THE EFFECT OF LIME AND NITROGEN SOURCES ON THE YIELD AND YIELD PARAMETERS OF TOMATO *(Lycopersicon esculentum* Mill)

BY

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DECLARATION

I declare that this thesis has been written by me and that it is a record of my own research work. It has not been presented before in any previous application for a higher degree. All sources of information has been specifically acknowledged by means of references.

The above declaration is affirmed.

Dr. E. N. O. Iwuafor
(Major Supervisor)

CERTIFICATION

This thesis titled "THE EFFECT OF LIME AND NITROGEN SOURCES ON THE YIELD AND YIELD PARAMETERS OF TOMATO (*Lycopersicon esculentum* Mill)" by Samndi Musa Ayuba, meets the regulations governing the award of degree Master of Science (Soil Science) of Ahmadu Bello University Zaria and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

To my Father, Mr Musa Dimshani Samndi.

and

The entire members of my family, for their understanding and support.

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ABSTRACT

A greenhouse and two field studies (wet and dry seasons), were conducted over a two-year period (1994 to 1995) at Samaru (11° 11'N 7° 38'E) in the northern guinea savanna zone of Nigeria to evaluate the effects of lime and nitrogen sources on the yield and yield-related parameters of tomato *(Lycopersicon esculentum* mill). The treatments consisted of all possible combinations of five lime rates (0. 0.10. 0.25, 0.40 and 0.55 t/ha. for green house and wet season, while for dry season, the lime rates were increased to 0,1.12, 2.24, 4.48 and 8.96 t/ha), two N sources (Urea and CAN) and three tomato varieties (TI 221. TI 106 and TI 539). The treatments were replicated three times in a randomised complete block design.

Plant height, number of leaves, branches, fruits, mean fruit diameter, weight and total fruit yield, were significantly (at P=0.05) increased by liming at 0.40 and 0.55 t/ha for green house and wet season, while values were significantly (at P = 0.05) higher at 2.24 and 4.48 t/ha for dry season.

Yield and yield related parameters were significantly higher with the application of CAN than Urea, throughout the studies. Variety TI 221 gave significantly higher values in terms of yield and yield-related parameters than the other two varieties.

Generally nutrient concentrations in plant tissues from the green house and wet season was slightly increased, while for the dry season the increase was significant (for some elements) with increasing lime rates and N sources. Soil pH and exchangeable cations were slightly increased at 0.55/hlime rate in the wet season. For the dry season, soil pH and exchangeable cations were significantly (P = 0.05) increased at higher lime rates (4.48 and 8.96 t/ha).

There was no significant increase in soil pH and exchangeable cations with respect to N sources.

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CHAPTER ONE

INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill) is probably the most widely grown vegetable in the Tropics and its importance dietetically as a source of vitamin C can not be overstressed (Greensill, 1970).

Tomato is cultivated principally between latitude 10°N and 12° 30'N in the Northern Guinea and Sudan Savanna ecological zones. These areas are characterized by distinct wet and dry seasons, from either April or May to September or October for the wet season, and from October to March, for dry season when production is possible under irrigation.

Between 1973 to 1977, average annual production in Nigeria was 225,000 metric tons (Villareal, 1980), which rose to 403,000 metric tons in 1981 (FAO, 1993). By 1993, production was as high as 680,000 metric tons (FAO, 1993). This annual production was as a result of increasing land under cultivation and increase in yield per hectare. Despite the increase in the levels of production, the annual production is still low. The relatively low levels of production can be attributed to the nature of Savanna soils and cultural practices involved in the production.

Most of the West African Savanna soil especially those of latitude 7°N are low in organic matter (< 1%). The clay fraction which is predominantly Kaolinitic is also low. Consequently these soils are low in C.E.C, poorly buffered and rapidly lose their fertility under continuous cultivation (Lombin, 1980). Lombin (1981) reported that the Nigerian Savanna soils are fragile in nature and the balance between the major cations can easily be upset by injudicious use of fertilizer. He also reported that the addition of chemicals to the soil in the form of mineral fertilizers especially on a long term continuous basis inevitably affects the soil chemistry. A common

problem associated with savanna soil, is soil acidity which limits crop production (Lombin, 1983).

Acid soils have toxic concentrations of mineral elements like Al, Mn and Fe and low Ca concentrations. Soil acidity inhibits root growth through Al concentrations. Friessen *et al.* (1980) reported that Al toxicity has been implicated as a major cause of poor plant growth on highly acidic tropical soil.

Tomato plant is sensitive to low pH especially when NH_4-N is used as N source, growth is restricted at pH4.0, but developed well between pH 5.0 and 7.0 (Evans and Troxler, 1953). Doss *et al.* (1977) reported that tomato yield were influenced by subsoil pH with maximum yield occurring at pH 5.6 and 5.8. They also reported that yield of some varieties were greater at pH above than below 5.0. Worley (1979) reported that best marketable yields were obtained when the soil pH was between 6.5 - 6.9.

Soil acidity constraints are largely corrected by liming to increase the soil pH near neutrality. Liming not only neutralizes the soil acidity and reduces Al and Mn toxicities, but also improves the soil chemistry (Adams 1981) and fertility which is manifested in increase in crop yields.

A number of studies in many parts of the world have shown that tomato production can be improved through liming (Worley, 1977, Rhue and Everret, 1987, Prezotti and Balbino, 1990).

In Nigeria, Asiegbu and Uzo (1983) carried out studies on the effect of lime and Mg on tomato growth in a ferrallic sandy loam and reported that tomato yield and dry matter accumulation were significantly increased by liming upto pH 5.2.

Soil acidity problem was observed by Horticultural Crops Research programme of Institute for Agricultural Research, A.B.U., Zaria as contributing to low yields of tomato in tomato growing areas especially on I.A.R. research form.

This necessitated some studies with the following objectives:

a. To determine the effect of lime and nitrogen sources on tomato performance and yield.

b. To determine the effect of lime and nitrogen sources on some soil properties.

CHAPTER TWO

LITERATURE REVIEW

2.1 Soil Acidity

Acid soils have been defined as soils with pH values less than 6.6 (USDA Year Book, 1957). The pH range for acid soils originally is from 4 - 7.0. values much below 4.0 are obtained only when free acids (Such as $H_2 SO_4$) are present as in cat clays (Seatz and Peterson 1964). The pH is perhaps the most widely used criterion for judging whether a soil is acid or not. The problems of acidity are however not evident until soil pH falls below 5.5 (Kamprath 1971 and Friesen *et al.*, 1970). Soil pH is a measure of the intensity of acidity it does not indicate the quantity of acid present.

The work of Coleman and Thomas (1967) showed that exchangeable aluminum is the dominant cation associated with soil acidity. As the soil becomes more and more acid, more Al and Fe are released from clay minerals and Al^{3+} remains as the dominant, exchangeable cation (Jackson 1960). Work carried out by Narottama (1974) showed that oxides of Al and Fe dominate soil structure and are the major source of soil acidity. Hydrogen ions produced by organic matter decomposition are unstable in mineral soils because they react with layer silicates releasing exchangeable Al and siliceous acid (Coleman and Thomas, 1967). The levels of Al in the soil solution depend on the organic matter and salt contents (Kamprath, 1972). Soils with pH lower than 5.5 may contain a large amount of their Mn in water soluble and exchangeable forms. Biswas (1953) observed that acid soils pH (4.3 - 6.9) contain 2.8 - 15.6 percent of the total Mn in water soluble exchangeable forms.

There are three main types of acid soils. These are acid sulphate soils, acid peat soils and acid mineral soils. Acid sulphate are soils that have been drained and contain free adsorbed sulphite showing pale yellow mottles with pH less than 4.0 (Bloomfield and Coulter, 1973). The second type are organic soils with low pH. Such soils are mostly found in temperate world. The acid minerals are mostly in the humid Tropics and are poorly buffered, well drained and coarse textured. They are low in clay and organic matter contents. Most of the soils in Nigeria fall into the mineral acid soils. The inherent natural fertility of the soil is therefore generally low (Lombin, 1983). These mineral acid soils are associated with siliceous sedimentary rocks mainly sand stones and have their exchangeable bases leached to varying degrees and replaced with hydrogen ions and Al ions.

Soil acidity constraints to crop production are largely due to Al and Mn toxicities and Ca and Mg deficiencies (Pedro *et al.*, 1981). Biswas and Gowande (1964) stated that exchangeable Mn is more related to pH than clay content. Al toxicity is a major factor contributing to acid soil infertility (Pearson and Adams, 1967).

2.2 Causes of Soil Acidity

Soil acidification is a process that is closely related to all aspects of production practice. The development of new technology, the use of mineral fertilizers, the introduction of tillage, the increase in cropping intensity, the reduction in fallow system and leaching of basic cations increase the acidification of low buffered sandy soils (Pieri, 1983).

Removal of basic cations from soil solution is an important agency of soil acidification. The greatest losses of metallic cations are channelled through leaching

and crop removal during harvest. Nitrate (NO_3) is a more mobile ion in the soil than NH_4^+ (Nye and Tinker, 1977), and thus is more susceptible to leaching by water movement and subsequent loss of basic cations from the ecosystem. Raney (1960) noted that nitrate content of perculating or drainage water was the main factor associated with the amount of bases in the leachate. Removal of basic cations will result in low percentage base saturation (increased soil acidity). Mclean (1971) reported that leaching action of CO_2 charged water percolating through the soil profile of a base-saturated soil removes free salts very quickly and exchangeable basic cations more slowly. Stumpe and Vlek (1991) reported that the loss of Ca was nearly linear with decreasing pH and Ca virtually disappeared from the soil exchangeable complex at pH 4.2, while Mg was completely lost by the time the soil pH has reached 5.0. On the other hand exchangeable Mn increased between pH 6.5 and 5.0 and decreased subsequently to insignificant level at pH 4.0. Exchangeable H and Al increased as the pH declined below 5.0. Hydrogen ions initially adsorbed to the cation exchange sites eventually become sufficiently concentrated to crystals releasing Si^{4+} and Al^{3+} . As soil become more acid, more Al and Fe are released from clay minerals and Al^{3+} remains as the dominant exchangeable cation and forms the exchangeable acidity (Jackson 1960). Coulter and Coleman (1969); Colman and Thomas (1967), reported that exchangeable Al^{3+} was the predominant cation in acid mineral soil with pH values of 5 or less.

It is well established that the use of most nitrogenous fertilizers increases soil acidity (Yayock, 1986). Abruna *et al.* (1958), Obi (1976) Mahler and Harder (1984) have reported the acidifying conditions emanating from continuous use of nitrogen fertilizers. The magnitude of the acidity developed is a function of both the type of

nitrogen fertilizer (Fox and Hoffman, 1981) the rate and method of application (Mahler and Harder, 1984). The intensity of acidification is affected by rate and type of N fertilizer and different tillage system. Soil pH decreased linearly with increasing N application (Stumpe and Vlek, 1991). Soil pH drops by 0.6 units as N level increased from O to 100 kg N/ha (Harban, 1989). Stumpe and Vlek (1991) worked on Alfisol in Nigeria and reported that the application of N decreases the pH of the top soil by 2 units and subsoil by 0.2 to 2.5 units depending on the N source and the rate of application. Jarvis (1988) reported that addition of 200kgN/ha increased the leaching of Al by 94%. Ammonium and ammonium yielding fertilizers are acid forming and continuous use under intensive cultivation has been shown to aggravate soil acidity (Obi, 1976 and Jones, 1976).

Stumpe and Vlek (1991) reported that application of urea and ammonium Sulphate resulted in a massive elution of Ca and Mg from exchange complex, these cations were largely replaced by Al, Mn and H. For every 100kg of ammonium Sulphate added to soil, 45 kg of Ca^{2+} are removed in drainage water (Leutenegger, 1956).

In long term experiment at Samaru Nigeria annual applications of ammonium Sulphate (12 and 24 kgN/ha/annum) significantly decreased top soil exchangeable Ca and Mg, but not K (Bache and Heat Cote, 1969). Bache (1965) reported that 14 annual applications of ammonium Sulphate at rate of 22kgN/ha lowered soil pH at Samaru to 3.53 compared to 4.56 in the control plot. Jones (1976) reported that soil pH was significantly reduced by 3 years application of 135kgN/ha/annum as calcium ammonium nitrate (CAN). Studies conducted at Samaru and Mokwa Nigeria

showed that although urea and CAN produced less acidity than ammonium sulphate the acidity produced by these two fertilizers was still significant (Jones, 1976).

Fauck *et al.* (1969) and Charrean and Fauck (1970) reported that surface soils tend to become more acid under continuous cultivation, whether acidifying fertilizers are used or not. Experiment carried by Obi (1991) on ultisol revealed that continuous cropping of tropical ultisol with or without N fertilization increased soil acidification and reduced soil organic matter productivity.

Microbial oxidation of fertilizer NH_4 to $N0_3$ results in the liberation of two moles of H for each mole of NH_4 oxidised. Nitrification of ammonium in one mole of ammonium nitrate results in two moles of nitric acid. Nitrification of the ammonium in one mole ammonium sulphate results in two moles of nitric acid and one mole of sulphuric acid, also nitrification of one mole of ammonium hydroxide produces one mole of nitric acid (Black, 1967). The addition of hydrogen ions to the soil caused the pH of the soil solution to decrease until a buffer system becomes active (Van Breeman *et al.,* 1983).

Other processes leading to acidification during N cycling in soils are the imbalance of cation over anion uptake in the rhizosphere of plants either actively fixing N_2 gas or taking up NH^+_4 ion as the major source of N and the net nitrification of N derived from the fixation or from NH_4^+ and $R\text{-}NH_2$ based fertilizer (Bolan *et al.,* 1991). The greatest effects of acidity development do occur in the surface soil because of the greater activity of micro-organisms and plant roots in the horizon (Volk, 1955).

Organic acids from decomposing organic matter also provide an important source of acidity. The dissociation of protons from carboxylic acid groups is thought

to be the major mechanism involved in cation exchange and pH buffering in slightly acid soil horizons which contain organic matter (Bloom *et al*., 1979 and Bache, 1985). The carboxylic groups are strong enough to ionize appreciably when soil pH is below 7.0 (Schnitzer and Gaup, 1965). Most organic acids are weakly dissociated and could not be expected to contribute to acidity at low pH values (Overrein, 1978) Coleman and Thomas (1967) reported that the hydrogen ions produced by organic matter decomposition are unstable in mineral soils because they react with layer silicate clays releasing exchangeable Al and Siliceous acid.

