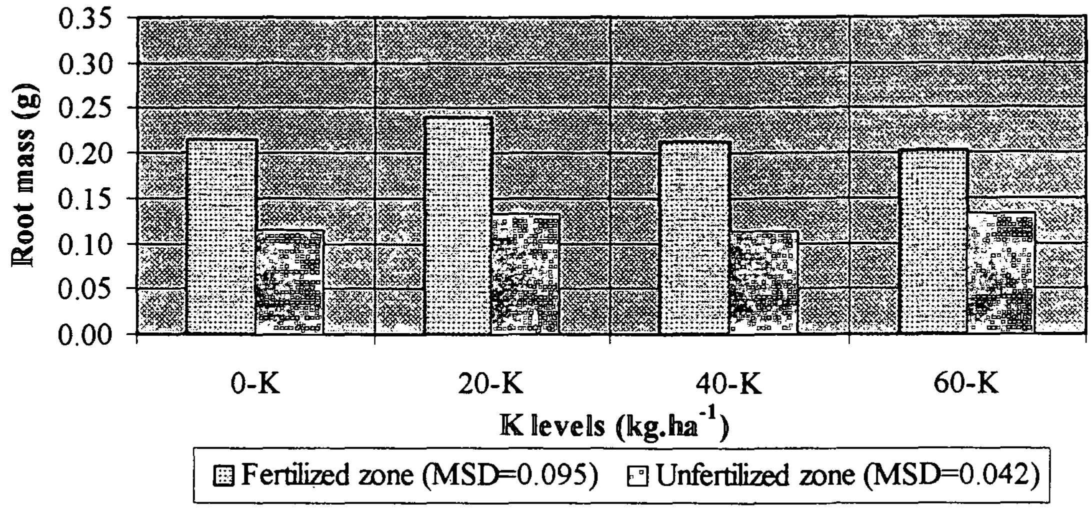


FIGURE 3.21b: Root mass as a result of potassium application to the sandy soil

The results revealed that 20 kg N.ha^{-1} resulted in an optimum root mass of the maize plant in the sandy loam soil, while 20 to 40 kg N.ha^{-1} was suitable for the sandy soil. The application of K had no significant effects on root mass, hence 0 and 20 kg K.ha^{-1} were found to be suitable for the sandy loam and sandy soils, respectively.

The N and K application levels which were found to be suitable for the optimum growth and development of the maize plant with regards to the subsoil plant parameters are illustrated in Table 3.5. Generally, it seems that an application level of 20 kg N.ha^{-1} for the sandy loam soil and 40 to 60 kg N.ha^{-1} for the sandy soil will be adequate to ensure optimum growth and development of maize during the first four weeks of plant growth. The addition of 0 to 20 kg K.ha^{-1} seems to be sufficient for the optimum growth and development of the maize plant during the first four weeks of plant growth in both soils.

TABLE 3.4: Nitrogen and potassium levels (kg.ha^{-1}) appropriate for the optimum growth and development of subsoil parameters of maize during the first four weeks of plant growth

Parameter	**Sandy loam soil**		**Sandy soil**	
	N	K	N	K
Root length	20	-	20-40	-
Root volume	20	20-40	40-60	20
Root area	20	-	20	20
Root mass	20	-	20-40	20

3.3.3 Nutrient concentration and accumulation in the biomass

The interaction of N and K application levels had no significant effect on the nutrient concentration and accumulation in the biomass for both soils (Appendices 3.49-3.88). However, the application of N and K separately had significant effects on the concentration and accumulation of some nutrients in the biomass. Consequently, the discussion on the concentration and accumulation of nutrients in the biomass will be confined to these two main factors.

Sandy loam soil:

The application of N did not significantly influence the concentration of any nutrient in the biomass (Table 3.5a). Despite of no significant differences with increasing N application levels the concentration of N, Zn and Cu increased, while that of P decreased. The concentration of other nutrients showed no consistent trend with regards to N application. However, the accumulation of all the nutrients in the biomass was stimulated by increasing N application levels (Table 3.5a).

TABLE 3.5a: **Effects of nitrogen application (kg.ha^{-1}) to the sandy loam soil on the concentration and accumulation of nutrients in the biomass**

		Nutrient concentration									
		N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (mg.kg^{-1})	Fe (mg.kg^{-1})	Zn (mg.kg^{-1})	Mn (mg.kg^{-1})	Cu (mg.kg^{-1})
N-levels	0	1.273a	0.227a	2.701a	0.211a	0.126a	96.583a	79.960a	28.543a	75.083a	2.500a
	20	2.199a	0.202a	2.722a	0.200a	0.119a	80.542a	72.620a	31.208a	68.667a	2.500a
	40	2.213a	0.191a	2.262a	0.184a	0.123a	79.708a	73.000a	35.417a	73.458a	2.875a
	60	3.232a	0.190a	2.539a	0.219a	0.144a	83.250a	88.750a	40.125a	81.208a	3.667a
	MSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
		Nutrient accumulation									
		N (mg.pot^{-1})	P (mg.pot^{-1})	K (mg.pot^{-1})	Ca (mg.pot^{-1})	Mg (mg.pot^{-1})	Na (mg.pot^{-1})	Fe (mg.pot^{-1})	Zn (mg.pot^{-1})	Mn (mg.pot^{-1})	Cu (mg.pot^{-1})
N-levels	0	340.051b	59.931b	703.566b	55.325c	33.676c	2.543b	2.093b	0.723b	1.968c	0.065b
	20	872.101ab	81.139a	1097.724a	79.917b	47.783bc	3.230ab	2.896ab	1.285ab	2.752b	0.102b
	40	987.417ab	86.733a	1027.016a	83.406b	56.344b	3.613a	3.319ab	1.637a	3.339ab	0.132ab
	60	1602.882a	96.048a	1293.277a	109.580a	72.321a	4.199a	4.389a	2.067a	4.085a	0.188a
	MSD (0.05)	878.400	21.165	294.440	20.343	15.667	1.029	1.733	0.823	0.776	0.075

Means followed by the same letter are not significantly different at $P>0.05$ according to Tukey's studentized range test

The application of K had no significant influence on the concentration of N, P, Ca, Mg, Na, Fe, Mn and Cu, but it markedly increased the concentration of K and Zn in the biomass (Table 3.5b). Despite of no significant differences, the concentration of Mg and Fe decreased and that of Cu increased with the raising of the K application level from 0 to 60 kg.ha^{-1}. The concentration of N, P, Ca, Na and Mn increased slightly when the application of K was raised to a certain level, but decreased as the application of K was raised beyond this level. In the case of N and P this level was 20 kg K.ha^{-1}, while in the case of Ca, Na and Mn it was 40 kg K.ha^{-1}. Only the accumulation of K increased significantly as a result of K application (Table 3.5b). Although not significant, the accumulation of N, P, Ca, Mg, Na, Zn, Mn and Cu increased as the application of K was raised to a certain level and decreased as the application of K was raised beyond this level. This level was 20 kg K.ha^{-1} for N and P, and 40 kg K.ha^{-1} for Ca, Mg, Na, Zn, Mn and Cu. It seems that any K application level reduced the accumulation of Fe.

TABLE 3.5b: Effects of potassium application (kg.ha^{-1}) to the sandy loam soil on the concentration and accumulation of nutrients in the biomass

		Nutrient concentration									
		N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (mg.kg^{-1})	Fe (mg.kg^{-1})	Zn (mg.kg^{-1})	Mn (mg.kg^{-1})	Cu (mg.kg^{-1})
K-levels	0	2.618a	0.212a	2.123c	0.196a	0.135a	74.917a	96.000a	26.333b	70.583a	2.500a
	20	2.890a	0.221a	2.349bc	0.197a	0.131a	86.583a	84.790a	28.667ab	77.750a	2.417a
	40	1.943a	0.197a	2.752ab	0.222a	0.128a	94.625a	68.920a	39.792a	79.917a	3.500a
	60	1.466a	0.182a	3.000a	0.199a	0.118a	83.958a	64.620a	39.208a	70.167a	3.125a
	MSD (0.05)	NS	NS	0.538	NS	NS	NS	NS	11.810	NS	NS
		Nutrient accumulation									
		N (mg.pot^{-1})	P (mg.pot^{-1})	K (mg.pot^{-1})	Ca (mg.pot^{-1})	Mg (mg.pot^{-1})	Na (mg.pot^{-1})	Fe (mg.pot^{-1})	Zn (mg.pot^{-1})	Mn (mg.pot^{-1})	Cu (mg.pot^{-1})
K-levels	0	1087.234a	79.204a	770.763b	76.751a	53.443a	2.913a	3.585a	1.066a	2.752a	0.097a
	20	1246.256a	89.370a	972.807ab	80.618a	53.680a	3.540a	3.539a	1.209a	3.198a	0.101a
	40	827.683a	79.691a	1120.057a	88.937a	54.171a	3.725a	2.833a	1.725a	3.238a	0.149a
	60	641.279a	75.587a	1257.957a	81.923a	48.831a	3.406a	2.740a	1.713a	2.957a	0.140a
	MSD (0.05)	NS	NS	294.440	NS	NS	NS	NS	NS	NS	NS

Means followed by the same letter are not significantly different at P>0.05 according to Tukey's studentized range test

Sandy soil:

The application of N showed no significant influence on the concentration of P, K, Ca, Mg, Na, Zn, Mn and Cu, but it markedly increased the concentration of N and Fe in the biomass (Table 3.6a). Although there were no significant differences, the concentration of P, K and Zn increased as the application of N was raised to a certain level and decreased as the application of N was raised beyond this level. With regards to P and K this level was 40 kg N.ha^{-1}, while in the case of Zn it was 20 kg N.ha^{-1}. The trend of other nutrient concentrations was not so consistent with regard to N application levels. Like in the sandy loam soil, the application of N stimulated the accumulation of all the nutrients by the biomass in a positive way in the sandy soil (Table 3.6a).

TABLE 3.6a: Effects of nitrogen application ($kg.ha^{-1}$) to the sandy soil on the concentration and accumulation of nutrients in the biomass

		N	P	K	Ca	Mg	Na	Fe	Zn	Mn	Cu
	Nutrient concentration										
		N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na ($mg.kg^{-1}$)	Fe ($mg.kg^{-1}$)	Zn ($mg.kg^{-1}$)	Mn ($mg.kg^{-1}$)	Cu ($mg.kg^{-1}$)
N-levels	0	1.060c	0.256a	3.535a	0.267a	0.157a	70.420a	15.583b	74.790a	63.708a	5.958a
	20	1.827b	0.292a	3.850a	0.213a	0.156a	78.750a	16.000b	101.750a	63.583a	5.417a
	40	2.206a	0.303a	3.930a	0.200a	0.169a	74.580a	18.500ab	89.870a	72.375a	5.833a
	60	2.387a	0.284a	3.761a	0.234a	0.173a	79.460a	20.292a	86.460a	72.958a	7.250a
	MSD (0.05)	0.315	NS	NS	NS	NS	NS	3.572	NS	NS	NS
	Nutrient accumulation										
		N ($mg.pot^{-1}$)	P ($mg.pot^{-1}$)	K ($mg.pot^{-1}$)	Ca ($mg.pot^{-1}$)	Mg ($mg.pot^{-1}$)	Na ($mg.pot^{-1}$)	Fe ($mg.pot^{-1}$)	Zn ($mg.pot^{-1}$)	Mn ($mg.pot^{-1}$)	Cu ($mg.pot^{-1}$)
N-levels	0	122.490c	30.115b	415.175b	30.781b	18.364b	0.805b	0.181c	0.849b	0.740c	0.068b
	20	571.964b	90.362a	1201.209a	67.748a	50.051a	2.425a	0.496b	3.000a	1.957b	0.168a
	40	766.288a	105.084a	1348.982a	69.282a	60.048a	2.546a	0.643ab	3.026a	2.460a	0.199a
	60	826.947a	97.972a	1295.143a	81.586a	61.261a	2.755a	0.704a	2.916a	2.479a	0.250a
	MSD (0.05)	192.570	23.998	279.060	25.402	23.057	0.855	0.184	1.351	0.357	0.090

Means followed by the same letter are not significantly different at $P>0.05$ according to Tukey's studentized range test

The application of K only had a significant effect on the concentration of N, P, Mg and Fe in the biomass (Table 3.6b). A decrease in the concentration of N, P and Mg was measured as a result of K application, while no general trend in the concentration of Fe evolved. Only the accumulation of P, Mg, Zn and Mn in the biomass was significantly affected by the application of K (Table 3.6b). A decline in the accumulation of P and Mg was registered on account of K application, while no general trend in the accumulation of Zn and Mn evolved.

TABLE 3.6b: Effects of potassium application ($kg.ha^{-1}$) to the sandy soil on the concentration and accumulation of nutrients in the biomass

		Nutrient concentration									
		N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na ($mg.kg^{-1}$)	Fe ($mg.kg^{-1}$)	Zn ($mg.kg^{-1}$)	Mn ($mg.kg^{-1}$)	Cu ($mg.kg^{-1}$)
K-levels	0	2.006a	0.321a	3.684a	0.238a	0.195a	72.21a	18.208ab	114.830a	72.250a	5.917a
	20	1.833ab	0.310ab	4.006a	0.210a	0.153ab	71.92a	16.750ab	69.790a	67.000a	5.542a
	40	1.682b	0.253b	3.546a	0.229a	0.160ab	78.79a	15.125b	69.920a	64.750a	6.083a
	60	1.960ab	0.252b	3.840a	0.236a	0.148b	80.29a	20.292a	98.330a	68.625a	6.917a
	MSD (0.05)	0.315	0.060	NS	NS	0.043	NS	3.572	NS	NS	NS
		Nutrient accumulation									
		N ($mg.pot^{-1}$)	P ($mg.pot^{-1}$)	K ($mg.pot^{-1}$)	Ca ($mg.pot^{-1}$)	Mg ($mg.pot^{-1}$)	Na ($mg.pot^{-1}$)	Fe ($mg.pot^{-1}$)	Zn ($mg.pot^{-1}$)	Mn ($mg.pot^{-1}$)	Cu ($mg.pot^{-1}$)
K-levels	0	677.607a	100.897a	1141.390a	72.881a	63.271a	2.156a	0.576a	3.483a	2.186a	0.178a
	20	559.119a	87.604ab	1113.328a	57.102a	43.416ab	2.072a	0.485a	1.951b	1.851ab	0.159a
	40	505.543a	69.354b	978.277a	61.871a	45.006ab	2.221a	0.418a	1.879b	1.765b	0.165a
	60	545.421a	65.678b	1027.515a	57.542a	38.032b	2.081a	0.545a	2.477ab	1.835ab	0.184a
	MSD (0.05)	NS	23.998	NS	NS	23.057	NS	NS	1.351	0.357	NS

Means followed by the same letter are not significantly different at $P > 0.05$ according to Tukey's studentized range test

These results revealed that for both soils an N application level of 20 to 40 $kg.ha^{-1}$ resulted in optimum uptake of most nutrients by maize during the early growth and development stage. An application level of 20 kg $K.ha^{-1}$ in the sandy loam soil and 0 kg $K.ha^{-1}$ in the sandy soil seems suitable to ensure optimum uptake of most nutrients by maize during the early growth and development stage. Generally, nitrogen stimulated the accumulation of all the nutrients in a positive way, whilst potassium affected them in a negative manner, particularly nitrogen.

3.4 CONCLUSION

The aerial and subsoil plant parameters were measured to determine the influence of different levels of banded N and/or K on the early growth and development of the maize plant. The uptake of N, P, K, Ca, Mg, Na, Fe, Zn, Mn and Cu by the biomass was also assessed. All the plant parameters which were measured showed that the interaction of N and K application levels had no significant influence on the early growth and development of the maize plant in both soils. However, the application of N and K individually had significant effects on some of the plant parameters.

Generally, the best results for the aerial and subsoil plant parameters were obtained with the application of 20 to 40 kg N.ha^{-1} in both soils. An application level of 0 to 20 kg K.ha^{-1} was also found to be the most appropriate rate for most of the aerial and subsoil plant parameters in both soils. The possible reason for the lack of response to the higher K application levels was that the soils had sufficient levels of K. The best results for the uptake of N, P, K, Na, Fe, Zn, Mn and Cu were attained with the application of 20 to 40 kg N.ha^{-1}, while 60 kg N.ha^{-1} accounted for the best uptake of Ca and Mn in the sandy loam soil. As for the sandy soil, the best results for the uptake of N, P, K, Ca, Mg, Na, Fe, Zn,. Mn and Cu were obtained with the application of 20 to 40 kg N.ha^{-1}. An application level of 20 to 40 kg K.ha^{-1} gave the best results regarding the uptake of K in the sandy loam soil, while 0 kg K.ha^{-1} accounted for the best uptake of P, Mg, Zn and Mn in the sandy soil.

Based on these findings, it was, therefore, concluded that the N and K application levels of 20 to 40 kg N.ha^{-1} and 20 kg K.ha^{-1} respectively seemed to be the most effective application levels for the optimum early growth and development of the maize plant. Furthermore, the applications of 40 to 60 kg N.ha^{-1} and 0 to 20 kg K.ha^{-1} levels were found to be ideal for the optimum uptake of other essential nutrients which are vital for the early growth and development of the maize plant by the biomass. Application levels of 20 to 40 kg N.ha^{-1} and 0 to 20 kg K.ha^{-1} which seemed to be suitable for the optimum early growth and development of the maize plant without causing any adverse effects.

CHAPTER 4

INFLUENCE OF POTASSIUM PLACEMENT ON THE EARLY GROWTH AND DEVELOPMENT OF MAIZE (*Zea mays* L.)

4.1 INTRODUCTION

The low production of maize, particularly under small scale farming are usually associated with the inherent low fertility of most soils. As a result, fertilization programs are designed to supply plant nutrients needed to sustain maximum crop productivity, while minimizing environmental contamination from the nutrients (Randall & Hoeft, 1988). In the design of such programs the determining of the proper placement of fertilizers is just as important as choosing the correct amount of plant nutrients (Tisdale *et al.*, 1993). Fertilizer placement options generally involve surface and subsurface applications before, at or after planting as discussed in detail in the literature review.

