# THE EFFECT OF TIME OF NITROGEN APPLICATION ON THE GROWTH, YIELD AND NITROGEN CONTENT OF THREE MAIZE (*Zea mays L*) VARIETIES.

By

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## DECLARATION

This is my original work and has not been presented for a degree in any other University

Date 4/2/92

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# DEDICATION

To my beloved parents the late Mzee Edward Oringe Magunga and Mama Wilkista Amolo Oringe and to all members of our family.

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## ABSTRACT

A study was conducted at the Kabete field station of the University of Nairobi, Kenya over two rainy seasons with the first crop planted in 1989 and the second in early 1990. The objectives was to investigate the best time to apply N to Maize (Zea Mays L.) crop. Three maize varieties, Katumani composite B, Embu 511 and Kitale 614 were used as the test varieties. The fertilizer timing treatments were based on the maturity periods of each variety but in general the applications were made at planting, 1/3 and 2/3 the periods to flowering and at flowering.

The results showed that the timing of N application was generally insignificant with regard to crop growth, grain yield and quality. However application at 1/3 and 2/3 periods to tasselling was generally superior to application at planting and the control( No N application). All the varieties portrayed a similar response to N application time and in fact there was virtually no interaction between variety and time of N application for all the considered parameters. In spite of all these, the long maturing Kitale 614 was generally superior to the short maturing Embu 511 which was in turn better than Katumani composite B both in terms of growth and grain yield.

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# CHAPTER ONE

## 1. INTRODUCTION

### 1.1 Origin and distribution of Maize (Zea Mays L.) in Kenya

Maize, botanically a grass, is purported to have originated in Mexico. Archeologists found pollen grains going as far back as 80,000 years well before human habitation in the new world. After being brought to Europe, it soon appeared in various parts of Africa, mostly in areas of Portuguese contact along the coast including those of East Africa. There is some evidence that it spread inland along the routes followed by the Arab slave caravans. The major increase in the importance of maize in Kenya, however, came with the introduction of white maize varieties from South Africa after 1900 by the white settlers. Today, maize is widely grown in Kenya by both small and large scale farmers. The small scale farms range from 0.2 - 0.8 ha in size and the produce from this sector accounts for about 70-90% of the national annual production although much of this i.e. about 70-80% is retained for home consumption by the farmers (Akello and Odhiambo, 1986).

Much of Kenya's maize is produced in the western part of the country i.e. Rift Valley, Nyanza and Western provinces. Rift Valley is, however, the major maize producer on both small and large scale farms. The province accounted for about 27-43% of the total small scale output between 1976 and 1982 and over 85%

of large scale farms total output between 1980 and 1982. The rest of the country i.e. the North, East and Southern parts are considered marginal for maize production and the demand for this commodity is higher than local production levels almost throughout the year. Thus, the deficit areas and urban centres are mainly supplied with maize from Western and Rift Valley (Kariungi, 1976). In those areas, the production of the crop has a dual seasonal pattern because of the short and long rainy seasons although the long rains' crop accounts for over 70% of the annual output (Kakuba, 1986).

### 1.2 Economic importance of Maize in Kenya

Agriculture is the backbone of Kenyas economy and it is through increased production of major crops like maize that the country hopes to attain her objectives in employment, income generation, foreign exchange earnings, rural-urban balance, food security and overall growth. Maize is an important crop in Kenyas agricultural economy whether considered in terms of its value, planted acreage or its role as a basic dietary staple. It is the main source of starch and to some extent proteins for most families. Through increased production the nutritional status of the citizens will be raised and importation of the commodity reduced thereby improving on our foreign exchange imbalance. It is due to some of these factors that the promotion of maize growing has been outlined as a matter of policy by the Government so as to achieve the development goals and targets established for Agriculture.

## 1.3 Economic importance of fertilizers in maize production

Fertilizer is one of the most important farm inputs and, in Kenya, its consumption has varied between 100,000 tons and 250,000 tons/year and this is expected to rise to 400,000 tons by the year 1993 (Anon, 1989). Based on the findings of Booker and Gathongo, cited by Akello and Odhiambo (1986), unless agricultural production is increased by 5-10% per year, Kenya would experience serious economic problems in meeting the demands of her ever growing population, estimated at 3.7% per annum (Anon, 1989). Almost all the additional output will have to be produced under rainfed conditions on land which is heavily cropped due to limited possibility for further expansion. The natural fertility of such land is exhausted in most of the small scale farming areas and shows a steep decline especially in Rift Valley province which is actually the centre of maize production in Kenya. Kenyan farmers are therefore faced with the great task of increasing output per unit area of land, restoring lost soil fertility and enlarging the nutrient cycle within the farms. This is a formidable undertaking considering the fact that it has to be achieved within a short period of time or else serious economic difficulties will be inevitable. The natural resources and human potential required to meet these goals are available but the required productivity increases can only be achieved through large increases in the application of fertilizers. According to Harrison (1984), Kenya can only support 17% of her population in the year 2000, unless inputs such as fertilizers, high yielding varieties etc are used. Specifically, maize production must be increased fast enough to keep pace with the growing demand through expansion of useable land and intensification of land utilization. It is estimated that for the demand of maize to be met in the year 2000, an annual production rate, for the commodity, of 4.7% would be required (Anon, 1986c). However land expansion seems unlikely and therefore increased use of high quality inputs is the only option left. The introduction of high yielding maize varieties such as Kitale and Embu hybrids has resulted in greater demands for plant nutrients which cannot be met by the inherent soil fertility, hence the need for fertilization.

## 1.4 Management of Fertilizer Nitrogen

Fertilizer use has received world wide support and has been advocated for over the years, but it is a costly undertaking that absorbs large sums of foreign exchange earnings and yet there is little information on how to invest this capital properly. As much as 25% of fertilizers now applied results in little or no output increases and this proportion is likely to rise steeply unless adequate and correct information regarding fertilizer use is made available (Anon, 1982). This has resulted in fewer people using fertilizers and the Government, in an effort to counteract the subsequent fall in food production, resorted to fertilizer subsidy and determined from time to time, the level of subsidy required to cushion the farmer (Anon, 1981). But this did not work well and the Government has since decontrolled fertilizer prices as the impact of such subsidies was seldom ascertained. Dalrymple (1975), cited by Shields (1976), in his attempt to evaluate fertilizer subsidies admitted that it was virtually impossible to draw any general conclusions either for or against fertilizer subsidies. But by considering the ascertained importance of fertilizers in maize production and the costs involved, there is a great need to determine the most judicious use of this input. In maize production, nitrogen has been found to be the most critical nutrient which limits both yield and grain quality. The management of nitrogenous fertilizers is therefore an important aspect of crop production that needs serious attention (Novoa and Loomis, 1981).

In Kenya, split application of N fertilizer has been emphasised for maize production especially in the major growing areas, presumably, for the purpose of minimising leaching losses. However, in some areas, leaching losses are not as significant to necessitate splitting and, besides that, little has been done with regard to the best time to apply the second portion of the dose. Kenyan extension services, however, recommend that maize be top dressed at 'Knee height'. The questions are whose knee?, for which variety?, and for which area? Leaf number, stem girth etc that may be used as indicators of stage of development vary with the environment and the variety used. Leaf number, for example is influenced by temperature, day length, soil fertility, soil moisture stress and the speed of tassel initiation (Duncan and Hesketh, 1968; Hesketh, et al; 1969; Bonaparte, 1976). Maize hybrids of late maturity also tend to have more leaves than the early maturing ones (Bonaparte, 1976) and this is probably due to their long vegetative phase.

Therefore, if maximum benefit is to be derived from fertilizer N, then we need to come up with a more precise prescription based on crop phenology which is a good indicator of crop development. It is because of the outlined problems that this study was undertaken with the sole objective of determining the best time to apply N fertilizer to maize with regard to

i) Crop growth and development
ii) Grain yield and quality
iii) Differences among varieties

# CHAPTER TWO

## 2. LITERATURE REVIEW

### 2.1 Nitrogen Application And Crop Development

Nitrogen is an important nutrient during the vegetative growth of a crop and this is manifested in its positive effects on leaf Area (LA) development. Maizlish, et al. (1980) observed that, besides accelerating root growth, progressive increases in N also increased LA in maize plant and hence the Leaf Area Index (LAI). As the LA increased, plant vigour was also significantly improved and this was manifested in taller and greener plants (Laycock and Allan, 1978). Similar observations on the effect of N on LA have been recorded by Thorne and Watson (1955), Yadav (1981), Bunting and Drennan (1966) and Pearman, et al. (1979).

In all plants, photosynthesis per unit area of ground covered is determined by LA available for light interception. Cooper (1977), cited by Remison (1978), found that distribution of light over a greater LA reduces the average light intensity falling on each leaf and hence increases the efficiency of photosynthetic conversion. As a result of increased LAI, yields would be improved due to increased quantity of solar radiation absorbed. Jain (1971) observed that, while the leaf comprised of only 66.6% of the total photosynthetic surface, it contributed about 80% of the total dry matter (DM) accumulated in the ears, the remaining 20% being shared by the stem and the ears themselves. Not all the leaf whorls contribute equally to the dry matter accumulation in the ears, since, as shown by Tabentskii (1971), the top 4-5 leaves contributed about 70% of the total DM contained in the grains. Jain (1971), also showed that the photosynthetic rate of the top three leaves was much higher than that of the bottom leaves. The contribution of the lower leaves depends on light penetration but, generally, decreases with increase in plant density.

In a study of East European and Russian maize genotypes ranging from early to late maturity, Fuchs (1968), cited by Tollenar (1977), concluded that the assimilation surface available to the plant at tassel initiation determined the number of kernel initials laid down. In contrast to this, Siemer, _et al_. (1969) argued that, hybrids produced more kernels per row not because of the large LA but because of the longer duration of ear initiation period in these varieties. Whether grain yield is more limited by post anthesis photosynthate supply than by the capacity of the grain to accommodate the photosynthates has not been fully elucidated. Bingham (1967) and Evans and Rawson (1970), concluded from their findings that the sink was the limiting factor whereas Welbank, _et al_. (1966) and Simpson (1968) concluded that the source was the limiting factor for grain yield. But for other researchers like Gifford, _et al_. (1973), neither source nor sink presented an overriding limitation to grain yield. Other reports (Fischer, 1975; Stoy, 1976) suggest that both sink and source limitation may occur and that the particular combination of genotype and the environment determines which limitation predominates. Advocates of sink limitation like Allison and Watson (1966) and Allison, et al. (1975), argue that the stem is capable of supplying more DM to the grain when plants are defoliated during the post-silking period than normally occurs and hence the grain yield can only be limited by the size of the grain sink. In contrast, the reallocation of the stem and husk carbohydrates to grain in the later part of the grain filling period (Daynard, et al. 1969; Hume and Campbell, 1972) seems to indicate that the source (LA) may be limiting under certain conditions.

## 2.2 The Effect of N on Maize Grain Yield and Quality.

### 2.2.1 The effect of rate of N application on grain yield.

According to Jugenheimer (1958), cited by Obi, et al. (1985), of all cereals, maize makes the highest demand on nutrients particularly N, deficiency of which limits production more often than other factors. It has been shown beyond reasonable doubts that N has a significant effect on grain yield and DM production in general. Allan (1972), observed a positive correlation between rates of N and maize grain yield. Other studies (Laycock and Allan, 1978; Croy and Hageman, 1970; Nunez and Kamprath, 1969) agree with this observation. In an attempt to explain this N effect, various researchers have come up with different hypotheses. Rault and Masood (1977), observed that increasing N rates led to increased rates of grain filling and they attributed this to the adequate supply of the building block materials during the critical period of grain development. Based on the findings of Daynard, et al. (1971) and Johnson and Tanner (1972), as quoted by Rault and Masood (1977), there exists a positive correlation between the rate and duration of grain filling and the grain yield. This observation agrees with the findings of Daynard and Duncan (Unpublished) cited by Nass and Reisser (1975).

Excess N application to maize has a negative effect on grain yield. Such reductions in yields have been recorded by Verma and Singh (1976) and Powell and Webb (1972). The latter observed that application of $NH_4$-N fertilizers at rates above the recommended ones, lowered the soil pH of the upper 15cm depth at an average rate of 0.05 pH units per 112 Kg N $ha^{-1}$. pH reductions affected yields through induced nutrient deficiencies and salt toxicities. Excessive application of $NO_3$-N, on the other hand, resulted in its excessive absorption over reduction by the nitrate reductase enzyme in the root system (Hageman and Flesher (1960), cited by Verma and Singh, (1976). And since this reduction requires energy and the organic acid skeleton for amino acids and acid amides, which can only be provided by carbohydrates, the accumulation of the latter in general and starch in particular, would be reduced in the grains and hence reduced grain yield. According to Paar (1967), cited by Verma and Singh (1976), large amounts of $NO_3^-$ in plant tissues makes the nitrate reductase enzyme inefficient and the subsequent $NO_3^-$ accumulation gives rise to plant metabolites that limit grain yield.