2.3 Effects of Soil pH on Soil Macronutrients

Soil pH is an excellent single indicator of general soil conditions. The most universal effect of pH is nutritional. It influences the rate of nutrient release by weathering and the solubility of all materials in the soil. The soil pH also influences the amount of extractable and exchangeable cations on the exchange sites (Helling, 1964; Pratt, 1964; Karbo and Folorunsho, 1986). Its primary effect is on the availability of some of the essential nutrients in the soil. The deficiency of Ca, Mg, Mo and P and excessive availability of Mn and Al have commonly been reported to be associated with pH (Monnerat 1970). Acidic condition increases the availability of Fe, Mn and Al (Schmehl *et al*., 1950).

The effect of soil acidity is very complex and can not be attributed solely to a single factor. Release of bases from exchangeable form is affected by soil acidity. With increase in acidity, the amount of exchangeable bases decreases, the CEC also decreases due to loss of pH dependent exchange position, and accumulation of polymeric hydroxy - Al interlayers in clays. The toxic effect of Al and Mn as influenced by soil acidity depends upon the type of soil, the buffering capacity of the

clay and organic matter content and the presence of other cations and anions (Narottama, 1974; Kamprath, 1974). Aluminium in the soil solution increases with increasing salt content because other cations displaces exchangeable A1 by Mass action (Pearson, 1975).

Soil acidity affects the supply of available nitrogen from resources in the soil and from fertilizers. Ammonia producing organisms in the soil are not greatly affected by soil acidity. Nitrogen in the form of ammonium is available in acid soils because nitrification is slow below pH 5.5, Ammonium ions may accumulate in acid forest soil because the microbes that mineralizes organic N to ammmonia depend on soil pH. Low pH will reduce the mineralization of organic N (Harmsen and Van Schreven 1955). Noborg and Hoyt (1978) reported that soil acidity restricts the rate at which organic N is converted into inorganic form. Another important facet of N availability in acid soils is the pH dependence of ammonium ion fixation between the lattices of expanding layer silicate minerals. Such fixation generally decreases with decreasing pH.

The most favourable pH condition for phosphate (PO_4) availability lies between 6.5 and 7.5 in soils. Below pH 6.5, PO_4 availability in the soil decreases rapidly, sooner or later all the available phosphates are converted into poorly available forms due to the formation of insoluble Fe and A1 phosphates. Adams (1978) reported that increasing soil pH is believed to increase the availability of P because it inhibits the adsorption - precipitation reaction between P and Fe or A1. Increasing soil pH may however decrease reaction between P and Ca. Change in soluble exchangeable and extractable phosphates were related to the simultaneous changes in soil pH, soluble cations and phosphate sorption characteristics.

Phosphate solubility in acid soils is controlled more by the dissociation of Fe and Al phosphates than by the desorption of exchangeable phosphate (Holdfold, 1991). Work carried out by Krairapanond and Krairapanond (1992) in Thailand showed that P sorption increased significantly with increasing pH. Enwenzor (1966) reported that acid soils tend to accumulate more total organic P than alkaline soils, because organic phosphate reacts with Al and Fe under acid conditions and become insoluble resulting into low P reserves. Thompson *et al.* (1954) reported an increase in mineralization of organic P with increase in soil pH in the field and laboratory.

The supply of exchangeable K in the soil is often very low under acid conditions due to the formation of soluble K salts with soil acids. The predominant reaction depends on the conditions. Changing the soil pH also changes the relative preference of soil colloids for divalent and monovalent cations. This makes it important in K exchange because of the complementary ion effect. More K ions are retained against displacement and leaching in a Ca-K soil than in a Al-K soil. The K also competes effectively with Ca than Al for initial exchange sites on colloids. The availability of K in soil begins to fall at pH below 6.0 (Anonymous, 1969).

Stumpe and Vlek (1991) worked on Egbeda soil in Nigeria, and showed that the changes in the composition of exchange complex of Egbeda soil is a function of pH. The low amount of Ca was nearly linear with decreasing pH and Ca had virtually disappeared from the soil exchange complex at pH 4.2. Magnesium was completely lost at pH below 5.0. They concluded that the process of acidification can be visualised as an acid - based titration of a moving acidification front.

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2.4 Effect of Soil pH on the Micronutrients

Soil pH has been identified as a particularly critical parameter in the regulation of micronutrients (Mn, B, Cu Zn Co Mo) availability (Truog, 1947; Thomas, 1986). The activity as well as the availability of Mn, Fe and A1 increases as soil acidity increases (Maynard, 1979).

Manganese has been found to exist as water soluble, exchangeable and higher oxides. The immobilization of mobile Mn has been reported to be related to pH (Biswas 1953). Biswas and Gawande (1964) stated that the exchangeable Mn is more to pH than the soil clay content. Soil with pH lower than 5.5 may contain a large amount of their Mn in the soluble and exchangeable forms. Biswas (1953) observed that acid soils pH (4.3 - 6.9) contained 2.8 - 15.6 percent of the total Mn in the water soluble and exchangeable forms. Lombin (1982) also reported that extractable Mn was strongly related to pH and to lesser extent to soil organic matter. Thomas (1986) studied micronutrients over a pH range of 4.0 - 7.7 and reported that Mn and Zn were generally the dominant species of elements below pH 5.2, while at higher pH values, organically bound forms were dominant.

The availability of Zn in the soil is also related to the soil pH. In many normal soils the relation between pH and Zn extractability has been negative, such that an increase in soil pH decreased Zn availability (Shaw and Dean, 1952). The tendency of Zn concentration to increase in solution at high pH values has been shown to be due to mobilization of Zn by soluble or dispersed organic matter (Jeffery and Uren, 1983; Jahiruddin *et al.,* 1985). John (1956) reported that a soluble form of Zn at lower pH may be converted to a less soluble and less available forms in the soil at a higher pH values. Shuman (1975) reported increase in Zn-

sorption with increasing soil pH particularly on coarse textured soils. Similar decreases in exchangeable Zn as pH increased were reported by Iyengar *et al.* (1981). McBride and Blsiak (1979) observed increases in soil solution Zn at pH values greater than 7.5 due to the formation of soluble -Zn organic complexes. Shuman (1977) also added that the adsorption of Zn on all oxides (geothite and gibbsite) is affected by soil pH. In general low pH results in less adsorption of Zn (Stanton and Burger, 1970).

The availability of Cu is dependent upon soil pH, but does not normally increase appreciably until pH falls below 5.0. Mclaren and Crawford (1973), found increased Cu adsorption as pH increased, but in a later work Mclaren *et al.* (1981) using lower Cu levels found minimal changes in adsorption over a pH range of 5.0 to 7.0. Work carried by Lombin (1983) on Nigerian Savanna soils showed that extractable Cu levels appeared to be strongly related more to organic matter than to clay fraction.

The availability of Fe increases and decreases the same way as with Mn in acid soils. High soil pH affects the availability of Fe in the soil (Brown *et al.*, 1971).

Most studies indicate that a pH around 6.5 is required in order to get maximum availability of soil Molybdenum (Kamprath, 1972). Mo deficiency is usually associated with soil pH below 5.5. Adsorption of Mo anions to soil components becomes greater as acidity increases. Reisenauer *et al.* (1962) presented a graph from a number of studies showing increases in soil solution Mo with increases in pH, and the parallel increases in Mo content of plant tissue. The increases in Mo content of plant as the pH rises apparently reflects the end of two

opposing actions. Lucas and Knezek (1972) indicate that at higher soil pH values plants are able to utilize more Mo because of the incresed solubility in the soil.

Peterson and Newman (1976) reported that soil pH affects B availability only above pH 6.3.

2.5 Effects of Soil pH on Soil Microbes

Soil pH alter the populations and activities of Micro-organisms responsible for transformations involving nitrogen, sulphur and phosphorus in the soil. This indirectly affect the availability of these elements to higher plants. Symbiotic and parasitic relationships between microbes and higher plants may be altered directly or indirectly with pH changes. Most microbes operate best at near neutral soil pH. Apart from the effect of soil pH on the microbial activity, it also affects the microbial biomass (Carter, 1986). The growth and survival of many strains of rhizobia are strongly influenced by soil acidity. Bryron (1923) observed that soybean rhizobia were able to survive in soils down to about pH 4.0, red clover rhizobia to pH 4.5 and alfalfa rhizobia to about pH 5.0.

Sartain (1985) pointed out that the reduction in microbial population due to acidic soil conditions may result in slowing down nitrification rate. Jansson and Clark (1952) and Norrmnik (1956) reported that acidity strongly inhibits denitrification and that inhibition becomes very strong below pH 6.0. Bremner and Shaw (1958) concluded that significant losses of N will not occur if the pH is less than 5.0 (Wijler and Delwiche, 1954). Gillian and Gambell (1978) found that nitrate loss readily occurred at pH 4.5 when an energy source was added, but at a much slower rate. Waring and Gillian (1983) found substaintial denitrification to occur at less than pH 4.0. As acidity increases N_2O becomes the major product of

denitrification (Blacker and Bremner, 1978), in the neutral soils (pH 6.9 - 7.3) denitrification was much higher (Waring and Gillian, 1983).

Thompson *et al.* (1954) noted that mineralization of organic P after 25 days incubation was positively associated with soil pH. Evidence from the study also showed that mineralization of organic *P* increased with pH during soil development in the field.

Nelson (1964) reported that decreasing acidity from pH 5.0 to pH 4.0 resulted in about a threefold increase in sulphate production after three months incubation, little further increase was found as soil acidity was decreased from pH 5.0 - 7.0.

2.6 Effects of Soil pH on Nutrient Uptake

Soil pH influences the availability and uptake of nutrients. Both cation and anion transport are markedly affected by the pH of the ambient solution. Hydrogen sharply reduces cation absorption at pH values below 5.0 (Moore *et al.*, 1961). If the pH of nutrient solution is low enough, there is no absorption and cations previously absorbed tend to leak out of the plants into the solution because the cations probably exchange for hydrogen in the cation selective site and hence higher hydrogen activity in the external solution (Black, 1967).

LynMarcus (1983) reported that NH^{+}_{4} uptake rate increased with decreased ambient acidity from pH 5.5 to 4.5, NO_3^- absorption rate was reduced slightly in the presence of NH_4. Ammonium ion absorption rate of root mass was approximately 42% greater at pH 5.5 or 6.5 than at pH 4.5, while NO_3^- absorption rate was inhibited at pH less than 5.5, but at 5.5 the NO_3^- absorption rate was increase. Munn and Jackson (1978) reported that a decrease in ambient acidity generally restricted NO_3 absorption in the presence or absence of NH_4.

Soil pH has been shown to affect P uptake by plants (Gijsman. 1990). The effect of soil pH on the availability of P has been measured with plant growth experiments. Increases in either plant weight or uptake of P has been the measure of soil pH (Barber Hen-Hshua, 1990). Wallihan *et al.* (1978) reported that when soil pH attained pH 8 or higher, leaf analysis revealed P deficiency even though P was apparently adequate.

Jocobson *et al.* (1961) showed that the influence of calcium on the uptake of monovalent ions is dependent on soil pH.

Gorlach and Gambus (1983) reported that at higher pH of 7.2 to 7.5, the availability of Cu to plants decreased, but at a lower pH 4.1 to 4.7 there was an excessive uptake of Cu by plants. At lower pH, Cu concentration of canary grass was found to increse from an optimal 10ppm to 17ppm (Levesque and Mathur, 1983). The Cu content of barley tissue increased with increase in the soil pH from 4.2 - 5.2 (Umesh, 1972). In the vegetable crops Cu concentration generally decreased sharply as soil pH rose above 4.0 (Levesque and Mathur, 1983).

John (1956) showed a highly significant relationship between pH value of the soil and the amount of Zn taken up by plant.

The iron uptake by plants is also affected by high soil pH (Brown *et al.*, 1971). Umesh (1972) reported that Fe content of barley tissue increases with pH upto 5.2 and decreses above pH 5.2.

Molybdenum deficiency is usually associated with soil pH. Lucas and Knezek (1972) indicated that at higher soil pH values, plants are able to utilize more Mo because of increased solubility in the soil and better absorption within plants. The Mo concentration in plant tissue increased with increase in soil pH (Umesh, 1972).

The uptake of manganese by plants appear to be closely related to soil pH and accompanying solubility of Mn. With increased soil pH from 4.2 - 6.2, Mn concentration of plant tissue increased (Umesh, 1972). Jackson *et al.* (1974) reported that leaf tissue Mn levels were reduced over four fold with increase in soil pH from 5.8 to 6.3. White *et al.* (1970) while studying factors contributing to Mn toxicity concluded that the uptake of Mn by plants was related to the acidity of the entire soil rather than to the Mn dissolved by acid solution diffusing from fertilizer band.

Soil pH is one of the most important factors affecting the availability of Boron in soil and plants. Generally B becomes less available to plants with increasing soil pH. Several workers have observed negative correlations between B uptake by plants and soil pH (Bennnet and Mathia, 1973; Bartlett and Picarelli, 1973; Gupta, 1972). Studies by Peterson and Newman (1976) and Gupta and Macleod (1977) have shown that negative relationship between soil pH and B occurs when soil pH levels are greater than 6.3 - 6.5. The availability of B to plants decreases sharply at higher pH levels. They also showed that liming to pH 7.3 - 7.5 markedly decreased B content of pea tissue from 117 - 198 ppm at pH 5.4 - 5.6 to 43 ppm.

2.7 Effects of Soil pH on Plants Growth and Development

Low soil pH is a major constraints to plant growth. On acid mineral soils plant growth can be limited by a variety of specific chemical factors and interaction between these factors. Under such conditions the major constraints to plant growth are increase in hydrogen ion and Mn concentration. There is also decrease in metal cation concentration (Ca, Mg, K) and decrease in P and Mo solubility (Horst, 1991).

Low soil pH restricts root and shoot growth of many plants, often resulting in a limited root system and drought tolerance. This is believed to be the reason why plants often fail to develop vigorous root system in highly weathered and leached soils (Pearson, 1966). Restriction of root extension due to subsoil acidity severely affect crop productivity particularly in seasonally dry climates where subsoil reserves of moisture and nutrients are important in plant growth (Bouldin, 1979). The pH of external medium markedly affects absorption of both cations and anions by roots. In experiment with excised roots, maximum absorption occurs at pH values between 5.0 to 7.0 (Moore, 1974). Below pH 5.0, cation adsorption was greatly reduced (Arnon *et al.*,1942 and Murphy, 1959). Most plants show complete lack of root growth at pH 3.0, however, substantial growth may occur at pH 4.0 (Volz and Jacobson, 1974 and Islam *et al.*, 1980).