The methods of application most commonly used by maize growers to apply K before, at or after planting are broadcasting and band placement (Smith *et al.*, 1990). Band placement has generally proven to be the most effective of the two methods for achieving maximum starter benefit and greatest yield increase per unit of applied K for maize. Broadcast applications of K were only 73% as effective as band placement, but as the application rate of K or the K content of the soil increased, the effect of band placement diminished (Parks & Walker, 1969). Walker & Parks (1969) reported that K fertilization significantly reduced percent lodging, especially on soils with low K contents, but differences in lodging were not found between broadcast and band placement. According to Randall & Hoeft (1988) K when placed in a band as a starter, has resulted in substantial yield increases with ridge-plant and no-tillage systems on soils with medium K contents.

In the case of band application mixing of the fertilizer is restricted to a smaller volume of soil, hence the concentration of K in the fertilized zone increases substantially and the chance to remain available for plant uptake improves. This effect is of particular importance in soils that have a high fixation capacity for K which implies that the rate of supply to the roots is great from the fertilized zone, but less or nonexistent from the unfertilized zone. Hence, to be beneficial, the uptake rate of K by the roots in the fertilized zone must increase enough to compensate for the small percentage of roots in this zone (Randall & Hoeft, 1988). It is suggested by Barber (1959) that potassium-containing fertilizers should be distributed throughout enough soil so that 10 to 20% or more of the roots would be in the fertilized soil.

The localized placement of potassium containing fertilizers should, therefore, be more efficient than the broadcast application of them, barring any adverse effects from concentrating the fertilizer too near to the seed. A glasshouse experiment was conducted to evaluate the effects of K applied through banding, topdressing and a combination of banding and topdressing on the early growth and development of maize.

4.2 MATERIALS AND METHODS

4.2.1 Execution of experiment

This pot experiment on banding, topdressing and a combination of banding and topdressing of K was conducted during the 1999/00 growing season in a glasshouse at the University of the Orange Free State, Bloemfontein. As in the previous experiment described in Chapter 3, two types of soil were also used in the experiment, *viz.* a sandy loam soil collected from Ficksburg and a sandy soil collected from Boshof. With the exception of the fertilization procedure and the time of terminating growth (six weeks after emergence), all other aspects regarding the execution of the experiment were the same as those given in Section 3.2.

4.2.2 Procedure of fertilization

The K was applied as potassium chloride (50% K) in a factorial combination to each soil at rates equivalent to 0, 20, 40 and 60 kg.ha^{-1} through banding, topdressing and a combination of banding and topdressing for a row spacing of 1.5 m (Table 4.1). In the case of the combination application half of K was banded and the other half topdressed. Banding of K was done at planting 50 mm below and 50 mm away from the seed, while topdressing of K was done four weeks after planting.

A uniform basal application of 1.90 g N.pot^{-1} and 0.96 g P.pot^{-1} was also banded to all pots at the equivalent rates of 40 kg N.ha^{-1} and 20 kg P.ha^{-1}, respectively. The N was supplied in the form of limestone ammonium nitrate (28% N), while P was furnished as superphosphate (10.5% P).

TABLE 4.1: The amount of potassium banded, topdressed and banded and topdressed as potassium chloride (50% K) for a row spacing of 1.5 m

Potassium rate (kg.ha^{-1})	Potassium application (g.pot^{-1})
0	0
20	0.96
40	1.91
60	2.88

4.2.3 Experimental design and data processing

A complete randomized experimental design with a factorial combination consisting of two main factors, *viz.* four levels and three methods of K application which were replicated four times was used for each soil. However, the statistical analysis of this experiment was conducted in two ways, namely with and without the results obtained from the 0 kg K.ha^{-1} treatment. This was done in order to take into account the fact that it is only reasonable to consider application methods when dealing with tangible fertilization rates such as 20, 40 and 60 kg K.ha^{-1}, unlike when dealing with application levels alone where 0 kg K.ha^{-1} would also be relevant. All the analyses of variance were done at a 5% level of probability (SAS Institute, Inc., 1985) and the procedure of Tukey was used to compare the treatment means, also at 5 % probability level (Gomez & Gomez, 1984).

4.3 RESULTS AND DISCUSSION

Only the appendices of those plant parameters which were significantly influenced by the K application levels and methods will be included in the discussion.

4.3.1 Growth analysis on the aerial plant parameters

The interaction of K application levels and methods did not significantly influence any of the aerial plant parameters for both soils (Appendices 4.1-4.15). However, the K application levels and methods individually had significant effects on some of the aerial plant parameters. Consequently, the discussion on aerial plant parameters will be confined to these two main factors.

4.3.1.1 Leaf count

Sandy loam soil:

The K application levels had a significant influence on leaf count only during the third week of plant growth (Appendix 4.1). During this week there were no marked differences in leaf count between the 0, 20 and 60 kg $K.ha^{-1}$ applications, but the 40 kg $K.ha^{-1}$ application resulted in a significant increase in leaf count compared to 20 and 60 kg $K.ha^{-1}$applications (Table 4.2a). However, the K application methods had no significant influence on leaf count during any week of plant growth.

TABLE 4.2a: Effects of potassium application levels and methods on leaf count during the first six weeks of plant growth in the sandy loam soil

Potassium application levels (kg.ha^{-1})						
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
0	1.389a	3.000a	4.056ab	4.972a	5.945a	6.667a
20	1.361a	2.972a	4.000b	5.056a	6.028a	6.722a
40	1.556a	2.972a	4.194a	5.056a	6.000a	6.861a
60	1.389a	2.972a	3.972b	5.028a	5.972a	6.667a
MSD(0.05)	NS	NS	0.193	NS	NS	NS
Potassium application methods						
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Banding	1.361a	2.972a	4.055a	5.083a	6.000a	6.695a
Topdressing	1.417a	2.972a	4.055a	5.028a	6.000a	6.833a
Banding & Topdressing	1.528a	2.972a	4.055a	5.028a	6.000a	6.722a
MSD(0.05)	NS	NS	NS	NS	NS	NS

Means followed by the same letter are not significantly different at $P>0.05$ according to Tukey's studentized range test.

Sandy soil:

Leaf count in this soil was not significantly affected by either the K application levels or methods during the six weeks of plant growth (Table 4.2b).

TABLE 4.2b: Effects of potassium application levels and methods on leaf count during the first six weeks of plant growth in the sandy soil

Potassium application levels (kg.ha^{-1})						
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
0	2.000a	3.000a	4.583a	5.778a	6.417a	7.333a
20	1.861a	3.111a	4.472a	5.722a	6.500a	7.222a
40	1.917a	3.028a	4.500a	5.722a	6.417a	7.333a
60	1.889a	3.028a	4.611a	5.778a	6.639a	7.444a
MSD(0.05)	NS	NS	NS	NS	NS	NS
Potassium application methods						
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Banding	1.833a	3.000a	4.417a	5.722a	6.472a	7.278a
Topdressing	1.889a	3.056a	4.667a	5.778a	6.528a	7.333a
Banding & Topdressing	1.945a	3.111a	4.500a	5.722a	6.555a	7.389a
MSD(0.05)	NS	NS	NS	NS	NS	NS

Means followed by the same letter are not significantly different at $P>0.05$ according to Tukey's studentized range test.

4.3.1.2 Stem thickness

Sandy loam soil:

The K application levels showed a significant effect on stem thickness only during the sixth week of plant growth (Appendix 4.2). During this week stem thickness was significantly lower at 0 kg K.ha^{-1} in comparison to 40 and 60 kg K.ha^{-1} application levels, with no marked differences between the three higher levels (Table 4.3a).

Stem thickness was significantly influenced by the K application methods only during the first week of plant growth (Appendix 4.3). As it is illustrated in Table 4.3a there were no significant differences in stem thickness between banding and a combination of banding and topdressing, but topdressing resulted in a markedly inferior stem thickness than a combination of banding and topdressing.

TABLE 4.3a: Effects of potassium application levels and methods on stem thickness during the first six weeks of plant growth in the sandy loam soil

Potassium application levels ($kg.ha^{-1}$)						
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
0	2.639a	4.983a	8.671a	12.447a	16.485a	17.968b
20	2.644a	4.845a	8.402a	12.135a	16.369a	18.406ab
40	2.788a	5.038a	8.767a	12.672a	16.963a	19.392a
60	2.697a	4.934a	8.431a	12.436a	16.806a	19.068a
MSD(0.05)	NS	NS	NS	NS	NS	1.100
Potassium application methods						
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Banding	2.700ab	4.944a	8.477a	12.398a	16.824a	18.899a
Topdressing	2.641b	4.865a	8.536a	12.132a	16.541a	18.842a
Banding & Topdressing	2.789a	5.008a	8.587a	12.712a	16.773a	19.125a
MSD(0.05)	0.143	NS	NS	NS	NS	NS

Means followed by the same letter are not significantly different at $P>0.05$ according to Tukey's studentized range test.

Sandy soil:

The K application levels had a significant effect on stem thickness only during the third and fourth weeks of plant growth (Appendices 4.4 and 4.5). It is evident from Table 4.3b that there were no marked differences in stem thickness between the K application levels of 0, 20 and 40 $kg.ha^{-1}$, but the 0 and 20 $kg\ K.ha^{-1}$ levels resulted in a significantly greater stem thickness than the 60 $kg\ K.ha^{-1}$ level during the third week of plant growth. During the fourth week of plant growth, the K application levels of 0, 20 and 40 $kg.ha^{-1}$ resulted in a significantly greater stem thickness than the 60 $kg\ K.ha^{-1}$ level, but they did not markedly differ from each other.

The K application methods showed a significant effect on stem thickness during the second, third, fourth and sixth weeks of plant growth (Appendices 4.6, 4.7, 4.8 and 4.9). It is clearly illustrated in Table 4.3b that there were no marked differences in stem thickness between topdressing and a combination of banding and topdressing during the second, third and sixth weeks of plant growth. However, topdressing resulted in a significantly greater stem thickness than banding during the second, third, fourth and sixth weeks of plant growth. During the fourth week of plant growth no marked differences were noticed in stem thickness between banding and a combination of banding and topdressing, but both of these methods accounted for a significantly inferior stem thickness compared to topdressing.

TABLE 4.3b: Effects of potassium application levels and methods on stem thickness during the first six weeks of plant growth in the sandy soil

Potassium application levels ($kg.ha^{-1}$)						
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
0	2.821a	5.409a	10.073a	16.359a	19.764a	21.134a
20	2.808a	5.362a	10.076a	16.565a	20.267a	21.633a
40	2.847a	5.463a	9.951ab	16.565a	20.543a	21.964a
60	2.790a	5.013a	9.117b	15.593b	19.930a	21.630a
MSD(0.05)	NS	NS	0.892	0.759	NS	NS
Potassium application methods						
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Banding	2.768a	5.093b	9.193b	15.983b	19.983a	21.446b
Topdressing	2.801a	5.519a	10.332a	16.837a	20.641a	22.200a
Banding & Topdressing	2.876a	5.227ab	9.619ab	15.903b	20.115a	21.580ab
MSD(0.05)	NS	0.417	0.851	0.794	NS	0.748

Means followed by the same letter are not significantly different at $P>0.05$ according to Tukey's studentized range test.

4.3.1.3 Plant height

Sandy loam soil:

Neither the potassium application levels, nor the K application methods had any significant influence on plant height during any of the six weeks of plant growth (Table 4.4a)

TABLE 4.4a: Effects of potassium application levels and methods on plant height during the first six weeks of plant growth in the sandy loam soil

Potassium application levels (kg.ha^{-1})						
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
0	144.361a	299.694a	518.944a	721.194a	899.694a	1125.195a
20	134.972a	311.944a	511.056a	727.750a	904.444a	1080.083a
40	134.361a	291.389a	516.000a	718.556a	904.695a	1121.250a
60	138.194a	296.833a	497.861a	709.111a	909.806a	1121.778a
MSD(0.05)	NS	NS	NS	NS	NS	NS
Potassium application methods						
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Banding	135.278a	302.583a	500.890a	727.360a	911.500a	1110.030a
Topdressing	134.611a	294.611a	505.420a	714.970a	905.970a	1115.280a
Banding & Topdressing	137.639a	302.972a	518.610a	713.080a	901.470a	1097.810a
MSD(0.05)	NS	NS	NS	NS	NS	NS

Means followed by the same letter are not significantly different at $P>0.05$ according to Tukey's studentized range test.

Sandy soil:

The K application levels showed a significant effect on plant height during the second and third weeks of plant growth (Appendices 4.10 and 4.11). During the second week of plant growth there were no marked differences in plant height between the K application levels of 0 and 20 kg.ha^{-1}, as well as, 40 and 60 kg.ha^{-1} (Table 4.4b). The 40 and 60 kg K.ha^{-1} levels significantly decreased plant height compared to the control. Furthermore, the application level of 20 kg K.ha^{-1} resulted in a markedly greater plant height than the 60 kg K.ha^{-1} level, but still was not better than the control. During the third week of plant growth, the K application levels of 0, 20 and 40 $kg.ha^{-1}$ contributed to a markedly greater plant height than the 60 kg $K.ha^{-1}$ level, but they did not significantly differ from each other.

Plant height was significantly influenced by the K application methods during the first, second, third and sixth weeks of plant growth (Appendices 4.12, 4.13, 4.14 and 4.15). As it is illustrated in Table 4.4b, there were no marked differences in plant height between topdressing and a combination of banding and topdressing, but topdressing resulted in a significantly greater plant height than banding during the first, second, third and sixth weeks of plant growth. Topdressing contributed to the greatest increase in plant height, followed by a combination of topdressing and banding and banding, respectively. This might be due to the fact that with topdressing the fertilizer is spread over a larger area of soil, hence minimizing the risk of salt injury. The risk of salt injury is enhanced with a combination of topdressing and banding and banding, since the fertilizer concentration in the root zone is relatively higher in these two methods compared to topdressing.

TABLE 4.4b: Effects of potassium application levels and methods on plant height during the first six weeks of plant growth in the sandy soil

Potassium application levels ($kg.ha^{-1}$)						
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
0	162.444a	332.278a	541.889ab	808.111a	1039.528a	1238.639a
20	156.139a	321.528ab	553.583a	813.389a	1052.861a	1259.917a
40	153.861a	303.944bc	513.500ab	784.805a	1013.250a	1237.417a
60	152.306a	295.167c	499.028b	780.139a	1043.639a	1269.722a
$MSD_{(0.05)}$	NS	26.229	49.802	NS	NS	NS
Potassium application methods						
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Banding	148.917b	285.670b	494.720b	771.390a	1007.390a	1208.810b
Topdressing	159.250a	329.420a	550.280a	817.720a	1066.720a	1299.610a
Banding & Topdressing	154.139ab	305.560ab	521.110ab	789.220a	1035.640a	1258.640ab
$MSD_{(0.05)}$	10.041	25.602	46.048	NS	NS	86.397

Means followed by the same letter are not significantly different at $P>0.05$ according to Tukey's studentized range test.

4.3.1.4 Other aerial plant parameters

Sandy loam soil:

The leaf area and biomass that were measured upon termination of the experiment are summarized in Table 4.5a. Neither the K application levels, nor the K application methods had any significant effect on leaf area or biomass.

Sandy soil:

The leaf area and biomass were not significantly affected by either the K application levels or K application methods as it is illustrated in Table 4.5b.

TABLE 4.5a: Effects of potassium application levels and methods on leaf area and biomass after six weeks of plant growth in the sandy loam soil

Potassium application levels (kg.ha^{-1})		
	Leaf area	Biomass
0	3141.000a	75.858a
20	3163.000a	75.869a
40	3223.900a	78.067a
60	3248.500a	77.339a
MSD(0.05)	NS	NS
Potassium application methods		
	Leaf area	Biomass
Banding	3246.000a	77.070a
Topdressing	3184.400a	77.165a
Banding & Topdressing	3205.000a	77.040a
MSD(0.05)	NS	NS

Means followed by the same letter are not significantly different at $P>0.05$ according to Tukey's studentized range test.

TABLE 4.5b: Effects of potassium application levels and methods on leaf area and biomass after six weeks of plant growth in the sandy soil

Potassium application levels ($kg.ha^{-1}$)		
	Leaf area	Biomass
0	4005.300a	92.078a
20	4049.000a	94.549a
40	4109.600a	93.560a
60	4175.500a	88.702a
MSD(0.05)	NS	NS
Potassium application methods		
	Leaf area	Biomass
Banding	3996.300a	89.665a
Topdressing	4188.600a	96.470a
Banding & Topdressing	4149.200a	90.676a
MSD(0.05)	NS	NS

Means followed by the same letter are not significantly different at $P>0.05$ according to Tukey's studentized range test.

The K application levels or methods did not have a pronounced effect on most of the aerial plant parameters measured. For those few parameters which were significantly affected by the K application levels or methods this occurred only during one or two weeks. As a result, it is rather difficult to conclude which particular K application level or method would be suitable for the optimum early growth and development of maize. However, an application level of 20 kg $K.ha^{-1}$ seemed to be adequate for the optimum early growth and development of maize in both soils. As for the K application methods, a combination of banding and topdressing seemed to be adequate for the optimum early growth and development of maize in the sandy loam soil, while topdressing appeared to be ideal for the sandy soil.

4.3.2 Growth analysis on the subsoil plant parameters

The interaction of K application levels and methods did not significantly influence any of the subsoil plant parameters for both soils (Appendices 4.16 to 4.18). Even the K application levels and methods individually had little effect on the subsoil plant parameters, *viz.* root length, volume, area and mass. In fact only the root mass was significantly affected. As a result, the discussion on subsoil plant parameters will be focussed on root mass.

Sandy loam soil:

The K application levels had a significant effect only on the mass of the roots in the fertilized zone (Appendix 4.16). There is a consistent trend of declining root parameters in the fertilized zone with increasing levels of K applications. It reached significance with root mass, where 60 kg K.ha^{-1} significantly reduced root mass compared to 0 kg K.ha^{-1}. However, the K application methods had no significant influence on the root mass.