### 2.2.2 The Influence of N on leaf chlorophyll content

According to Hodges and Kanemasu (1977) and Aase (1978), as reported by Yadav (1981), photosynthesis, respiration, DM accumulation and growth, could all be expressed as a function of LAI. Other researchers attribute the increase in grain yield to the increase in leaf chlorophil content following N applications. Grunwald, et al. (1977) observed that increased N fertilization increased the chlorophyll and carotenoids contents of the leaves and from the findings of Buttery and Buzzel (1977), chlorophyll contents of soybeans leaves is highly correlated, positively, to the photosynthetic rate. Natr (1972) while reviewing experiments under controlled environment, concluded that photosynthesis is very sensitive to the level of N nutrition and that a decrease in the N status of the leaves, generally, results in a lower photosynthetic rate. Similarly, Ma and Hunt (1975), showed that the carbon exchange rate of barley leaves was lower, at all irradiances when the N content of the growing medium was reduced below half the normal level. Photosynthetic rate has a powerful influence on grain yield especially at the silking stage when it greatly influences the number of kernels per ear (Edmeades and Daynard, 1979). Throughout the early life of a cereal crop, the leaf blades are the main photosynthetic organs and the crop growth rate depends very much on the rate of LA expansion and the rate of photosynthesis per unit LA. But once the leaf canopy has closed, leaf photosythetic rate becomes the more important determinant depending not only on the weather conditions but also on the geometry of the canopy (Evans and Wardlaw, 1976). This effect of N on photosythesis is, however, being challenged by some researchers. Gregory, (1937), reporting a study with barley, did not detect any reductions in the rate at which $CO_2$ was assimilated by leaves even when the N available to the plant was only 1.25% of the control. More recent work by Thomas and Thorne (1977), cited by Gregory, et al. (1981), has also failed to show any increase in the rate of photosynthesis of individual leaves when applied N was increased. Pearman, et al. (1979), went further to show a decrease in photosynthesis for a light saturated flag leaf when N was increased. However, the fact that the N translocated to the ears principally comes from the stems and that about 75% of leaf N is in the chroloplasts (Stocking and Ongun, 1962), provides strong indications that the leaf N status and photosythesis are likely to be interrelated. Besides increasing the total chrolophyll per unit LA, Moursi, et al. (1976), found that N also increased the stability of chrolophyll in the leaves.

### 2.2.3 The effect of nitrogen on grain quality

Nitrogen is an important nutrient required for the synthesis of amino acids which form the building block materials for the proteins stored in the grains. Applications of N could therefore have some influence on the grain protein content. Verma and Singh (1976), observed that besides increasing grain protein content, N application also significantly increased the starch and fat contents of the grains. The increase in starch content could be attributed to the increase in photosynthetic rate following N application. A similar observation was made by Johnson, et al. (1967) who reported that continuous N uptake during the grain filling period resulted in a linear increase in both the protein and starch contents of the grains upto maturity. Considerable translocation of assimilates from the leaves and the stems to the developing grains do occur and this is more marked in times of N deficiency (Friedrich, et al. 1979). This process will therefore lower the quality of stover at the expense of the grains.

### 2.2.4 Yield and quality of the grains as affected by redistributed nitrogen

Milburn (1977) reported by Remison, (1978), observed that in the temperate regions, 20-30% of grain weight originates from the stem tissue through remobilization two weeks after pollination. Bunting (quoted by Remison, 1978) indicated that the translocation of photosynthates from the stem makes a significant contribution to the final grain weight and this may represent about 40-45% of the shoot dry weight at maturity. In maize, the N redistributed soon after silking contributes 50-60% of the total grain N (Hanway, 1962, 1963; Hay, Earley and DeTurch, 1953; Friedriech, et al. 1979). Redistribution may occur despite a constant supply of N for plant growth and this has been shown by Hocking and Steer (1983) in sunflower. In fact, it was observed by Christensen, et al. (1981) and Swank, et al. (1982) that N uptake from the soil, by maize, was inadequate for the initiation and filling of kernels and therefore redistribution of vegetative N is highly significant to grain yield. As much as it contributes to grain yield, the redistributed N also increases the grain quality with respect to protein and N contents. However, in times of N deficiency, redistribution of N becomes so severe that the positive contribution on grain yield and quality is not realised. This is, probably, due to the fact that loss of protein-N from the leaves to the grains reduces the leaves capacity to supply photosynthates for seed filling and, as a consequence, the leaves senesce. If this occurred early in life, the subsequent premature loss of the lower leaves of the canopy would result in a decrease in N uptake due to inadequate supply of sugars to the roots (Pate, 1980) and this would hasten the senescence of recently expanded leaves (Clarkson and Hanson, 1980).

## 2.3 The Effect of Variety on crop Performance

### 2.3.1 Varietal differences in N uptake

As to whether or not there exist varietal differences with regard to N uptake, is still not clear to most researchers. The physiological basis of protein content differential among varieties has not been fully elucidated. Seth, *et al*. (1960) and Johnson, *et al*. (1967, 1968, 1973), argued that N concentration, on a whole plant basis, is never, at any time during the growing season, high in the high protein wheat (*Triticum aestivum L.*) varieties as compared to the low protein ones. They concluded that the protein content of the grains could not be associated with the differential N uptake. They presented a strong evidence that more efficient and complete translocation of N from the vegetative parts of the plant to the grains is the physiological basis of higher grain protein content in high protein wheat varities. Peterson *et al*. (1975) reached the same conclusion based on their study on oats (*Avena sativa L*). Schrader (1978) also reported that varietal differences in the amount of $NO_3$-N accumulated in the leaves could not be attributed to the available $NO_3$-N in the soil during the grain filling period since the available $NO_3$N did not affect N uptake. In their study, Mc.Neal, *et al*. (1972), concluded that both high and low protein wheat varieties absorb the same amounts of N and transport equal amounts to the grains and that the grain protein concentration is inversely proportinal to the amounts of carbohydrates deposited in the grains.

However, findings of Hoerner and DeTurk (1938), cited by Bahram and LaCroix (1977), seems to contradict the preceeding observations since they showed that high protein Illnois maize had a high protein content in the vegetative parts compared to the low protein varieties and they attributed this to differential N uptake. Warnke and Barber (1974), cited by Bahram and LaCroix (1977), presented a strong evidence for the existence of differences among maize cultivars in their capacity to reduce soil $NO_3$ to their minimum levels. Kenya's Kitale H613 has been shown to have a high uptake of N as compared to other varieties and much of the absorbed N is stored in the stem, leaf sheaths and the leaves (Anon, 1973). Chevailier (1977), quoted by Friedrich, _et al_. (1979), observed that, maize accumulates large amounts of $NO_3^-$ in their roots and stems and there exists genotypic differences in $NO_3^-$ absorption and partitioning of N among plant parts.

### 2.3.2 Varietal differences in N remobilization and partitioning

Yield potential is genetically coded but the expression of this trait depends on the environment and its interaction with the genotype. The magnitude of N redistribution in plants depends, partially, on the amount of N taken up from the soil and hence the soil fertility status. Friedrich, _et al_. (1979) observed that translocation of assimilates was more severe in times of N deficiency in the soil. However, if the environment is held constant, genotypic variation will influence the amount of N remobilized and partitioned in the plant parts (Beauchamp, *et al*; 1976: Chevailer and Schrader, 1977; Below, *et al*. 1981). Chevailer and Schrader (1977), even suggested that some of the differences in N redistribution are related to sink strength since high uptake of N by maize does not necessarily result in extensive redistribution to grains. This is because some hybrids lack a strong sink to promote the movement of N (Pollmer, *et al*. 1979). In fact, it has been shown that more prolific varieties tend to partition more biomass and N to the ear and less to the stalk compared to the less prolific ones and this is because of the stronger sink that exist in the prolific varieties. The preferential partitioning of N to the grains, makes the prolific varieties have higher N use efficiency than the semi and non prolific varieties.

## 2.4 The Influence of Time of N Application on Grain Yield and Quality

### 2.4.1 Effect of time of N application on grain yield

Nitrogen fertilizer use efficiency in crop production may be improved by minimizing the amount of N lost through leaching in percolating water. One way of doing this is by maintaining low soil solution N levels when leaching is likely to occur through good timing of fertilizer application. However, it is also necessary to maintain the concentration of total available N at a desirable level to permit uptake of N by the crop plant.

Over half the total N accumulated in maize occurs before tasselling and essentially ceases 15-20 days after (Sayre, 1948; Viets and Hageman, 1971), as quoted by Hicks and Peterson (1976). The nitrates necessary for protein synthesis should therefore be stored prior to the end of the N accumulation period. Part of the stored N is later translocated from the stalk to the leaves for reduction and assimilation since the stalk has a low capacity to reduce $NO_3^-$ (Schrader and Hageman, 1965). In a soil prone to leaching, full dose application of fertilizer N at planting may restricts leaf expansion in the vegetative phase. This is because in such soils the available soil N during the vegetative phase would be lower than that required to maintain leaf expansion (Muchow, 1988). Soil type is therefore an important factor in the determination of N fertilization schedule. However, proneness to leaching alone cannot be used as the basis for decision-making with regard to when to apply the fertilizer N because we might apply the fertilizer when it is not needed by the crop.

The number of florets initiated by a crop is usually determined early in development and this sets the maximum number of seeds that can be produced. This potential seed number can only be reduced by poor floret growth, poor fertilization or seed abortion. Adequate supply of N to support maximum floret initiation is therefore critical for seed crops even though the amount of N required by the plant so early in its development may not be significant. All the same, early application is important for the developing root system which enhances N uptake before and during floral initiation. Studies on Oats have shown that the later the application of N during the vegetative growth, the lesser is the desirable effect on crop growth and hence the final grain yield (Ohm, 1976). Grain number and single grain weight are determined by the N supply before anthesis, the major response occuring before floret initiation. Besides its positive influence on floret initiation, early N supply also prevents excessive N redistribution from the leaves and hence premature senescence. Gregory, et al. (1981) found that the maximum rate of photosynthesis in wheat after anthesis was inversely related to the proportion of N redistributed from the leaves and suggested that N applied at anthesis may prolong the longevity of green leaves, thereby prolonging photosynthesis and increasing grain yield. Even though early application enhances root development, proponents of late application argue that the leaching losses, likely to occur as a result, should be considered first before anything else. In fact some workers argue that N required for the initial development of roots can be supplied by the seeds. Oaks (1983), observed that the peptides and amino acids produced during the hydrolysis of the endosperm of a seed are the main source of reduced N required for the developing seedling, even in the presence of external N. Thorne and Watson (1955), however reported that early or late N application on wheat, makes little difference on the grain yield, the arguement being that early application increases the LAI towards maximum whereas late application increases yields through delayed senescence. But from their work, it is not clear as to how early or late the application should be made so as to observe this small difference. In general, the response to late application of N depends on the prevailing climatic conditions. If the photosynthetic period is not long enough after ear emergence, then the positive attributes of late application shall not be realised (Khalifa, 1973). This emphasises the need for recommendations based on the ecological zone where research is carried out.

### 2.4.2 Effect of time of N application on grain N content

It has been proved beyond reasonable doubt that N application tends to increase the grain N and protein contents. Whether this effect is independent of the time of application is not very clear. Martin (1980) observed that when N was applied at ear initiation, for those treatments with no nitrogen at planting, LA increased and this resulted in an increase in yield but not the grain N content. The grain N content was derived almost entirely from the reserves present at the initiation stage and was not related to grain yield. However, he observed that application of N at around silking significantly increased grain N content. On the other hand, Santivich (1968) and Nakviroj (1968) observed that grain N content was not affected by the time of N application. According to Santivich (1968), uptake and storage of N were not affected by the time of N application and therefore the grain N content will remain the same regardless of the time of application. However, based on their findings, Rennie, et al. (1970) concluded that N application could only be made at any time upto tasselling with equal effectiveness on grain N content, if part of the fertilizer N in combination with P had been applied at planting.

# CHAPTER THREE

## 3. MATERIALS AND METHODS

### 3.1 Experimental Site

The study was conducted at the Kabete Field Station of the University of Nairobi, Kenya. The site is located at latitude 1° 15'S, longitude 36° 44'E and an altitude of 1800m. Annual rainfall for the area is characteristed by a bimodal distribution with the short rains, coming in October - December and the long rains in March - July. Mean maximum temperature is 23°C and minimum temperature is 12°C. Soil at the site is dark reddish brown classified as humic Nitosol (Siderius and Muchena, 1977). The experiment was conducted over the two rainy seasons with the first crop being planted on 14th October, 1989 and the second on 2nd February, 1990.Soils were analysed for nutrients prior to each experiment (appendices 1 and 2). Over the short rainy period, the area received an average monthly rainfall of 94.51mm and experienced a mean maximum and minimum temperatures of 23°C and 13.3°C respectively. The long rains had a mean monthly amount of 208mm; mean monthly minimum and maximum temperatures were 14.2°C and 23.5°C, respectively.