The detrimental effect of low pH on root growth has been clearly demonstrated to be intimately associated with exchangeable or solution Al (Adams, 1967). The maximum concentration of exchangeable and extractable Al occured between pH 4.0 to 5.0 (Narrottama, 1974). Studies by (Abruna *et al.*, 1970) showed that primary effect of Al toxicity is direct injury to the root system. Root development is restricted and roots become thicker and stubby and show dead spots. Foy (1974) indicated that roots affected by Al toxicity have a characteristic stubby and spatulate appearance. Lateral roots are greatly inhibited and thickened and the fine branching roots is much reduced. Root tips frequently turn brown.

Manganese is very soluble at pH values lower than 5.5 (Black, 1967). If this element is present in sufficient amount, Mn toxicity could occur along side with Al toxicity at pH values between 5.5 - 6.0. Exchangeable soil Mn is closely related to

soil pH (Gyori *et al.*, 1971) and its solubility is markedly influenced by soil acidity (Schmehl, 1950). Nickolas and Kirton (1971) found that at pH 4.7 to 4.8 exchangeable and water soluble Mn levels were sensitive to slight changes in soil reaction. Changes in pH from 5.2 - 6.0 caused only slight alteration in the Mn levels in soil and plant. Bot (1990) reported that Mn is an important factor limiting plant growth on acid and water logged soils. Kamprath (1972) also reported that Mn has been identified as the cause of poor growth in certain acid soils. Plants affected by Mn toxicity are stunted in growth and are subjected to severe defoliation which usually starts from the basal portion of the plant. Necrosis of leaves usually start at the tip and progressed along the main veins to the stem by means of simple attachment. Affected plants in the field also had brown spotting on sepal and stem and highly reduced fruits (Monnerat, 1970).

Other factors responsible for inhibition of root growth in acid mineral soils are low calcium concentrations combined with high concentrations of hydrogen ions. As the soil pH falls, the concentrations of Ca ions in the external solution required for maintenance of root elongation growth increases markedly (Horst, 1991).

2.8 *Effects of Soil pH on Tomato Growth and Yield*

Soil pH affects the solubility of many soil constituents and the levels of extractable and exchangeable cations (Pratt, 1961 and Helling, 1964). Poor growth and yield of tomato as well as other crops have been attributed to low soil pH. Evans and Troxler (1953) reported that tomato growth was restricted at pH 4.0, but developed well between pH 5.0 and 7.0. Tomato is sensitive to low pH especially where NH_4-N is used as a nitrogen source (Coltman, 1979).

Tomato has been reported to be sensitive to Al and have been suggested for use as an indicator to Al availability in acid soils (Mercado and Velasco 1961 and Foy *et al.*, 1963). Rivera *et al.* (1986) reported that at pH 4.4 and 43% Al saturation, yields of tomato was highly reduced. It was therefore concluded that yields of tomato were closely correlated to soil pH, exchange Al and Ca and the Al:Ca ratios.

Doss *et al.* (1977) worked on the effect of subsoil acidity on tomato yields and reported that yields were influenced by subsoil pH with maximum yields occuring at pH 5.5 to 5.8. Worley (1977) also reported that best marketable yields were obtained when soil pH (Loamy soil) was between 6.5 to 6.9. Yields were reduced when pH was below 6.0.

Nutritional disorders are often related to specific soil conditions which either directly or indirectly influence the availability of essential plant nutrients. A common nutritional disorder which occurs due to low soil pH is the blossom end-rot which occurs due to low calcium availability in the soil (Geraldson, 1975).

2.9 Liming materials

An agricultural liming material is defined as a material whose calcium and magnesium compounds are capable of neutralizing soil acidity. These materials include quick lime, hyrated lime, limestone (both calcitic and dolomitic), marl, shell and by-products such as slag (Stanley, 1967). Liming is the addition to the soil any calcium or calcium and magnesium containing compounds that is capable of reducing soil acidity and its effects (Tisdale and Nelson, 1975).

Liming improves the soil environment for plant roots by enhancing the availability of plant nutrients and depressing the toxicity of elements such as aluminium and manganese.

2.9.1 Application methods

Lime is usually broadcast on the soil surface, mixed or incorporated into the top 15cm of the soil. Hourigan *et al.* (1961) found that when the surface soil was adequately limed, liming the subsoil had little effect on yield. Longnecker and Merkle (1952) found the root extension into acid soil pH (4.0) was limited unless limed, but they obtained maximum yields with liming only the surface layers. Liming can be as effective when broadcast on the soil surface as when incorporated into 15cm according to Vicente-Chandler *et al.* (1974).

2.9.2 Effects of lime on soil pH and exchange properties

The purpose of liming is primarily to neutralize the effect of exchangeable aluminium and this is normally accomplished by raising the pH 5.5. When Mn toxicity is suspected the pH could be raised to 6.0.

Liming also increases the soil pH. When this happens its effect on the colloidal surface is to neutralize the acidity by hydrolying the base saturation (Coleman and Thomas, 1967). Lime reduces both pH dependent and exchange acidity (Brauner and Catani, 1970). Levesque and Mathur (1983) reported that average soil pH increased linearly with liming. These increases were about 0.090 and 0.093 pH units per ton of lime per hectare. Increasing the rate of lime from 0 to 3,584 kg/ha raised the pH significantly from 4.76, 4.38, 4.58 to 7.30, 7.28 and 7.31 respectively. Lime applications caused a 75 - 91% rise in pH and 63 to 88%

reduction in neutralizable soil acidity. Lime treatment at 4480kg/ha produced soil pH value approximately 5.1 and reduced the toxic concentration of soil Al (Narrottama, 1974). Liming to pH 5.0 to 5.5 on some soils (ultisols and Oxisols) satisfied the need of cowpea and maize with respect to Ca requirement and correction of Al and Mn toxicities (Abruna *et al.*, 1974). Wilson *et al.* (1974) worked on dark red latosol in Brazilian cerrado and reported that 6 tons/ha lime reduced exchangeable Al to Zero and Produced pH of 5.5, while 5 tons/ha was sufficient to maintain the Al saturation at less than 10%. CI - Fu *et al.* (1990) showed that application of calcic limestone (3.75 - 15 tones/ha) increased the pH of surface soil from 4.9 - 5.9 - 7.6 and decreased the content of exchange Al from 5.46 - 0.38 $Cmolkg^{-1}$. The increase in soil pH and decrease in exchangeable Al, occurred mainly at the 0 to 20cm depth.

The CEC's of very acid soils with oxides or oxide coated systems particularly oxisols, ultisols and Andepts can be increased by liming because of the predominance of pH dependent charges. Liming soils with pH 4.0 or 4.5 to pH 5.5 can produce a large increase in CEC (Pedro 1976). Fox *et al.* (1991) also reported that adding lime to variable - charge soil may increase CEC in proportion to the increase in exchangeable Ca, in which case percentage base saturation does not increase, and Ca activity in the system will not change much. Chen and Ouellette (1971) reported that pH increase due to liming acid soils resulted in a threefold decrease in the amount of exchangeable Mn.

2.10 Effect of Liming on Macronutrients

Liming not only neutralises the soil acidity and reduces aluminuim and manganese toxicies, but also contributes to the availability of nutrient elements and improving soil fertility (Martini and Multers, 1985).

Liming the soil to about pH 6.7 approximately doubled the amount of nitrogen mineralization during incubation (Nyborb and Hoyt, 1978). Christensen *et al.* (1985) reported that liming hastened disappearance of NH^+_4-N and increased the appearance of NO_3-N in soil. Singh and Seatz (1961) also demonstrated that liming strongly acid soils increased the availability of P that was added to the soil after liming. Holfold (1991) reported that liming appeared to change the dominant sorption process from precipitation to adsorption. Soluble phosphate was increased by liming most soils. It therefore suggests that phosphate solubility in some acid soils is controlled more by the dissolution of Fe and Al phosphate than by desorption of exchangeable phosphate. Similarly, Hayne and Naidu (1992) reported that liming caused decreases in phosphate adsorption in some soils. The decreased adsorption was explained in terms of the surface charge on soil colloids becoming more negative following liming. Where phosphate adsorption was increased, this was attributed to polymerization of exchangeable Al and Al associated with organic matter to form hydroxy - Al species as the pH was raised. Ragland and Seay (1971) reported that where pH of clay was raised from 5.8 -5.9 to 6.6 - 6.7, adsorption of P was increased. They concluded that when Ca saturation was greater than 60% the amount of P retained by clay soil increases. Amarasire and Olsen (1973) reported that liming increases the concentration of solution P in soils, because lime hydrolysis certain phosphates of Al and Fe thereby releasing P to solution. They concluded

that lime did not increase P solubility when soil pH was below 6.5. Friesen *et al.* (1980) worked on Nigerian ultisols and reported that the effects of P adsorption in mineral systems and soils have not been wholly consistent with oxidic minerals such as gibbsite, heamatite geothite as well as kaolinite. They observed that P adsorption generally decreased with increasing pH and the optimum P avaiability occurred between pH 5 and 6.

Liming acid soils results in decreased inavailability of exchangeable K. Ayres (1961) reported that fixation of K in two Hawallion soils was increased by liming, resulting into K deficiency (Adams and Pearson, 1967). Phillips *et al.* (1988) reported that liming may increase K concentration in solution and ultimately their susceptibility to loss through leaching. The extent to which K can be leached depends on the effect of lime on cation exchange equilibria. Foster *et al.* (1993) reported that liming appeared to increase the soil K buffer capacities. York *et al.* (1953) showed that adequate liming was necessary for availability of K to plants. Rojas and Adams (1987) reported that soil K:Ca and K:Mg ratios decreased with increased lime application. While the Ca+Mg:K ratio and Ca+Mg+K increased.

Soil sulphur decrease with decreasing pH values, a pH unit increment was related to sulphate-sulpur decrease of 15 ppm in the A-horizon and 7.2 ppm in the B - horizon of coastal plain soils (Mutter and Martini, 1984). More sulphate-sulphur is adsorbed as soil becomes more acid. This implies that liming soil will result in increased availability of sulphur (Nelson, 1964). Hayne and Naidu (1992) reported that addition of lime and phosphate in soil resulted in net mineralization of organic S and the accumulation of sulphate in the soil. Fox *et al.* (1964) reported that liming will undoubtedly speed up the mineralization of native soil organic sulphur as well

as enhancing the activity of thiobacillus micro-organisms responsible for these processes.

Calcium and Magnesium are low in acid soils and are less available to plants. Soil application of Ca to meet plant requirements using lime and gypsum, presents unique differences to other fertilizers. Both of these calcium compounds supply available Ca and also influence soil pH (Carter, 1986).

The available Ca and Mg in a 0-90cm depth increased with increasing lime rates (Lutz and Jones, 1974). Pearson *et al.* (1962) found that under intensive pasture management, an application of 12 tons lime/ha caused soil Ca to move from the top 15cm to the subsoil.

2.11 *Effect of liming on micronutrients*

With the exception of Mo, the availability of micronutrients decreases as the soil pH increases . Excessive lime application to highly depleted soils can therefore be expected to induce micronutrient deficiencies (Friesen *et al.*, 1980). Kamprath (1972) reported that the availability of Zn, Cu Mn and B is often drastically reduced when highly weathered soils are limed much above pH 6.0. The availability of Fe, Cu, Mn and Zn in orchard soils of Bhatinda district India was very low on account of high pH due to the presence of high $CaC0_3$ in the soil (Singh and Randhawa, 1969).

Barshad (1951) reported the sorption of Mo from acid solutions by soil clays and the release of Mo as the pH increased. Barrow (1970) observed that the decrease in anion adsorption with increased pH was greatest for Molybdate, when compared with phosphate and sulphate. Liming decreased adsorption of molybdate (Haynes, 1983). Water-soluble Mo generally increases with liming (Jones, 1957).

Gidden's and Perkins (1960) reported that in some soils where the native Mo is verly low, responses to applied Mo have been noted even at high lime rates.

Several factors control the availability of Boron. It is adsorbed to an increasing extent as the soil pH is increased above pH 7.0. There is weak a adsorption at lower pH values. Boron availability in the soil decreased by liming, but the need is probably related more to the Ca:B ratio in plant tissue (Jones and Scareth, 1944 and Marsh and Shive, 1941). Fox (1968) observed that high Ca concentrations or high pH had little influence on the B adsorption rate. Deficiency can be induced by application of high rates of lime to acid sands (Walsh and Golden, 1952: Purvis and Davison, 1948). Lime induced B deficiency does not occur frequently below pH 6.5 (Adam, 1967). Midgley and Dunklee (1935) stated that capacity of a soil to fix B greatly affects the amount of lime that can be safely used in field practices.

Managanese has been found to exist as water-soluble, exchangeable and higher oxides. The immobilization of mobile Mn has been reported to be related to clay and pH (Biswas, 1953; Biswas and Gawande, 1964). Liming is aimed at decreasing the solubility of Mn and to keep it between toxicity and deficiency (Abruna *et al.*, 1970). Application of lime have resulted in the reduction of the mobility of Mn in soils (Reeve and Summer, 1970). Mulder and Gerraten (1952) reported that Mn was fixed by adsorption on the surface of $CaC0_3$ particles. The binding is so strong enough that Mn can not be released with neutral ammonium acelate. Liming the soil to pH 5.5 or above significantly reduced the concentration of extractable soil Mn (Jones and Nelson, 1978). Narottama (1974) reported that

4480kglime/ha reduced the level of Mn in the soil to above half, compared to unlimed soil.

The availability of iron in the soil is influenced by soil pH. The solubility of Fe^{3+} decreases 1000 fold for each unit increase. An increase in soil pH without oxidation may lead to precipitation of one or more insoluble Fe^{2+} (iron II) compounds. Most commonly are carbonate, sulphide or hyrated silicate (Konrad, 1972). The solubility of the precipitates is therefore very low under normal soil conditions. Iron deficiency is frequently encountered on calcareous soils due to high $CaC0_3$ levels (Murphy and Walsh, 1972).

Zinc solubility is also controlled by pH. The solubility of soil Zn decreases as the soil pH increases. Jeffery and Uren (1983) reported that total concentration of Zn in the soil solution decreased about 100 fold as the pH of the soil increased from 4.4 to 7.5. Liming may induce deficiency because of the control of Zn solubility by soil pH. Wear and Hagler (1963) reported that Zn deficiency has frequently been aggrevated by liming. Zinc activity in soil solution declined sharply when the soil was limed to pH above 5.0 (Friesen, 1980). There is a proportion of $CaC0_3$ in soils (Navrot and Ravikovitch, 1969). Sharifunddin and Yusof (1990) reported that higher application of limestone (>4.0 tons/ha) induced Zn deficiency in soils.