TABLE 4.6a: Effects of potassium application levels and methods on subsoil plant parameters in the fertilized (F) and unfertilized (U) zones of the sandy loam soil

Potassium application levels (kg.ha^{-1})								
	Root length		Root volume		Root area		Root mass	
	F	U	F	U	F	U	F	U
0	437.516a	284.791a	9.833a	5.250a	231.348a	135.578a	0.811a	0.370a
20	394.346a	268.739a	9.167a	4.917a	211.903a	126.137a	0.688ab	0.328a
40	402.213a	268.547a	8.417a	4.833a	206.420a	128.163a	0.656ab	0.355a
60	380.916a	283.001a	7.750a	4.583a	191.424a	125.503a	0.542b	0.359a
MSD(0.05)	NS	NS	NS	NS	NS	NS	0.209	NS
Potassium application methods								
	Root length		Root volume		Root area		Root mass	
	F	U	F	U	F	U	F	U
Banding	380.920a	253.330a	8.000a	4.250a	195.090a	114.150a	0.661a	0.315a
Topdressing	405.670a	290.290a	7.917a	4.917a	201.590a	133.320a	0.567a	0.361a
Banding & Topdressing	390.890a	276.670a	9.417a	5.167a	213.060a	132.340a	0.659a	0.366a
MSD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Means followed by the same letter are not significantly different at $P>0.05$ according to Tukey's studentized range test.

Sandy soil:

The K application levels significantly influenced the mass of the roots in the fertilized (Appendix 4.17) and unfertilized (Appendix 4.18) zones. In the fertilized zone, no significant differences were detected in the root mass of 0, 40 and 60 kg $K.ha^{-1}$ applications, but the 20 kg $K.ha^{-1}$ application resulted in a significantly greater root mass than the 0 and 60 kg $K.ha^{-1}$ applications (Table 4.6b). In the unfertilized zone, there were no marked differences in the root mass of the 0, 20 and 40 kg $K.ha^{-1}$ levels, but the 20 kg $K.ha^{-1}$ level accounted for a significantly greater root mass than the 60 kg $K.ha^{-1}$ level. The K application methods had no significant effect on the root mass.

TABLE 4.6b: Effects of potassium application levels and methods on subsoil plant parameters in the fertilized (F) and unfertilized (U) zones of the sandy soil

Potassium application levels ($kg.ha^{-1}$)								
	Root length		Root volume		Root area		Root mass	
	F	U	F	U	F	U	F	U
0	339.153a	254.029a	6.500a	4.083a	164.770a	112.876a	0.407b	0.263ab
20	359.491a	257.931a	8.333a	4.833a	194.252a	125.635a	0.577a	0.322a
40	357.636a	280.315a	6.583a	4.000a	171.116a	117.871a	0.421ab	0.260ab
60	318.112a	233.627a	6.417a	3.833a	158.623a	104.352a	0.361b	0.217b
MSD (0.05)	NS	NS	NS	NS	NS	NS	0.166	0.094
Potassium application methods								
	Root length		Root volume		Root area		Root mass	
	F	U	F	U	F	U	F	U
Banding	352.390a	256.970a	7.083a	4.417a	175.440a	118.833a	0.460a	0.276a
Topdressing	325.340a	246.740a	6.833a	3.833a	166.950a	108.455a	0.431a	0.254a
Banding & Topdressing	357.510a	268.160a	7.417a	4.417a	181.600a	120.571a	0.467a	0.269a
MSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Means followed by the same letter are not significantly different at $P>0.05$ according to Tukey's studentized range test.

As with the aerial plant parameters, the K application levels had little effect on the subsoil plant parameters. Consequently, it is not very clear which K application level resulted in optimum early growth and development of maize in both soils. However, it seems as if an application level of 0 kg $K.ha^{-1}$ for the sandy loam soil and 20 kg $K.ha^{-1}$ for the sandy soil will be adequate for optimum early growth and development of subsoil plant parameters. The K application methods had no significant effect on any of the subsoil plant parameters in both soils.

4.3.3 Nutrient concentration and accumulation in the biomass

The interaction of K application levels and methods had no significant influence on the nutrient concentration and accumulation in the biomass for both soils (Appendices 4.19-4.34). However, the K application levels and methods separately had significant effects on the concentration and accumulation of some nutrients in the biomass. The discussion on nutrient concentration and accumulation in the biomass will, therefore, be confined to these two main factors.

Sandy loam soil:

The K application levels significantly stimulated the concentration of K, but had a negative influence on the concentration of Mg in the biomass (Table 4.7a). Despite of no significant differences, the concentration of P decreased, while that of Zn increased with the raising of K application from 0 to 60 $kg.ha^{-1}$. The concentration of N increased slightly when the application was raised from 0 to 40 kg $K.ha^{-1}$, but decreased as the application was raised beyond 40 kg $K.ha^{-1}$. However, the concentration of the other nutrients demonstrated no consistent trend with regards to K application. Furthermore, the K application levels also significantly stimulated the accumulation of K, but had a negative effect on the accumulation of Mg in the biomass (Table 4.7a). The decline in Mg concentration and accumulation in the biomass was probable due to the antagonistic effect of K on the absorption Mg. High soil levels of potassium reduce the uptake of magnesium and can intensify deficiency problems. Although there were no significant differences, the accumulation of Zn increased with the raising of K application from 0 to 60 kg $K.ha^{-1}$. The accumulation of other nutrients showed no general trend as a result of the K levels.

TABLE 4.7a: Effects of potassium application levels on the concentration and accumulation of nutrients in the biomass for the sandy loam soil

		Nutrient concentration									
		N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (mg.kg^{-1})	Fe (mg.kg^{-1})	Zn (mg.kg^{-1})	Mn (mg.kg^{-1})	Cu (mg.kg^{-1})
K-levels	0	0.333a	0.198a	1.765c	0.253a	0.209a	203.000a	177.167a	30.083a	69.333a	7.333a
	20	0.339a	0.189a	1.982bc	0.231a	0.190ab	189.750a	165.167a	31.500a	67.917a	7.833a
	40	0.382a	0.187a	2.147ab	0.210a	0.164bc	193.417a	163.500a	32.333a	71.000a	7.000a
	60	0.365a	0.182a	2.322a	0.218a	0.156c	190.083a	170.250a	43.500a	70.250a	6.667a
	MSD (0.05)	NS	NS	0.262	NS	0.027	NS	NS	NS	NS	NS
		Nutrient accumulation									
		N (mg.pot^{-1})	P (mg.pot^{-1})	K (mg.pot^{-1})	Ca (mg.pot^{-1})	Mg (mg.pot^{-1})	Na (mg.pot^{-1})	Fe (mg.pot^{-1})	Zn (mg.pot^{-1})	Mn (mg.pot^{-1})	Cu (mg.pot^{-1})
K-levels	0	258.787a	149.299a	1341.596c	188.744a	157.711a	15.322a	13.577a	2.282a	5.249a	0.550a
	20	263.081a	143.012a	1505.275bc	175.593a	144.210ab	14.448a	12.547a	2.383a	5.131a	0.602a
	40	307.293a	146.330a	1678.291ab	164.962a	129.069b	15.043a	12.831a	2.543a	5.574a	0.548a
	60	282.158a	140.386a	1787.666a	169.822a	121.151b	14.697a	13.137a	3.414a	5.439a	0.514a
	MSD (0.05)	NS	NS	257.190	NS	27.952	NS	NS	NS	NS	NS

Means followed by the same letter are not significantly different at $P>0.05$ according to Tukey's studentized range test

The K application methods significantly influenced the concentration of Mg in the biomass (Table 4.7b). Despite of no significant differences, the concentration of P, Zn and Cu increased in accordance to banding, topdressing and a combination of banding and topdressing. The concentration of the other nutrients showed no consistent trend with regards to the K application methods. Only the accumulation of Mg in the biomass was markedly influenced by the K application methods (Table 4.7b). Topdressing accounted for the highest Mg accumulation, followed by a combination of topdressing and banding and banding, respectively. This could be attributed to the fact that with topdressing the fertilizer is spread over a larger volume of soil, hence reducing the risk of salt injury, which is more likely to occur with a combination of topdressing and banding and banding, since in these two methods fertilizer concentration is higher in the root zone compared to topdressing.

Although there were no significant differences, the accumulation of P and Cu increased according to banding, topdressing and a combination of banding and topdressing. The accumulation of other nutrients demonstrated no general trend as a result of the K application methods.

TABLE 4.7b: Effects of potassium application methods on the concentration and accumulation of nutrients in the biomass for the sandy loam soil

		Nutrient concentration									
		N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (mg.kg^{-1})	Fe (mg.kg^{-1})	Zn (mg.kg^{-1})	Mn (mg.kg^{-1})	Cu (mg.kg^{-1})
K-methods	Banding	0.419a	0.181a	2.211a	0.217a	0.150b	200.167a	158.500a	34.083a	68.667a	7.000a
	Topdressing	0.327a	0.185a	2.075a	0.242a	0.194a	177.750a	180.167a	36.333a	71.833a	7.167a
	Banding & Topdressing	0.341a	0.192a	2.164a	0.200a	0.166b	195.333a	160.250a	36.917a	68.667a	7.333a
	MSD (0.05)	NS	NS	NS	NS	0.025	NS	NS	NS	NS	NS
		Nutrient accumulation									
		N (mg.kg^{-1})	P (mg.kg^{-1})	K (mg.kg^{-1})	Ca (mg.kg^{-1})	Mg (mg.kg^{-1})	Na (mg.kg^{-1})	Fe (mg.kg^{-1})	Zn (mg.kg^{-1})	Mn (mg.kg^{-1})	Cu (mg.kg^{-1})
K-methods	Banding	328.962a	139.751a	1701.405a	169.520a	116.986b	15.486a	12.230a	2.654a	5.328a	0.541a
	Topdressing	256.055a	142.182a	1602.589a	186.922a	149.499a	13.666a	13.923a	2.846a	5.522a	0.552a
	Banding & Topdressing	267.515a	147.796a	1667.238a	153.936a	127.945ab	15.036a	12.361a	2.841a	5.294a	0.571a
	MSD (0.05)	NS	NS	NS	NS	26.972	NS	NS	NS	NS	NS

Means followed by the same letter are not significantly different at *P*>0.05 according to Tukey's studentized range test

Sandy soil:

The K application levels markedly influenced the concentration of K, Ca and Mg in the biomass (Table 4.8a). Despite of no significant differences, the concentration of N, P and Mn increased as the application of K was raised from 0 to 60 kg.ha^{-1}. The concentration of Fe increased slightly when the application was raised from 0 to 40 kg K.ha^{-1}, but decreased as the application was raised beyond 40 kg K.ha^{-1}. However, the concentration of the other nutrients showed no consistent trend with regards to K application. The K application levels significantly influenced the accumulation of K, but had a negative influence on the accumulation of Mg (Table 4.8a).

Topdressing accounted for the highest K accumulation, followed by a combination of topdressing and banding and banding, respectively. This could possible be due to the fact that with topdressing the fertilizer is spread over a larger volume of soil, hence minimizing the risk of salt injury. The risk of salt injury is increased with a combination of topdressing and banding and banding, since in these two methods fertilizer concentration is higher in the root zone compared to topdressing. The negative influence on the accumulation of Mg might be due to the antagonistic effect K has on the uptake of Mg. Although there were no significant differences, the accumulation of N and Ca increased with the raising of the K level from 0 to 60 kg.ha^{-1}. The accumulation of Fe, Mn and Cu increased slightly when the application of K was raised to a certain level, but decreased as the application of K was raised beyond this level. In the case of Fe and Mn this level was 40 kg K.ha^{-1}, while in the case of Cu it was 20 kg K.ha^{-1}. The accumulation of other nutrients demonstrated no general trend.

TABLE 4.8a: Effects of potassium application levels on the concentration and accumulation of nutrients in the biomass for the sandy soil

		Nutrient concentration									
		N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (mg.kg^{-1})	Fe (mg.kg^{-1})	Zn (mg.kg^{-1})	Mn (mg.kg^{-1})	Cu (mg.kg^{-1})
K-levels	0	0.391a	0.191a	2.249c	0.221b	0.179a	190.417a	130.083a	32.917a	61.167a	4.167a
	20	0.396a	0.199a	2.484c	0.224ab	0.166ab	189.500a	136.083a	51.667a	63.000a	5.250a
	40	0.431a	0.202a	2.878b	0.230ab	0.158b	172.000a	140.833a	22.917a	65.750a	4.000a
	60	0.550a	0.204a	3.285a	0.251a	0.161b	210.167a	92.917a	28.167a	66.417a	4.250a
	MSD (0.05)	NS	NS	0.375	0.030	0.017	NS	NS	NS	NS	NS
		Nutrient accumulation									
		N (mg.pot^{-1})	P (mg.pot^{-1})	K (mg.pot^{-1})	Ca (mg.pot^{-1})	Mg (mg.pot^{-1})	Na (mg.pot^{-1})	Fe (mg.pot^{-1})	Zn (mg.pot^{-1})	Mn (mg.pot^{-1})	Cu (mg.pot^{-1})
K-levels	0	355.276a	175.969a	2061.894c	203.108a	164.743a	17.117a	11.859a	3.102a	5.630a	0.385a
	20	375.279a	188.590a	2348.474bc	211.599a	157.729ab	17.739a	12.754a	4.704a	5.960a	0.492a
	40	398.705a	187.827a	2673.997ab	214.429a	147.576ab	16.090a	13.076a	2.140a	6.174a	0.374a
	60	474.989a	179.907a	2899.074a	221.469a	143.428b	18.530a	8.174a	2.523a	5.869a	0.373a
	MSD (0.05)	NS	NS	341.140	NS	21.139	NS	NS	NS	NS	NS

Means followed by the same letter are not significantly different at P>0.05 according to Tukey's studentized range test

The K application methods significantly influenced the concentration of P and Mg in the biomass (Table 4.8b). Despite of no significant differences, banding contributed to the highest concentration of N, K, Fe and Zn, while topdressing resulted in the highest concentration of Ca, Na, Mn and Cu. On the other hand, the K application methods significantly influenced the accumulation of Ca, Mg and Mn in the biomass (Table 4.8b). Although there were no significant differences, banding resulted in the highest accumulation of N, P, Fe and Zn, while topdressing contributed to highest accumulation of K, Na and Cu.

TABLE 4.8b: Effects of potassium application methods on the concentration and accumulation of nutrients in the biomass for the sandy soil

		Nutrient concentration									
		N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na ($mg.kg^{-1}$)	Fe ($mg.kg^{-1}$)	Zn ($mg.kg^{-1}$)	Mn ($mg.kg^{-1}$)	Cu ($mg.kg^{-1}$)
K-methods	Banding	0.498a	0.211a	2.946a	0.231a	0.146b	194.333a	150.333a	50.417a	64.167a	4.583a
	Topdressing	0.393a	0.188b	2.783a	0.244a	0.183a	203.833a	108.417a	23.583a	68.000a	4.750a
	Banding & Topdressing	0.486a	0.206ab	2.918a	0.230a	0.155b	173.500a	111.083a	28.750a	63.000a	4.167a
	MSD (0.05)	NS	0.021	NS	NS	0.017	NS	NS	NS	NS	NS
		Nutrient accumulation									
		N ($mg.kg^{-1}$)	P ($mg.kg^{-1}$)	K ($mg.kg^{-1}$)	Ca ($mg.kg^{-1}$)	Mg ($mg.kg^{-1}$)	Na ($mg.kg^{-1}$)	Fe ($mg.kg^{-1}$)	Zn ($mg.kg^{-1}$)	Mn ($mg.kg^{-1}$)	Cu ($mg.kg^{-1}$)
K-methods	Banding	440.646a	188.721a	2636.241a	205.963b	131.280b	17.343a	13.547a	4.465a	5.735b	0.410a
	Topdressing	382.410a	181.575a	2677.028a	234.851a	177.330a	19.702a	10.313a	2.283a	6.589a	0.455a
	Banding & Topdressing	425.917a	186.029a	2608.276a	206.683b	140.124b	15.314a	10.145a	2.620a	5.678b	0.375a
	MSD (0.05)	NS	NS	NS	24.355	20.747	NS	NS	NS	0.785	NS

Means followed by the same letter are not significantly different at *P*>0.05 according to Tukey's studentized range test

The K application levels or methods had no pronounced effect on the uptake of most nutrients by maize during the early growth and development in both soils. As a result, it is rather difficult to conclude which particular K application level or method would be suitable for the optimum uptake of most nutrients by maize. However, an application level of 0 kg $K.ha^{-1}$ for the sandy loam soil and 0 to 20 kg $K.ha^{-1}$ for the sandy soil might be adequate for the optimum uptake of some nutrients by maize. As for the K application methods, topdressing seemed to favour the optimum uptake of most nutrients during the early growth and development of maize in both soils.

4.4 CONCLUSION

The effect of different levels of banded, topdressed, and a combination of banded and topdressed K on the early growth and development of the maize plant was determined by measuring the aerial and subsoil plant parameters. The uptake of N, P, K, Ca, Mg, Na, Fe, Zn, Mn and Cu by maize was also evaluated. All the plant parameters which were studied demonstrated that the interaction of K application levels and methods had no marked effect on the early growth and development of maize in both soils. However, the K application levels and methods separately had significant effects on some of the plant parameters.

In most cases, the best results for those aerial and subsoil plant parameters which were significantly influenced by the application of K were attained with an application of 0 to 20 kg $K.ha^{-1}$ in both soils. A combination of banding and topdressing contributed to the best results for aerial plant parameters in the sandy loam soil, while topdressing alone gave the best results for aerial plant parameters in the sandy soil. On the other hand, the subsoil plant parameters were not significantly affected by the K application methods in both soils. The best results on the uptake of most nutrients by maize were accomplished with an application of 0 kg $K.ha^{-1}$ in the sandy loam soil, while 0 to 20 kg $K.ha^{-1}$ accounted for the best uptake of most nutrients in the sandy soil. The K application method of topdressing contributed to the best results with regards to the uptake of most nutrients by maize in both soils.

Following these results, it was, therefore, concluded that an application of 0 to 20 kg $K.ha^{-1}$ seemed to be the most effective for the optimum early growth and development of maize in both soils. The K application methods of a combination of banding and topdressing in the sandy loam soil and topdressing alone in the sandy soil were also noticed to be the most effective methods for the optimum early growth and development of maize.

CHAPTER 5

GENERAL DISCUSSION AND CONCLUSION

According to Jones & Wendt (1994) soil fertility is one of the major agronomic constraints of maize production in the southern and eastern Africa regions. Most small scale farmers usually broadcast fertilizers, which is a wasteful practice since most of the fertilizer is applied in zones where it cannot be utilized efficiently by the crop. Proper fertilization of maize is required to promote uniform vigorous seedling establishment as a prerequisite for attaining yield potential and grain quality at harvest (Peck, MacDonald & Barnard, 1989). The primary reason for conducting this study was to establish the N and/or K application rates which are optimum for the early growth and development of maize without causing any adverse effects.