### 3.2 Experimental Design

The experiment was laid out in a completely randomised split plot design with varieties on the main plots and time of N application on the subplot. Three maize varieties, Kitale 614, Embu 511 and Katumani Composite B were planted at the recommended spacings of 90cm by 30cm for both Kitale 614 and Embu 511 and 75cm by 30cm for Katumani Composite B, with two seeds per hole. Two weeks after emergence, the plants were thinned to one per hole. Each main plot measured 10 x $12m^2$ and consisted of 5 subplots of size 5 x $4m^2$ each. The following N fertilizer timing treatments were randomly assigned to the subplots with N being applied at a rate of 100kg N/ha.

Katumani Composite B

(a) Control (no fertilizer N)
(b) Single dose at planting
(c) Single dose at 20 days post planting
(d) Single dose at 40 days post planting
(e) Single dose at tasselling

Embu 511

(a) Control (no fertilizer N)
(b) Single dose at planting
(c) Single dose at 27 days post planting
(d) Single dose at 54 days post planting
(e) Single dose at tasselling

Kitale 614

(a) Control (no fertilizer N)
(b) Single dose at planting
(c) Single dose at 30 days post planting
(d) Single dose at 60 days post planting

(e) Single dose at tasselling

The specific timings were based on the differences in maturity periods for the three varieties, i.e. four, five and six months for Katumani Composite B, Embu 511 and Kitale 614 respectively and were meant to coincide with planting, 1/3 period to flowering, 2/3 period to flowering and at flowering. The assumption was that, for example, at 20 days post planting, Katumani Composite B was at the same stage of development as Embu 511 and Kitale 614 at 27 and 30 days respectively, since this coincided with 1/3 period to flowering in each case. For all the varieties, uniform rates of 100Kg N ha $^{-1}$ and 46KgP $_2O_5$ ha $^{-1}$ were applied with phosphorus being applied once at planting as triple superphosphate (T.S.P) and nitrogen at the specified stages as calcium ammonium nitrate (C.A.N). At every time of N top dressing, plant height, stem girth and total number of leaves were recorded from five randomly selected plants in each plot.

## 3.3 Soil Sampling

From each main plot, two subplots were randomly chosen at planting time and from these, soil samples randomly collected within 60cm. This sampling depth tends to give data that evaluates inorganic N with acceptable precision for cereal crops (Smith, 1977). The sampling within the soil profile was partitioned into three depths of 0 - 15cm, 15 - 30cm and 30 - 60cm and these were air dried for one week. Composite samples for each depth from every main plot were then ground with a

### 3.3.2 Determination of Organic Carbon Content of the Soil

The Walkley-Black method was used. The ground soil samples (<2mm) were further passed through a 0.5mm sieve to increase uniformity and to facilitate the oxidation process. For each of the samples, 0.5g of the sample was weighed into conical flask and to it 10ml of 1.0N potassium dichromate was added. After complete mixing, 20ml of concentrated $H_2SO_4$ was added in a steady stream and the soil-dichromate-sulphuric acid mixture allowed to cool for about 20 min. Distilled water was then added upto the 200ml-mark followed by 5ml of 85% orthophosphoric acid and about 5ml of diphenylamine sulphonate indicator. The resultant solution was titrated with 0.5N ferrous sulphate until the end point, marked by a clear pale green coloration, was reached. Carbon content of the soil was calculated from the formula:

$$\%C = \frac{\text{concentration of dichromate (M.e)} - \text{Conc. } FeSO_4 \text{ (M.e)} \times 0.3}{\text{Wt. of soil (g)}} \qquad \text{------------} \quad (2)$$

### 3.3.3 Determination of the Other Macronutrients

5g of the soil samples were each weighed into 50ml plastic bottles and to each a scoop of acid washed charcoal added. 25ml of extracting solution (0.1N HCl + 0.025N $H_2SO_4$) was added and the mixture allowed to soak for 1 hour. They were then placed in a mechanical shaker for 10 min and filtered through a Whatman No. 2 quality filter paper into 50 ml flasks. The extracts were each used for the determination of the elements

P, K, Ca, Na, Mg and Mn.

### 3.3.4 Soil Phosphorus Measurements

Standard P solutions ranging between 0 - 10ppm P were prepared and their absorbances taken at 430nm. A calibration curve was then constructed by ploting absorbance against concentration. 5ml of each of the soil extracts were pipetted into test tubes and to each 1ml of a mixture of ammonium molybdate and ammonium vanadate added. Absorbance reading at 430nm were then taken and from the standard calibration curve, P concentration in ppm were obtained.

### 3.3.5 Determination of Manganese Content of the Soil

Standard solutions of concentrations ranging between 0 - 2m.e% Mn were prepared by dissolving 2.2306g $MnSo_4.4H_2O$ in 1 litre of double acid (0.1 N HCl + 0.025N $H_2SO_4$) and accordingly diluted with the double acid. A standard calibration curve was obtained by plotting absorbance reading, taken at 520nm, against concentration.

1.0ml each of the already prepared soil extracts were measured into test tubes and then a mixture of 2ml 8% NaOH and 4ml potassium periodate - phosphoric acid mixture added. The final mixture was allowed to settle for 1 hour and absorbance readings taken at 520nm. From the already constructed standard curve, the concentration of Mn expressed as m.e% were obtained.

### 3.3.6 Magnessium Content Determination

Standard solutions of concentrations ranging between 0 - 10 m.e% Mg were prepared by dissolving 24.69g $MgSO_4.7H_2O$ in 1 litre of double acid and accordingly diluting with the DA. Absorbance reading for each of the concentrations were recorded at 540nm and a standard calibration curve was drawn. 1ml of each of the soil extracts were measured into test tubes and to each 5ml magnessium compensating solution and then 2ml each of 8% NaOH and thiazol yellow-sodium polyacrylate mixture added. Absorbance readings at 540nm were taken and from the standard calibration curve, the concentration of Mg in m.e% obtained.

### 3.3.7 Determination of Soil Na, Ca and K Concentrations by Flame Photometric Method

2ml of each of the soil extracts were treated with 15 ml of distilled water and 2g of resin (anion) so as to remove the sulphates and phosphates that could have interfered with the flame analysis. The mixture was left to settle for 24 hours and later used to analyse for Na, Ca and K.

Na was analysed by flame emission at a wave length of 589nm. Reading from standard solutions containing between 0 - 20ppm Na were used to construct a standard calibration curve. This curve was then used in the conversion of sample readings to Na concentrations in ppm. The concentrations in ppm were then converted to % using the equation by Allen (1974):

a pH meter. Room temperature was adjusted for in the measurements.

## 3.4 Plant Measurements

For each treatment, two rows were set aside for plant material sampling. Plant biomass accumulation, stem weight, stem girth, leaf number, plant height and leaf area development were measured after every two weeks starting from two weeks post emergence upto the initial occurence of a visual black layer. Reuch and Shaw (1971) showed that the stage of maximum dry matter accumulation coincides with the initial occurrence of a visual black layer.

### 3.4.1 Leaf Area and Plant Biomass Measurements

Two plants were randomly collected from the sampling rows and from each, the number of leaves, leaf area, stem girth and plant height were recorded. The plants were then partitioned into stem, leaves and the reproductive parts. Leaf area measurements, based on the total number of live green leaves were then taken by means of an electronic leaf area meter.

The stem, the leaves and the reproductive organs were put in an oven at 100°C for four days. By means of an electronic balance, dry weight measurements of these plant parts were taken and the summation of these weights constituted the total above ground plant biomass.

### 3.4.2 Total Leaf Nitrogen Analyses

Leaf N content was analysed at flowering and hard dough stages for each of the treatments. At each stage, five ear leaf samples were randomly sampled from the subplots and dried in the oven at 70°C for three days and then later analysed for total N using Kjeldahl method of N determination. Exphasis was given to the ear leaves because total N content of the ear leaves gives a good estimation of the N status of a crop and can easily be used to check the adequacy of fertilizer N application.

### 3.4.3 Chlorophyll Content Measurements

This was also done at flowering and hard dough stages. At each stage for each treatment, five randomly sampled flag leaves were taken for chlorophyll concentration measurements. These samples were stored in a deep freezer during the analyses so as to limit chlorophyll degradation. Composite samples were cut and put together from which 2.0g were weighed into a mortar and macerated with a pestle as 85% acetone was added little at a time until the plant tissue was finely ground. The mixture was filtered and the residue transfered for more extraction. The procedure was repeated until the washings were colorless and the filtrate volume noted.

25ml aliquots from each extract were pipetted into separations containing 50ml ether solution. A series of decantations and washings each time with 100ml distilled water were carried out until all the fat soluble pigments had entered the ether layer and all the acetone removed. The ether solution was then taken and diluted with ether itself to ensure that the absorbance readings at 660nm ranged between 0.2 - 0.8. To determine the total chlorophyll concentration, triplicate absorbance values were taken at 660nm and 642.5nm wave lengths. The concentrations of chlorophyll 'a', chlorophyll 'b' and total chlorophyll were then calculated from the formulae:

$$\text{Chlorophyll a} = 9.93\ A_{660} - 0.777\ A_{642.5} \quad \text{---} \quad (5)$$

$$\text{Chlorophyll b} = 17.6\ A_{642.5} - 2.81\ A_{660} \quad \text{---} \quad (6)$$

$$\text{Total Chlorophyll} = 7.12\ A_{660} + 16.8\ A_{642.5} \quad \text{--} \quad (7)$$

Where 'A' denotes absorbance readings at the specified wave lengths.

## 3.5 Harvesting and Grain Yield Measurements

Harvesting was done after the black layer formation since black layer is an accurate indicator of maturity (Daynard and Duncan, 1969) and maximum dry matter accumulation coincides with the initial occurence of a visual black layer (Reuch and Shaw, 1971). The three unsampled rows were used for yield determination, and before harvesting, the number of plants bearing two cobs were recorded. The harvested cobs were then bulked for each treatment and then air dried in a greenhouse for a week, before taking yield measurements. Random grain samples of the harvested maize variety were taken and then bulked together for moisture content determination using a capacitance meter (KM Tester). Five randomly selected cobs were used for the determination of the average number of rows per cob and the average number of kernels per row. 100 seed weight was also determined at the time of yield measurements and both of these were adjusted to 15.0% moisture content.

### 3.6 Grain N Content Determination

The grains were dried at 70°C for 3 days and then ground and passed through a 2mm sieve. The samples were then analysed for N in the same way the leaves were analysed.

FIG.1a Kitale 614.

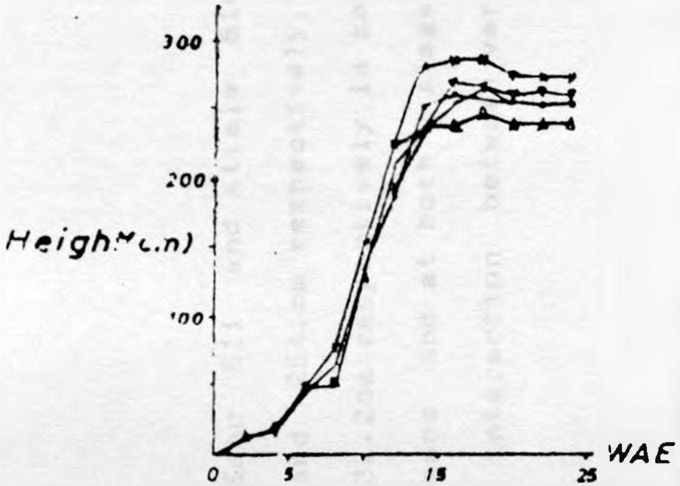


FIG.1b Embu 511

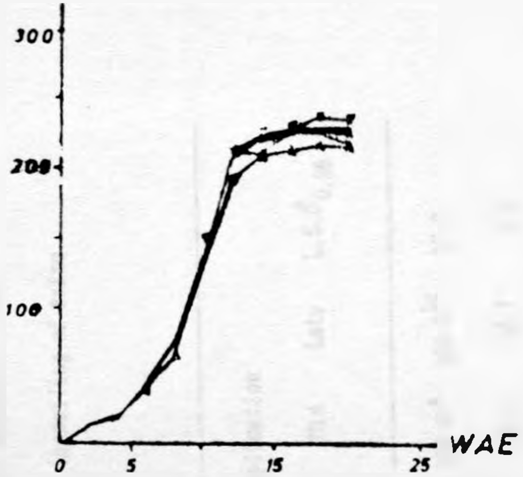
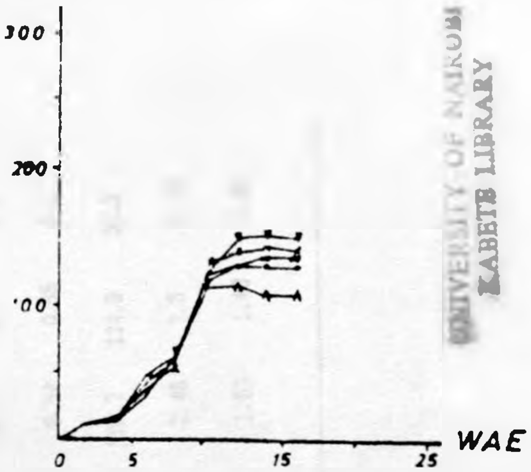


FIG.1c Katumani Comp.B.