The availability of copper is dependent upon soil pH, but does not normally increase appreciably until the pH falls below 5.0 (Lucas and Knezek, 1972). At pH values of about 7 and above, $Cu(OH)^+$ is present in significant concentrations and may enter in soil adsorption reactions (Ellis and Knezek, 1972). Reuther and Labananskas (1969) indicated that sandy alkaline soils are deficient in available Cu.

Pearson (1958) reported that liming has played a special role in reducing Cu availabilty in certain areas of Florida. Yount and Fiskell (1963) concluded that the most practicable control for reducing Cu availability is by liming the soil to about pH 7.0 higher application of limestone (>4.0t/ha induced Cu deficiency in Malaysian Soil (Sharrifuddin and Yusof, 1990).

2.12 Effect of lime on soil micro-organisms

Liming not only neutralized the soil acidity but also created favourable conditions for biological reactions (Sattawattanonon and Suparp, 1983). Valeur and Nilsson (1993) incubated limed and unlimed humus soil at 15°C and reported that limed humus soil had the highest microbial activity. The use of lime was observed to increase heat output and decrease the C:N ratio in organic horizons of a spruce forest soil (Zelles and Zsolay, 1990). Adams and Adams (1984) also reported that lime application increased C and N in the biomass by approximately 30%.

Lime stimulates microbial activity in the soil, resulting into excessive rates of microbial decompostion of soil organic matter (Mclean, 1971). Shah *et al.* (1990) reported that liming increased the bacterial population in a brown podzolic soil and caused substantial increase in both soil respiration and net nitrogen mineralization, despite a high C:N ratio of the organic matter. Blues (1974) observed that lime treatment stimulated nitrification ($NH_4^+ - NO_3^-$), allowing the NO_3^- to be utilized in biological cycles and in the absorption and storage of N in the stolon - root system of bahia grass (Teare *et al.* 1987).

Valuer and Nilssol (1983) reported that sulphur immobilization seemed to be greater in limed than unlimed soil.

2.13 Effect of Lime on Soil Physical Properties

Lime application was observed to significantly increase the moisture retention and structural charactistics of soil (Badanur and Venkata, 1975). Russel (1932) stated that lime could enhance flocculation of clay particles and promote aggregation and water holding capacity of soils.

Eades *et al.* (1962) proposed that stabilization is a result of the slow formation of calcium silicate hydroxide bonds between particles. Lime [$Ca(OH)_2$] decreased the plasticity index by increasing the plastic limit and producing hydrated Ca-A1 silicate a cementing agent (Borchardt, 1977). Shanmuganathan and Oades (1984) suggested that both coagulation and cementing in a soil may be achieved by the addition of lime, with significant improvement of soil structure. Calcium carbonate appears to have direct cementing effect and contributes to structural and aggregate stability (Martti 1984).

Boaader (1984) reported that the stability of soil aggregates, the total pore space and the number of coarse pore (More than 10um) were increased with the application of hydrated lime, (CaO). Similarly compaction of the soil under pressure was reduced in hydrated lime treated soils compared with control Experimental evidence in Belgium showed that plow-sole compaction and aggregate stability deterioration was twice as great in soils low in lime as compared with those with visible $CaCO_3$ (Deleeher, 1964). Liming to pH 6.5 improves water permeability of soils poor in humus and reduces soil compaction by wheels (Quast, 1984).

Study of some physical properties of soils from leached column indicated that hydrated lime decreased the bulk density (Sharma and Fehrenbacher, 1977).

Liming at 15 tons CaO/ha slightly reduced shear strength in subsoil (Martti, 1984). Ledin (1982) reported that limed soils are more rigid, they swell and shrink less than unlimed soils. The limited swelling may be partly due to suppressive effect of Ca ions that diffused through the double layer of the clay particles. He also reported that air enters more readily into limed soils during drying which is probably one cause of crop yield response to lime.

2.14 Effect of Lime on Fertilizers

Goeder (1983) reported that liming soils increases fertilizer efficiency. Liming reduces the concentration of soluble and exchangeable Fe and A1 ions which react with added phosphate Fertilizer to form spraring soluble Fe and A1 phosphate (Amarasiri and Olsen, 1973). Work on Hawaiian Latosols indicates an increased uptake of fertilizer by plants with modest rates of liming (Fox *et al.*, 1964).

Uzo (1971) reported that in the absences of lime and organic matter, tomato responded poorly to N, P, K fertilizer. Hoyt and Henning (1982) reported that yields of barley were greatly increased by fertilizer and lime treatment, while the treatment with fertilizer only failed to give an increase in yield.

2.15 Effects of Overliming

Overliming can be defined as liming at rates higher than necessary to neutralize the exchangeable aluminium or eliminate manganese toxicity. The consequencies of liming are yield reduction, soil structure deterioration and decreased availability of P, B, Zn and Mn (Kamprath 1971 and Sumner *et al.*, 1978).

Liming of five central American ultisols to pH 6.4 increased P lability and desorption into 0.01m $CaCl_2$ while overliming depresses P solubility due to the

formation of more insoluble calcium phosphates (Lindsay and Vlek, 1972). When soils with high P fixaion capacity was limed to pH 7.0 P uptake decreased and severe P deficiency was observed, because of the formation of insoluble calcium phosphates (Kamprath, 1971). Levesque and Mathur (1983) reported that at high liming rates, the Mg and P concentrations in canary grass declined as Ca absorption increased. Narottama (1974) also reported that over liming may create lime-induced Mn phosphate, Fe or Zn deficiency. Friesen *et al.* (1980) reported that overliming highly depleted Nigerian ultisols to neutrality may be detrimental to availability of nutrients such as P, Zn and Mn. Overliming results in reduction in plant (Maize) available Mg and yield depression (Summer, 1978). Soil sulphur increased with decreasing pH values, a pH unit increament is related to sulphate sulphur decrease. Therefore overliming affects the plant sulphur uptake (Martini and Multers, 1984).

2.16 Effect of Lime on Nutrient Uptake, Growth and Yield

The direct and indirect effects of lime application to acid soils generally lead to enhanced crop growth. The magnitude of such effects varies widely under different soil conditions and cropping systems. Response to lime by various crops varies considerably even on the same soil. There are also great differences in response to lime even among varieties and species (Foy and Brown, 1964). Most economic crop, yield best in soils where the exchange complex is dominated by calcium ions. High Ca^{2+} ion indicates a near neutral pH which is desirable for most plants (Bohn *et al.*, 1979).

Volk (1962) found that liming reduced the yield of grasses receiving urea or ammonium fertilizer, but did not reduce the yield of those receiving nitrate-N. In the field lime increased uptake of soil N by 15-42kgN/ha (Nyborg and Hoyt, 1978).

Liming significantly increased yield of fresh and dry biomass, grain and juice sugar extract from stalk of sweet sorghum, the Mn concentration of the biomass was also greatly decreased (John *et al.*, 1985).

Kehoe and Curnow (1963) suggested that lime applications might increase P uptake by improving the physiological conditions of the plant. Liming acid soils often increases P uptake by decreasing Al toxicity rather than soil P availability (Haynes and Ludeck, 1981; Vickers and Zak, 1978). Synder and Krestchmer (1985) reported that lime and P treatment resulted into maximum yield for legumes. Dry matter yield was also increased with high lime levels. High rates of P without lime reduced yield. There was a significant interaction between lime and P treatment with respect to yield (Rhue and Evert, 1987). Field experiment on acid soils showed that alfalfa dry matter yields increased with increasing soil pH, as a result of lime applications (Adams, 1984).

Narottama (1974) stated in his work that Ca content of the plants studied in relation to lime increased with increasing lime levels. The Ca:Mg ratio in plants increased with liming (Mathur and Levesque, 1983). Christenson *et al.* (1973) reported that liming of acid soils may influence Mg uptake. It was concluded that Mg uptake was significantly greater as $CaCO_3$ was applied. There has however been several reports of lime induced reduction in tissue Mg level and Mg uptake by plants (Christenson *et al.*, 1973, Juo and Uzo, 1977). Mathur and Levesque (1983) also stated that plant concentrations of N, P and K generally decreased with high liming rates (2,000 kg - 3,000 kg/ha). Juo and Ballaux (1977), studied the response of maize to liming in the greenhouse using an acid ultisol from Southern Nigeria. The soil was limed to various pH levels and maize grown for 10 weeks. The largest growth

response occurred when the soil pH was raised from 4.3 to 5.0, and the highest yield was obtained when the soil pH was between 5.5 to 6.0.

The uptake of Mn by plants appears to be closely related to soil pH and the accompanying solubility. Chen and Quelletle (1971) reported that pH increases due to liming acid soils resulted in a twofold decrease in Mn content of plants when limed (Juo and Uzo, 1991). Kowalenko *et al.* (1980) also reported that oat Mn uptake decreased significantly with increased limestone application, Oat Mn concentraions were below critical levels in heavily limed soils. Liming soils to pH 5.5 or above decreased foliar concentrations and eliminated the toxic effects of Mn in soyabean and increased yields (Jones and Nelson, 1978). Mandal and Sinha (1964) observed that Mn content of soyabean, cotton and groundnut was depressed by the application of lime and the magnitude of depression varied for different crops. Umesh *et al.* (1978) reported increase in Mo concentration in wheat and barley tissues at higher rates of limestone application. When red clover was grown on a soil of pH 5.4, the uptake of Mo was increased by as much as six fold when limed to pH 6.4 (Mitchel and Burridge, 1979).

Liming an acid soil may decrease the amount of plant available B (Wear and Paffer, 1969). Fox (1968) observed that high pH values reduced B uptake by nearly 50% in cotton. Liming strongly acid soil reduces B concentration in the aerial portion of several crops (Gupta, 1972) and in some cases may induce B deficiency in cereals like barley. A study conducted on 3 podsol soils with original pH values of between 5.0 - 5.4, showed that the sharpest decrease in B concentration (from 117 to 388 down to 58 to 83 ppm) in barley and chick pea plant tissues occurred with the

addition of 2.5glime/kg, while 5glime/kg resulted in a further decrease in tissue B concentration at a lesser magnitude than 2.5glime/kg rate.

Patiran (1990) reported that iron content in 45 -day old wheat plants were reduced by liming and plant Fe concentration correlated with available Fe. It has also been reported that Fe content of tissues increased at pH beyond 5.2, and decrease at pH beyond 5.2 (Umesh, 1972). Mahendra and Dahiya (1976) worked on pea and reported that Fe concentration and uptake decreased with increase in $CaCO_3$.

Liming depressed the uptake of Zn by plants (Juo and Uzo, 1991). Kowalenko *et al.* (1980) reported that Zn uptake decreased significantly with increased lime application and plant Zn concentrations were below critical levels in highly lime treatments. Duguma *et al.* (1988) reported that Zn levels in leucaena were reduced with increased lime application. Aurther and Abou Zam-Zam (1989) reported that at high Zn levels increase in Ca resulted in more Zn in both leaves and roots of soyabean.

The Cu content of barley tissue increased with increase in soil pH from 4.2 to 5.2, but little change occurred when the pH was above 5.2 (Umesh, 1972).

2.17 Effects of Lime on Tomato Growth and Yield

Tomatoes grow moderately well over a range of levels of each nutrient. Improving the nutrient supply is however essential in achieving high yields and good quality fruits for profitable production. When lime is applied to acidic soils many chemical parameters are altered, making it difficult to determine which changes are responsible for improved crop growth (Doerge *et al.*, 1985; Thomas and Hangrove, 1984).

The growth of shoot and root tissues in tomatoes was reduced by NH_4-N when pH of the medium was not buffered, but when lime was added, there was an increase in growth (Claasen and Wilcox, 1975). Liming had little effect on yield at low level of N, but depressed the yield by an average of 12% at high N levels (Winsor *et al.*, 1967).

Pombo and Smith (1986) reported that at high pH 5.5 tomato yields tend to be lower. Asiegbu and Uzo (1983), in field experiment on ferrallic sandy loam (dry and wet seasons), showed that tomato fruit yield and dry matter accumulation were significantly increased by liming at pH 5.2, while at pH 5.7 and above, liming had little effect. Graves *et al.* (1978) reported that total yield of fruits decreased (18-24%). When peat soil was limed to pH greater than 6.0. They also reported that combination of heavy liming and ommission of micronutrients was particularly detrimental and depressed yield by 40-87% as compared to most favourable treatment. Liming the soil from pH 6.3 to 7.4 had an adverse effect and depressed yield by 10-16% (Winsor *et al.*, 1967) and increased the proportion of unevenly ripened fruits (Winsor and Long, 1967). Worley (1977) reported that best marketable yields were obtained when soil pH (Loamy sand) was between 6.5 - 6.9. Yields were reduced when pH was below 6.0. Tomato yields are reported to be closely correlated with soil pH (Rivera *et al.*, 1986).

A number of physiological disorders in tomato are related to inadequate Ca. Blossom-end rot of tomatoes is a physiological disorder caused by a deficiency of Ca in the fruit (Vangoor, 1968; Millican *et al.*, 1971; Geraldson, 1975) has shown that blossom-end rot is sometimes attributed to low Ca in the fruit. Liming increases the levels of soil Ca (Hayslip and Ozaki, 1958). Prezotti and Balbino *et al.* (1990)

reported that liming reduced the incidence of blossom-end rot. High Ca content of plant tissues has been associated with reduced disease severity. The severity of bacterial Canker disease development has been inversely correlated with the concentration of Ca in the nutrient solutions and in the petiole and stem tissues of tomato (Foster and Echandi, 1975). Berry *et al.* (1988) also reported that Ca depresses severity of bacterial canker in both susceptible and resistant cultivars.

CHAPTER THREE

MATERIALS AND METHODS

A greenhouse and two field experiments during wet and dry season were carried out at the Institute for Agricultural Research (IAR), ABU, irrigation site, Samaru (Latitude 11° 11'N and longitude 7° 38'E).

3.1 Green House Experiments

3.1.1 Collection and preparation of soil samples

The soil samples for the greehouse experiment were collected from the Institute for Agricultural Research irrigation site at Samaru in the Northern guinea savanna ecologica Zone. The soils are developed from drift sand, overlaying basement complex (Klinkiberg and Higgins, 1968), and classified as Alfisols (Awujoola, 1979). The area has a mean annual rainfall of about 1050mm stretching from May to September (Kowal and Knabe, 1972). Global radiation is evenly distributed through out the year, ranging from 440 $CalCm^{-2}$ day^{-1} in August to 550$CalCm^{-2}$ day^{-1} in April and May (Kowal and Knabe, 1972). The field is fairly flat and has been used for production of tomato under irrigation.