As a result, two experiments were conducted in this study using a sandy loam soil and a sandy soil. The first trial was undertaken to determine the influence of band placed N and/or K on the early growth and development of maize. A second trial was set up to investigate the effect of K on the early growth and development of maize applied through banding, topdressing and a combination of banding and topdressing.

In the first experiment, it was observed that the interaction of N and K showed no significant differences on the early growth and development of maize in both soils. However, the main factors, *viz*. N or K separately resulted in a significant variation on the early growth and development of maize in both soils.

The application of N significantly increased all the aerial (leaf count, stem thickness, plant height, leaf area and biomass) and subsoil (root length, root volume, root area and root mass) plant parameters in both soils. The application of K only significantly increased plant height and leaf area in the sandy loam soil, but had no marked effect on all the aerial plant parameters in the sandy soil. Furthermore, the addition of K only significantly increased root volume in the sandy loam soil, as well as, root volume, root area and root mass in the sandy soil. Most of the parameters studied did not significantly responded to the application of K probable because the two soils used in the experiment had sufficient levels of K. Another possible reason for the lack of response by most parameters measured could be that the application of K resulted in toxic levels of K in the soil, thereby imposing a negative effect on the maize plant. The application of N or K also markedly affected the uptake of some nutrients by maize in both soils.

A significant increase in the early growth and development of maize with regards to leaf count, stem thickness and plant height was observed as the application of N was increased from 0 to 60 kg $N.ha^{-1}$. This is comparable with the findings of Miller & Ohlrogge (1958) who reported that maize grew rapidly and had reached a height of 0.75 to 1.0 m as measured to the tip of the longest extended leaf at the end of a 30-day growth period when fertilized with N.

The biomass of maize was markedly increased with increasing N application rates in both soils. This is consistent with work done by Mackay & Barber (1986) who found that biomass of maize was significantly increased by the application of N fertilizer. Bennet, Pesek & Hanway (1964) also observed some significant differences in biomass of maize due to N fertilization.

Peck *et al.* (1988) observed that rates of maize seedling growth in dry weight from blends of N-P-K fertilizers were greater than the total sum of increases from applications of individual sources of N, P and K. They also indicated that maize seedlings grown with sources of N such as urea, $(NH_4)_2SO_4$, NH_4NO_3 and $Ca(NO_3)_2$ had the highest dry weight at an application of 3g $N.m^{-1}$ row. Seedlings grown with $(NH_4)_2SO_4$ or NH_4NO_3 grew more rapidly than seedlings grown with urea, especially at high rates of N applications and much more rapidly than seedlings grown with $Ca(NO_3)_2$.

However, Samater, Van Cleemput & Ertebo (1998) observed that the biomass of maize decreased with increasing NO_3-N application rates. This decrease might be attributed to a high salt or nitrate content on maize growth. Salinity causes damage to maize biomass production with a greater reduction in dry weight than grain yield. Most plants tolerate high NO_3^- concentrations without any physiological disorder, but excess NO_3^- nutrition can be toxic.

The root length of maize increased as the N application levels were increased from 0 to 60 $kg.ha^{-1}$ in the sandy soil. Cooke (1954) also indicated that root length of most crops was stimulated by the dressings of N-P-K fertilizer mixtures placed near the seed. It has been observed that N and P induce root mass in the soil when both are present in a zone of the soil (Duncan & Ohlrogge, 1958). Teyker (1992) reported that root length in the fertilized zone declined with increasing NH_4OH rates. In contrast, Anghinoni & Barber (1988) found that maize root length increased with the concentration of NH_4-N in the fertilized zone. However, increasingly toxic NH_4-N concentrations could lead to a decline in root length. Mackay & Barber (1986) also found that the application of N increased the root length of maize. Mengel & Barber (1974) confirmed a maximum root length of maize when N was added.

The root area of maize was markedly increased with increasing N application rates. Duncan & Ohlrogge (1958) found that the roots that developed in the presence of N and P in combination were much finer and silkier in appearance, and the number of roots was obviously much greater. The many fine hair-like roots contributed to a large part of root surface area in contact with the soil.

A significant increase in the root mass of maize was observed as the N application levels were increased. Bennett *et al.*(1964) also reported that maize plants harvested at four weeks showed that their root mass was significantly increased when grown with nitrate.

The results of the first experiment revealed that an application level of 20 to 40 kg $N.ha^{-1}$ seemed to be adequate to ensure optimum early growth and development of maize in both soils. In most cases, the application of K had a negative influence on the early growth and development of maize in both soils. This is consistent with work done by Heckman & Kamprath (1992) who also found that the early growth of maize was adversely affected by increasing K application rates. The application of K could probable have contributed to excess levels of K in both soils (Bornman *et al.*, 1989) and, therefore, leading to a negative impact on the early growth and development of maize. This decrease in early growth and development of maize with increasing K application rates might be attributed to a salt or antagonistic effect (Benton, Wolf & Mills, 1991; Heckman & Kamprath, 1992). However, Peck & MacDonald (1989) contended that increasing the level of soil K through K fertilization did not affect the dry weight of maize seedlings.

The K application levels which were required for optimum early growth and development of maize were higher in the sandy loam soil than in the sandy soil. This is contrary to the findings of Heckman & Kamprath (1992) who reported that sandy soils have a lower K buffer capacity than sandy loam soils and thus require a higher K application rate to satisfy the K requirements of maize.

As for the uptake of nutrients by maize, an application level of 0 to 20 kg $N.ha^{-1}$ for both soils contributed to optimum uptake of most nutrients by the maize plant during early growth and development. The uptake of N, P, K, Ca, Mg, Na, Fe, Zn, Mn and Cu increased with increasing N application rates in both soils. Peck *et al.* (1988) reported that blends of N-P-K fertilizers contributed to optimum uptake of N, P, K, Ca, Mg, Na, Fe, Zn, Mn and Cu by maize seedlings, which resulted in such seedlings having the greatest growth rates in dry weight per day. The application of N fertilizer increased N uptake of maize in a silt loam soil (Mackay & Barber, 1986). However, these results are in contrast with those of Samater *et al.* (1998) and Reddy & Reddy (1993) who observed that the N uptake efficiency of maize decreased with increasing N fertilization.

An application level of 0 to 20 kg $K.ha^{-1}$ in the sandy loam soil and 0 kg $K.ha^{-1}$ in the sandy soil accounted for optimum uptake of most nutrients by maize during early growth and development. The uptake of K increased consistently as the K application level was increased in the sandy loam soil. Studies conducted by Peck & MacDonald (1989) and Heckman & Kamprath (1992) have also demonstrated that the uptake of K increased with increasing K application levels.

The application levels of 20 to 40 kg $N.ha^{-1}$ and 0 to 20 kg $K.ha^{-1}$, respectively, seemed to be suitable to ensure optimum early growth and development of maize without causing any adverse effects. The results of this first experiment are in agreement with the band placement guidelines of N and/or K fertilizer for maize as stipulated by the FSSA (Bornman *et al.*, 1989; Du Toit, 1997).

It is not clear what would have happened to the yield of maize since the first trial was not run up to the yield level. Under these circumstances the existing claims that maize yields could be increased by as much as 25% when topdressed with K could not be verified. As a result, further investigations should be undertaken in order to verify if indeed topdress K could increase maize yield.

Similarly, in the second experiment, the interaction of K application levels and methods showed no significant effects on the early growth and development of maize. Even the K application levels and methods individually had little effect on the early growth and development of maize. The possible reason for this state of affairs could be that the two soils used in this experiment had adequate supplies of K. It has been previously reported (Parks & Walker, 1969) that in soils with medium to high K contents the response of maize to K fertilization diminishes. Barber (1959) also found that the response of maize to K fertilizer was affected by the K content of a soil.

The uptake of Ca and Mg in the sandy loam soil and Mg in the sandy soil decreased with increasing K application rates. Reduced uptake of Ca and Mg with increasing K application rates in the soil has been reported in previous studies (Peck & MacDonald 1989; Tisdale *et al.*, 1993). Surprisingly, the uptake of Ca in the sandy soil increased with increasing K application rates. The reason for this state of affairs is not known.

The results of the second trial demonstrated that an application level of 0 to 20 kg $K.ha^{-1}$ seemed to be adequate for the optimum early growth and development of maize in both soils. A combination of banding and topdressing in the sandy loam soil and topdressing alone in the sandy soil appeared to be appropriate for the optimum early growth and development of maize.

Finally, since the two experiments were conducted in a glasshouse, field trials should be conducted to verify these results under field conditions.

REFERENCES

ALKANANI, T. & MACKENZIE, A.F., 1996. Banding urea and lignosulfonate in corn (*Zea mays* L.) production and ^{15}N recovery. *Can. J. of Soil Sci.* 76(3):365-371.

ANGHINONI, I. & BARBER, S.A., 1980. Phosphorus application rate and distribution in the soil and phosphorus uptake by corn. *Soil. Sci. Soc. Am. J.* 44:1041-1044.

ANGHINONI, I. & BARBER, S.A., 1988. Corn root growth and nitrogen uptake as affected by ammonium placement. *Agron. J.* 80:799-802.

ARCHER, J., 1988. Crop nutrition and fertilizer use, 2nd ed. Ipswich: Farming Press Ltd.

ARNON, I., 1992. Agriculture in dry lands: principles and practice. Armsterdam: Elsevier Science Publishers B.V.

BARBER, S.A., 1959. Relation of fertilizer placement to nutrient uptake and crop yield. II. Effects of row potassium, potassium soil-level and precipitation. *Agron. J.* 51: 97-99.

BENNET, W.F., PESEK, J. & HANWAY, J.J., 1964. Effect of nitrate and ammonium on growth of corn in nutrient solution sand culture. *Agron. J.* 56:342-345.

BENTON, J.J., WOLF, B. & MILLS, H.A., 1991. Plant analysis handbook, a practical sampling, preparation, analysis and interpretation guide. Athens: Micro-Macro Publishing, Inc.

BIGERIEGO, M., HAUCK, R.D. & OLSON, R.A., 1979. Uptake, translocation and utilization of ^{15}N-depleted fertilizer in irrigated corn. *Soil Sci. Soc. Am. J.* 43:528-533.

BORDOLI, J.M. & MALLARINO, A.P., 1998. Deep and shallow banding of phosphorus and potassium as alternatives to broadcast fertilization for no-till corn. *Agron J.* 90:27-33.

BORNMAN, J.J., RANWELL, J.F., VENTER, G.C.H. & VOSLOO, L.B., 1989. Fertilizer handbook, 3rd ed. Hennospmeer: The Fertilizer Society of South Africa.

BREMNER, J.M. & KROGMEIER, M.J., 1989. Evidence that the adverse effect of urea fertilizer on seed germination in soil is due to ammonia formed through hydrolysis of urea by soil urease. *Proc. Natl. Acad. Sci.* 86:8185-8188.

CERONIO, G.M., 1997. Invloed van bandgeplaaste stikstof en fosfor op die vroeë groei en ontwikkeling van mielies. MSc. Thesis, University of the Orange Free State.

COOKE, G.W., 1954. Recent advances in fertilizer placement. II. Fertilizer placement in England. *J. Sci. Food Agric.* 429-440.

CUMMINGS, D.G. & PARKS, W.L., 1961. The germination of corn and wheat as affected by various fertilizer salts at different soil temperatures. *Soil Sci. Soc. Amer. Proc.* 25:47-49.

DIVISION OF PLANNING & STATISTICS, 1993. Botswana agricultural statistics. Gaborone: Ministry of Agriculture.

DUNCAN, W.G. & OHLROGGE, A.J., 1958. Principles of nutrient uptake from fertilizer bands. II. Root development in the band. *Agron. J.*:605-608.

DU TOIT, W., 1997. Handleiding vir die verbouing van mielies in die Somerreënvalgebied. Landbounavorsingsraad.

ECKERT, D.J. & JOHNSON, J.W., 1985. Phosphorus fertilization in no-tillage corn production. *Agron. J.* 77:789-792.

FINK, R.J. & WESLEY, D., 1974. Corn yield as affected by fertilization and tillage system. *Agron. J.* 66:70-71.

FOLLET, R.H., MURPHY, L.S. & DONAHUE, R.L., 1981. Fertilizers and soil amendments. Englewood Cliffs: Prentice-Hall, Inc.

GAKALE, L.P., 1983. Potential use of grain legumes for improved cereal production in low input cropping systems. *Bulletin of Agric. Research in Botswana.* 2:18-26.

GOMEZ, K.A. & GOMEZ, A.A., 1984. Statistical procedures for agricultural research, 2nd ed. New York: John Wiley & Sons, Inc.

HECKMAN, J.R. & KAMPRATH, E.J., 1992. Potassium accumulation and corn yield related to potassium fertilizer rate and placement. *Soil Sci. Soc. Am. J.* 56:141-148.

HERRON, G.M., DREIER, A.F., FLOWERDAY, A.D., COLVILLE, W.L. & OLSON, R.A., 1971. Residual mineral N accumulation in soil and its utilization by irrigated corn (*Zea mays* L.). *Agron. J.* 63:322-327.

HESSE, P.R., 1971. A textbook of soil chemical analysis. London: John Murrag Ltd.

HIPP, B.W., 1970. Phosphorus requirements for tomatoes as influenced by placement. *Agron. J.* 62:203-206.

JOKELA, W.E. & RANDALL, G.W., 1989. Corn yield and residual soil nitrate as affected by time and rate of nitrogen application. *Agron. J.* 81:720-726.

JONES, L.G. & WARREN, G.F., 1954. The efficiency of various methods of application of P for tomatoes. *Proc. Amer. Soc. Hort. Sci.* 63:309-319.

JONES, R.B. & WENDT, J.W., 1994. Contribution of soil fertility research to improved maize production by smallholders in eastern and southern Africa. *Proc. Of the fourth eastern and southern Africa regional maize conference*: 2-14.

LAWTON, K., APOSTOLAKIS, C. COOK, R.L. & HILL, W.L., 1956. Influence of particle size, water solubility and placement of fertilizer on the nutrient value of phosphorus in mixed fertilizers. *Soil Sci.* 82:465-476.

LOCASCIO, S.J., WARREN, G.F. & WILCOX, G.E., 1960. The effect of placement on uptake of P and growth of direct seeded tomatoes. *Proc. Amer. Soc. Hort.* Sci. 76:503-514.

MACKAY, A.D. & BARBER, S.A., 1986. Effect of nitrogen on root growth of two corn genotypes in the field. *Agron. J.* 78:699-703.

MADDUX, L.D., RACZKOWSKI, C.W., KISSEL, D.E. & BARNES, P.L., 1991. Broadcast and subsurface-banded urea nitrogen in urea ammonium nitrate applied to corn. *Soil Sci. Soc. Am. J.* 55:264-267.

MAHLER, R.L. LUTCHER, L.K. & EVERSON, D.O., 1989. Evaluation of factors affecting emergence of winter wheat planted with seed-banded nitrogen fertilizers. *Soil Sci. Soc. Am. J.* 53:571-575.

MARTIN, J.H., LEONARD, W.H. & STAMP, D.L., 1976. Principles of field crop production, 3rd ed. New York: Macmillan Publishing Co., Inc.

MENGEL, D.B. & BARBER, S.A., 1974. Development and distribution of the corn root system under field conditions. *Agron. J.* 66:341-344.

MILLER, H.F., KAVANAUGH, J. & THOMAS, G.W., 1975. Time of N application and yields of corn in wet alluvial soils. *Agron. J.* 67:401-404.

MILLER, M. H. & OHLROGGE, A.J., 1958. Principles of nutrient uptake from fertilizer bands. 1. Effect of placement of nitrogen fertilizer on the uptake of band-placed phosphorus at different soil phosphorus levels. *Agron. J.* 50:95-97.

MOSCHLER, W.W., SHEAR, G.M., MARTENS, D.C., JONES, G.D. & WILMOUTH, R.R., 1972. Comparative yield and fertilizer efficiency of no-tillage and conventionally tilled corn. *Agron. J.* 64:229-231.

OLSEN, S.R., WATANABE, F.S. & DANIELSON, R.E., 1961. Phosphorus absorption by corn roots as affected by moisture and phosphorus concentration. *Soil Sci. Soc. Am. Proc.* 25:289-294.

OLSON, R.A. & DREIER, A.F., 1956. Nitrogen, a key factor in fertilizer phosphorus efficiency. *Proc.Soil Sci. Soc. of Amer.* 20:509-514.

OLSON, R.A., DREIER, A.F., LOWERY, G.W. & FLOWERDAY, A.P., 1956. Availability of phoshpate carriers to small grains and subsequent clover in relation to: I. Nature of soil and method of placement. *Agron. J.* 48:106-111.

OLSON, R.A. & SANDER, D.H., 1988. Corn production. In G.F.SPRAGUE & J.W.DUDDLEY (eds.) Corn and corn improvement, 3rd ed. Madison: American Society of Agronomy, Inc., Crop Science Society of America, Inc. & Soil Science Society of America, Inc.

PARKS, W.L. & WALKER, W.M., 1969. Effect of soil potassium, potassium fertilizer and method of fertilizer placement upon corn yields. *Soil Sci. Soc. Amer. Proc.* 33: 107-123.

PECK, N.H., MACDONALD, G.E. & BARNARD, J., 1988. Sweet corn seedlings responses to band-applied nitrogen, phosphorus and potassium fertilizers. *J. Amer. Soc. Hort. Sci.* 113(3):336-342.

PECK, N.H., MACDONALD, G.E. & BARNARD, J., 1989. Sweet corn seedling responses to band-applied sources and rates of nitrogen fertilizers. *Hort. Sci.* 24(4):616-619.

PECK, N.H. & MACDONALD, G.E., 1989. Sweet corn plant responses to P and K in the soil and to band-applied monoammonium phosphate, potassium sulfate and magnesium *J. Amer. Soc. Hort. Sci.* 114(2):269-272.

PRUMMEL, J., 1957. Fertilizer placement experiments. *Plant and Soil.* 8:231-253.

RANDALL, G.W. & HOEFT, R.G., 1988. Placement methods for improved efficiency of P and K fertilizers: A review. *J. Prod. Agric.* 1:70-79.

REDDY, G.B. & REDDY, K.R., 1993. Fate of nitrogen-15 enriched ammonium nitrate applied to corn. *Soil. Sci. Soc. Am. J.* 57:111-115.