## CHANGES IN PLANT HEIGHT(cm) IN SEASON 2

FIG. 2a Kitale 614

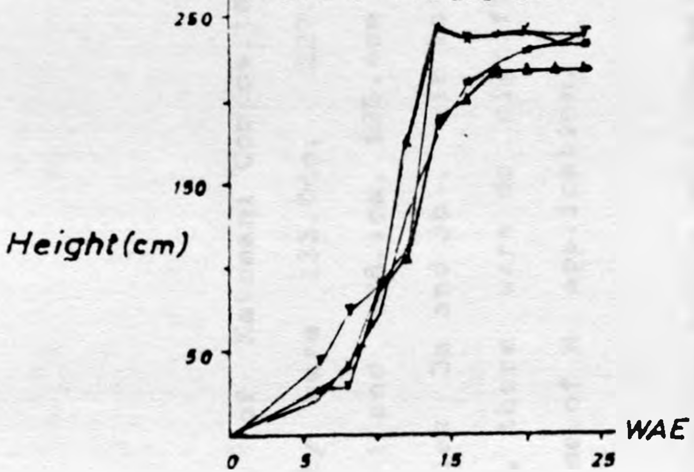


FIG. 2b Embu 511

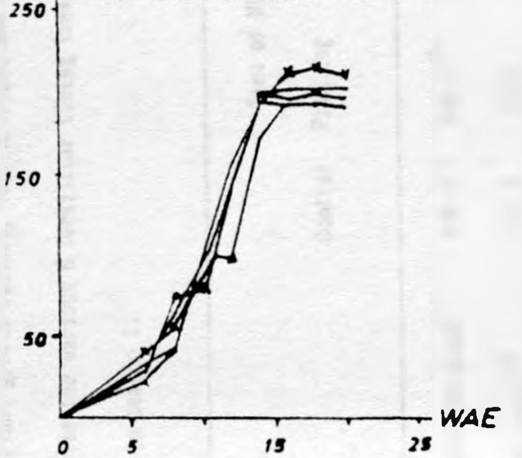
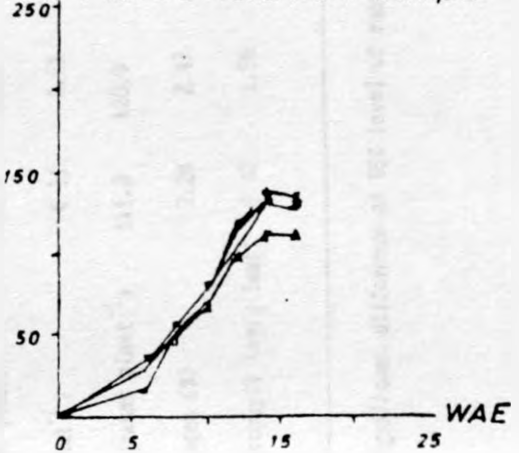


FIG. 2c Katumani CompB



KEY: △ CONTROL ▼ PLANTING ● EARLY TOP DRESSING

X MID TOP DRESSING ■ LATE TOP DRESSING

heights of Katumani Composite B, Embu 511 and Kitale 614 at maturity were 133.0cm, 227.6cm and 254.cm respectively, in season 1 and 128.1cm, 195.4cm and 232.2cm respectively in season 2 (Tables 3a and 3b). In both seasons and at both stages of growth, there were no significant interaction between variety and time of N application.

Table 1a: Plant growth factors, leaf nitrogen and chlorophyll concentrations for the various N fertilizer timing treatments at tasselling of maize in season 1.

| PARAMETERS | Time of Nitrogen application | | | | | |
|---|---|---|---|---|---|---|
| | Control | Planting | Early | Mid | Late | L.S.D[#]$_{0.05}$ |
| Plant height (Cm plant$^{-1}$) | 178.0$^{c}$ | 201.6$^{ab}$ | 201.5$^{ab}$ | 202.8$^{a}$ | 183.8$^{bc}$ | 17.8 |
| Leaf number plant$^{-1}$ | 13.6 | 13.8 | 13.7 | 14.3 | 13.7 | 1.2 |
| LA (m$^{2}$ plant$^{-1}$) | 0.51 | 0.61 | 0.56 | 0.54 | 0.55 | 0.1 |
| Biomass (grams plant$^{-1}$) | 111.3 | 120.9 | 120.4 | 119.7 | 114.9 | 31.2 |
| Leaf nitrogen (%) | 2.28 | 2.47 | 2.43 | 2.45 | 2.3 | 0.29 |
| Leaf chlorophyll (mg/g leaf) | 1.47 | 1.56 | 1.54 | 1.53 | 1.48 | 0.39 |

[#] Least significant difference at 95% level of confidence

Table 1b: Plant growth factors, leaf Nitrogen and chlorophyll concentrations for the various N fertilizer timing treatments at tasselling of maize in season 2

| PARAMETERS | Time of Nitrogen application | | | | | |
|---|---|---|---|---|---|---|
| | Control | Planting | Early | Mid | Late | $L.S.D^{\#}_{0.05}$ |
| Plant height (Cm $plant^{-1}$) | 112.7 | 131.1 | 125.5 | 127.9 | 112.3 | 30.7 |
| Leaf number $plant^{-1}$ | 13.0 | 13.1 | 13.0 | 12.9 | 13.1 | 1.1 |
| LA ($m^2$ $plant^{-1}$) | 0.31 | 0.41 | 0.41 | 0.40 | 0.34 | 0.10 |
| Biomass (g $plant^{-1}$) | 98.6 | 126.3 | 123.9 | 118.4 | 93.3 | 40.0 |
| Leaf Nitrogen (%) | 1.92 | 2.07 | 2.15 | 1.93 | 1.92 | 0.37 |
| Leaf chlorophyll (mg/g leaf) | 1.36 | 1.39 | 1.38 | 1.37 | 1.27 | 0.31 |

[#] Least significant difference at 95% level of confidence

Table 2a: Plant growth factors, leaf Nitrogen and chlorophyll concentrations for the various N fertilizer timing treatments at hard dough stage of maize in season 1.

| PARAMETERS | Time of Nitrogen application | | | | | |
|---|---|---|---|---|---|---|
| | Control | Planting | Early | Mid | Late | L.S.D[#]$_{0.05}$ |
| Plant height (Cm plant$^{-1}$) | 183.3$^{b}$ | 216.00$^{a}$ | 206.10$^{a}$ | 211.50$^{a}$ | 203.4$^{ab}$ | 16.4 |
| Leaf number plant$^{-1}$ | 11.60$^{b}$ | 12.80$^{a}$ | 12.60$^{a}$ | 12.80$^{a}$ | 13.0$^{a}$ | 0.8 |
| LA (m$^{2}$ plant$^{-1}$) | 0.35$^{b}$ | 0.47$^{a}$ | 0.47$^{a}$ | 0.46$^{a}$ | 0.44$^{a}$ | 0.06 |
| Biomass (grams plant$^{-1}$) | 306.60$^{c}$ | 372.10$^{a}$ | 357.70$^{ab}$ | 355.9$^{ab}$ | 323.2$^{bc}$ | 36.7 |
| Leaf Nitrogen (%) | 1.80 | 2.07 | 2.06 | 2.02 | 2.04 | 0.33 |
| Leaf chlorophyll (mg/g leaf) | 1.20 | 1.30 | 1.30 | 1.26 | 1.25 | 0.29 |

[#] Least significant difference at 95% level of confidence

Table 2b: Plant growth factors, leaf Nitrogen and chlorophyll concentrations for the various N fertilizer timing treatments at hard dough stage of maize in season 2

| PARAMETERS | Time of Nitrogen application | | | | | |
|---|---|---|---|---|---|---|
| | Control | Planting | Early | Mid | Late | L.S.D[#]$_{0.05}$ |
| Plant height (Cm plant$^{-1}$) | 17.3.$^{b}$ | 187.3$^{a}$ | 188.7$^{a}$ | 192.0$^{a}$ | 184.6$^{a}$ | 14.7 |
| Leaf number plant$^{-1}$ | 9.9$^{b}$ | 10.8$^{ab}$ | 10.5$^{ab}$ | 11.4$^{a}$ | 11.0$^{a}$ | 0.99 |
| LA (m$^{2}$ plant$^{-1}$) | 0.27 | 0.34 | 0.34 | 0.34 | 0.37 | 0.104 |
| Biomass (grams plant$^{-1}$) | 199.1 | 221.0 | 239.4 | 223.1 | 224.4 | 44.9 |
| Leaf Nitrogen (%) | 1.55 | 1.84 | 1.75 | 1.69 | 1.71 | 0.41 |
| Leaf chlorophyll (mg/g leaf) | 1.05 | 1.14 | 1.13 | 1.12 | 1.12 | 0.29 |

[#] Least significant difference at 95% level of confidence

Table 3a: Plant growth factors, leaf Nitrogen and chlorophyll concentrations of three maize varieties at hard dough stage in season 1.

| PARAMETERS | VARIETIES | | | |
|---|---|---|---|---|
| | Kitale 614 | Embu 511 | Katumani Comp. B | $\mathrm{LSD}^{1}_{0.05}$ |
| Plant height (cm/plant) | $254.6^{a}$ | $227.6^{a}$ | $133.0^{b}$ | 41.6 |
| Leaf number $\mathrm{plant}^{-1}$ | $14.7^{a}$ | $13.1^{b}$ | $9.7^{c}$ | 1.3 |
| LA ($m^2$/plant) | $0.68^{a}$ | $0.50^{b}$ | $0.14^{c}$ | 0.08 |
| Biomass (g/plant) | $593.6^{a}$ | $345.3^{b}$ | $90.4^{c}$ | 73.0 |
| Leaf nitrogen (%) | 2.21 | 1.93 | 1.86 | 0.36 |
| Leaf chlorophyll (mg/g leaf) | $1.47^{a}$ | $1.21^{b}$ | $1.11^{b}$ | 0.18 |

---

[1] **Least significant difference at 95% level of confidence**

Table 3b: Plant growth factors, leaf Nitrogen and chlorophyll concentrations of three maize varieties at hard dough stage in season 2

| PARAMETERS | VARIETIES | | | |
|---|---|---|---|---|
| | Kitale 614 | Embu 511 | Katumani Comp. B | $LSD^{*}_{0.05}$ |
| Plant height (cm/plant) | $232.2^a$ | $195.4^b$ | $128.1^c$ | 37.1 |
| Leaf number $plant^{-1}$ | $13.4^a$ | $10.9^b$ | $7.8^c$ | 1.1 |
| LA ($m^2$/plant) | $0.54^a$ | $0.32^b$ | $0.13^c$ | 0.08 |
| Biomass (g/plant) | $350.1^a$ | $246.6^b$ | $67.5^c$ | 59.4 |
| Leaf nitrogen (%) | $1.93^a$ | $1.74^a$ | $1.45^b$ | 0.36 |
| Leaf chlorophyll (mg/g leaf) | 1.07 | 1.12 | 1.15 | 0.31 |

*Least significant difference at 95% level of confidence

### .1.2 The Effect of Variety and Time of N Application on Leaf Area

Although statistical analyses were not carried out prior to tasselling, late N application and the control treatments were generally inferior to the other three treatments, with regard to leaf area (LA) development (Figures 3 and 4). In both seasons at flowering, the effect of time of N application was not significant. The average leaf area at this stage was 0.55 and $0.37m^2$ per plant in seasons 1 and 2 respectively. But, variety had a significant influence on LA with Kitale 614, Embu 511 and Katumani Composite B recording LA values of 0.91, 0.56 and $0.19m^2$ per plant, respectively, in Season 1 and 0.68, 0.33 and $0.12m^2$ per plant, respectively, in season 2 (Tables 4a and 4b). At hard dough stage, time of N application did not significantly affect LA in both seasons (Tables 2a and 2b) but N application had a significant influence on LA in season 1. Variety effects were significant at 1.0% level of significance with Kitale 614 recording the highest value of $0.68m^2$ per plant and Katumani Composite B, the lowest with $0.14m^2$ per plant in season 1 (table 3a). In the second season, the observed LAs were generally lower than those of season 1 with Kitale 614, Embu 511 and Katumani Composite B recording 0.54, 0.32 and $0.13m^2$ per plant respectively. In both seasons, there were no significant interaction betwen variety and time of N application at 5% level of significance. On average, LA readings were higher in season 1 than season 2 at hard dough stage and the observed average values were 0.44m$^2$ and 0.33m$^2$ per plant for season 1 and 2, respectively.