Soil samples were collected from 20 equally spaced points at 0-15cm depth from the field. The samples were bulked and mixed thoroughly and allowed to air dry after which they were sieved through a 2mm stainless sieve and sub-samples removed for characterization of the soil.

3.1.2 Treatments and experimental design

The treatments consist of five levels of lime (hydrated lime (CaO), (O, 0.10, 0.25, 0.40 and 0.55t/ha), two nitrogen sources (Urea and calcium ammonium nitrate)

and three tomato varieties namely TI 221 (local indeterminate), TI 106 (Roma V.F. determinate) and TI 539 (Compact determinate).

The Nitrogen sources were applied at the rate of 100kgN/ha with a blanket application of single super phosphate (SSP) at the rate of 45kg/ha. The treatment combinations were arranged in a randomised complete block design and replicated three times.

3.1.3 Green house technique

Five kilograms of the sieved soil were weighed in to 90 pots. Each pot was mixed with appropriate lime rate and single superphosphate fertilizer. The soils were wetted to field capacity and left to incubate for 4 days. The seedlings were transplanted in to the pots at 5 weeks after sowing in the nursery. The N sources were applied in two split doeses. The first dose was applied after transplanting while the second dose was at flowering.

The soils were maintained at field capacity through regular watering. Any drained water in the receiver was returned into the pot.

Non-destructive measurements of plant height, number of leaves, branches, flowers and fruits were taken at 14 days intervals. A plant was harvested from each pot at flowering for tissue analysis as recommended by Zurbick (1961). Each sample was washed with tap water, rinsed with distilled water, seperated into 4th and 5th leaves, which best reflects the nutrient levels as recommended by Geraldson *et al.* (1973). Samples were enveloped and dried in an oven at 65°C to a constant weight. The dried samples were then ground with stainless mill and were stored in small polythene bags for elemental analysis.

3.2 Wet Season Experiment

3.2.1 Site description and history

The field trial was carried out on the Institute for Agricultural Research, A.B.U. irrigation field located in Samaru. The site is the same as where the soil sample for the greenhouse experiment was collected.

3.2.2 Treatment, design and cultural practices

The treatments and design were as described for the greenhouse study. The field was ploughed and harrowed. Plots of 5m x lm were marked out and raised into beds above the ground level to provide better drainage. Appropriate rates of lime were applied to appropriate plots according to treatments. The lime was mixed thoroughly with the soil, by incorporating with hoe and allowing to incubate for four days. The seedlings were transplanted at 6 weeks after sowing in the nursery. With the exception of the second split dose of N, all other fertilizers were applied after transplanting.

3.2.3 Weeding

Three hoe weedings were carried out at 6, 10 and 14 weeks after transplanting. The most predominant weed was nut grass (*Cyperus Rotundus*).

3.2.4 Disease and pest control

A mixture of Benlate + Dithane M-45 at (0.7 kg/ha + 2.5 kg/ha) were sprayed to crops at 14 days interval until harvesting to control fungal diseases. There was an incidence of fungal disease (*Sclerotum rolfsii*). The attack was minimal due to control measure taken.

3.3 Dry Season Experiment

3.3.1 *Site description and history*

This is the same as that used for both green house and wet season experiments.

3.3.2 Treatments, design and cultural practices

The treatments and design were as described for both greenhouse and wet season experiments, except that the levels of lime were increased. The rates were 0, 1.22, 2.24, 4.48 and 8.96t/ha.

The field was ploughed and harrowed. Plots of 5m x 1m were marked out. The plots were bounded by low levees to form slightly sunken basin to contain irrigation water.

Appropriate rates of lime were applied to appropriate plots according to treatments. The lime was mixed thoroughly with the soil, by incoporating with hoe, then irrigated and allowed to incubate for four days. The seedlings were transplanted at 5 weeks after sowing in the nursery. With the exception of the second split dose of N, all other fertilizers were applied after transplanting.

3.3.3 Weeding and irrigation

There was less weed problem during the dry season experiment, it was therefore weeded three times, at 3, 8 and 14 weeks after transplanting.

The crops were irrigated once a week throughout their field life.

3.3.4 Disease and pest control

A mixture of Benlate – Dithane M-45 at (0.7kg/ha + 2.5 kg/ha) were sprayed twice throughout the growth period of the crops to control fungal diseases.

3.4 Observations and Measurements

Observations and measurements were taken on tagged plants, inorder to have constant plants for sampling. Five plants were randomly tagged per plot on which parameters were observed at two weekly intervals (4, 6, 8, 10, 12 and 14 weeks after transplanting).

3.4.1 Plant height

The plant height was taken as the length of the shoot apex of the main axis of the plant to the ground level, measured with meter rule. Measurements were made fort nightly from 4 WAT till 8 WAT for the wet season and upto 12 WAT for the dry season trials.

3.4.2 Number of leaves and branches

Counts of the number of leaves and primary branches per plant were made starting 4 WAT till 8 WAT for the wet season and upto 12 WAT for the dry season trials.

3.4.3 Number of flowers

The number of flowers were recorded fortnightly from 4 WAT to 8 WAT for wet season and upto 12 WAT for dry season trials.

3.4.4 Number of fruits

The number of fruits were also recorded from 6 to 14 WAT.

3.4.5 Total numbers of fruits

The cummulative number of fruits (marketable and unmarketable), were also recorded at the final harvest.

3.4.6 Fruit diameter

Five fruits were randomly selected per plot. The diameter of the sample fruits were measured using a measuring tape, and the mean fruit diameter calculated.

3.4.7 Mean fruit weight

Five fruits were randomly selected per plot at every harvest. The weight was determined using a metre balance. The mean weight was expressed in grammes.

3.4.8 Total fruit yield

Matured (ripe) fruits were harvested manually at weekly intervals. The harvests from each plot were weighed and used to determine the fruit yield expressed per hectare.

3.5 Soil Samplimg and Preparation

Soil samples were taken at 0-15cm depth from the whole field before land preparation and from each plot at flowering and after harvest. The samples were air-dried and sieved through a 2mm stainless steel sieve. The sieved samples were stored in polythene bags for routine physical and chemical analysis.

3.5.1 Soil analysis

The soil smaples were analysed for particle size by the standard hydrometer method (Day, 1965). The soil pH was determined in 1:2.5 soil: water and salt (0.0lm $CaCl_2$) suspension with a glass electrode pH meter. Organic carbon content was determined by the wet oxidation method of Walkley - Black method as described by Juo (1979). The total nitrogen was determined by semi - micro - Kjeldahl method

(Bremner and Mulvaney, 1982), available P was extracted by Bray I method and P in solution was determined by the molydate blue colour method (Murphy and Riley, 1962). Exchangeable bases were determined by extraction with neutral **IN** NH_4OAC saturation method. Sodium and K were determined by the flame emission (Kundsen *et al.*, 1982), while Ca, Mg and the micronutrients were determined by using Pye unicam model SP 192 Atomic Absorption spectrophotometer. Cation exchange capacity was determined by summation. Details of the analytical procedures are as described by Juo (1979).

3.6 Plant Sampling

The 4th and 5th top leaves were taken from tagged plants as recommended by Geraldson *et al.* (1973). These were washed in tap water and rinsed in distilled water, enveloped and dried in an oven at 65°C for 48 hours. The dried samples were ground in a stainless steel mill and stored in polythene bags for subsequent laboratory analysis.

3.6.1 Plant tissue analysis

A 0.5g sample of plant material was weighed into 125ml Erlenmeyer flask and digested with an acid mixture of perchloric acid, 32.5 ml nitric acid and 1ml sulphuric acid. Potassium in the diluted digest was determined by flame photometry, while Ca, Mg, Mn, Zn, Cu and Fe were determined from the digest using Pye unicam model SP 192 atomic absorption spectrophotometry. Phosphorus was determined by the vanadomolybdate yellow colour method (Juo, 1979). Nitrogen in plant tissue was determined by the mico-kjeldahl wet-digestion method outlined by Bremner (1965).

3.7 Statistical Analysis

All the data collected were subjected to analysis of variance (ANOVA) using GENESTAT PACKAGE for statistical analysis at the Institute for Agricultural Research Computer Unit. The treatment differences were evaluated by the Duncan's Multiple range test (DMRT). Simple correlation studies were also run for some selected parameters.

CHAPTER FOUR

RESULTS

4.1 Physical and Chemical Properties of the Soil and Lime Material Used

Table 1 shows the physical and chemical properties of the soil from the experimental site. The soil is silty loam in texture, it is acidic in reaction with low content of total N, organic carbon and available P. The cation exchange capacity (CEC) is also low (3.50 and 4.10 Cmolkg^{-1}). Jones and Wild (1975) reported that Savanna soils generally have CEC of less than 5.0 cmol kg^{-1} soil. The exchangeable bases and micronutrients were also found to be low. The acidic nature is attributed to the serious acidifying effect of fertilizers on the poorly buffered savanna soils (Bache 1965). In a long-term experiment at Samaru 19 small annual applications of ammonium sulphate (12 and 24 kgNha^{-1} annum^{-1}) significantly decreased top soil exchangeable calcium and Magnesium but not potassium (Bache and Heathcots, 1969). Abruna *et al.* (1958) reported that heavy applications of nitrogen caused acidification not only in the top soil, but to considerable depth in subsoil as well.

The lime used in the study was powdery white. Results of the analysis showed that the lime contained 47% calcium.

4.2 Green House Studies

4.2.1 Effect of lime and N Sources on plant height

At all stages of measurement, plant height increased with increaing rates of lime (Table 2). At 4 WAT, the response was significant (at p=0.05) with values at 0.40 and 0.55t/ha being significantly higher than at other rates. At 6 WAT, value at 0.55t ha gave significantly taller plants than the other rates, while at 8 WAT, the

Table 1. Some Physico- Chemical Properties of the Soil used

Property	Values
Sand (g kg^{-1})	220
Silt (g kg^{-1})	680
Clay (g kg^{-1})	100
Texture	Silty loam
pH (1:2.5 H_20)	4.90
pH (1:2.5 0.01M$CaCl_2$)	4.60
Organic Carbon (g kg^{-1})	6.00
Total N (g kg^{-1})	0.70
Exchangeable K (cmol kg^{-1})	0.27
Exchangeable Ca (cmol kg^{-1})	2.70
Exchangeable Mg (cmol kg^{-1})	0.42
Exchangeable Na (cmol kg^{-1})	0.11
Available P (Mg kg^{-1})	19.54
Extractable Zn (mg kg^{-1})	21.50
Extractable Fe (mg kg^{-1})	80.10
Extractable Cu (mg kg^{-1})	1.10
Extractable Mn (mg kg^{-1})	65.00
C E C (cmol kg^{-1})	3.50

Table 2. Effect of lime and N Sources on Plant height in the green house.

Treatment	Plant height (cm) Weeks after Transplanting 4	6	8
Lime t/ha)			
0	39.19b	44.36b	53.85b
0.10	39.89b	45.42b	56.85b
0.25	41.69ab	47.58b	58.33ab
0.40	42.92a	50.64ab	60.67a
0.55	44.58a	56.00a	63.58a
SE±	1.14	1.51	1.41
Nitrogen Sources			
Urea	40.47b	47.07b	56.64b
CAN	42.84a	49.03a	60.61a
SE±	0.72	0.97	0.89
Varieties			
TI 221	42.93a	49.72a	62.41a
TI 106	40.63b	47.65b	55.73b
TI 539	41.40ab	49.03b	57.73b
SE±	0.88	1.19	
Interactions			
L x N	NS	NS	NS
L x V	NS	NS	NS
N x V	*	NS	*
L x N x V	NS	NS	NS

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of significance using DMRT. NS = Not Significant * = Significant.

response was significant with values at 0.40 and 0.55t/ha being significantly higher than at 0 to 0.25t/ha rates. Significantly taller plants were observed when CAN was applied. Varietal differences were also significant with variety TI 221 giving significantly taller plants than the other varieties. Significant interaction effect between N sources and varieties was recorded at 4 and 8 WAT (Tables 3 and 4). Application of CAN significantly increased plant height in variety TI 221 at both sampling periods.

4.2.2 Effect of lime and N sources on the number of leaves per plant

Number of leaves per plant was significantly higher with application of 0.55/ha lime, while the control and other rates did not differ significantly at all the sampling periods (Table 5). Higher number of leaves was also obtained when CAN was applied. With respect to varieties, variety TI 221 gave significnatly higher number of leaves than the other varieties. A significant interaction between N sources and varieties was obtained (Table 6), variety TI 221 gave significantly higher number of leaves with the application of CAN.

4.2.3 Effect of lime and N sources on the number of branches per plant

The response of branching in tomato plants to the treatments is shown in Table 7. At 4 WAT, no significant increase in the number of branches per plant was observed. At 6 and 8 WAT, values were significant at 0.40 and 0.55t/ha. Higher number of branches were obtained with the application of CAN at all stages of measurement. With respect to varieties, values were significantly higher in variety TI 221. Interaction effects were not significant.

Table 3. Interaction effect of N Sources and Varieties on Plant height at 4 WAT

Nitrogen sources	Varieties		
	TI221	TI106	TI539
Urea	39.60b	40.80	41.00b
CAN	46.27a	40.47b	41.00b
SE±		1.24	

Table 4. Interaction effect of N Source and Varieties on Plant height at 8 WAT.

Nitrogen sources	Varieties		
	TI221	TI106	TI539
Urea	57.74b	55.07b	57.13b
CAN	67.09a	56.40b	58.33b
SE±		1.55	

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of significance using DMRT.

Table 5. Effect of lime and N Sources on the number of leaves per plant in the green house.

Treatment	Number of leaves — Weeks after Transplanting 4	6	8
Lime t/ha)			
0	14.17b	21.78b	26.28b
0.10	14.61b	23.94b	28.06b
0.25	16.22b	26.11b	30.11b
0.40	18.89ab	29.61ab	32.78ab
0.55	24.17a	32.72a	35.89a
SE±	1.55	1.50	1.07
Nitrogen Sources			
Urea	15.69b	24.07b	29.91b
CAN	19.53a	29.60a	31.33a
SE+	0.99	0.95	0.66
Varieties			
TI 221	22.33a	31.47a	34.97a
TI 106	15.60b	24.93b	28.00b
TI 539	14.90ab	24.10b	28.90b
SE±	1.20	1.16	0.83
Interactions			
L X N	NS	NS	NS
L X V	NS	NS	NS
N X V	NS	*	NS
L X N X V	NS	NS	NS

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of significance using DMRT. NS = Not Significant * = Significant.