ROBERTSON, W.K., SMITH, P.M., OHLROGGE, A.J. & KINCH, D.M., 1954. Phosphorus utilization by corn as affected by placement and nitrogen and potassium fertilization. *Soil Sci.* 72:219-226.

ROBINSON, R.R., SPRAGUE, V.G. & GROSS, C.F., 1959. The relation of temperature and phosphate placement to growth of clover. *Soil Sci. Soc. Am. Proc.* 23:225-228.

ROWSE, H.R. & PHILLIPS, D.A., 1974. An instrument for estimating the total length of root in a sample. *J. Appl. Ecol.* 11:309-314.

RUSSELLE, M.P., DEIBERT, E.J., HAUCK, R.D., STEVANOVIC, M. & OLSON, R.A., 1981. Effects of water and nitrogen management on yield and ^{15}N-depleted fertilizer use efficiency of irrigated corn. *Soil. Sci. Soc. Am. J.* 45:553-558.

SAMATER, A.H., VAN CLEEMPUT, O. & ERTEBO, T., 1998 Influence of the presence of nitrite and nitrate in soil on maize biomass production, nitrogen immobilization and nitrogen recovery. *Biol. Fertil. Soils.* 27:211-218.

SANCHEZ, C.A., PORTER, P.S. & ULLOA, M.F., 1991. Relative efficiency of broadcast and banded phosphorus for sweet corn produced on histosols. *Soil Sci. Soc. Am. J.* 55:871-875.

SAS INSTITUTE, 1985. SAS User's Guide: Statistics. Cary, North Carolina: SAS Institute, Inc.

SHEAR, G.M. & MOSCHLER, W.W., 1969. Continuous corn by the no-tillage and conventional tillage methods: A six-year comparison. *Agron. J.* 61:524-526.

SINGH, T.A., THOMAS, G.W., MOSCHLER, W.W. & MARTENS, D.C., 1966. Phosphorus uptake by corn (*Zea mays* L.) under no-tillage and conventional practices. *Agron. J.* 58:147-148.

SMITH, C.B., DEMCHAK, K.T. & FERRETTI, P.A., 1990. Fertilizer placement effects on growth responses and nutrient uptake of sweet corn, snapbeans, tomatoes and cabbage. *Comm. in Soil Sci. Plant Anal.* 21(1&2):107-123.

SOUTH AFRICA, DEPARTMENT OF AGRICULTURE., 1999. Abstract of agricultural statistics. Pretoria: Die Afdeling.

STANFORD, G. & NELSON, L.B., 1949. Utilization of phosphorus as affected by placement. I Corn in Iowa. *Soil. Sci.*68:129-135.

TEYKER, R.H., 1992. Seedling responses to band applied NH_4 OH rates and to N form in two maize hybrids. *Plant and Soil.* 144:289-295.

THE NON-AFFILIATED SOIL ANALYSIS WORK COMMITTEE, 1990. Handbook of standard soil testing methods for advisory purposes. *Soil Sci. Soc. of S.A.*, P.O. Box 30030, Sunnyside, Pretoria.

TIMMONS, D.R., BURWELL, R.E. & HOLT, R.F., 1973. Nitrogen and phosphorus losses in surface runoff from agricultural land as influenced by placement of broadcast fertilizer. *Water Resources Res.* 9:658-667.

TISDALE, S.L., NELSON, W.L., BEATON, J.D. & HAVLIN, J.L., 1993. Soil fertility and fertilizers, 5th ed. New York: Macmillan Publishing Co.

VAN RENSBURG, J.B.J., 1994. The history of maize. Potchefstroom: Agricultural Research Centre.

WALKER, W.M. & PARKS, W.L., 1969. Effect of soil potassium, potassium fertilizer and method of placement upon lodging in corn (*Zea mays.* L.). *Soil Sci. Soc. Am. Proc.* 33:909-912.

WEBB, J.R. & PESEK, J.T., 1958. An evaluation of phosphorus fertilizers varying in water solubility. I. Hill application for corn. *Soil Sci. Soc. Am. Proc.* 22:533-538.

WELCH, L.F., JOHNSON, P.E., MCKIBBEN, G.E., BOONE, L.V. & PENDLETON, J.W., 1966a. Relative efficiency of broadcast versus banded potassium for corn. *Agron. J.* 58:618-621.

WELCH, L.F., MULVANEY, D.L., BOONE, L.V., MCKIBBEN, G.E. & PENDLETON, J.W., 1966b. Relative efficiency of broadcast versus banded phosphorus for corn. *Agron. J.* 58:283-286.

WELCH, L.F., MULVANEY, D.L., OLDHAM, M.G., BOONE, L.V., MCKIBBEN, G.E. & PENDLETON, J.W., 1971. Corn yields with fall, spring and sidedress nitrogen. *Agron. J.* 63:119-123.

WILCOX, G.E., 1967. Effect of fertilizer P on tomato seedling growth rate. *Proc. Amer. Soc. Hort. Sci.* 90:330-334.

WILKINSON, S.R. & OHLROGGE, A.J., 1962. Principles of nutrient uptake from fertilizer bands. I. Mechanism responsible for intensive root development in fertilized zones. *Agron. J.* 54:288-291.

APPENDIX 3

APPENDIX 3.1: Analysis of variance of electrical resistance in the fertilized zone as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	0.42052392	0.02803493	1.48	0.1701
Error	32	0.60463800	0.01889494		
Corrected Total	47	1.02516192			
	R-Square	C.V.	Root MSE		ELRF Mean
	0.410202	29.37417	0.137459		0.46795833
		$MSD_{(0.05)}$=0.114			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	0.19610175	0.06536725	3.46	0.0277
N	3	0.11265342	0.03755114	1.99	0.1357
K*N	9	0.11176875	0.01241875	0.66	0.7402

APPENDIX 3.2: Analysis of variance of electrical resistance in the unfertilized zone as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	2.60246667	0.17349778	0.82	0.6538
Error	32	6.80620000	0.21269375		
Corrected Total	47	9.40866667			
	R-Square	C.V.	Root MSE		ELRU Mean
	0.276603	14.15409	0.461187		3.25833333
		$MSD_{(0.05)}$=0.510			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	0.57475000	0.19158333	0.90	0.4516
N	3	0.19396667	0.06465556	0.30	0.8223
K*N	9	1.83375000	0.20375000	0.96	0.4914

APPENDIX 3.3: Analysis of variance of electrical resistance in the fertilized zone as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	0.49259381	0.03283959	1.26	0.2820
Error	32	0.83399667	0.02606240		
Corrected Total	47	1.32659048			
	R-Square	C.V.	Root MSE		ELRF Mean
	0.371323	43.30771	0.161439		0.37277083
		MSD(0.05)=0.179			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	0.05669356	0.01889785	0.73	0.5445
N	3	0.27688873	0.09229624	3.54	0.0254
K*N	9	0.15901152	0.01766795	0.68	0.7228

APPENDIX 3.4: Analysis of variance of electrical resistance in the unfertilized zone as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	5.01121458	0.33408097	0.79	0.6779
Error	32	13.51153333	0.42223542		
Corrected Total	47	18.52274792			
	R-Square	C.V.	Root MSE		ELRU Mean
	0.270544	21.64034	0.649796		3.00270833
		MSD(0.05)=0.719			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	1.65112292	0.55037431	1.30	0.2903
N	3	1.08638958	0.36212986	0.86	0.4730
K*N	9	2.27370208	0.25263356	0.60	0.7887

APPENDIX 3.5: Analysis of variance of leaf count as influenced by N, K and N*K during week 1 in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	0.212787731	0.01418582	0.41	0.9656
Error	32	1.10977867	0.03468058		
Corrected Total	47	1.32256598			
	R-Square	C.V.	Root MSE		LCOU Mean
	0.160890	8.880033	0.186227		2.09714583
		MSD(0.05)=0.206			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	0.04628706	0.01542902	0.44	0.7226
N	3	0.04628706	0.01542902	0.44	0.7226
K*N	9	0.12021319	0.01335702	0.39	0.9335

APPENDIX 3.6: Analysis of variance of leaf count as influenced by N, K and N*K during week 2 in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	0.58995865	0.03933058	1.42	0.1988
Error	32	0.88866733	0.02777085		
Corrected Total	47	1.47852698			
	R-Square	C.V.	Root MSE		LCOU Mean
	0.398991	4.232254	0.166646		3.93752083
		MSD(0.05)=0.184			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	0.11784740	0.03928247	1.41	0.2566
N	3	0.15497690	0.05165897	1.86	0.1562
K*N	9	0.31713435	0.03523715	1.27	0.2912

APPENDIX 3.7: Analysis of variance of leaf count as influenced by N, K and N*K during week 3 in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	3.92409748	0.26160650	5.14	0.0001
Error	32	1.62881600	0.05090050		
Corrected Total	47	5.55291348			
	R-Square	C.V.	Root MSE		LCOU Mean
	0.706674	4.661132	0.225611		4.84027083
		MSD(0.05)=0.250			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	0.13652323	0.04550774	0.89	0.4548
N	3	2.63674540	0.87891513	17.27	0.0001
K*N	9	1.15082885	0.12786987	2.51	0.0266

APPENDIX 3.8: Analysis of variance of leaf count as influenced by N, K and N*K during week 4 in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	2.74081531	0.18272102	2.19	0.0306
Error	32	2.66711200	0.08334725		
Corrected Total	47	5.40792731			
	R-Square	C.V.	Root MSE		LCOU Mean
	0.506814	4.996688	0.288699		5.77781250
		MSD(0.05)=0.319			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	0.05555556	0.01851852	0.22	0.8803
N	3	1.90720373	0.63573458	7.63	0.0006
K*N	9	0.77805602	0.08645067	1.04	0.4331

APPENDIX 3.9: Analysis of variance of leaf count as influenced by N, K and N*K during week 1 in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	0	0	99999.99	0.0
Error	32	0	0		
Corrected Total	47	0			
	R-Square	C.V.	Root MSE		LCOU Mean
	0.000000	0	0		2.00000000
		MSD(0.05)=0.000			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	0	0	99999.99	0.0
N	3	0	0	99999.99	0.0
K*N	9	0	0	99999.99	0.0

APPENDIX 3.10: Analysis of variance of leaf count as influenced by N, K and N*K during week 2 in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	3.62149148	0.24143277	2.22	0.0287
Error	32	3.48252000	0.10882875		
Corrected Total	47	7.10401148			
	R-Square	C.V.	Root MSE		LCOU Mean
	0.509781	8.962986	0.329892		3.68060417
		MSD(0.05)=0.365			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	1.19430573	0.39810191	3.66	0.0225
N	3	1.75097240	0.58365747	5.36	0.0042
K*N	9	0.67621335	0.07513482	0.69	0.7122

APPENDIX 3.11: Analysis of variance of leaf count as influenced by N, K and N*K during week 3 in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	7.07249125	0.47149942	7.03	0.0001
Error	32	2.14718600	0.06709956		
Corrected Total	47	9.21967725			
	R-Square	C.V.	Root MSE		LCOU Mean
	0.767108	5.542504	0.259036		4.67362500
		MSD(0.05)=0.287			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	0.28441675	0.09480558	1.41	0.2570
N	3	6.34180575	2.11393525	31.50	0.0001
K*N	9	0.44626875	0.04958542	0.74	0.6708

APPENDIX 3.12: Analysis of variance of leaf count as influenced by N, K and N*K during week 4 in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	10.42326481	0.69488432	10.00	0.0001
Error	32	2.22311267	0.06947227		
Corrected Total	47	12.64637748			
	R-Square	C.V.	Root MSE		LCOU Mean
	0.824210	4.810420	0.263576		5.47927083
		MSD(0.05)=0.292			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	0.69196773	0.23065591	3.32	0.0320
N	3	9.32183823	3.10727941	44.73	0.0001
K*N	9	0.40945885	0.04549543	0.65	0.7421

APPENDIX 3.13: Analysis of variance of stem thickness as influenced by N, K and N*K during week 1 in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	1.35983065	0.09065538	0.98	0.4934
Error	32	2.94976533	0.09218017		
Corrected Total	47	4.30959598			
	R-Square	C.V.	Root MSE		STHI Mean
	0.315536	7.134541	0.303612		4.25552083
		MSD(0.05)=0.335			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	0.19989656	0.06663219	0.72	0.5458
N	3	0.18799456	0.06266485	0.68	0.5709
K*N	9	0.97193952	0.10799328	1.17	0.3456

APPENDIX 3.14: Analysis of variance of stem thickness as influenced by N, K and N*K during week 2 in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	13.92602365	0.92840158	2.60	0.0114
Error	32	11.430521233	0.35720379		
Corrected Total	47	25.35654498			
	R-Square	C.V.	Root MSE		STHI Mean
	0.549208	7.622289	0.597665		7.84102083
		MSD(0.05)=0.661			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	0.51646373	0.17215458	0.48	0.6971
N	3	11.09111540	3.69703847	10.35	0.0001
K*N	9	2.31844452	0.25760495	0.72	0.6860

APPENDIX 3.15: Analysis of variance of stem thickness as influenced by N, K and N*K during week 3 in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	80.34851931	5.35656795	5.40	0.0001
Error	32	31.76246867	0.99257715		
Corrected Total	47	112.11098798			
	R-Square	C.V.	Root MSE		STHI Mean
	0.716687	8.709121	0.996282		11.4395208
		MSD(0.05)=1.102			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	2.32691290	0.77563763	0.78	0.5131
N	3	72.98604240	24.32868080	24.51	0.0001
K*N	9	5.03556402	0.55950711	0.56	0.8161

APPENDIX 3.16: Analysis of variance of stem thickness as influenced by N, K and N*K during week 4 in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	78.21931192	5.21462079	6.13	0.0001
Error	32	27.23689133	0.85115285		
Corrected Total	47	105.45620325			
	R-Square	C.V.	Root MSE		STHI Mean
	0.741723	6.489441	0.922579		14.2166250
		MSD(0.05)=1.020			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	2.83972242	0.94657414	1.11	0.3586
N	3	66.08518175	22.02839392	25.88	0.0001
K*N	9	9.29440775	1.03271197	1.21	0.3213

APPENDIX 3.17: Analysis of variance of stem thickness as influenced by N, K and N*K during week 1 in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	1.25426192	0.08361746	1.13	0.3710
Error	32	2.36738000	0.07398063		
Corrected Total	47	3.62164192			
	R-Square	C.V.	Root MSE		STHI Mean
	0.346324	9.502105	0.271994		2.86245833
		MSD(0.05)=0.300			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	0.19783908	0.06594636	0.89	0.4561
N	3	0.74139825	0.24713275	3.34	0.0314
K*N	9	0.31502458	0.03500273	0.47	0.8817

APPENDIX 3.18: Analysis of variance of stem thickness as influenced by N, K and N*K during week 2 in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	14.40834100	0.96055607	2.25	0.0263
Error	32	13.63283200	0.42602600		
Corrected Total	47	28.04117300			
	R-Square	C.V.	Root MSE		STHI Mean
	0.513828	11.59080	0.652707		5.63125000
		MSD(0.05)=0.722			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	2.36374917	0.78791639	1.85	0.1581
N	3	11.03786967	3.67928989	8.64	0.0002
K*N	9	1.00672217	0.11185802	0.26	0.9803

APPENDIX 3.19: Analysis of variance of stem thickness as influenced by N, K and N*K during week 3 in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	153.3443343	10.2229556	4.15	0.0004
Error	32	78.7379067	2.4605596		
Corrected Total	47	232.0822410			
	R-Square	C.V.	Root MSE		STHI Mean
	0.660733	15.97004	1.568617		9.82225000
		MSD(0.05)=1.735			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	3.7422857	1.2474286	0.51	0.6803
N	3	144.3724835	48.1241612	19.56	0.0001
K*N	9	5.2295652	0.5810628	0.24	0.9863

APPENDIX 3.20: Analysis of variance of stem thickness as influenced by N, K and N*K during week 4 in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	274.6748953	18.3116597	19.00	0.0001
Error	32	30.8375727	0.9636741		
Corrected Total	47	305.5124680			
	R-Square	C.V.	Root MSE		STHI Mean
	0.899063	7.809942	0.981669		12.5694792
		MSD(0.05)=1.085			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	1.2577352	0.4192451	0.44	0.7294
N	3	270.2172021	90.0724007	93.47	0.0001
K*N	9	3.1999580	0.3555509	0.37	0.9415

APPENDIX 3.21: Analysis of variance of plant height as influenced by N, K and N*K during week 1 in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	7969.439945	531.295996	0.76	0.7125
Error	32	22495.924373	702.997637		
Corrected Total	47	30465.364318			
	R-Square	C.V.	Root MSE		PLHT Mean
	0.261590	9.464158	26.51410		280.152792
		MSD(0.05)=29.327			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	1703.403093	567.801031	0.81	0.4990
N	3	2483.120741	827.706914	1.18	0.3337
K*N	9	3782.916112	420.324012	0.60	0.7890

APPENDIX 3.22: Analysis of variance of plant height as influenced by N, K and N*K during week 2 in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	51105.92443	3407.06163	1.28	0.2691
Error	32	85081.72237	2658.80382		
Corrected Total	47	136187.64680			
	R-Square	C.V.	Root MSE		PLHT Mean
	0.375261	11.49601	51.56359		448.534687
		MSD(0.05)=57.034			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	14371.38395	4790.46132	1.80	0.1667
N	3	20693.17504	6897.72501	2.59	0.0696
K*N	9	16041.36544	1782.37394	0.67	0.7291

APPENDIX 3.23: Analysis of variance of plant height as influenced by N, K and N*K during week 3 in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	167348.8167	11156.5878	3.29	0.0023
Error	32	108508.3004	3390.8844		
Corrected Total	47	275857.1171			
	R-Square	C.V.	Root MSE		PLHT Mean
	0.606650	8.392860	58.23130		693.819479
		MSD(0.05)=64.409			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	14906.6330	4968.8777	1.47	0.2425
N	3	121521.7877	40507.2626	11.95	0.0001
K*N	9	30920.3959	3435.5995	1.01	0.4503

APPENDIX 3.24: Analysis of variance of plant height as influenced by N, K and N*K during week 4 in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	453469.9054	30231.3270	5.46	0.0001
Error	32	177180.1627	5536.8801		
Corrected Total	47	630650.0682			
	R-Square	CV	Root MSE		PLHT Mean
	0.719052	8.044831	74.41021		924.944458
		MSD(0.05)=82.304			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	17244.7922	5748.2641	1.04	0.3889
N	3	402576.0044	134192.0015	24.24	0.0001
K*N	9	33649.1088	3738.7899	0.68	0.7250