Table 4a: Plant growth factors, leaf Nitrogen and chlorophyll concentrations of three maize varieties at the tasselling stage in season 1

| PARAMETERS | VARIETIES | | | |
|---|---|---|---|---|
| | Kitale 614 | Embu 511 | Katumani Comp. B | $LSD^a_{0.05}$ |
| Plant height (cm/plant) | $261.4^a$ | $203.3^b$ | $115.9^c$ | 21.6 |
| Leaf number plant$^{-1}$ | $16.9^a$ | $13.3^b$ | $11.2^c$ | 1.2 |
| LA (m$^2$/plant) | $0.91^a$ | $0.56^b$ | $0.19^c$ | 0.11 |
| Biomass (g/plant) | $260.5^a$ | $73.9^b$ | $17.9^c$ | 22.2 |
| Leaf Nitrogen (%) | 2.53 | 2.39 | 2.24 | 0.44 |
| Leaf chlorophyll (mg/g leaf) | $1.89^a$ | $1.51^b$ | $1.15^b$ | 0.36 |

[a] Least significant difference at 95% level of confidence

FIG.3a Kitale 614

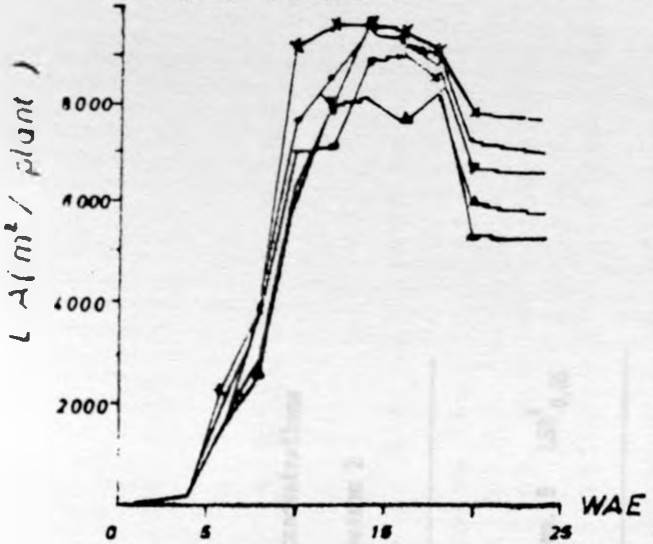


FIG.3b Embu 511

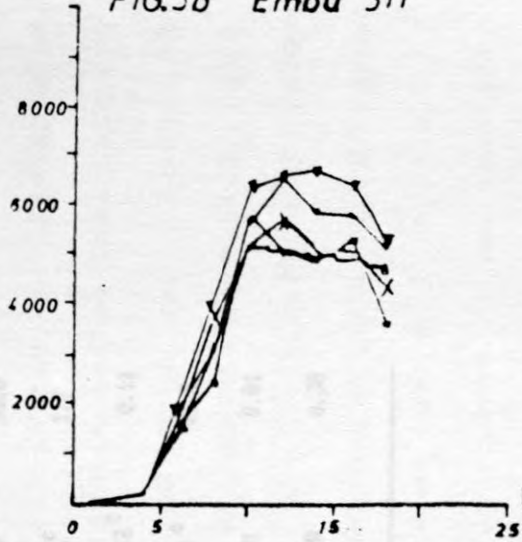
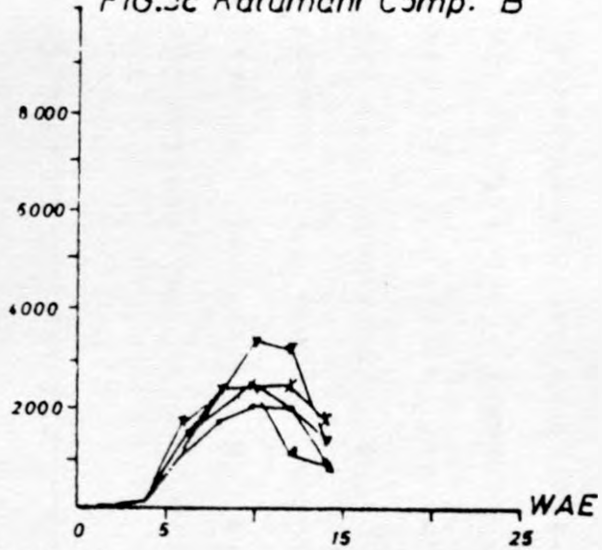


FIG.3c Katumani Comp. B



LEAF AREA DEVELOPMENT IN SEASON 2.

FIG.4a Kitale 614

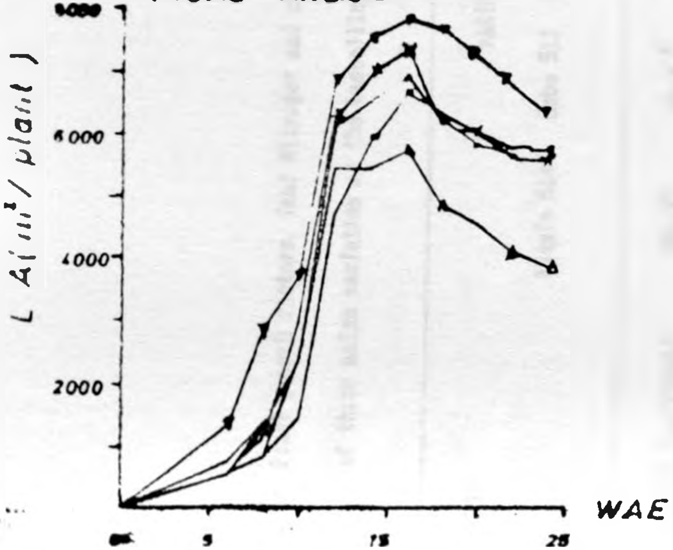


FIG.4b Embu 511

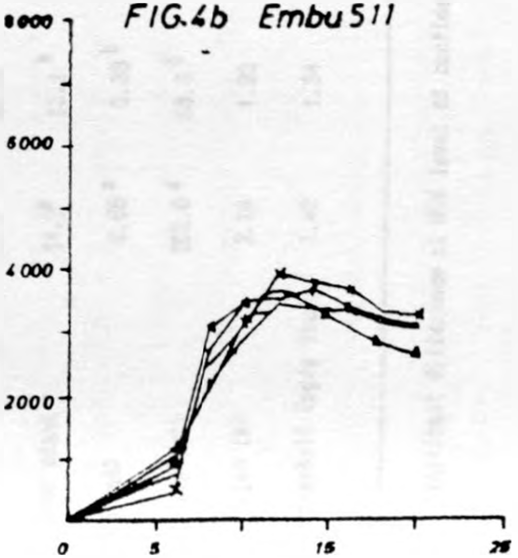
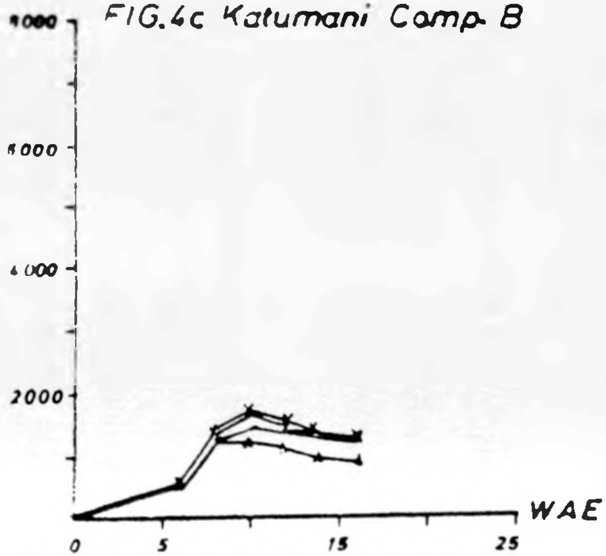


FIG.4c Katumani Comp. B



△ CONTROL
× MID TOP DRESSING
▼ PLANTING
■ LATE TOP DRESSING
● EARLY TOP DRESSING.

Table 4b: Plant growth factors, leaf Nitrogen and chlorophyll concentrations of three maize varieties at the tasselling stage in season 2

| PARAMETERS | VARIETIES | | | |
|---|---|---|---|---|
| | Kitale 614 | Embu 511 | Katumani Comp. B | LSD[#]$_{0.05}$ |
| Plant height (cm/plant) | 218.4$^{a}$ | 95.9$^{b}$ | 51.0$^{b}$ | 50.0 |
| Leaf number plant$^{-1}$ | 14.9$^{a}$ | 13.1$^{b}$ | 11.1$^{c}$ | 1.7 |
| LA ($m^2$/plant) | 0.68$^{a}$ | 0.33$^{b}$ | 0.12$^{c}$ | 0.11 |
| Biomass (g/plant) | 262.0$^{a}$ | 58.6$^{b}$ | 15.8$^{c}$ | 41.8 |
| Leaf nitrogen (%) | 2.16 | 1.93 | 1.91 | 0.61 |
| Leaf chlorophyll (mg/g leaf) | 1.42 | 1.34 | 1.29 | 0.36 |

[#] Least significant difference at 95% level of confidence

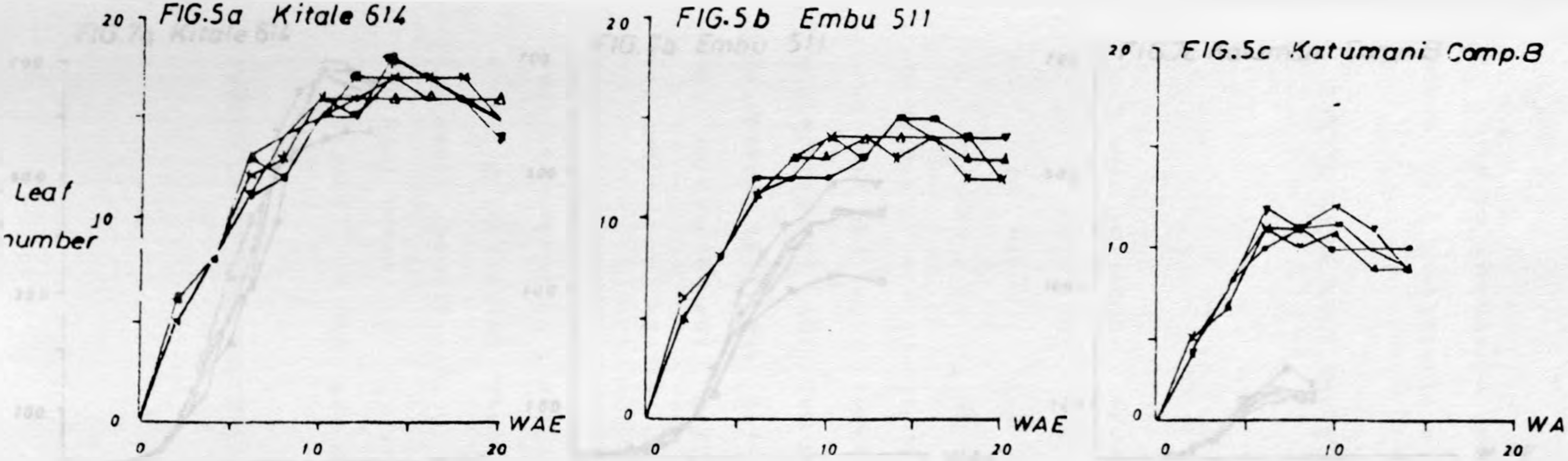
### 4.1.3 The Effect of Variety and Time of N Application on Leaf Number

The number of leaves per plant did not seem to be influenced by the time of N application in the initial stages of crop growth (figures 5 and 6). In fact, even at tasselling, leaf number for each treatment was statistically the same in both seasons (Tables 1a and 1b). However, in both seasons, variety effects were significant with Kitale 614 having more leaves than Embu 511 which in turn had more leaves than Katumani Composite B (Tables 4a and 4b). The observed leaf numbers at flowering for Katumani, Embu 511 and Kitale 614 were 11.2, 13.3 and 16.9, respectively, in season 1 and 11.1, 13.1 and 14.9, respectively, in season 2. In both seasons at tasselling, there were no significant interactions between time of N application and variety. The average leaf number in season 1 was generally greater than that of season 2 i.e. 13.8 and 13.0 respectively.