Table 6. Interaction effect of N Sources and Varieties on the number of leaves per plant at 6 WAT.

Nitrogen Sources	Varieties		
	TI221	TI106	TI539
Urea	26.40b	24.20b	21.60b
CAN	36.53a	25.67b	26.60b
SE±	1.64		

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of significance using DMRT.

Table 7. Effect of lime and N sources on the number of branches per plant in the green house.

Treatment	Number of branches (Weeks after Transplanting) 4	6	8
Lime (t/ha)			
0	1.67	2.39b	3.11b
0.10	1.67	2.11b	3.44b
0.25	1.33	2.17b	4.33b
0.40	1.61	3.22b	6.11a
0.55	1.78	4.72a	7.78a
SE±	0.45	0.42	0.43
Nitrogen Sources			
Urea	1.22	2.36b	4.22b
CAN	2.00	3.49a	5.89a
SE±	0.29	0.27	0.27
Varieties			
TI221	3.00a	4.57a	7.03a
TI106	1.00b	2.25b	5.23b
TI539	0.83b	1.70c	2.90c
SE±	0.30	0.29	0.28
Interactions			
L X N	NS	NS	NS
L X V	NS	NS	NS
N X V	NS	NS	NS
L X N X V	NS	NS	NS

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of significance using DMRT. NS = Not Significant.

4.2.4 Effect of lime and N sources on the number of flowers per plant

Number of flowers per plant as influenced by liming and N sources is shown in Table 8. At 4 WAT, liming and N source did not significantly affect number of flowers per plant. At 6 and 8 WAT, values were significant at 0.40 and 0.55t/ha. Application of CAN significantly increased number of flowers per plant at 4 and 6 WAT. Interaction effect was not significant.

4.2.5 Effect of lime and N sources on the number of fruits per plant

Generally, number of fruits per plant tended to increase with increasing levels of lime (Table 9). At 6 WAT, number of fruits per plant at the highest level of application of 0.55t/ha was significantly higher than at other levels. At 8 WAT and at harvest values were only significantly higher at 0.40 and 0.55t/ha. Application of CAN was only significant at 6 WAT. With respect to varieties, values were significantly higher with TI 221 at all stages of measurement. A significant interaction between N sources and varieties was obtained at 6 WAT (Table 10). With the application of CAN, value was significant with variety TI 221.

4.2.6 Effect of lime and N sources on the mean fruit diameter and weight

Mean fruit diameter and weight tended to increase with increasing lime rates (Table 11). Fruit mean diameter was significantly increased with 0.55t/ha. Similar trend was also observed with mean fruit weight. Both mean fruit and weight were significantly increased with application of CAN. Varietal differences were noticed with varieties TI 221 and TI 539 having significantly higher mean diameter, significantly higher mean diameter, while fruit weight was significant with variety TI 539. Interaction effects were not significant.

Table 8: Effect of lime and N sources on the number of flowers per plant in the greenhouse.

Treatment	Number of flowers (Weeks after Transplanting) 4	6	8
Lime (t/ha)			
0	3.28	3.50b	4.56b
0.10	3.22	4.50b	5.44b
0.25	2.28	5.28b	6.67b
0.40	3.22	6.89ab	9.44a
0.55	2.39	8.44a	11.72a
$SE_{\pm}$	0.53	0.56	0.60
Nitrogen Sources			
Urea	2.58b	5.24b	7.04
CAN	3.81a	6.20a	8.09
SE ±	0.34	0.36	0.38
Varieties			
TI 221	2.87	5.30	7.67
TI 106	2.43	5.10	7.50
TI 539	3.33	6.77	7.53
$SE_{\pm}$	0.41	0.44	0.47
Interaction			
L x N	NS	NS	NS
L x V	NS	NS	NS
N x V	NS	NS	NS
L x N x V	NS	NS	NS

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of significance using DMRT. NS = Not Significant.

Table 9. Effect of lime and N sources on the number of fruits per plant in the green house.

	Number of fruits		
	Weeks after Transplanting		
Treatment	6	8	At harvest
Lime (t/ha)			
0	3.83c	5.56b	4.78c
0.10	4.33c	7.39b	6.22c
0.25	4.83c	9.56b	9.28b
0.40	7.89b	12.44a	12.06a
0.55	12.89a	14.06a	14.61a
SE±	0.41	0.06	0.67
Nitrogen Sources			
Urea	6.02b	9.33b	9.90
CAN	7.47a	10.27a	9.64
SE±	0.26	0.40	0.43
Varieties			
TI221	7.37a	10.90a	9.90a
TI106	6.60b	6.67b	9.23b
TI539	6.27b	8.83b	9.24b
SE±	0.31	0.49	0.52
Interactions			
L X N	NS	NS	NS
L X V	NS	NS	NS
N X V	*	NS	NS
L X N X V	NS	NS	NS

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of significance using DMRT. NS = Not Significant * Significant.

Table 10: Interaction effect of N Sources and Varieties on the number of fruits per plant at 6 WAT.

Nitrogen Sources	Varieties		
	TI221	TI106	TI539
Urea	6.07bc	5.87c	6.13b
CAN	8.67a	7.33ab	6.40b
SE±		0.47	

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of significance using DMRT.

Table 11. Effect of lime and N sources on the mean fruit diameter and weight in the greenhouse.

Treatment	Mean diameter (cm)	Mean weight (g)
Lime (t/ha)		
0	10.50c	22.03c
0.10	12.81c	26.25bc
0.25	14.75c	29.11b
0.40	17.53b	31.44ab
0.55	21.81a	36.64a
SE±	0.76	1.39
Nitrogen Sources		
Urea	14.50b	27.39b
CAN	16.46a	30.80a
SE±	0.48	0.88
Varieties		
TI221	16.38a	29.07b
TI106	14.05b	26.83c
TI533	16.00a	31.38a
SE±	0.59	1.08
Interactions		
L X N	NS	NS
L X V	NS	NS
N X V	NS	NS
L X N X V	NS	NS

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of significance using DMRT. NS = Not Significant

4.2.7 Effect of lime and N sources on the total fruit yield

Total fruit yield is given in Table 12. Pots receiving 0.40 and 0.55t/ha lime gave significantly higher values than the other rates. With the application of CAN, value was significantly higher than with urea. Variety TI 221 significantly out yielded the other varieties. Interaction effects were not significant.

4.2.8 Effect of lime and N sources of the macronutrient concentrations in tomato leaves

Generally the concentrations of macronutrient elements increased with increasing levels of lime (Table 13). The concentrations of N, P, Ca and Mg were significantly increased when lime was applied at 0.40 and 0.55t/ha, while K was not affected by the application of lime. The concentrations of N and Mg were significantly higher in tomato leaves when CAN was applied. Nitrogen source did not have any significant effect on P, Ca and K concentrations. Interaction effect between N source and Lime on Ca concentration was significant (Table 14). Calcium concentration was significantly higher with lime at 0.40 and 0.55t/ha for both N sources.

4.2.9 Effect of lime and N sources on the micronutrient concentration in tomato leaves

The concentrations of micronutrients in tomato leaves presented in Table 13, indicate a reduction in concentration with increasing levels of lime. The levels, tended to be significantly reduced by liming especially at the highest levels. The concentration of Mn was significantly higher with the application of urea, while Zn, Fe and Cu were not significantly affected by N sources.

Table 12. Effect of lime and N sources on the total fruit yield in the greenhouse.

Treatment	Total fruit yield(g)
Lime (t/ha)	
0	99.90b
0.10	125.70b
0.25	137.20ab
0.40	151.40a
0.55	165.20a
SE±	7.55
Nitrogen Sources	
Urea	128.60b
CAN	143.20a
SE±	4.77
Varieties	
TI221	138.60a
TI106	131.50b
TI539	137.20a
SE±	5.84
Interactions	
L X N	NS
L X V	NS
N X V	NS
L X N X V	NS

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of significance using DMRT. NS = Not Significant

Table 13: Effect of lime and N Sources on Nutrient concentrations in tomato leaves in the greenhouse

Treatment	Nutrient element concentrations								
	N	P	K	Ca	Mg	Zn	Mn	Fe	Cu
	%					$Mgha^{-1}$			
Lime (t/ha)									
0	1.95c	0.35c	3.32	2.33d	0.30c	108.70a	103.20a	128.10a	12.27a
0.10	2.45b	0.36c	3.70	2.46cd	0.35c	108.50a	112.60a	117.50bc	11.96a
0.25	2.28b	0.41bc	3.96	2.93c	0.37c	103.50b	71.00c	122.60ab	12.17a
0.40	2.92a	0.44b	3.68	3.84b	1.70b	100.90b	80.50b	113.40c	10.29b
0.55	3.07a	0.52a	3.77	4.65a	1.93a	100.80b	63.30c	88.40d	8.00c
SE±	0.26	0.05	0.16	0.33	0.16	3.12	3.89	6.24	0.44
Nitrogen Sources									
Urea	2.36b	0.42	3.67	3.33	0.40b	104.30	83.10b	113.30a	10.96
CAN	2.71a	0.41	3.70	3.16	0.61a	105.70	89.20a	114.70b	10.92
SE±	0.26	0.05	0.16	0.33	0.16	1.97	2.46	3.95	0.28
Interaction									
L x N	NS	NS	NS	*	NS	NS	NS	NS	NS
L x V	NS	NS	NS	NS	NS	NS	NS	NS	NS
N x V	NS	NS	NS	NS	NS	NS	NS	NS	NS
L x N x V	NS	NS	NS	NS	NS	NS	NS	NS	NS

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of significance using DMRT. NS = Not Significant.
* = Significant

Table 14. Interaction effect of lime and N Sources on Ca concentration (%) in tomato leaves.

Treatment	Nitrogen Sources	
	Urea	CAN
Lime(t/ha)		
0	2.14c	2.53bc
0.10	2.94b	1.99c
0.25	2.85b	3.01b
0.40	4.53a	3.14ab
0.55	4.17a	5.13a
SE±	0.97	

Table 15. Interaction effect of lime and N Sources on Mn Concentration (mg/kg) in tomato leaves

Treatment	Nitrogen Sources	
	Urea	CAN
Lime(t/ha)		
0	97.60b	108.80b
0.10	107.00b	118.20a
0.25	60.60f	81.40cd
0.40	84.00c	77.10d
0.55	66.50e	60.20f
SE±	5.50	

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of Significance using DMRT.

Interaction between lime and N source on Mn concentration was significant (Table 15). Increasing lime rates significantly reduced Mn concentration in the leaves for both N sources.

4.2.10 Correlation coefficient between yield and yield related parameters

Correlation studies between tomato fruit yield per pot and yield-related parameters are presented in Table 16. The result of the analyses showed that there was a very strong positive correlation at P = 0.01 level of significance between fruit yield and plant height at 6 and 8 WAT (r = 0.418** and r = 0.492**), number of leaves per plant at 6 and 8 WAT (r = 0.372** amd r = 0.438**), number of branches per plant at 6 and 8 WAT (r = 0.394** and r = 0.352), number of flowers per plant at 6 and 8 WAT (r = 0.566** and r = 0.486**), number of fruits per plant at 6, 8 WAT and at harvest (r = 0.457**, r = 0.564** and r = 0.567**), mean fruit diameter (r = 0.413**) and mean fruit weight (r = 0.522**).

4.2.11 Correlation coefficient between yield-related parameters and nutrient element concentrations in leaves

The correlation coefficient between yield-related parameters and nutrient concentration is given in Table 17. Nitrogen concentration was positively and significantly (at p = 0.01 and 0.05) correlated with plant height (r = 0.486** and r = 0.255**), number of leaves per plant (r = 0.210** and 0.227*), branches (r = 0.210** and r = 0.325**), flowers (r = 0.353** and r = 0.419**),fruits (r = 0.464**, r = 0.400** and r = 0.338**), mean fruit diameter (r = 0.362**) and weight (0.345**). Phosphorus concentration and plant height (r = 0.200*), number of leaves per plant (r = 0.304* and r = 0.345**), branches (r = 0.295*), flowers (r = 0.218* and 0.513**), fruits (r = 0.484**, r = 0.357** and r = 0.421**), mean fruit

Table 16: Matrix of Correlation coefficients (r) between tomato fruit yield per pot and yield - related parameters in the green house.

Variables															
	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}
x_1	1.000														
x_2	0.413**	1.000													
x_3	0.523**	0.553**	1.000												
x_4	0.412**	0.510**	0.559**	1.000											
x_5	0.457*	0.364**	0.484**	0.689**	1.000										
x_6	0.564**	0.366**	0.517**	0.587**	0.662**	1.000									
x_7	0.567**	0.414**	0.633**	0.640**	0.677**	0.689**	1.000								
x_8	0.566**	0.354**	0.494**	0.601**	0.600**	0.620**	0.708**	1.000							
x_9	0.486**	0.342**	0.551**	0.567**	0.551**	0.571**	0.558**	0.500**	1.000						
x_{10}	0.492**	0.354**	0.517**	0.421**	0.479**	0.506**	0.566**	0.501**	0.392**	1.000					
x_{11}	0.418**	0.359**	0.485**	0.517**	0.378**	0.519**	0.562**	0.551**	0.406**	0.533**	1.000				
x_{12}	0.372**	0.361**	0.377**	0.492**	0.469**	0.504**	0.522**	0.496**	0.331**	0.400**	0.363**	1.000			
x_{13}	0.438**	0.360**	0.473**	0.498**	0.464**	0.536**	0.559**	0.511**	0.378**	0.582**	0.388**	0.600**	1.000		
x_{14}	0.396**	0.310**	0.354**	0.478**	0.538**	0.591**	0.570**	0.467**	0.312**	0.459**	0.322**	0.571**	0.535**	1.000	
x_{15}	0.352**	0.352**	0.350**	0.404**	0.369**	0.441**	0.511**	0.374**	0.416**	0.436**	0.371**	0.488**	0.382**	0.654	1.000

X_1 = fruit yield per pot
x_2 = Mean fruit weight (g)
x_3 = Dry matter yield
x_4 = Mean fruit diameter
x_5 = Total number of fruits per plant
X_6 = Number of fruits per plant at 6 WAT
X_7 = Number of fruits per plant at 8 WAT
x_8 = Number of flowers per plant at 8 WAT
x_9 = Plant height at 6 WAT
x_{10} = Plant height at 8 WAT
x_{11} = Number of leaves per plant at 6 WAT
x_{12} = Number of leaves per plant at 8 WAT
x_{13} = Number of branches per plant at 8 WAT
x_{14} = Number of branches per plant at 6 WAT
x_{15} = Number of branches per plant at 8 WAT

* = Significant at 0.05 level
** = Significant at 0.01 level

Table 17: Correlation between tomato performance and Nutrient element concentration in tomato leaves in the green house.