APPENDIX 3.25: Analysis of variance of plant height as influenced by N, K and N*K during week 1 in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	15244.83473	1016.32232	0.65	0.8124
Error	32	50159.03852	1567.46995		
Corrected Total	47	65403.87325			
	R-Square	C.V.	Root MSE		PLHT Mean
	0.233088	16.67537	39.59129		237.423688
		MSD(0.05)=43.792			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	1191.67060	397.22353	0.25	0.8583
N	3	11249.09952	3749.69984	2.39	0.0868
K*N	9	2804.06461	311.56273	0.20	0.9926

APPENDIX 3.26: Analysis of variance of plant height as influenced by N, K and N*K during week 2 in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	68919.20315	4594.61354	1.63	0.1214
Error	32	90392.07756	2824.75242		
Corrected Total	47	159311.28071			
	R-Square	C.V.	Root MSE		PLHT Mean
	0.432607	12.66275	53.14840		419.722271
		MSD(0.05)=58.787			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	23167.44554	7722.48185	2.73	0.0599
N	3	38258.85835	12752.95278	4.51	0.0095
K*N	9	7492.89926	832.54436	0.29	0.9711

APPENDIX 3.27: Analysis of variance of plant height as influenced by N, K and N*K during week 3 in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	183628.4751	12241.8983	1.69	0.1033
Error	32	231312.4153	7228.5130		
Corrected Total	47	414940.8904			
	R-Square	C.V.	Root MSE		PLHT Mean
	0.442541	14.07724	85.02066		603.958333
		MSD(0.05)=94.040			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	24272.1864	8090.7288	1.12	0.3558
N	3	142652.5186	47550.8395	6.58	0.0014
K*N	9	16703.7702	1855.9745	0.26	0.9817

APPENDIX 3.28: Analysis of variance of plant height as influenced by N, K and N*K during week 4 in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	464048.0770	30936.5385	6.31	0.0001
Error	32	156868.6978	4902.1468		
Corrected Total	47	620916.7748			
	R-Square	CV	Root MSE		PLHT Mean
	0.747360	9.032698	70.01533		775.132000
		MSD(0.05)=77.443			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	28591.3126	9530.4375	1.94	0.1423
N	3	419718.9843	139906.3281	28.54	0.0001
K*N	9	15737.7801	1748.6422	0.36	0.9472

APPENDIX 3.29: Analysis of variance of leaf area as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	8792031.138	586135.409	9.45	0.0001
Error	32	1984626.671	62019.583		
Corrected Total	47	10776657.809			
	R-Square	C.V.	Root MSE		LARE Mean
	0.815840	12.89881	249.0373		1930.70054
		MSD(0.05)=275.460			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	166669.746	55556.582	0.90	0.4540
N	3	8221101.839	2740367.280	44.19	0.0001
K*N	9	404259.554	44917.728	0.72	0.6834

APPENDIX 3.30: Analysis of variance of leaf area as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	14480391.39	965359.43	7.10	0.0001
Error	32	4353980.66	136061		
Corrected Total	47	18834372.06			
	R-Square	C.V.	Root MSE		LARE Mean
	0.768828	22.05561	368.8657		1672.43473
		MSD(0.05)=408.000			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	835797.73	278599.24	2.05	0.1269
N	3	12917744.98	4305914.99	31.65	0.0001
K*N	9	726848.68	80760.96	0.59	0.7925

APPENDIX 3.31: Analysis of variance of biomass as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	4167.225232	277.815015	7.91	0.0001
Error	32	1124.225547	35.132048		
Corrected Total	47	5291.450779			
	R-Square	C.V.	Root MSE		BMAS Mean
	0.787539	14.63231	5.927229		40.5078125
		MSD(0.05)=6.556			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	61.112844	20.370948	0.58	0.6325
N	3	3811.035364	1270.345121	36.16	0.0001
K*N	9	295.077025	32.786336	0.93	0.5104

APPENDIX 3.32: Analysis of variance of biomass as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	4553.526829	303.568455	9.32	0.0001
Error	32	1042.115655	32.566114		
Corrected Total	47	5595.642484			
	R-Square	C.V.	Root MSE		BMAS Mean
	0.813763	20.36095	5.706673		28.0275417
		MSD(0.05)=6.312			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	130.214947	43.404982	1.33	0.2810
N	3	4345.873701	1448.624567	44.48	0.0001
K*N	9	77.438182	8.604242	0.26	0.9799

APPENDIX 3.33: Analysis of variance of root length in the fertilized zone as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	83122.91319	5541.52755	0.80	0.6692
Error	32	221653.78546	6926.68080		
Corrected Total	47	304776.69866			
	R-Square	C.V.	Root MSE		RLF Mean
	0.272734	25.32760	83.22668		328.600687
		MSD(0.05)=92.056			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	5863.95067	1954.65022	0.28	0.8379
N	3	49025.00237	16341.66746	2.36	0.0900
K*N	9	28233.96016	3137.10668	0.45	0.8948

APPENDIX 3.34: Analysis of variance of root length in the unfertilized zone as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	18524.74513	1234.98301	0.67	0.7936
Error	32	59018.52211	1844.32882		
Corrected Total	47	77543.26724			
	R-Square	C.V.	Root MSE		RLU Mean
	0.238896	20.61550	42.94565		208.317292
		MSD(0.05)=47.502			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	2964.958899	988.319633	0.54	0.6611
N	3	7807.261913	2602.420638	1.41	0.2576
K*N	9	7752.524316	861.391591	0.47	0.8857

APPENDIX 3.35: Analysis of variance of root length in the fertilized zone as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	239142.0360	15942.8024	1.97	0.0526
Error	32	258778.8578	8086.8393		
Corrected Total	47	497920.8938			
	R-Square	C.V.	Root MSE		RLF Mean
	0.480281	34.38098	89.92686		261.559917
		MSD(0.05)=99.467			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	3940.5462	1313.5154	0.16	0.9209
N	3	198841.8567	66280.6189	8.20	0.0003
K*N	9	36359.6331	4039.9592	0.50	0.8637

APPENDIX 3.36: Analysis of variance of root length in the unfertilized zone as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	72487.42086	4832.49472	1.99	0.0497
Error	32	77522.69414	2422.58419		
Corrected Total	47	150010.11500			
	R-Square	C.V.	Root MSE		RLU Mean
	0.483217	28.09016	49.21975		175.220604
		MSD(0.05)=54.441			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	4376.30873	1458.76958	0.60	0.6184
N	3	56127.89004	18709.29668	7.72	0.0005
K*N	9	11983.22209	1331.46912	0.55	0.8270

APPENDIX 3.37: Analysis of variance of root volume in the fertilized zone as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	169.2500000	11.2833333	1.07	0.4218
Error	32	338.6666667	10.5833333		
Corrected Total	47	507.9166667			
	R-Square	C.V.	Root MSE		RVF Mean
	0.333224	40.45434	3.253204		8.04166667
		MSD(0.05)=3.598			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	11.0833333	3.6944444	0.35	0.7900
N	3	107.4166667	35.8055556	3.38	0.0300
K*N	9	50.7500000	5.6388889	0.53	0.8396

APPENDIX 3.38: Analysis of variance of root volume in the unfertilized band as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	6.97916667	0.46527778	0.40	0.9692
Error	32	37.33333333	1.16666667		
Corrected Total	47	44.31250000			
	R-Square	C.V.	Root MSE		RVU Mean
	0.157499	29.29148	1.080123		3.68750000
		MSD(0.05)=1.195			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	0.39583333	0.13194444	0.11	0.9518
N	3	1.72916667	0.57638889	0.49	0.6890
K*N	9	4.85416667	0.53935185	0.46	0.8888

APPENDIX 3.39: Analysis of variance of root volume in the fertilized zone as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	172.8125000	11.5208333	2.97	0.0047
Error	32	124.0000000	3.8750000		
Corrected Total	47	296.8125000			
	R-Square	C.V.	Root MSE		RVF Mean
	0.582228	39.86839	1.968502		4.93750000
		MSD(0.05)=2.177			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	6.5625000	2.1875000	0.56	0.6424
N	3	139.2291667	46.4097222	11.98	0.0001
K*N	9	27.0208333	3.0023148	0.77	0.6403

APPENDIX 3.40: Analysis of variance of root volume in the unfertilized zone as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	30.64583333	2.04305556	3.38	0.0019
Error	32	19.33333333	0.60416667		
Corrected Total	47	49.97916667			
	R-Square	C.V.	Root MSE		RVU Mean
	0.613172	30.83431	0.777282		2.52083333
		MSD(0.05)=0.859			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	1.22916667	0.00147558	0.99	0.4118
N	3	19.56250000	0.01347431	9.00	0.0002
K*N	9	9.85416667	0.00180469	1.21	0.3256

APPENDIX 3.41: Analysis of variance of root area in the fertilized zone as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	52431.71680	3495.44779	1.06	0.4245
Error	32	105244.22660	3288.88208		
Corrected Total	47	157675.94340			
	R-Square	C.V.	Root MSE		RAEF Mean
	0.332528	31.36988	57.34878		182.814792
		MSD(0.05)=63.433			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	2743.30521	914.43507	0.28	0.8408
N	3	32757.91932	10919.30644	3.32	0.0320
K*N	9	16930.49227	1881.16581	0.57	0.8097

APPENDIX 3.42: Analysis of variance of root area in the unfertilized zone as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	1833.784058	122.252271	0.29	0.9927
Error	32	13292.938533	415.404329		
Corrected Total	47	15126.722592			
	R-Square	C.V.	Root MSE		RAEU Mean
	0.121228	20.94928	20.38147		97.2895833
		MSD(0.05)=22.544			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	166.605942	55.535314	0.13	0.9393
N	3	535.770025	178.590008	0.43	0.7330
K*N	9	1131.408092	125.712010	0.30	0.9685

APPENDIX 3.43: Analysis of variance of root area in the fertilized zone as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	81549.92429	5436.66162	2.55	0.0128
Error	32	68216.72834	2131.77276		
Corrected Total	47	149766.65263			
	R-Square	C.V.	Root MSE		RAEF Mean
	0.544513	36.38027	46.17112		126.912542
		MSD(0.05)=51.069			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	1742.09589	580.69863	0.27	0.8448
N	3	68861.76296	22953.92099	10.77	0.0001
K*N	9	10946.06543	1216.22949	0.57	0.8108

APPENDIX 3.44: Analysis of variance of root area in the unfertilized zone as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	17842.56615	1189.50441	2.78	0.0074
Error	32	13695.85649	427.99552		
Corrected Total	47	31538.42264			
	R-Square	C.V.	Root MSE		RAEU Mean
	0.565741	28.05834	20.68805		73.7322708
		MSD(0.05)=22.883			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	497.29835	165.76612	0.39	0.7629
N	3	13168.26472	4389.42157	10.26	0.0001
K*N	9	4177.00308	464.11145	1.08	0.4008

APPENDIX 3.45: Analysis of variance of root mass in the fertilized zone as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	0.90513058	0.06034204	1.72	0.0966
Error	32	1.12151933	0.03504748		
Corrected Total	47	2.02664992			
	R-Square	C.V.	Root MSE		RMF Mean
	0.446614	38.96482	0.187210		0.48045833
		MSD(0.05)=0.207			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	0.18171742	0.06057247	1.73	0.1809
N	3	0.58743608	0.19581203	5.59	0.0034
K*N	9	0.13597708	0.01510856	0.43	0.9082

APPENDIX 3.46: Analysis of variance of root mass in the unfertilized zone as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	0.03443258	0.00229551	0.59	0.8642
Error	32	0.12544867	0.00392027		
Corrected Total	47	0.15988125			
	R-Square	C.V.	Root MSE		RMU Mean
	0.215363	28.93683	0.062612		0.21637500
		MSD(0.05)=0.069			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	0.00083842	0.00027947	0.07	0.9749
N	3	0.01293175	0.00431058	1.10	0.3636
K*N	9	0.02066242	0.00229582	0.59	0.7989

APPENDIX 3.47: Analysis of variance of root mass in the fertilized zone as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	0.39818448	0.02654563	3.59	0.0012
Error	32	0.23634600	0.00738581		
Corrected Total	47	0.63453048			
	R-Square	C.V.	Root MSE		RMF Mean
	0.627526	39.56225	0.085941		0.21722917
		MSD(0.05)=0.095			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	0.00922606	0.00307535	0.42	0.7424
N	3	0.34332506	0.11444169	15.49	0.0001
K*N	9	0.04563335	0.00507037	0.69	0.7155

APPENDIX 3.48: Analysis of variance of root mass in the unfertilized zone as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	0.06109192	0.00407279	2.72	0.0085
Error	32	0.04789600	0.00149675		
Corrected Total	47	0.10898792			
	R-Square	C.V.	Root MSE		RMU Mean
	0.560538	31.57118	0.038688		0.12254167
		MSD(0.05)=0.043			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	0.00442675	0.00147558	0.99	0.4118
N	3	0.04042292	0.01347431	9.00	0.0002
K*N	9	0.01624225	0.00180469	1.21	0.3256

APPENDIX 3.49: Analysis of variance of nitrogen concentration as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	42.70466681	2.84697779	0.94	0.5298
Error	32	96.51873000	3.01621031		
Corrected Total	47	139.22339681			
	R-Square	C.V.	Root MSE		N Mean
	0.306735	77.91276	1.736724		2.22906250
		MSD(0.05)=1.971			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	15.02880123	5.00960041	1.66	0.1950
N	3	23.04925190	7.68308397	2.55	0.0733
K*N	9	4.62661369	0.51406819	0.17	0.9958

APPENDIX 3.50: Analysis of variance of nitrogen accumulation as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	13116356.88	874423.79	1.39	0.2127
Error	32	20181312.42	630666.01		
Corrected Total	47	33297669.31			
	R-Square	C.V.	Root MSE		N Mean
	0.393912	83.54030	794.1448		950.612898
		MSD(0.05)=878.400			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	2602428.779	867476.260	1.38	0.2680
N	3	9669114.665	3223.038.222	5.11	0.0053
K*N	9	844813.441	93868.160	0.15	0.9975

APPENDIX 3.51: Analysis of variance of phosphorus concentration as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	0.02965781	0.00197719	1.45	0.1837
Error	32	0.04361667	0.00136302		
Corrected Total	47	0.073274448			
	R-Square	C.V.	Root MSE		P Mean
	0.404750	18.16625	0.036919		0.20322917
		MSD(0.05)=0.041			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	0.01083906	0.00361302	2.65	0.0655
N	3	0.01051823	0.00350608	2.57	0.0713
K*N	9	0.00830052	0.00092228	0.68	0.7238

APPENDIX 3.52: Analysis of variance of phosphorus accumulation as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	12606.30096	840.42006	2.30	0.0238
Error	32	11717.00206	366.15631		
Corrected Total	47	24323.30302			
	R-Square	C.V.	Root MSE		P Mean
	0.518281	23.63454	19.13521		80.9628979
		MSD(0.05)=21.165			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	1251.623540	417.207847	1.14	0.3480
N	3	8438.609009	2812.869670	7.68	0.0005
K*N	9	2916.068410	324.007601	0.88	0.5488

APPENDIX 3.53: Analysis of variance of potassium concentration as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	11.37744792	0.75849653	3.20	0.0028
Error	32	7.58295000	0.23696719		
Corrected Total	47	18.96039792			
	R-Square	C.V.	Root MSE		K Mean
	0.600064	19.04479	0.486793		2.55604167
		MSD(0.05)=0.538			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	5.59111042	1.86370347	7.86	0.0005
N	3	1.61979375	0.53993125	2.28	0.0984
K*N	9	4.16654375	0.46294931	1.95	0.0793

APPENDIX 3.54: Analysis of variance of potassium accumulation as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	4784423.025	318961.535	4.50	0.0002
Error	32	2267601.741	70862.554		
Corrected Total	47	7052024.766			
	R-Square	C.V.	Root MSE		K Mean
	0.678447	25.83475	266.2002		1030.39594
		MSD(0.05)=294.440			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	1566588.904	522196.301	7.37	0.0007
N	3	2165628.023	721876.008	10.19	0.0001
K*N	9	1052206.098	116911.789	1.65	0.1431

APPENDIX 3.55: Analysis of variance of calcium concentration as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	0.02875681	0.00191712	1.18	0.3326
Error	32	0.05186200	0.00162069		
Corrected Total	47	0.08061881			
	R-Square	C.V.	Root MSE		Ca Mean
	0.356701	19.72815	0.040258		0.20406250
		MSD(0.05)=0.045			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	0.00544490	0.00181497	1.12	0.3556
N	3	0.00834690	0.00278230	1.72	0.1833
K*N	9	0.01496502	0.00166278	1.03	0.4411

APPENDIX 3.56: Analysis of variance of calcium accumulation as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	22001.57667	1466.77178	4.34	0.0002
Error	32	10824.07745	338.25242		
Corrected Total	47	32825.65411			
	R-Square	C.V.	Root MSE		Ca Mean
	0.670256	22.41320	18.39164		82.0571854
		MSD(0.05)=20.343			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	930.89971	310.29990	0.92	0.4435
N	3	17742.26530	5914.08843	17.48	0.0001
K*N	9	3328.41166	369.82352	1.09	0.3948

APPENDIX 3.57: Analysis of variance of magnesium concentration as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	0.01118967	0.00074598	1.04	0.4438
Error	32	0.02295400	0.00071731		
Corrected Total	47	0.03414367			
	R-Square	C.V.	Root MSE		Mg Mean
	0.327723	20.85609	0.026783		0.12841667
		MSD(0.05)=0.030			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	0.00188050	0.00062683	0.87	0.4648
N	3	0.00426117	0.00142039	1.98	0.1376
K*N	9	0.00504800	0.00056089	0.78	0.6343

APPENDIX 3.58: Analysis of variance of magnesium accumulation as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	11444.42097	762.96140	3.80	0.0007
Error	32	6420.11680	200.62865		
Corrected Total	47	17864.53776			
	R-Square	C.V.	Root MSE		Mg Mean
	0.640622	26.96371	14.16434		52.5311458
		MSD(0.05)=15.667			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	222.340710	74.113570	0.37	0.7756
N	3	9410.503186	3136.834395	15.64	0.0001
K*N	9	1811.577071	201.286341	1.00	0.4575