### 4.1.4 The Effect of Variety and Time of N Application on Biomass Accumulation

Over the two seasons, there were no distinctive differences between the treatments in terms of biomass accumulation prior to tasselling (Figures 7 and 8). Biomass accumulation was far much greater in the first season than the second season. And at all stages of growth, Kitale 614 accumulated the highest biomass and Katumani Composite B, the lowest. In both seasons, at tasselling, time of N application was not significant, but application of N, regardless of the time, was numerically greater than the control (Tables 1a and 1b). However at hard dough stage in season 1, application time significantly influenced biomass accumulation with application at planting, early, and mid top dressings being superior to the other treatments (Table 2a).

FIG.5a Kitale 614 FIG.5b Embu 511 FIG.5c Katumani Comp.B



CHANGES IN LEAF NUMBER IN SEASON 2

FIG.6a Kitale

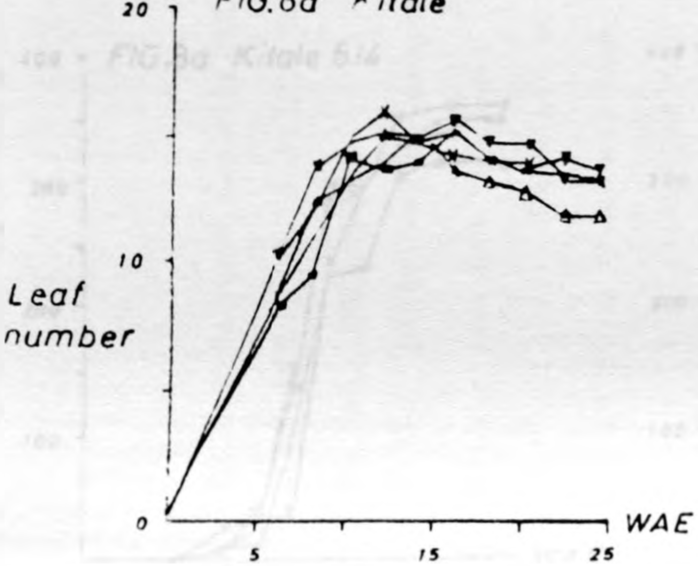


FIG.6b Embu 511

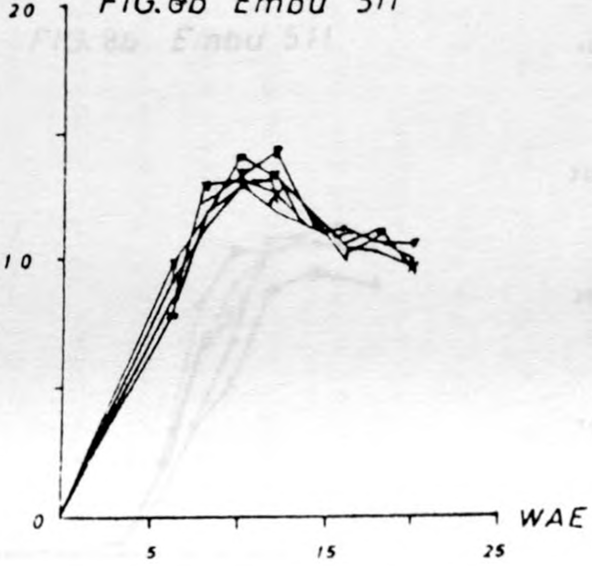
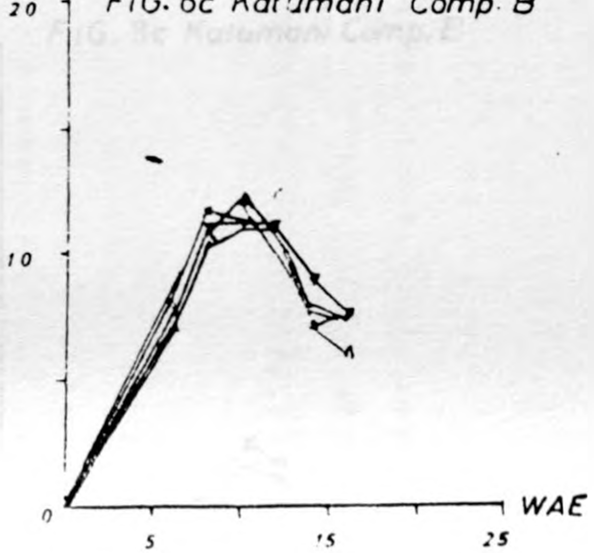


FIG.6c Katumani Comp.B



△ CONTROL
× MID TOP DRESSING
▼ PLANTING
▬ LATE TOP DRESSING
● EARLY TOP DRESSING

## CHANGES IN PLANT BIOMASS IN SEASON 1.

FIG.7a Kitale 614

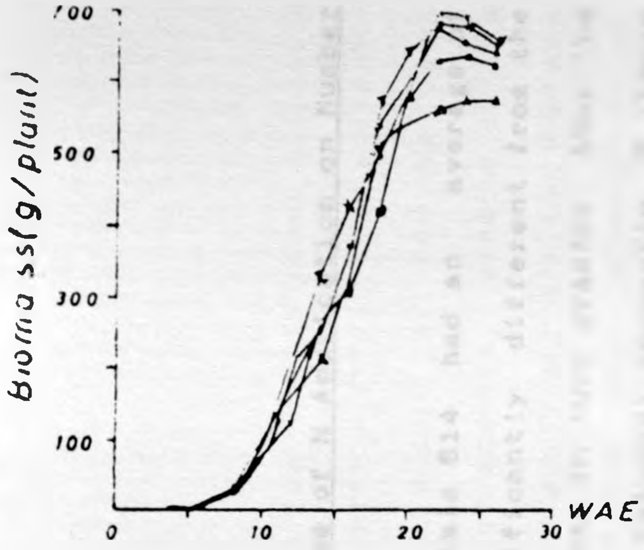


FIG.7b Embu 511

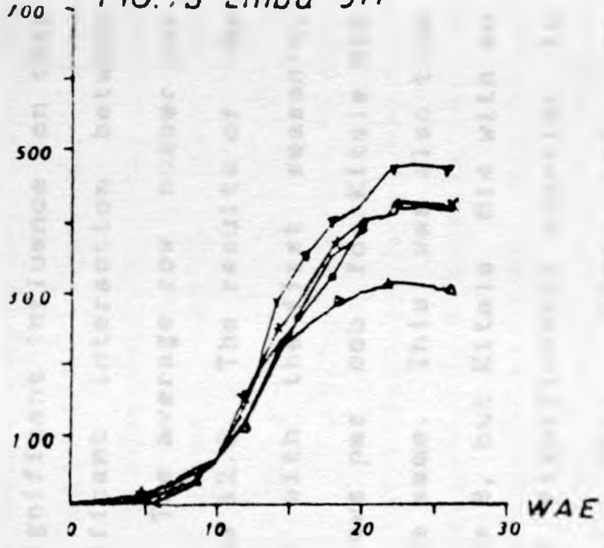
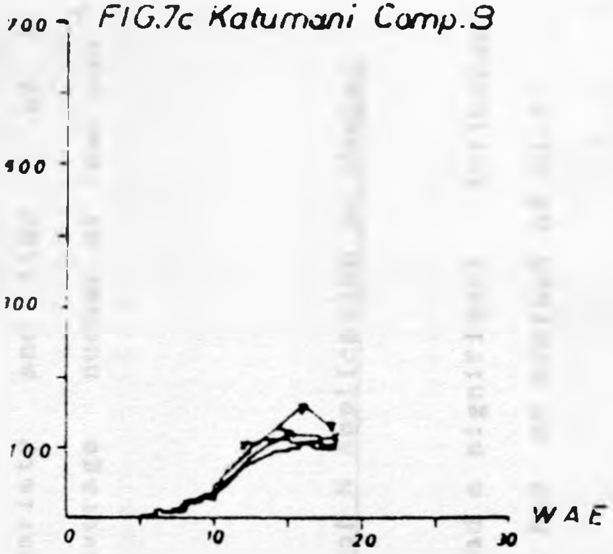


FIG.7c Katumani Comp.B



## CHANGES IN PLANT BIOMASS IN SEASON 2

FIG.8a Kitale 614

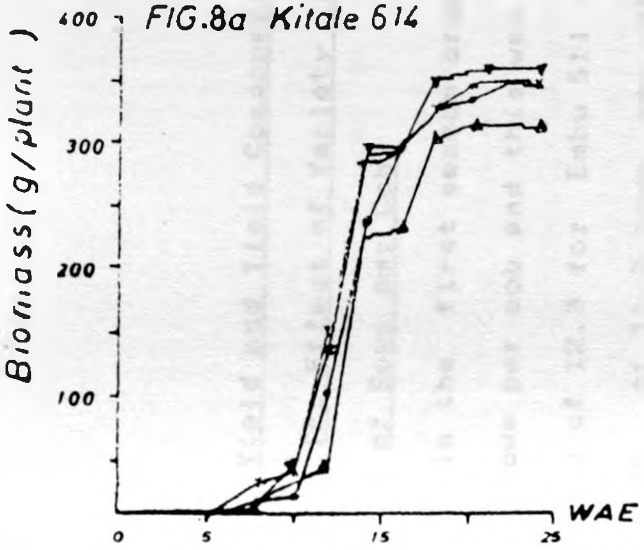


FIG. 8b Embu 511

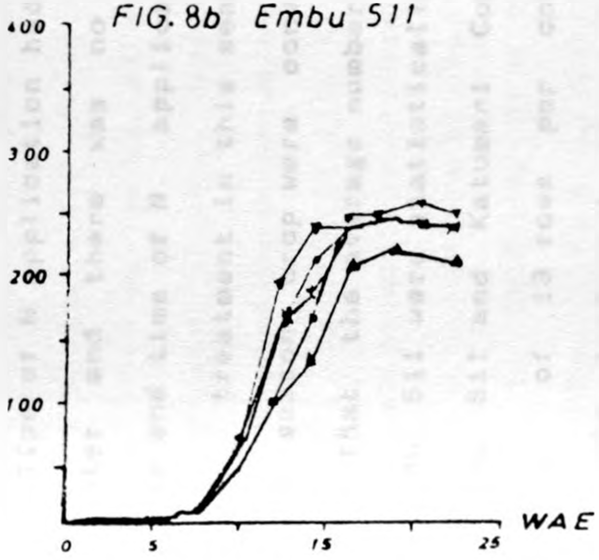
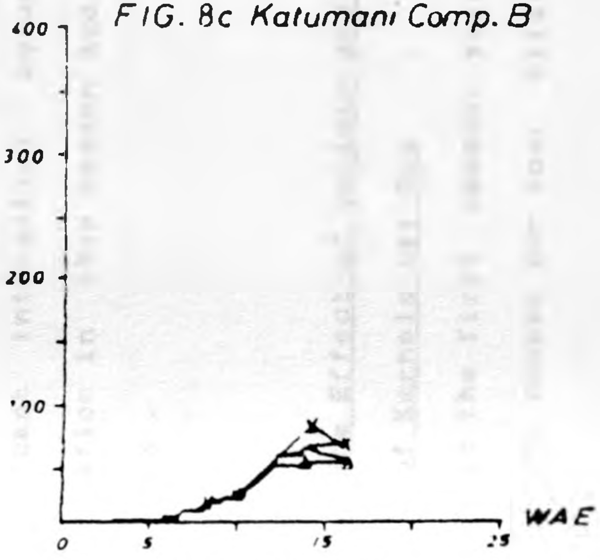


FIG. 8c Katumani Comp. B



△ CONTROL ▼ PLANTING EARLY TOP DRESSING

## 4.2 Yield and Yield Components

### 4.2.1 The Effect of Variety and Time of N Application on Number of Rows per Cob

In the first season crop, Kitale 614 had an average of 13.1 rows per cob and this was significantly different from the average of 12.3 for Embu 511 which was in turn greater than the average of 11.2 rows per cob for Katumani Composite B (Table 5a). Time of N application had no significant influence on this parameter and there was no significant interaction between variety and time of N application. The average row number per cob per treatment in this season was 12.2. The results of the second season crop were consistent with the first season's, except that the average number of rows per cob for Kitale 614 and Embu 511 were statistically the same. This was also true for Embu 511 and Katumani Composite B, but Kitale 614 with an average of 13 rows per cob was significantly superior to Katumani's 11.6 rows per cob (Table 5b). There was no significant interaction between variety and time of N application in this season and the average number of rows cob $^{-1}$ was 12.3 .