Nutrients	Plant Performance												
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}
N	0.468**	0.255*	0.210*	0.227*	0.210*	0.325**	0.353**	0.419	0.464	**0.400****	0.338	0.362	0.345
P	0.200*	0.165	0.304*	0.345**	0.108	0.295**	0.218*	0.513**	0.484**	**0.357****	0.421**	0.349**	0.285**
K	0.064	0.204	0.055	0.057	0.020	0.036	0.138	0.093	0.197	**0.089**	0.264**	0.196	0.100
Ca	0.314**	0.181	0.144	0.195	0.047	0.146	0.411	0.523**	0.442**	**0.381****	0.471**	0.446**	0.421**
Mg	0.248**	0.189	0.214*	0.205*	0.231	0.351**	0.210*	0.453**	0.480**	**0.374****	0.417**	0.233**	0.236*
Zn	-0.100	-0.126	-0.001	-0.003	0.154*	-0.176	-0.041	-0.048	-0.125	**-0.049**	-0.28	-0.111	-0.035
Mn	-0.421**	-0.317**	-0.229*	-0.364*	-0.132**	-0.297**	-0.423**	-0.451**	-0.404**	**-0531****	-0.468**	-0.513**	-0.388**
Fe	-0.258**	-0.214*	-0.252*	-0.185	-0.171	-0.199	-0.369**	-0.178	-0.436**	**-0.305****	-0.357**	-0.390**	-0.238**
Cu	-0.481**	-0.255*	-0.397*	-0.368**	-0.272**	-0.386**	-0.390**	-0.498**	-0.587**	**-0.365****	-0.477**	-0.496**	-0.266**

* = Significant at 0.05 level ** = Significant at 0.01 level

X_1 = Plant height at 6 WAT
x_2 = Plant at 8 WAT
x_3 = Number of leaves per plant at 6 WAT
x_4 = Number of leaves per plant at 8 WAT
x_5 = Number of branches per plant at 6 WAT
X_6 = Number of branches per plant at 8 WAT
X_7 = Number of flowers per plant at 6 WAT
x_8 = Number of flowers per plant at 8 WAT
x_9 = Number of fruits per plant at 6 WAT
x_{10} = Number of fruits per plant at 8 WAT
x_{11} = Total number of fruits per plant
x_{12} = Mean fruit diameter
x_{13} = Mean fruit weight.
x_{14} = Number of branches per plant at 8 WAT

diameter (r = 0.449**) and weight (r = 0.285**). Potassium concentration was positively correlated to all yield-related parameters, but not significant except the total number of fruits per plant was significantly correlated (r = 0.264**). There was a positive and significant correlation between plant height (r = 0.314**), number of flowers (r= 0.411** and r = 532**), fruits (r = 0.442**, r = 0.381** and r = 0.477**), mean fruit diameter (r - 0.446**) and weight (r = 0.421**). Similarly plant height (r = 0.248*), number of leaves, (r = 0.214* and r = 0.205*), branches (r = 0.231* and r = 0.351**), flowers (r = 0.210* and r = 0.453**) fruits (r = 0.480** r = 0.374** and r = 0.417**), mean fruit diameter (r = 0.333*) and weight (r= 0.236*), were positively and significantly correlated to Mg concentration.

Manganese concentration and plant height (r = -0.248* and r = -0.317**), number of leaves (r = -0.229* and r = -0.364**), branches (r = -0.312** and r = -0.297*), flowers (r = -0.423** and r = -0.451**), fruits (r = -0.404**, r = -0.513**) and r = -0.468**), mean fruit diameter (r = -0.513) and weight (r = -0.388**), were found to be negative and significantly correlated. Correlation between Fe concentration and plant height (r = -0.258** and r = -0.214**) number of leaves (r = -0.252*), flower (r = -0.369**) fruits (r = -0.436**, r = -0.305** and r = -0.357**) mean diameter (r= -0.390**) and weight (r = -0.266**) were found to be negative and significantly correlated. While Cu concentration was found to be negetive and significantly correlated to plant height (r = -0.481 and r = - 0.255*) number of leaves (r = -0.397* and r = -0.386**) branches (r = -0.272* and r = -0.386**), flowers (r = -0.390** and r = -0.498**), fruits (r= -0.587**, r = -0.365** and r = -0.477**), r = -0.456**) and weight (r = -0.266**) .

4.3 Wet Season Trial

4.3.1 Effect of lime and N Sources on plant height.

At all stages of measurement, plant height increased with increasing rates of lime (Table 18). At 4 WAT, the response was significant with value at 0.55t/ha being significantly higher than at other rates. At 6 WAT, values between 0.25 to 0.55t/ha were significantly higher than the control and 0.10t/ha, while at 8 WAT, there was no significant difference between the control and upto 0.40t/ha. Value at 0.55t/ha was significantly higher. Plants were significantly taller when CAN was applied except at 4 WAT. Varietal differences were also significant at all stages of measurement, values were significantly lower when variety TI 106 was planted. Interaction effects were not significant.

4.3.2 Effect of lime and N sources on the number of leaves per plant

The effect of lime and N sources on the number of leaves per plant is shown in Table 19. Generally number of leaves per plant tended to increase with increasing levels of lime. At 6 WAT, number of leaves per plant at the highest level of application was significantly higher than at other levels. At 8 WAT, liming upto 0.40t/ha did not significantly influence the number of leaves per plant, while at 0.55t/ha values were significantly higher. Nitrogen sources did not affect the number of leaves per plant. With respect to varieties, variety TI 221 gave values that were significantly higher than the other varieties at all stages of measurement. A significant interaction between lime and varieties was recorded at 6 WAT (Table 20). With variety TI 221, values at 0.40 and 0.55t/ha were significantly higher than the control, 0.10 and 0.25t/ha rates, while with varieties TI 106 and 539, values were significantly higher at 0.55t/ha rate.

Table 18: Effect of lime and N sources on plant height in the wet season

Treatment	Plant height (cm)		
	Weeks after transplanting		
	4	6	8
Lime (t/ha)			
0	36.08C	53.03b	67.31b
0.10	40.64b	56.31b	70.28b
0.25	42.88b	62.08ab	76.11b
0.40	44.68b	64.75a	78.11ab
0.55	49.57a	67.47a	84.48a
SE ±	1.11	1.30	1.96
Nitrogen Sources			
Urea	43.08	60.18b	73.86b
CAN	42.42	61.28a	76.65a
SE ±	0.70	0.83	1.24
Varieties			
TI 221	44.02a	64.03a	79.38a
TI 106	39.92b	57.20 b	71.55c
TI 539	44.32a	60.95a	74.80b
SE ±	0.86	1.01	1.52
Interaction			
L x N	NS	NS	NS
L x V	NS	NS	NS
N x V	NS	NS	NS
L x N x V	NS	NS	NS

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of significance using DMRT. NS = Not Significant.

Table 19 Effect of lime and N sources on the number of leaves per plant in the wet season.

Treatment	Number of Leaves (Weeks after Transplanting) 4	6	8
Lime (t/ha)			
0	19.20	27.42d	42.50b
0.10	19.31	29.92d	44.40b
0.25	29.92	34.75c	45.20b
0.40	20.05	38.81b	51.00ab
0.55	20.00	48.53a	55.00a
SE ±	1.22	1.81	3.23
Nitrogen Sources			
Urea	20.67	33.49	45.40
CAN	21.02	32.50	44.80
SE ±	0.71	1.42	2.05
Varieties			
TI 221	25.35a	44.13a	57.50a
TI 106	19.17b	31.63 b	45.20b
TI 539	18.57b	31.88b	40.10b
SE ±	0.87	1.40	2.50
Interaction			
L x N	NS	NS	NS
L x V	NS	*	NS
N x V	NS	NS	NS
L x N x V	NS	NS	NS

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of significance using DMRT. NS = Not Significant. * = Significant

Table 20. Interaction effect of lime and varieties on the number of leaves per plant at 6 WAT.

Treatment	Varieties		
	TI 221	TI 106	TI 539
Lime (t/ha)			
0	30.17c	26.75c	25.33c
0.10	35.92c	29.08c	24.75c
0.25	42.58b	31.50b	30.17b
0.40	55.33a	27.83c	33.25b
0.55	56.67a	43.00a	45.92a
SE ±		3.13	

Table 21. Effect of lime and N sources on the number of brances per plant in the wet season.

Treatment	Number of branches		
	Weeks after Transplanting		
	4	6	8
Lime (t/ha)			
0	2.17	5.21	6.56
0.10	2.63	4.96	6.89
0.25	2.44	5.14	6.06
0.40	2.47	5.43	7.36
0.55	2.68	5.54	7.47
SE ±	0.35	0.48	0.55
Nitrogen Sources			
Urea	2.39	4.59	6.32
CAN	2.56	5.01	7.41
SE ±	0.25	0.30	0.35
Varieties			
TI 221	4.07a	7.45a	9.23a
TI 106	1.99b	4.38b	6.18b
TI 539	1.37b	3.94b	5.18b
SE ±	0.27	0.37	0.43
Interaction			
L x N	NS	NS	NS
L x V	NS	NS	*
N x V	NS	NS	NS
L x N x V	NS	NS	NS

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of significance using DMRT. NS = Not Significant. * = Significant

4.3.3 Effect of lime and N sources on the number of branches per plant

Number of branches per plant was not significantly influenced by lime at all the stages of measurement. Similar trend was observed with respect to N sources (Table 21). With respect to varieties, values were significantly higher with TI 221 at all stages of measurements. A significant interaction effect between lime and varieties was observed at 8 WAT (Table 22). Number of branches were significantly higher in variety TI 221, with lime at 0.40t/ha. With TI 106, values were not significantly different between the control and other rates. For TI 539, values were not significant.

4.3.4 Effect of lime and N sources on the number of flowers per plant

Liming at 0.10t/ha gave a significantly higher number of flowers per plant than other rates at 4 WAT (Table 23). At 6 and 8 WAT values were significantly higher at 0.10 and 0.55t/ha than at other levels. The effect of N source was significant. At all periods of measurement, application of CAN gave significantly more number of flowers than urea. Varietal difference was also significant, values were significantly higher for varieties TI 221 and 106 than TI 539. Interaction effects of lime and varieties were significant at 6 and 8 WAT (Table 24 and 25). At 6 WAT, variety TI 221 gave significantly higher value at 0.55t/ha. While varieties TI 106 and 539 were not significantly different. At 8 WAT, values at 0.40 and 0.55t/ha were significantly higher than the control, 0.10 and 0.25t/ha with TI 221, while with variety TI 106, values were significantly higher at 0.10 and 0.55t/ha. For variety TI 539, value was significantly high at 0.55t/ha, with the control significantly lower than other rates.

Table 22. Interaction effect of lime and varieties on the *branches per plant* at 8 WAT.

Treatment	Varieties		
	TI 221	TI 106	TI 539
Lime (t/ha)			
0	7.75c	6.42de	5.50ef
0.10	8.17c	7.00d	5.50ef
0.25	7.58c	5.75e	4.83f
0.40	12.50a	5.00f	4.58f
0.55	10.17b	6.75d	5.50ef
SE ±		0.96	

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of significance using DMRT.

Table 24. Interaction effect of lime and varieties on the number of flowers per plant at 6 WAT.

Treatment	Varieties		
	TI 221	TI 106	TI 539
Lime (t/ha)			
0	7.00f	7.92ef	12.92c
0.10	16.08b	9.67d	11.75c
0.25	12.17c	12.00c	9.33de
0.40	18.67b	8.67e	11.58cd
0.55	20.92a	10.17d	13.17c
SE ±		2.21	

Table 25. Interaction effect of lime and varieties on the number of flowers per plant at 6 WAT.

Treatment	Varieties		
	TI 221	TI 106	TI 539
Lime (t/ha)			
0	21.75ab	20.17b	17.33c
0.10	20.50b	23.00a	20.75b
0.25	18.92b	18.33bc	21.50b
0.40	24.92a	17.58c	18.58b
0.55	22.25a	22.33a	23.92a
SE ±		3.38	

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of significance using DMRT.

4.3.5 Effect of lime and N sources on the number of fruits per plant

There was a highly significant increase in the number of fruits per plant with liming (Table 26). At 6 WAT, values did not differ significantly among the rates, but were significantly higher than the control. At 8 WAT and, at harvest, liming upto 0.40t/ha significantly increased number of fruits per plant. Number of fruits were significantly higher with the application of CAN. At 8 WAT, varieties TI 221 and 106 had significantly more fruits than variety TI 539, while at harvest value was significantly higher with variety TI 221.

4.3.6 Effect of lime and N sources on mean fruit diameter and weight.

The effect of lime and N sources on mean fruit diameter and weight is shown in Table 27. Lime effect on mean fruit diameter was significant, while the effect on mean fruit weight was only significant on application of upto 0.40t/ha and above. Nitrogen source did not affect mean fruit diameter, while its effect on mean fruit weight shows that CAN gave significantly higher values. With respect to varieties fruit diameter and weight were significantly higher with variety TI 221.

4.3.7 Effect of lime and N sources on the total fruit yield

The influence of lime and N sources on fruit yield per hectare is shown in Table 28. Results showed that liming effect, was not significant upto 0.40t/ha, but significant increase in yield was achieved by liming at 0.55t/ha.

Application of CAN gave significantly higher yields than urea. Variety TI 221 significantly out yielded the other two varieties.

Table 26. Effect of lime and N sources on the number of fruits per plant in the wet season.

Treatment	Number of fruits		
	Weeks after Transplanting		
	6	8	At Harvest
Lime (t/ha)			
0	3.97b	23.41c	19.45c
0.10	5.71a	29.10b	25.51b
0.25	5.42a	29.40b	26.21b
0.40	6.79a	31.80a	29.64a
0.55	8.90a	34.40a	31.04a
SE ±	0.59	2.58	1.99
Nitrogen Sources			
Urea	5.10b	28.70b	25.29b
CAN	6.02a	30.50a	27.45a
SE ±	0.37	1.63	1.26
Varieties			
TI 221	6.09	29.80a	28.42a
TI 106	5.08	32.50a	26.77b
TI 539	5.50	28.50b	23.92c
SE ±	0.45	2.00	1.54
Interaction			
L x N	NS	NS	NS
L x V	NS	NS	NS
N x V	NS	NS	NS
L x N x V	NS	NS	NS

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of significance using DMRT. NS = Not Significant.