APPENDIX 3.59: Analysis of variance of sodium concentration as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	9150.645833	610.043056	1.79	0.0825
Error	32	10925.333333	341.416667		
Corrected Total	47	20075.979167			
	R-Square	C.V.	Root MSE		Na Mean
	0.455801	21.73287	18.47746		85.0208333
		MSD(0.05)=20.438			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	2374.854167	791.618056	2.32	0.0941
N	3	2221.354167	740.451389	2.17	0.1110
K*N	9	4554.437500	506.048611	1.48	0.1968

APPENDIX 3.60: Analysis of variance of sodium accumulation as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	31.86666864	2.12444458	2.46	0.0161
Error	32	27.66734543	0.86460454		
Corrected Total	47	59.53401406			
	R-Square	C.V.	Root MSE		Na Mean
	0.535268	27.38073	0.929841		3.39596875
		MSD(0.05)=1.029			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	4.34975262	1.44991754	1.68	0.1916
N	3	17.35635969	5.78545323	6.69	0.0012
K*N	9	10.16055632	1.12895070	1.31	0.2725

APPENDIX 3.61: Analysis of variance of iron concentration as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	16486.33333	1099.08889	0.75	0.7181
Error	32	46893.33333	1465.41667		
Corrected Total	47	63379.66667			
	R-Square	C.V.	Root MSE		Fe Mean
	0.260120	48.71359	38.28076		78.5833333
		MSD(0.05)=42.342			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	7561.958333	2520.652778	1.72	0.1826
N	3	2063.125000	687.708333	0.47	0.7058
K*N	9	6861.250000	762.361111	0.52	0.8489

APPENDIX 3.62: Analysis of variance of iron accumulation as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	50.26709517	3.35113968	1.37	0.2232
Error	32	78.53950915	2.45435966		
Corrected Total	47	128.80660431			
	R-Square	C.V.	Root MSE		Fe Mean
	0.390252	49.35448	1.566640		3.17426042
		MSD(0.05)=1.733			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	7.27879664	2.42626555	0.99	0.4106
N	3	32.92753247	10.97584416	4.47	0.0099
K*N	9	10.06076606	1.11786290	0.46	0.8932

APPENDIX 3.63: Analysis of variance of zinc concentration as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	3198.500000	213.233333	1.06	0.4292
Error	32	6454.500000	201.703125		
Corrected Total	47	9653.000000			
	R-Square	C.V.	Root MSE		Zn Mean
	0.331348	42.39469	14.20222		33.5000000
		$MSD_{(0.05)}$=11.810			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	1762.708333	587.569444	2.91	0.0494
N	3	1102.541667	367.513889	1.82	0.1630
K*N	9	333.250000	37.027778	0.18	0.9945

APPENDIX 3.64: Analysis of variance of zinc accumulation as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	17.84728824	1.18981922	2.15	0.0339
Error	32	17.70579503	0.55330609		
Corrected Total	47	35.55308328			
	R-Square	C.V.	Root MSE		Zn Mean
	0.501990	52.07703	0.743845		1.42835625
		$MSD_{(0.05)}$=0.823			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	4.19130757	1.39710252	2.53	0.0751
N	3	11.63811760	3.87937253	7.01	0.0009
K*N	9	2.01786307	0.22420701	0.41	0.9230

APPENDIX 3.65: Analysis of variance of manganese concentration as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	2509.979167	167.331944	1.15	0.3575
Error	32	4663.000000	145.718750		
Corrected Total	47	7172.979167			
	R-Square	C.V.	Root MSE		Mn Mean
	0.349921	16.18060	12.07140		74.6041667
		MSD(0.05)=13.352			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	887.7291667	295.9097222	2.03	0.1293
N	3	964.9375000	321.6458333	2.21	0.1064
K*N	9	657.3125000	73.0347222	0.50	0.8625

APPENDIX 3.66: Analysis of variance of manganese accumulation as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	34.86341620	2.32422775	4.73	0.0001
Error	32	15.73361053	0.49167533		
Corrected Total	47	50.59702673			
	R-Square	C.V.	Root MSE		Mn Mean
	0.689041	23.09602	0.701196		3.03600208
		MSD(0.05)=0.776			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	1.84657303	0.61552434	1.25	0.3073
N	3	28.98068308	9.66022769	19.65	0.0001
K*N	9	4.03616009	0.44846223	0.91	0.5270

APPENDIX 3.67: Analysis of variance of copper concentration as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	27.11979167	1.80798611	0.93	0.5399
Error	32	62.00000000	1.93750000		
Corrected Total	47	89.11979167			
	R-Square	C.V.	Root MSE		Cu Mean
	0.304307	48.24056	1.391941		2.88541667
		$MSD_{(0.05)}$=1.540			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	9.64062500	3.21354167	1.66	0.1955
N	3	10.89062500	3.63020833	1.87	0.1539
K*N	9	6.58854167	0.73206019	0.38	0.9372

APPENDIX 3.68: Analysis of variance of copper accumulation as influenced by N, K and N*K in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	0.14674555	0.00978304	2.12	0.0369
Error	32	0.14793543	0.00462298		
Corrected Total	47	0.29468098			
	R-Square	C.V.	Root MSE		Cu Mean
	0.497981	55.85939	0.067993		0.12172083
		$MSD_{(0.05)}$=0.075			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	0.02563667	0.00854556	1.85	0.1583
N	3	0.09752402	0.03250801	7.03	0.0009
K*N	9	0.02358485	0.00262054	0.57	0.8137

APPENDIX 3.69: Analysis of variance of nitrogen concentration as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	14.21125115	0.94741674		
Error	32	2.59141533	0.08098173	11.70	0.0001
Corrected Total	47	16.802666489			
	R-Square	C.V.	Root MSE		N Mean
	0.845774	15.21695	0.284573		1.87010817
		MSD(0.05)=0.315			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	0.75694790	0.25231597	3.12	0.0398
N	3	12.44721856	4.14907285	51.23	0.0001
K*N	9	1.00708469	0.11189830	1.38	0.2372

APPENDIX 3.70: Analysis of variance of nitrogen accumulation as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	3953430.601	263562.040	8.70	0.0001
Error	32	969933.920	30310.435		
Corrected Total	47	4923364.521			
	R-Square	C.V.	Root MSE		N Mean
	0.802994	30.44102	174.0989		571.922162
		MSD(0.05)=192.57			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	197300.240	65766	2.17	0.1109
N	3	3657656.288	1219218.763	40.22	0.0001
K*N	9	98474.073	10941.564	0.36	0.9452

APPENDIX 3.71: Analysis of variance of phosphorus concentration as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	0.08203125	0.00546875	1.04	0.4418
Error	32	0.16790000	0.00524687		
Corrected Total	47	0.24993125			
	R-Square	C.V.	Root MSE		P Mean
	0.328215	25.47176	0.072435		0.28437500
		MSD(0.05)=0.060			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	0.04764375	0.01588125	3.03	0.0437
N	3	0.01440208	0.00480069	0.91	0.4447
K*N	9	0.01998542	0.00222060	0.42	0.9128

APPENDIX 3.72: Analysis of variance of phosphorus accumulation as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	53646.30408	3576.42027	7.6	0.0001
Error	32	15063.66422	470.73951		
Corrected Total	47	68709.96831			
	R-Square	C.V.	Root MSE		P Mean
	0.780765	26.82454	21.69653		80.8831604
		MSD(0.05)=23.998			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	9717.97256	3239.32419	6.88	0.0010
N	3	42539.83445	14179.94482	30.12	0.0001
K*N	9	1388.49707	154.27745	0.33	0.9594

APPENDIX 3.73: Analysis of variance of potassium concentration as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	6.42267531	0.42817835	1.19	0.3294
Error	32	11.53834067	0.36057315		
Corrected Total	47	17.96101598			
	R-Square	C.V.	Root MSE		K Mean
	0.357590	15.93139	0.600477		3.76914583
		MSD(0.05)=0.664			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	1.41972090	0.47324030	1.31	0.2874
N	3	1.05281090	0.35093697	0.97	0.4174
K*N	9	3.95014352	0.43890484	1.22	0.3191

APPENDIX 3.74: Analysis of variance of potassium accumulation as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	7814565.704	520971.047	8.18	0.0001
Error	32	2036909.184	63653.412		
Corrected Total	47	9851474.888			
	R-Square	C.V.	Root MSE		K Mean
	0.793238	23.68696	252.2963		1065.12745
		MSD(0.05)=279.06			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	205165.160	68388.387	1.07	0.3738
N	3	6893245.202	2297748.401	36.10	0.0001
K*N	9	716155.342	79572.816	1.25	0.3011

APPENDIX 3.75: Analysis of variance of calcium concentration as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	0.04783931	0.00318929	0.82	0.6495
Error	32	0.12444067	0.00388877		
Corrected Total	47	0.17227998			
	R-Square	C.V.	Root MSE		Ca Mean
	0.277684	27.24880	0.062360		0.22885417
		MSD(0.05)=0.069			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	0.00581906	0.00193969	0.50	0.6858
N	3	0.03056773	0.01018924	2.62	0.0677
K*N	9	0.01145252	0.00127250	0.33	0.9596

APPENDIX 3.76: Analysis of variance of calcium accumulation as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	20997.51664	1399.83444	2.65	0.0100
Error	32	16877.57440	527.42420		
Corrected Total	47	37875.09104			
	R-Square	C.V.	Root MSE		Ca Mean
	0.554389	36.83401	22.96572		62.3492229
		MSD(0.05)=25.402			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	1941.43669	647.14556	1.23	0.3159
N	3	17325.69741	5775.23247	10.95	0.0001
K*N	9	1730.38254	192.26473	0.36	0.9436

APPENDIX 3.77: Analysis of variance of magnesium concentration as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	0.02819125	0.00187942	1.21	0.3111
Error	32	0.04951600	0.00154738		
Corrected Total	47	0.07770725			
	R-Square	C.V.	Root MSE		Mg Mean
	0.362788	23.93106	0.039337		0.16437500
		MSD(0.05)=0.044			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	0.01626158	0.00542053	3.50	0.0265
N	3	0.00265842	0.00088614	0.57	0.6371
K*N	9	0.00927125	0.00103014	0.67	0.7330

APPENDIX 3.78: Analysis of variance of magnesium accumulation as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	19989.93584	1332.66239	3.07	0.0038
Error	32	13904.69685	434.52178		
Corrected Total	47	33894.63269			
	R-Square	C.V.	Root MSE		Mg Mean
	0.589767	43.94841	20.84519		47.4310375
		MSD(0.05)=23.057			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	4334.80945	1444.93648	3.33	0.0319
N	3	14426.87825	4808.95942	11.07	0.0001
K*N	9	1228.24815	136.47202	0.31	0.9645

APPENDIX 3.79: Analysis of variance of sodium concentration as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	3368.869792	224.591319	0.29	0.9934
Error	32	24900.000000	778.125000		
Corrected Total	47	28268.869792			
	R-Square	C.V.	Root MSE		Na Mean
	0.119172	36.79964	24.89489		75.8020833
		MSD(0.05)=30.854			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	685.265625	228.421875	0.29	0.8297
N	3	630.557292	210.185764	0.27	0.8465
K*N	9	2053.046875	228.116319	0.29	0.9716

APPENDIX 3.80: Analysis of variance of sodium accumulation as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	30.84109818	2.05607321	3.44	0.0016
Error	32	19.11379901	0.59730622		
Corrected Total	47	49.95489720			
	R-Square	C.V.	Root MSE		Na Mean
	0.617379	36.23937	0.772856		2.13264167
		MSD(0.05)=0.855			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	0.17624803	0.05874934	0.10	0.9604
N	3	28.87264417	9.62421472	16.11	0.0001
K*N	9	1.79220599	0.19913400	0.33	0.9571

APPENDIX 3.81: Analysis of variance of iron concentration as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	432.8281250	28.8552083	1.56	0.1409
Error	32	590.5000000	18.4531250		
Corrected Total	47	1023.3281250			
	R-Square	C.V.	Root MSE		Fe Mean
	0.422961	24.41611	4.295710		17.5937500
		MSD(0.05)=3.572			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	173.5572917	57.8524306	3.14	0.0390
N	3	176.1822917	58.7274306	3.18	0.0370
K*N	9	83.0885417	9.2320602	0.50	0.8632

APPENDIX 3.82: Analysis of variance of iron accumulation as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	2.26016887	0.15067792	5.48	0.0001
Error	32	0.88048279	0.02751509		
Corrected Total	47	3.14065166			
	R-Square	C.V.	Root MSE		Fe Mean
	0.719650	32.78466	0.165877		0.50595833
		MSD(0.05)=0.184			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	0.17429126	0.05809709	2.11	0.1182
N	3	1.96281722	0.65427241	23.78	0.0001
K*N	9	0.12306039	0.01367338	0.50	0.8655

APPENDIX 3.83: Analysis of variance of zinc concentration as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	38351.45312	2556.76354	0.94	0.5304
Error	32	86740.00000	2710.62500		
Corrected Total	47	125091.45312			
	R-Square	C.V.	Root MSE		Zn Mean
	0.306587	59.01655	52.06366		88.2187500
		MSD(0.05)=57.587			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	17821.97396	5940.65799	2.19	0.1082
N	3	4430.68229	1476.89410	0.54	0.6552
K*N	9	16098.79687	1788.75521	0.66	0.7379

APPENDIX 3.84: Analysis of variance of zinc accumulation as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	74.87457114	4.99163808	3.35	0.0020
Error	32	47.72868163	1.49152130		
Corrected Total	47	122.60325277			
	R-Square	C.V.	Root MSE		Zn Mean
	0.610706	49.89562	1.221279		2.44766667
		MSD(0.05)=1.351			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	19.69699120	6.56566373	4.40	0.0106
N	3	40.95975922	13.65325307	9.15	0.0002
K*N	9	14.21782072	1.57975786	1.06	0.4179

APPENDIX 3.85: Analysis of variance of manganese concentration as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	2146.411458	143.094097	0.51	0.9180
Error	32	9020.666667	281.895833		
Corrected Total	47	11167.078125			
	R-Square	C.V.	Root MSE		Mn Mean
	0.192209	24.63421	16.78975		68.1562500
		MSD(0.05)=18.571			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	359.0156250	119.6718750	0.42	0.7367
N	3	978.6406250	326.2135417	1.16	0.3412
K*N	9	808.7552083	89.8616898	0.32	0.9628

APPENDIX 3.86: Analysis of variance of manganese accumulation as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	25.87035235	1.72469016	16.57	0.0001
Error	32	3.33011805	0.10406619		
Corrected Total	47	29.20047040			
	R-Square	C.V.	Root MSE		Mn Mean
	0.885957	16.89648	0.322593		1.90923125
		MSD(0.05)=0.357			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	1.27401416	0.42467139	4.08	0.0146
N	3	23.95613246	7.98537749	76.73	0.0001
K*N	9	0.64020573	0.07113397	0.68	0.7180

APPENDIX 3.87: Analysis of variance of copper concentration as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	42.95312500	2.86354167	0.52	0.9112
Error	32	176.66666667	5.52083333		
Corrected Total	47	219.61979167			
	R-Square	C.V.	Root MSE		Cu Mean
	0.195579	38.42691	2.349645		6.11458333
		MSD(0.05)=2.599			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	12.14062500	4.04687500	0.73	0.5400
N	3	22.55729167	7.51909722	1.36	0.2720
K*N	9	8.25520833	0.91724537	0.17	0.9962

APPENDIX 3.88: Analysis of variance of copper accumulation as influenced by N, K and N*K in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	15	0.22682151	0.01512143	2.27	0.0251
Error	32	0.21273903	0.00664809		
Corrected Total	47	0.43956054			
	R-Square	C.V.	Root MSE		Cu Mean
	0.516019	47.56646	0.081536		0.17141458
		MSD(0.05)=0.090			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K	3	0.00486181	0.00162060	0.24	0.8651
N	3	0.21240415	0.07080138	10.65	0.0001
K*N	9	0.00955555	0.00106173	0.16	0.9967

APPENDIX 4

APPENDIX 4.1: Analysis of variance of leaf count as influenced by K levels, K methods and K levels*K methods during week 3 in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	11	0.51792642	0.04708422	1.53	0.1650
Error	36	1.11088950	0.03085804		
Corrected Total	47	1.62881592			
	R-Square	C.V.	Root MSE		LCOU Mean
	0.317977	4.331470	0.175665		4.05554167
		MSD(0.05)=0.193			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	3	0.35142608	0.11714203	3.80	0.0183
K methods	2	0.01859267	0.00929633	0.30	0.7417
K levels*K meth	6	0.14790767	0.02465128	0.80	0.5772

APPENDIX 4.2: Analysis of variance of stem thickness as influenced by K levels, K methods and K levels*K methods during week 6 in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	11	20.87610973	1.89782816	1.90	0.0730
Error	36	36.00099725	1.00002770		
Corrected Total	47	56.87710698			
	R-Square	C.V.	Root MSE		STHI Mean
	0.367039	5.345280	1.000014		18.7083542
		MSD(0.05)=1.100			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	3	14.84279573	4.94759858	4.95	0.0056
K methods	2	1.39205517	0.69602758	0.70	0.5052
K levels*K meth	6	4.64125883	0.77354314	0.77	0.5959

APPENDIX 4.3: Analysis of variance of stem thickness as influenced by K levels, K methods and K levels*K methods during week 1 in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	8	0.36904106	0.04613013	2.32	0.0484
Error	27	0.53582325	0.01984531		
Corrected Total	35	0.90486431			
	R-Square	C.V.	Root MSE		STHI Mean
	0.407841	5.198972	0.140873		2.70963889
		MSD(0.05)=0.143			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	2	0.12602939	0.06301469	3.18	0.0577
K methods	2	0.13342239	0.06671119	3.36	0.0497
K levels*K meth	4	0.10958928	0.02739732	1.38	0.2670

APPENDIX 4.4: Analysis of variance of stem thickness as influenced by K levels, K methods and K levels*K methods during week 3 in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	11	18.74644117	1.70422192	2.59	0.0155
Error	36	23.70475550	0.65846543		
Corrected Total	47	42.45119667			
	R-Square	C.V.	Root MSE		STHI Mean
	0.441600	8.276673	0.811459		9.80416667
		MSD(0.05)=0.892			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	3	7.67457217	2.55819072	3.89	0.0167
K methods	2	8.93525529	4.46762765	6.78	0.0032
K levels*K meth	6	2.13661371	0.35610228	0.54	0.7736