### 4.2.2 The Effect of Variety and Time of N Application on Number of Kernels per Row

In the first season, variety had a significant influence on kernel number per row. Kitale 614 had an average of 41.7

kernels row$^{-1}$, Embu 511 38.7 kernels row $^{-1}$and Katumani Composite B 26.7 kernels row$^{-1}$ and all these were significantly different from each other (Table 5a). Kernel number per row was also dependent on the time of N application and the general finding was that N application at planting, early and mid top dressing were not significantly different and they were superior to the control and late top dressing treatments (Table 6a). In fact late top dressing did not show any statistical superiority over the control as far as kernel number is concerned. In the second season, however, application time did not have any significant influence on kernel number but the effect of variety was still significant with Kitale 614 showing superiority over Embu 511 which was not different, statistically, from Katumani Composite B. Kitale 614 had an average of 32.9 kernels row $^{-1}$as compared to 29.0 and 27.0 kernels row$^{-1}$ for Embu 511 and Katumani Composite B respectively. The average kernel number per row in this season was 29.6 and this was numerically lower than the first season's average of 35.7. In both seasons, there was no significant interaction between time of N application and variety.

Table 5a: Yield and yield components of three maize varieties in season 1

| PARAMETERS | VARIETIES | | | |
|---|---|---|---|---|
| | Kitale 614 | Embu 511 | Katumani Comp. B | LSD[1]$_{0.05}$ |
| Rows cob$^{-1}$ | 13.1$^{a}$ | 12.3$^{b}$ | 11.2$^{c}$ | 0.3 |
| Kernels row$^{-1}$ | 41.7$^{a}$ | 38.7$^{b}$ | 26.7$^{c}$ | 2.8 |
| 100-seed weight (g) | 55.7$^{a}$ | 42.9$^{b}$ | 35.5$^{c}$ | 1.40 |
| Yield (g/m$^{2}$) | 1287.9$^{a}$ | 724.4$^{b}$ | 443.6$^{c}$ | 60.7 |
| Grain Nitrogen (%) | 1.34$^{a}$ | 1.25$^{b}$ | 1.23$^{b}$ | 0.06 |

[1] Least significant difference at 95% level of confidence

Table 5b: Yield and yield components of three maize varieties in season 2

| PARAMETERS | VARIETIES | | | |
|---|---|---|---|---|
| | Kitale 614 | Embu 511 | Katumani Comp. B | LSD$^{a}_{0.05}$ |
| Rows cob$^{-1}$ | 13.0$^{a}$ | 12.4$^{ab}$ | 11.6$^{b}$ | 0.8 |
| Kernels row$^{-1}$ | 32.9$^{a}$ | 29.0$^{b}$ | 27.0$^{c}$ | 3.8 |
| 100-seed weight (g) | 50.3$^{a}$ | 41.1$^{b}$ | 30.1$^{c}$ | 3.0 |
| Yield (g/m$^{2}$) | 875.5$^{a}$ | 436.2$^{b}$ | 254.5$^{c}$ | 74.9 |
| Grain Nitrogen (%) | 1.23$^{a}$ | 1.15$^{b}$ | 1.14$^{b}$ | 0.06 |

[a] Least significant difference at 95% level of confidence

### 4.2.3 The Effect of Variety and Time of N Application on Kernel Weight

In the first season, variety significantly influenced kernel weight and the observed 100-seed weights of 55.7, 42.9 and 35.5 for Kitale 614, Embu 511 and Katumani Composite B, respectively, were all significantly different from one another (Table 5a). Time of N application had no significant influence on seed weight. This is because all the treatments were statistically the same at .05 level of significance (table 6a). Similar observations were recorded in the second crop except that seed weights were generally lower in the second season compared to the first. The recorded averages for Kitale 614, Embu 511 and Katumani Composite B were 50.3, 41.1 and 30.1g, respectively (Table 5b). In both seasons there were no significant interactions between time of N application and variety.

### 4.2.4 The Effect of Variety and Time of N Application on Grain Yield

In season 1, Kitale 614 yielded 1287.9g/m$^2$ compared to 724.4g/m$^2$ and 443.6g/m$^2$ for Embu 511 and Katumani Composite B and all these were significantly different from each other (Table 5a). Even though N application time was significant, pairwise comparisons between the actual fertilizer timing treatments did not show significant differences (Table 6a) but were all significantly superior to the control.

The results for the second season were consistent with the first seasons except for the lower yields recorded in this season. The average yields for Katumani Composite B, Embu 511 and Kitale 614 in this season were 254.5g/m$^2$, 436.3g/m$^2$and 875.5g/m$^2$, respectively (Table 5b). There was no significant interaction between variety and time of N application in both seasons.

## 4.3 The Effect of Variety and Time of N Application on Leaf Chlorophyll Concentration

In both seasons and at both tasselling and hard dough stages, time of N application did not significantly affect the chlorophyll concentration of the flag leaf but it had some influence on this parameter. Earlier N application treatments had, numerically, higher values of leaf chlorophyll than the subsequent application treatments (Tables 1a, 1b, 2a and 2b). Varietal differences were only significant in season 1 and this was true at both tasselling and hard dough stages. Kitale 614 had significantly more leaf chlorophyll than Embu 511 which was not significantly different from Katumani Composite B (Tables 3a and 4a).

For both seasons, leaf chlorophyll at hard dough stage was lower than at tasselling and the interaction between variety and time of N application was not significant at both stages. Lower leaf chlorophyll concentrations were recorded in the second crop than in the first; 1.52 and 1.26 mg/g leaf were recorded at tasselling and hard dough stages, respectively, in season 1 and 1.35 and 1.11 mg/g leaf, respectively, in season 2.

## 4.4 The Effect of Variety and Time of N Application on Leaf Nitrogen

In both seasons and at both tasselling and hard dough stages time of N application did not significantly influence this parameter. However, earlier application had numerically higher values of leaf N than subsequent applications (Tables 1a, 1b, 2a and 2b). Varietal differences were only significant at hard dough stage of season 2, although in all the stages considered, Kitale 614 was numerically superior to Embu 511 which in turn was superior to Katumani Composite B. At hard dough stage of season 2, there were no statistical differences between Kitale 614 and Embu 511 but both were significantly greater than Katumani Composite B (Table 3b).

In both seasons, and at all stages considered, the interaction between variety and time of N application was not significant and, in general, leaf N at tasselling was higher than that at hard dough stage. The observed values were 2.39% and 2.0%, respectively, for season 1 and 2.0% and 1.71%, respectively, for season 2. Leaf N in season 2 was generally lower than that of season 1.

### 4.5 The Effect of Variety and Time of N Application on Grain Nitrogen Concentration

In both seasons, time of N application did not affect grain N significantly but all the fertilizer timing treatments had relatively more N in the grains than the control (Tables 6a and 6b)

Table 6a: Yield and yield components of maize at various fertilizer timing treatments in season 1

| PARAMETERS | Time of Nitrogen application | | | | | |
|---|---|---|---|---|---|---|
| | Control | Planting | Early | Mid | Late | L.S.D$^{\#}_{0.05}$ |
| Rows cob$^{-1}$ | 12.3 | 12.1 | 12.0 | 12.2 | 12.2 | 0.3 |
| Kernels row$^{-1}$ | 32.9$^{c}$ | 37.4$^{a}$ | 37.7$^{a}$ | 36.4$^{ab}$ | 34.1$^{bc}$ | 2.4 |
| 100-seed weight (g) | 43.2 | 44.6 | 45.5 | 45.4 | 44.7 | 2.6 |
| Yield (g/m$^{2}$) | 691.5$^{b}$ | 848.0$^{a}$ | 907.9$^{a}$ | 834.8$^{a}$ | 810.8$^{a}$ | 99.5 |
| Grain Nitrogen (%) | 1.23 | 1.27 | 1.27 | 1.23 | 1.27 | 0.08 |

[#] Least significant difference at 95% level of confidence

Table 6b: Yield and yield components of maize at various fertilizer timing treatments in season 2.

| PARAMETERS | Time of Nitrogen application | | | | | |
|---|---|---|---|---|---|---|
| | Control | Planting | Early | Mid | Late | L.S.D.[#]$_{0.05}$ |
| Rows cob$^{-1}$ | 12.4 | 12.7 | 12.2 | 12.0 | 12.4 | 0.6 |
| Kernels row$^{-1}$ | 28.8 | 30.6 | 29.8 | 28.9 | 30.0 | 2.5 |
| 100-seed weight (g) | 40.6 | 40.5 | 40.8 | 40.8 | 39.7 | 2.3 |
| Yield (g/m$^2$) | 496.7 | 526.9 | 526.7 | 533.9 | 526.1 | 65.0 |
| Grain Nitrogen (%) | 1.12 | 1.18 | 1.19 | 1.18 | 1.19 | 0.08 |

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[#] Least significant difference at 95% level of confidence

Varietal differences in both seasons were significant and in both cases, Kitale 614 had more grain N than either Embu 511 or Katumani Composite B, which were, however, statistically the same. The interaction between variety and time of N application was not significant and although no statistical analysis was carried out, grain N in season 2 was lower than that of season 1, for all the varieties. The recorded averages for Kitale 614, Embu 511 and Katumani Composite B were 1.34%, 1.25% and 1.23%, respectively, in season 1 and 1.23%, 1.15% and 1.14%, respectively, in season 2. Varietal differences, as can be seen from the above data, were not as great in season 2 as in season 1.

# CHAPTER FIVE

## 5. DISCUSSION

In both seasons, there were no significant differences between the fertilizer timing treatments, with regard to crop growth, although in the first season, N application at planting,and early and mid top dressings were generally better than the control and late top dressing treatments. Leaf number is determined early in the vegetative period and the amount of nutrients supplied to the crop, then, will influence the number of leaf initials laid down. Soil test results in both seasons (Appendices 1 and 2) did not indicate any serious mineral deficiences and so the available nutrients may have been enough to trigger leaf initiation. However, even if there was N stress, application of N at any stage of growth allows final leaf number to reach the unstressed number (Steer, and Hocking, 1983). The insignificant differences between the treatments with respect to leaf area (LA) may have been due to late application of N enhancing the longevity of green leaves whereas early application increased leaf expansion. Thorne and Watson (1955), observed that early N application increased Leaf Area Index (LAI) to a maximum whereas late application delayed senescence. The insignificant differences in leaf area were reflected in plant biomass. Cooper, (1977), cited by Remison (1978), reported a positive correlation between the amount of manufactured carbohydrates and LA. The level of manufactured carbohydrates is not dependent on LA *per se*, but the rate of photosynthesis per unit LA which is influenced by leaf chlorophyll. The insignificant differences in leaf chlorophyll concentration and LA amongst the actual fertilizer timing treatments may have contributed to the insignificant differences in plant biomass. And this is evident from the correlation studies (Appendices 3 and 4) which show high correlations between the three parameters. Similar findings were reflected on grain yield as there were no significant differences between the timing treatments. Leaf chlorophyll, which was statistically the same amongst the treatments, is positively correlated to photosynthetic rate (Buttery and Buzzel, 1977) and according to Edmeades and Daynard (1979), leaf photosynthetic rate has a powerful influence on grain yield especially at the silking stage. Correlation studies between yield and chlorophyll concentration at tasselling support this contention since the observed values of +0.958 and +0.702 in the first and second season respectively were both significant at 5% level of confidence. (Appendix 5). The implication is that over 70% of the observed variations in grain yield could be due to a linear function of leaf chlorophyll at tasselling. The insignificant differences in grain yield may also have been due to the lack of response of this parameter to N fertilizer. Odhiambo (1989) reported, from his work at Kabete, Kenya, that increasing N rates only resulted in slight increases in grain yield, indicating low response to N fertilization in these soils.

Thomas and Thorne (1975), also found that application of N to spring wheat (Triticum aestivum L.) only increased plant dry matter but not grain yield. However, yields from the fertilized plots were slightly higher than the control plot and this suggests some positive influence of N on grain yield.

Grain N was not affected by time of N application in both seasons. Much of grain N is derived from N redistribution which occurs later in plant development suggesting that application of N at any time prior to the commencement of the grain filling period may equally contribute to the final grain N. In maize (Zea mays L.), N redistributed soon after silking contributes upto 60% of the total grain N at maturity (Hanways, 1962, 1963; Hay, et al., 1953; Friedrich, et. al., 1979). Several other workers (Austin et. al., 1977; Honjyo and Hirano, 1979, cited by Gregory, et. al., 1981), have shown that over half the total ear N at harvest was taken up after anthesis. Even though much of the grain N is acquired early in the vegetative phase (Scarsbrook, 1958), research findings have shown that late N application is as effective as early application in terms of grain N since N uptake continues even after pollination. Hay, et. al. (1953), as reported by Muruli and Paulsen (1981), observed that about 40% of grain N is contributed by the soil and roots after pollination. Finney et. al. (1957) and Timms, et. al. (1981) also observed an increase in the protein content of wheat (Triticum aestivum L.) grains when late N applications were made. That, time of N application may not affect grain N has also been reported by Nakviroj (1968) and Santivich (1968) and according to the latter, stored N significantly contributes to the final grain N but uptake and storage of this N is not affected by time of N application. The observed insignificant differences in leaf N between the timing treatments support this contention. Poor response of grain N to application of N could also have contributed to the insignificant differences observed. Bathlomew and Clark (1965) concluded, from their work, that N contents of seeds is less affected by differences in N supply because the seed is the accumulator of N while other plant parts are the source. Hanway (1962), also observed that N fertilization does not alter the proportion of total N in maize (Zea mays L.) grains. Similar observations have been made in sorghum (Herron, et. al., 1963) and sunflower (Hocking and Streer, in press).