APPENDIX 4.5: Analysis of variance of stem thickness as influenced by K levels, K methods and K levels*K methods during week 4 in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	11	19.75416592	1.79583327	2.14	0.0424
Error	36	30.21703200	0.83936200		
Corrected Total	47	49.97119792			
	R-Square	C.V.	Root MSE		STHI Mean
	0.395311	5.630862	0.916167		16.2704583
		MSD(0.05)=0.759			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	3	7.68936958	2.56312319	3.05	0.0407
K methods	2	6.97455004	3.48727502	4.15	0.0238
K levels*K meth	6	5.09024629	0.84837438	1.01	0.4337

APPENDIX 4.6: Analysis of variance of stem thickness as influenced by K levels, K methods and K levels*K methods during week 2 in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	8	2.83329206	0.35416151	2.08	0.0736
Error	27	4.58843425	0.16994201		
Corrected Total	35	7.42172631			
	R-Square	C.V.	Root MSE		STHI Mean
	0.381756	7.808525	0.412240		5.27936111
		MSD(0.05)=0.417			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	2	1.33797172	0.66898586	3.94	0.0316
K methods	2	1.13836356	0.56918178	3.35	0.0502
K levels*K meth	4	0.35695678	0.08923919	0.53	0.7181

APPENDIX 4.7: Analysis of variance of stem thickness as influenced by K levels, K methods and K levels*K methods during week 3 in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	8	16.18772350	2.02346544	2.86	0.0192
Error	27	19.07454925	0.70646479		
Corrected Total	35	35.26227275			
	R-Square	C.V.	Root MSE		STHI Mean
	0.459066	8.652091	0.840515		9.71458333
		MSD(0.05)=0.851			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	2	6.51894717	3.25947358	4.61	0.0189
K methods	2	7.94894317	3.97447158	5.63	0.0091
K levels*K meth	4	1.71983317	0.42995829	0.61	0.6599

APPENDIX 4.8: Analysis of variance of stem thickness as influenced by K levels, K methods and K levels*K methods during week 4 in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	8	18.64932806	2.33116601	2.59	0.0303
Error	27	24.25916150	0.89848746		
Corrected Total	35	42.90848956			
	R-Square	C.V.	Root MSE		STHI Mean
	0.434630	5.836416	0.947886		16.2408889
		MSD(0.05)=0.794			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	2	7.56346289	3.78173144	4.21	0.0256
K methods	2	6.42581372	3.21290686	3.58	0.0419
K levels*K meth	4	4.66005144	1.16501286	1.30	0.2962

APPENDIX 4.9: Analysis of variance of stem thickness as influenced by K levels, K methods and K levels*K methods during week 6 in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	8	6.50794889	0.81349361	1.49	0.2071
Error	27	14.74257500	0.54602130		
Corrected Total	35	21.25052389			
	R-Square	C.V.	Root MSE		STHI Mean
	0.306249	3.398632	0.738933		21.7420556
		MSD(0.05)=0.748			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	2	0.88404422	0.44202211	0.81	0.4556
K methods	2	3.88914406	1.94457203	3.56	0.0424
K levels*K meth	4	1.73476061	0.43369015	0.79	0.5393

APPENDIX 4.10: Analysis of variance of plant height as influenced by K levels, K methods and K levels*K methods during week 2 in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	11	23554.29018	2141.29911	3.76	0.0012
Error	36	20486.56700	569.07131		
Corrected Total	47	44040.85718			
	R-Square	C.V.	Root MSE		PLHT Mean
	0.534828	7.615899	23.85522		313.229146
		MSD(0.05)=26.229			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	3	10130.03179	3376.67726	5.93	0.0021
K methods	2	10868.07361	5434.03681	9.55	0.0005
K levels*K meth	6	2556.18478	426.03080	0.75	0.6145

APPENDIX 4.11: Analysis of variance of plant height as influenced by K levels, K methods and K levels*K methods during week 3 in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	11	48306.23639	4391.47604	2.14	0.0423
Error	36	73857.62695	2051.60075		
Corrected Total	47	122163.86334			
	R-Square	C.V.	Root MSE		PLHT Mean
	0.395422	8.594802	45.29460		526.999937
		MSD(0.05)=49.802			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	3	22716.48993	7572.16331	3.69	0.0205
K methods	2	16861.41628	8430.70814	4.11	0.0247
K levels*K meth	6	8728.33019	1454.72170	0.71	0.6444

APPENDIX 4.12: Analysis of variance of plant height as influenced by K levels, K methods and K levels*K methods during week 1 in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	8	1421.604884	177.700610	1.81	0.1198
Error	27	2657.034724	98.408693		
Corrected Total	35	4078.639608			
	R-Square	C.V.	Root MSE		PLHT Mean
	0.348549	6.437374	9.920116		154.101889
		MSD(0.05)=10.041			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	2	89.2097161	44.6048580	0.45	0.6403
K methods	2	640.6707904	320.3353952	3.26	0.0541
K levels*K meth	4	691.7243771	172.9310943	1.76	0.1667

APPENDIX 4.13: Analysis of variance of plant height as influenced by K levels, K methods and K levels*K methods during week 2 in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	8	16887.05731	2110.88216	3.30	0.0093
Error	27	17273.64161	639.76450		
Corrected Total	35	34160.69892			
	R-Square	C.V.	Root MSE		PLHT Mean
	0.494342	8.242178	25.29357		306.879639
		MSD(0.05)=25.602			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	2	4324.49346	2162.24673	3.38	0.0490
K methods	2	11515.97099	5757.98550	9.00	0.0010
K levels*K meth	4	1046.59286	261.64821	0.41	0.8005

APPENDIX 4.14: Analysis of variance of plant height as influenced by K levels, K methods and K levels*K methods during week 3 in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	8	43067.67494	5383.45937	2.60	0.0300
Error	27	55881.87934	2069.69923		
Corrected Total	35	98949.55427			
	R-Square	C.V.	Root MSE		PLHT Mean
	0.435249	8.714698	45.49395		522.037000
		MSD(0.05)=46.048			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	2	19169.66212	9584.83106	4.63	0.0187
K methods	2	18533.96883	9266.98441	4.48	0.0209
K levels*K meth	4	5364.04399	1341.01100	0.65	0.6332

APPENDIX 4.15: Analysis of variance of plant height as influenced by K levels, K methods and K levels*K methods during week 6 in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	8	107093.1480	13386.6435	1.84	0.1134
Error	27	196714.7406	7285.7311		
Corrected Total	35	303807.8885			
	R-Square	C.V.	Root MSE		PLHT Mean
	0.352503	6.797603	85.35649		1255.68519
		MSD(0.05)=86.397			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	2	6584.18111	3292.09055	0.45	0.6412
K methods	2	49630.97320	24815.48660	3.41	0.0480
K levels*K meth	4	50877.99367	12719.49842	1.75	0.1691

APPENDIX 4.16: Analysis of variance of root mass in the fertilized zone as influenced by K levels, K methods and K levels*K methods in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	11	0.92522550	0.08411141	2.33	0.0277
Error	36	1.30026150	0.03611837		
Corrected Total	47	2.22548700			
	R-Square	C.V.	Root MSE		RMAS Mean
	0.415741	28.18663	0.190048		0.67425000
		MSD(0.05)=0.209			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	3	0.44073117	0.14691039	4.07	0.0138
K methods	2	0.10458838	0.05229419	1.45	0.2484
K levels*K meth	6	0.37990596	0.06331766	1.75	0.1369

APPENDIX 4.17: Analysis of variance of root mass in the fertilized zone as influenced by K levels, K methods and K levels*K methods in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	11	0.52518492	0.04774408	2.09	0.0470
Error	36	0.82089300	0.02280258		
Corrected Total	47	1.34607792			
	R-Square	C.V.	Root MSE		RMAS Mean
	0.390159	34.20600	0.151005		0.44145833
		MSD(0.05)=0.166			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	3	31683308	0.10561103	4.63	0.0077
K methods	2	0.00782079	0.00391040	0.17	0.8431
K levels*K meth	6	0.20053104	0.03342184	1.47	0.2176

APPENDIX 4.18: Analysis of variance of root mass in the unfertilized zone as influenced by K levels, K methods and K levels*K methods in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	11	0.14106967	0.01282452	1.74	0.1037
Error	36	0.26538900	0.00737192		
Corrected Total	47	0.40645867			
	R-Square	C.V.	Root MSE		RMAS Mean
	0.347070	32.35925	0.085860		0.26533333
		MSD(0.05)=0.094			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	3	0.06782217	0.02260739	3.07	0.0401
K methods	2	0.00113854	0.00056927	0.08	0.9258
K levels*K meth	6	0.07210896	0.01201816	1.63	0.1672

APPENDIX 4.19: Analysis of variance of potassium concentration as influenced by K levels, K methods and K levels*K methods in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	11	3.06162500	0.27832955	4.92	0.0001
Error	36	2.03710000	0.05658611		
Corrected Total	47	5.09872500			
	R-Square	C.V.	Root MSE		K Mean
	0.600469	11.58263	0.237878		2.05375000
		$MSD_{(0.05)}$=0.262			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	3	2.02782500	0.67594167	11.95	0.0001
K methods	2	0.29596250	0.14798125	2.62	0.0870
K levels*K meth	6	0.73783750	0.12297292	2.17	0.0685

APPENDIX 4.20: Analysis of variance of potassium accumulation as influenced by K levels, K methods and K levels*K methods in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	11	1952822.372	177529.307	3.24	0.0037
Error	36	1969805.240	54716.812		
Corrected Total	47	3922627.612			
	R-Square	C.V.	Root MSE		K Mean
	0.497835	14.82164	233.9163		1578.20713
		$MSD_{(0.05)}$=275.190			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	3	1382321.255	460773.752	8.42	0.0002
K methods	2	174294.710	87147.355	1.59	0.2174
K levels*K meth	6	396206.407	66034.401	1.21	0.3253

APPENDIX 4.21: Analysis of variance of magnesium concentration as influenced by K levels, K methods and K levels*K methods in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	11	0.04120617	0.00374602	6.10	0.0001
Error	36	0.02212250	0.00061451		
Corrected Total	47	0.06332867			
	R-Square	C.V.	Root MSE		Mg Mean
	0.650672	13.78465	0.024789		0.17983333
		MSD(0.05)=0.027			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	3	0.02137783	0.00712594	11.60	0.0001
K methods	2	0.01529804	0.00764902	12.45	0.0001
K levels*K meth	6	0.00453029	0.00075505	1.23	0.3147

APPENDIX 4.22: Analysis of variance of magnesium accumulation as influenced by K levels, K methods and K levels*K methods in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	11	21032.76244	1912.06931	2.96	0.0068
Error	36	23266.00692	646.27797		
Corrected Total	47	44298.76936			
	R-Square	C.V.	Root MSE		Mg Mean
	0.474793	18.41705	25.42200		138.035104
		MSD(0.05)=27.952			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	3	9488.530425	3162.843475	4.89	0.0059
K methods	2	7880.196382	3940.098191	6.10	0.0052
K levels*K meth	6	3664.035635	610.672606	0.94	0.4756

APPENDIX 4.23: Analysis of variance of magnesium concentration as influenced by K levels, K methods and K levels*K methods in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	8	0.02312239	0.00289030	4.83	0.0009
Error	27	0.01414750	0.00059806		
Corrected Total	35	0.03926989			
	R-Square	C.V.	Root MSE		Mg Mean
	0.588807	14.38070	0.024455		0.17005556
		MSD(0.05)=0.025			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	2	0.00761072	0.00380536	6.36	0.0054
K methods	2	0.01220239	0.00610119	10.20	0.0005
K levels*K meth	4	0.00330928	0.00082732	1.38	0.2661

APPENDIX 4.24: Analysis of variance of magnesium accumulation as influenced by K levels, K methods and K levels*K methods in the sandy loam soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	8	13384.89882	1673.11235	2.36	0.0458
Error	27	19171.94996	710.07222		
Corrected Total	35	32556.84878			
	R-Square	C.V.	Root MSE		Mg Mean
	0.411124	20.26763	26.64718		131.476547
		MSD(0.05)=26.972			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	2	3294.568564	1647.284282	2.32	0.1176
K methods	2	6566.821570	3283.410785	4.62	0.0188
K levels*K meth	4	3523.508688	880.877172	1.24	0.3174

APPENDIX 4.25: Analysis of variance of potassium concentration as influenced by K levels, K methods and K levels*K methods in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	11	8.73162292	0.79378390	6.83	0.0001
Error	36	4.18692500	0.11630347		
Corrected Total	47	12.91854792			
	R-Square	C.V.	Root MSE		K Mean
	0.675898	12.51976	0.341033		2.72395833
		MSD(0.05)=0.375			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	3	7.45523958	2.48507986	21.37	0.0001
K methods	2	0.15200417	0.07600208	0.65	0.5263
K levels*K meth	6	1.12437917	0.18739653	1.61	0.1724

APPENDIX 4.26: Analysis of variance of potassium accumulation as influenced by K levels, K methods and K levels*K methods in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	11	5897212.413	536110.219	5.57	0.0001
Error	36	3465521.370	96264.483		
Corrected Total	47	9362733.783			
	R-Square	C.V.	Root MSE		K Mean
	0.629860	12.43120	310.2652		2495.85961
		MSD(0.05)=341.140			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	3	4852370.187	1617456.729	16.80	0.0001
K methods	2	28440.577	14220.288	0.15	0.8632
K levels*K meth	6	1016401.649	169400.275	1.76	0.1354

APPENDIX 4.27: Analysis of variance of calcium concentration as influenced by K levels, K methods and K levels*K methods in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	11	0.01214025	0.00110366	1.51	0.1695
Error	36	0.02625700	0.00072936		
Corrected Total	47	0.03839725			
	R-Square	C.V.	Root MSE		Ca Mean
	0.316175	11.65966	0.027007		0.23162500
		MSD(0.05)=0.030			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	3	0.00657108	0.00219036	3.00	0.0430
K methods	2	0.00123113	0.00061556	0.84	0.4383
K levels*K meth	6	0.00433804	0.00072301	0.99	0.4458

APPENDIX 4.28: Analysis of variance of magnesium concentration as influenced by K levels, K methods and K levels*K methods in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	11	0.01484323	0.00134938	5.65	0.0001
Error	36	0.00860475	0.00023902		
Corrected Total	47	0.02344798			
	R-Square	C.V.	Root MSE		Mg Mean
	0.633028	9.321622	0.015460		0.16585417
		MSD(0.05)=0.017			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	3	0.00311240	0.00103747	4.34	0.0104
K methods	2	0.00705254	0.00352627	14.75	0.0001
K levels*K meth	6	0.00467829	0.00077972	3.26	0.3115

APPENDIX 4.29: Analysis of variance of magnesium accumulation as influenced by K levels, K methods and K levels*K methods in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	11	22493.64036	2044.87640	5.53	0.0001
Error	36	13306.82244	369.63396		
Corrected Total	47	35800.46280			
	R-Square	C.V.	Root MSE		Mg Mean
	0.628306	12.53569	19.22587		153.369060
		$MSD_{(0.05)}$=21.139			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	3	3369.02444	1123.00815	3.04	0.0414
K methods	2	11996.76244	5998.38122	16.23	0.0001
K levels*K meth	6	7127.85348	1187.97558	3.21	0.2125

APPENDIX 4.30: Analysis of variance of phosphorus concentration as influenced by K levels, K methods and K levels*K methods in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	8	0.00625000	0.00078125	1.91	0.1000
Error	27	0.01105000	0.00040926		
Corrected Total	35	0.01730000			
	R-Square	C.V.	Root MSE		P Mean
	0.361272	10.03148	0.020230		0.20166667
		$MSD_{(0.05)}$=0.021			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	2	0.00015000	0.00007500	0.18	0.8336
K methods	2	0.00335000	0.00167500	4.09	0.0280
K levels*K meth	4	0.00275000	0.00068750	1.68	0.1837

APPENDIX 4.31: Analysis of variance of calcium accumulation as influenced by K levels, K methods and K levels*K methods in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	8	9255.331908	1156.916489	2.00	0.0855
Error	27	15632.335356	578.975384		
Corrected Total	35	24887.667264			
	R-Square	C.V.	Root MSE		Ca Mean
	0.371884	11.14843	24.06191		215.832311
		MSD(0.05)=24.355			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	2	620.016147	310.008074	0.54	0.5915
K methods	2	6513.653756	3256.826878	5.63	0.0091
K levels*K meth	4	2121.662005	530.415501	0.92	0.4688

APPENDIX 4.32: Analysis of variance of magnesium concentration as influenced by K levels, K methods and K levels*K methods in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	8	0.01155922	0.00144490	5.07	0.0006
Error	27	0.00769375	0.00028495		
Corrected Total	35	0.01925297			
	R-Square	C.V.	Root MSE		Mg Mean
	0.600386	10.45057	0.016881		0.16152778
		MSD(0.05)=0.017			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	2	0.00041706	0.00020853	0.73	0.4903
K methods	2	0.00898372	0.00449186	15.76	0.0001
K levels*K meth	4	0.00215844	0.00053961	1.89	0.1405

APPENDIX 4.33: Analysis of variance of magnesium accumulation as influenced by K levels, K methods and K levels*K methods in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	8	19411.52413	2426.44052	5.78	0.0002
Error	27	11344.07415	420.15089		
Corrected Total	35	30755.59828			
	R-Square	C.V.	Root MSE		Mg Mean
	0.631154	13.70363	20.49758		149.577731
		MSD(0.05)=20.747			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	2	1299.14222	649.57111	1.55	0.2314
K methods	2	14332.43603	7166.21802	17.06	0.0001
K levels*K meth	4	3779.94588	944.98647	2.25	0.0901

APPENDIX 4.34: Analysis of variance of manganese accumulation as influenced by K levels, K methods and K levels*K methods in the sandy soil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	8	8.77630295	1.09703787	1.25	0.3103
Error	27	23.72254686	0.87861285		
Corrected Total	35	32.49884981			
	R-Square	C.V.	Root MSE		Mn Mean
	0.270050	15.62019	0.937344		6.00084444
		MSD(0.05)=0.785			

Source	DF	Anova SS	Mean Square	F Value	Pr > F
K levels	2	0.58800017	0.29400009	0.33	0.7185
K methods	2	6.24632772	3.12316386	3.55	0.0426
K levels*K meth	4	1.94197506	0.48549377	0.55	0.6988