In both seasons, the late maturing Kitale 614 performed better than the earlier maturing varieties in terms of crop growth, measured in terms of plant height, leaf number, LA and plant biomass. During the vegetative period, Kitale 614 accumulated more dry matter than either Embu 511 or Katumani Composite B and this was reflected at maturity. The long vegetative period in Kitale 614 could have contributed to this difference. It is during the vegetative phase that leaf initials are laid down (Kiesselbach, 1949) and according to Chase and Nanda, (1967), there exist a highly significant positive correlation between leaf number and days to anthesis.

Hunter, et al. (1974) and Hunter and Kannenberg (1970) also observed that short maturing varieties not only have reduced plant heights but also reduced leaf numbers and sizes. Besides initiation, leaf expansion also takes place during this period and hence the longer it is, the higher the LA as observed for Kitale 614 in this study. The high biomass accumulation in this variety could be attributed to the relatively large photosynthetic surface available in the variety. According to Hodges and Kanemasu, cited by Yadav (1981), dry matter accumulation and growth in general could all be expressed as a function of LA, that is, the available photosynthetic surface. The relatively high chlorophyll and N concentration in Kitale 614 could also be a contributing factor to the better growth observed in the variety. A high positive correlation between leaf chlorophyll, leaf nitrogen and all the considered growth parameters (Appendices 3 and 4), support this argument. Buttery and Buzzel (1977) also showed a positive correlation between leaf chlorophyll and photosynthetic rate which is a good determinant of total crop dry matter.

The observed varietal differences in grain yield, could be attributed to the corresponding differences in the considered yield components, that is, rows cob$^{-1}$, kernels row$^{-1}$and seed weight. In all these factors, the late maturing Kitale 614 was superior to Embu 511 and Katumani Composite B, in that order. The large photosynthetic surface in this variety is probably responsible for the better performance observed, since spikelet initiation that determines kernel number, requires a good supply of photosynthates. In a study of East European and Russian genotypes ranging from early to late maturing maize (Z. mays L.) varieties, Fuch (1968), cited by Tollenar (1977), concluded that the assimilation surface available to the plant at tassel initiation determined the number of kernel initials laid down. The late maturing Kitale 614 may have had a longer spikelet initiation period than the earlier maturing Embu 511 and Katumani Composite B and this could have positively influenced the number of kernels through a prolonged supply of assimilates to the differentiating cells. Work by Siemer, et. al. (1969) support this view as they observed that hybrids produced more kernels per row due to their long spikelet initiation period. The larger LA at tasselling in Kitale 614 may also have contributed to the higher grain yield through increased sink capacity. This is because large LA result in a prolonged photosynthate supply thereby enhancing the growth of more kernels during the flowering period, and thus, a greater sink capacity. A consequence of larger ear sink capacity is a longer grain filling period which is positively correlated to grain yield (Hanway and Russel, 1969; Daynard and Kannenberg, 1976).

Maturity period seemed to have had an influence on grain N since the late maturing Kitale 614 had more grain N that either Embu 511 or Katumani Composite B. The long vegetative and grain filling periods in the late maturing varieties is a possible cause of this variation. It is during the vegetative phase that grain N is acquired from the soil and hence the late maturity varieties will store more N as manifested in the high leaf N in Kitale 614 at both flowering and hard dough stages (Tables 3a, 3b, 4a and 4b). It is this stored N that is later remobolized to the grains with the leaf contributing about 80% of the total grain dry matter (Jain, 1971). Besides the possible longer duration of N uptake in the late maturing varieties, high grain N in such varieties could be due to their high N uptake capacity. Findings of Hoener and De Turk (1938), cited by Bahram and La Croix (1977), shows that high protein maize (Z. mays L.) varieties had high protein contents in their vegetative parts and they attributed this to differential N uptake. The high grain N in Kitale 614 could also have been due to a possible capacity to partition N to the ear more effeciently than the other two varieties. The generally larger cobs observed in this variety implies a stronger sink which could be the basis of a more efficient N partitioning. According to Pollmer, et. al. (1979), some varieties lack a strong sink to promote N movement from the leaves and stems to the grains and this may have resulted in the low grain N in Katumani Composite B.

The second season crop was generally poorer than the first season's and the observed differences between all the treatments were more conspicuous in the first season than the second. All these may be attributed to the relatively high rainfall and high air temperatures experienced early in the latter season . High precipitation results in waterlogging that may have reduced soil N through leaching and denitrification and hence poor crop growth. Odhiambo (1989) observed declines in available N in Kabete soils, following heavy storms and he attributed this to leaching, denitrification and erosion. The relatively high temperatures, early in the second season may have been responsible for the low leaf N and chlorophyll observed in this season. An increase in air temperature, within limits, cause a decrease in total leaf N (Burr, 1961). Similar findings have been reported on maize (Z. maiys L.) by Younis, et. al. (1965). The second crop also experienced early infection by maize streak virus which has been shown to reduce plant height and LA drastically (Anon, 1986b). This may have contributed substantially to the low leaf N observed in this season. Variable losses of N do occur from plants as a result of disease incidence and pest damage (Westselaar and Farquhar, 1980). The relatively high ear and kernel rot in this season could also have contributed to the low yields observed. Rots have been reported to cause considerable damage in humid areas especially when rainfall is above normal during silking to harvesting period (Anon. 1986a).

# CHAPTER SIX

## CONCLUSIONS

The potential yield benefits from maintaining an adequate supply of N and water cannot be over emphasised but crop response to this nutrient depends on a number of factors amongst them being the environment, time of application and possibly the interaction between the two. As is evident from this study, the environment played a significant role in the performance of all the three maize varieties i.e. Kitale 614, Embu 511 and Katumani Composite B. The relatively high rainfall experienced early in the second season coupled with the reported disease incidence could have led to inefficient utilization of soil nutrients and hence the poor response to N fertilization observed. Although N application time was generally insignificant with respect to grain yield and quality and crop growth in general, application of N at planting, 1/3 and 2/3 the period to tasselling were generally superior to the other treatments. This could be associated with the more developed root system, expected during this period, that would minimise leaching losses and hence greater uptake. Apart from this, application of N during this period usually enhances the growth of leaf or floret primordia towards maximum economic yield. However, an adequate N supply to crop plants early in their growth is also important for the initiation of these primordia and hence the need for split N application, especially when rainfall intensity and duration are on the upper limits. According to Sharma (1980), the effect of split N application is more pronounced with an intensive and continuous rainfall. When split application of N is done during the dry season, the beneficial effect will rarely be seen probably because of under-utilization of the applied fertilizers that would normally occur as a result of inadequate soil moisture. The generally adequate amount of rainfall in Kabete, Kenya, may require split N application and therefore this line of research should be advanced further with the sole objective of finding the best possible mode of N application. For universal application, these recommendations should be based on the stage of growth since from this study, all the three varieties had similar response to time of N application, which was actually based on the stage of growth. In fact there was virtually no interaction between variety and time of N application for all the considered parameters. But all in all, maturity period plays a significant role on crop growth and development and the final grain yield. The long maturing Kitale 614 was generally more superior, in all aspects of growth, compared to Embu 511 which was in turn better than the short maturing Katumani Compsition B.

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Appendix 1: Some chemical soil properties of the experimental site (Season 1)

| | Soil Depths | | |
|---|---|---|---|
| | 0 - 15cm | 15 - 30cm | 30 - 60cm |
| Soil pH | 5.63 | 5.50 | 5.95 |
| Na m.e% | 0.51 | 0.42 | 0.42 |
| K m.e% | 1.06 | 0.66 | 0.57 |
| Ca m.e% | 6.42 | 5.60 | 4.48 |
| Mg m.e% | 2.13 | 2.23 | 2.35 |
| Mn m.e% | 1.00 | 0.88 | 0.95 |
| P (ppm) | 19.83 | 18.50 | 20.33 |
| % N | 0.32 | 0.25 | 0.16 |
| % C | 3.19 | 2.5 | 1.58 |

Appendix 2: Some chemical soil properties of the experimental site (Season 2)

| | Soil Depths | | |
|---|---|---|---|
| | 0 - 15cm | 15 - 30cm | 30 - 60cm |
| Soil pH | 5.59 | 5.51 | 5.50 |
| Na m.e% | 0.53 | 0.40 | 0.39 |
| K m.e% | 1.10 | 0.71 | 0.54 |
| Ca m.e% | 6.50 | 5.81 | 4.39 |
| Mg m.e% | 2.16 | 2.23 | 2.40 |
| Mn m.e% | 1.03 | 0.91 | 0.99 |
| P (ppm) | 19.80 | 19.50 | 20.10 |
| % N | 0.33 | 0.21 | 0.18 |
| % C | 3.20 | 2.80 | 2.14 |

Appendix 3 Correlation coefficient between the studied plant traits at tasselling in season 1

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Leaf No. | 1.00 | | | | | | | | | |
| LA | 0.97 | 1.00 | | | | | | | | |
| Height | 0.93 | 0.98 | 1.00 | | | | | | | |
| Biomass | 0.96 | 0.94 | 0.90 | 1.00 | | | | | | |
| Chlorophyll | 0.98 | 0.98 | 0.99 | 0.95 | 1.00 | | | | | |
| Leaf Nitrogen | 0.86 | 0.84 | 0.86 | 0.76 | 0.84 | 1.00 | | | | |
| Rows Cob$^{-1}$ | 0.84 | 0.87 | 0.87 | 0.82 | 0.87 | 0.69 | 1.00 | | | |
| Kernels row$^{-1}$ | 0.85 | 0.90 | 0.95 | 0.76 | 0.90 | 0.85 | 0.82 | 1.00 | | |
| Seed weight | 0.98 | 0.97 | 0.96 | 0.98 | 0.98 | 0.81 | 0.86 | 0.86 | 1.00 | |
| Yield | 0.97 | 0.96 | 0.94 | 0.97 | 0.96 | 0.85 | 0.85 | 0.85 | 0.98 | 1.00 |
| | Leaf | LA | Height | Biomass | Ch'll | Leaf Nitr. | Rows Cob$^{-1}$ | Kernels row$^{-1}$ | Seed wt | Yield |

Appendix 4: Correlation coefficients between the studied plant traits at tasselling in season 2

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Rows cob$^{-1}$ | 1.000 | | | | | | | | | |
| Kernels row$^{-1}$ | 0.784 | 1.000 | | | | | | | | |
| Leaf chlorophyll | 0.594 | 0.778 | 1.000 | | | | | | | |
| Leaf Number | 0.808 | 0.907 | 0.720 | 1.000 | | | | | | |
| LA | 0.769 | 0.890 | 0.763 | 0.938 | 1.000 | | | | | |
| Biomass | 0.723 | 0.881 | 0.689 | 0.891 | 0.973 | 1.000 | | | | |
| Height | 0.752 | 0.891 | 0.722 | 0.908 | 0.983 | 0.988 | 1.000 | | | |
| Leaf Nitrogen | 0.595 | 0.782 | 0.807 | 0.725 | 0.818 | 0.890 | 0.809 | 1.000 | | |
| Seed weight | 0.810 | 0.885 | 0.759 | 0.978 | 0.956 | 0.904 | 0.927 | 0.776 | 1.000 | |
| Yield | 0.772 | 0.918 | 0.902 | 0.949 | 0.969 | 0.973 | 0.962 | 0.784 | 0.951 | 1.000 |
| | Rows cobs$^{-1}$ | Kernels | Ch'll | Leaf No. | LA | Biomass | Height | Leaf Nitr. | Seed Wt. | Yield |

## Appendix 5: Correlation coefficients between yield and other traits at tasselling in season 1 and 2

| TRAITS | Correlation Coefficients (r) | |
|---|---|---|
| | Season 1 | Season 2 |
| Leaf number | $0.967^{**}$ | $0.949^{**}$ |
| LA | $0.962^{**}$ | $0.969^{**}$ |
| Height | $0.940^{**}$ | $0.962^{**}$ |
| Biomass | $0.965^{**}$ | $0.973^{**}$ |
| Leaf chlorophyll | $0.958^{**}$ | $0.702^{**}$ |
| Leaf Nitrogen | $0.847^{**}$ | $0.784^{**}$ |
| Rows Cob$^{-1}$ | $0.849^{**}$ | $0.772^{**}$ |
| Kernels Row$^{-1}$ | $0.831^{**}$ | $0.918^{**}$ |
| 100-seed weight | $0.980^{**}$ | $0.951^{**}$ |

$^{*}$ denotes significance at 0.05

$^{**}$ denotes significance at 0.01