Table 27. Effect of lime and N sources on the mean fruit diameter and weight in the wet season.

Treatment	Mean diameter(cm)	Mean weight (g)
Lime (t/ha)		
0	4.01c	31.61b
0.10	4.12b	36.83b
0.25	4.11b	38.61ab
0.40	4.26a	40.33a
0.55	4.34a	41.94a
SE ±	0.09	1.40
Nitrogen Sources		
Urea	4.01	36.33b
CAN	4.23	39.40a
SE ±	0.58	0.89
Varieties		
TI 221	4.88a	44.15a
TI 106	3.63c	34.13b
TI 539	3.99bc	35.32b
SE ±	0.07	1.09
Interaction		
L x N	NS	NS
L x V	NS	NS
N x V	NS	NS
L x N x V	NS	NS

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of significance using DMRT. NS = Not Significant.

Table 28. Effect of lime and N sources on total fruit yield (t/ha) in the wet season.

Treatment	Total fruit yield (t/ha)
Lime (t/ha)	
0	5.69c
0.10	6.98c
0.25	7.06c
0.40	9.44b
0.55	10.74a
SE ±	0.90
Nitrogen Sources	
Urea	7.12b
CAN	8.85a
SE ±	0.55
Varieties	
TI 221	8.44a
TI 106	7.69b
TI 539	7.82b
SE ±	0.70
Interaction	
L x N	NS
L x V	NS
N x V	NS
L x N x V	NS

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of significance using DMRT. NS = Not Significant.

4.3.8 Effect of lime and N sources on the macronutrient concentration in tomato leaves

The macronutrient element concentrations increased with increasing levels of lime like with the green house studies (Table 29). The concentrations of N, Ca and Mg significantly increased when lime was applied at 0.40 and 0.55t/ha. The concentrations of N, K and Mg were significantly higher when CAN was applied. While N source did not have any effect on P and Ca.

4.3.9 Effect of lime and N sources on the micronutrient concentration in tomato leaves

The effect of liming on micronutrient concentrations shown in Table 29, indicates a reduction in concentrations with increasing levels of lime. The levels tended to be significantly reduced by liming especially at the highest levels. The concentrations of Fe and Cu were significantly higher, with the application of urea. While Zn and Mn were not affected by N source. Interaction effect of lime and N source on Zn concentration was significant (Table 30). Zinc concentration tended to decrease with increasing lime rates with respect to N sources. Similar trend was also obtained with respect to interaction effect between lime and varieties (Table 31).

4.3.10 Effect of lime and N sources on soil pH and exchangeable cations

Liming significantly increased soil pH (Table 32). Value at 0.55t/ha was significantly higher than those obtained at the other rates. The effect of N sources was not significant, though values were slightly higher were CAN was applied. The exchangeable cation contents of the soil were significantly improved by liming only at the high rates of 0.40 and 0.55t/ha. Application of CAN significantly increased

Table 29: Effect of lime and N sources on Nutrient concentrations in tomato leaves during the wet season.

Treatment	Nutrient element concentrations								
	N	P	K	Ca	Mg	Zn	Mn	Fe	Cu
	%					$Mgkg^{-1}$			
Lime (t/ha)									
0	2.36c	0.35	3.24	2.46c	0.42b	123.00a	90.30b	157.6a	13.90a
0.10	2.61c	0.49	3.24	3.71b	0.38b	119.90b	93.54a	159.54a	11.88b
0.25	2.52c	0.50	3.56	3.67b	0.60b	124.00a	87.32c	148.50b	10.07c
0.40	3.33b	0.51	3.41	3.96b	1.04a	121.40ab	66.26d	133.00c	10.07d
0.55	3.63a	0.54	3.29	4.88a	1.00a	94.40c	56.83e	101.60d	7.94e
SE ±	0.22	0.26	0.12	0.46	0.25	2.70	2.07	3.37	0.61
Nitrogen Sources									
Urea	2.76b	0.62	3.19b	3.57	0.51b	116.00	78.04	142.70a	11.01a
CAN	3.02a	0.48	3.50a	3.90	0.85a	117.00	79.60	137.30b	10.79b
SE ±	0.22	0.26	0.12	0.46	0.25	1.77	1.31	2.14	0.39
Interaction									
L x N	NS	NS	NS	NS	NS	*	NS	NS	NS
L x V	NS	NS	NS	NS	NS	*	NS	NS	NS
N x V	NS	NS	NS	NS	NS	NS	NS	NS	NS
L x N x V	NS	NS	NS	NS	NS	NS	NS	NS	NS

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of significance using DMRT. NS = Not Significant. * = Significant

Table 30. Interaction effect of lime and N sources on Zn concentration (Mg/kg) in tomato leaves.

Treatment	Nitrogen Sources	
	Urea	CAN
Lime (t/ha)		
0	124.30b	122.80c
0.10	114.80d	125.00b
0.25	132.80a	115.30d
0.40	115.80d	127.00b
0.55	92.80e	96.30e
SE ±	3.95	

Table 31: Interaction effct of lime and varieties on Zn concentration (Mg/kg) in tomato leaves.

Treatment	Varieties		
	TI 221	TI 106	TI 539
Lime (t/ha)			
0	120.80c	130.50a	119.30c
0.10	114.80d	118.10c	126.80b
0.25	106.50e	133.90a	131.60a
0.40	118.50c	116.60cd	129.00ab
0.55	97.10f	95.20f	91.10g
SE ±		4.84	

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of significance using DMRT.

Table 32: Effect of lime and N sources on Chemical properties during the wet season

Treatment	pH 1:2.5(H_2O)	pH 1:2.5(0.01m$CaCl_2$)	Exchangeable Cations (Cmol kg^{-1})			
			Ca	Mg	Na	K
Lime (t/ha)						
0	4.97c	4.62d	2.24c	0.43c	0.23b	0.50a
0.10	5.12b	4.83c	2.35c	0.49ab	0.23b	0.49a
0.25	5.03bc	4.95bc	2.39c	0.46bc	0.25b	0.52a
0.40	5.12b	4.99ab	2.58b	0.49ab	0.26b	0.48ab
0.55	5.36a	5.11a	2.91a	0.51a	0.35a	0.44b
SE ±	0.10	0.34	0.14	0.04	0.04	0.04
Nitrogen Sources						
Urea	5.08	4.86	2.43b	0.47	0.25	0.49
CAN	5.17	4.94	2.56a	0.49	0.27	0.48
SE ±	0.10	0.34	0.04	0.04	0.04	0.04
Interaction						
L x N	NS	NS	NS	NS	NS	NS
L x V	NS	NS	NS	NS	NS	NS
N x V	NS	NS	NS	NS	NS	NS
L x N x V	NS	NS	NS	NS	NS	NS

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of significance using DMRT. NS = Not Significant.

soil content of Ca, while the other exchangeable cations were not significantly affected.

4.3.11 Correlation coefficient between fruit yield and yield-related parameters

The result of the correlation coefficient analysis between tomato fruit yield and yield-related parameters is shown in Table 33. There was a very strong and positive correlation (P=0.01 and P=0.05) between fruit yield and plant height (r = 0.486** and r = 0.506**), number of leaves per plant (r 0.466** and r = 0.363**), number of flowers per plant (r = 0.279**), number of fruits per plant (r = 0.390**, r = 0.216* and r = 0.274**), mean fruit diameter (r = 0.281*) and mean fruit weight (r = 0.393**).

4.3.12 Correlation coefficient between yield-related parameters and nutrient element concentrations in leaves

Correlation coefficient between nutrient element concentrations and plant height, number of leaves per plant, branches, flowers, fruit mean fruit diameter and weight is presented in Table 34. Plant height, number of leaves, fruit mean fruit diameter and weight were positively and significantly correlated with N concentration (r = 0.528**, 0.489**, 0.256*, 0.220* and 0.368** respectively). Phosphorus concentration was positively correlated with all yield-related parameters but were not significant, except plant height, total number of fruit per plant, and mean fruit weight were significant (r = 0.241*, 0.243* and 0.311** respectively). Calcium concentration was positively and significantly correlated with all yield-related parameters except, number of branches per plant and mean fruit diameter. Similarly plant height and number of leaves per plant were significantly correlated with Mg concentration (r = 0.214* 0.210* and 0.210*). Correlations between Zn, Mn, Fe and

Table 33: Matrix of Correlation coefficients (r) between tomato fruit yield (t/ha) yeild-related parameters of a wet season experiment.

Variables	Variables													
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}
x_1	1.000													
x_2	0.393**	1.000												
x_3	0.281**	0.597**	1.000											
x_4	0.396**	0.251	0.149	1.000										
x_5	0.216*	0.232*	0.023	0.071	1.000									
x_6	0.274**	0.269*	0.204	0.272**	0.094*	1.000								
x_7	0.109	0.179	0.095	0.213*	0.241*	0.438**	1.000							
x_8	0.279**	0.361**	0.378**	0.276**	0.190	0.351**	0.181	1.000						
x_9	0.486**	0.546**	0.416**	0.340**	0.279**	0.412**	0.174	0.466**	1.000					
x_{10}	0.506**	0.497**	0.350**	0.353**	0.347**	0.176NS	0.180**	0.314**	0.579**	1.000				
x_{11}	0.466**	0.652**	0.467**	0.361**	0.353**	0.333**	0.340**	0.478**	0.647**	0.578**	1.000			
x_{12}	0.363**	0.643**	0.534**	0.254*	0.406**	0.204	0.271**	0.496**	0.480**	0.411**	0.648**	1.000		
x_{13}	0.163	0.536**	0.629**	0.120	0.195	0.200	0.216**	0.521**	0.360**	0.340**	0.602**	0.680**	1.000	
x_{14}	0.175	0.562**	0.472**	0.208	0.302**	0.236	0.328**	0.327**	0.407**	0.307**	0.629**	0.720**	644*	0.664** 1.000

* = Significant at 0.05 level ** = Significant at 0.01 level of

X_1 = Fruit yield (t/ha)
X_2 = Mean fruit weight (g)
X_3 = Mean fruit diameter (cm)
X_4 = Total number of fruits per plant
X_5 = Number of fruits per plant at 8 WAT
X_6 = Number of fruits per plant at 6 WAT
X_7 = Number of flowers per plant at 8 WAT
X_8 = Number of flowers per plant at 8 WAT
X_9 = Plant height at 6 WAT
X_{10} = Plant height at 8 WAT
X_{11} = Number of leaves per plant at 6 WAT
X_{12} = Number of leaves per plant at 8 WAT
X_{13} = Number of branches per plant at 6 WAT
X_{14} = Number of branches per plant at 8 WAT

Table 34: Correlation between tomato performance and Nutrient element concentrations in tomato leaves in the wet season.

Nutrient	Plant Performance												
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}
N	0.528**	0.445**	0.489**	0.256*	0.163	0.199	0.264*	0.047	0.187	0.271*	0.271*	0.220*	0.368**
P	0.109	0.241**	0.042	0.011	0.044	0.032	0.015	0.011	0.058	0.091	0.243*	0.104	0.311**
K	0.128	0.099*	0.106	0.051	0.114	0.018	0.180	0.034	0.071	0.134	0.145	0.024	0.117
Ca	0.449**	0.409	0.423**	0.213*	0.076	0.135	0.317**	0.257*	0.290**	0.365**	0.365**	0.064	0.256*
Mg	0.214*	0.192**	0.210*	0.210*	0.005	0.097	0.067	0.082	0.019	0.160	0.139	0.042	0.139
Zn	-0.337**	0.357	-0.363**	-0.249*	-0.200	-0.120	-0.325**	-0.092	-0.093	-0.080	-0.172	-0.172	-0.288*
Mn	-0.558**	-0.423**	-0.448**	-0.242*	-0.106	-0.106	-0.176	-0.151	-0.193	-0.193	-0.379**	-0.190	-0.285**
Fe	-0.467**	-0.465**	-0.515**	-0.247*	-0.108	-0.147	-0.289**	-0.140	-0.082	-0.255*	-0.300**	-0.199	-0.307**
Cu	-0.340**	-0.455**	-0.388**	-0.103	-0.021	-0.008	-0.146	-0.007	-0.174	-0.382**	-0.274**	-0.043	0.235*

* = Significant at 0.05 level ** = Significant at 0.01 level

X_1 = Plant height at 6 WAT
X_2 = Plant height at 8 WAT
X_3 = Number of leaves per plant at 6 WAT
X_4 = Number of leaves per plant at 8 WAT
X_5 = Number of branches per plant at 6 WAT
X_6 = Number of branches per plant at 8 WAT
X_7 = Number of flowers per plant at 6 WAT
X_8 = Number of flowers per plant at 8 WAT
X_9 = Number of fruits per plant at 6 WAT
X_{10} = Number of fruits per Plant at 8 WAT
X_{11} = Total number of fruits per plant at 8 WAT
X_{12} = Mean fruit diameter
X_{13} = Mean fruit Weight

Cu concentrations and plant height, number of leaves, mean fruit diameter and weight were found to be negative and significant.

4.4 Dry Season Trail

4.4.1 Effect of lime and N sources on plant height

The influence of lime and N sources on plant height is shown in Table 35. As in the green house and during the wet season, plant height increased with increasing lime rates upto 4.48t/ha, after which it tended to drop. At 6 and 8 WAT, values at 2.24 and 4.48t/ha, were significantly higher than the control, 1.12 and 8.96t/ha. While at 10 and 12 WAT, similar trend was also observed, plants were significantly taller at 2.24 and 4.48t/ha than the control, 1.12 and 8.96t/ha.

Nitrogen sources did not influence plant height at all the stages of measurement. Except at 4 and 6 WAT, variety TI 221 was significantly taller than other varieties at all stages of measurement.

A significant interaction effect of lime and N sources at 4, 6 and 12 WAT. were observed and are presented in Tables 36, 37 and 38. At 4 WAT, values between 2.24 to 8.96t/ha were significantly higher when urea was applied, similar trend was also observed with the application of CAN, but shorter plants were observed with the control and 1.12t/ha, with the application of CAN. At 6 WAT values at 8.96t/ha and control gave shorter plants than other rates with the application of urea. With CAN application, plants were significantly taller at 2.24 and 4.48t/ha. At 12 WAT, application of urea increased plant height, except the control and 8.96t/ha, while with CAN application, there was no significant difference in plant height except at 8.96t/ha rate. Interaction effect between lime and varieties was significant at 6 WAT (Table 39). With variety TI 221, values at 2.24 and

Table 35. Effect of lime and N Sources on Plant height in the dry season Plant height (CM).

	Plant height (cm)				
	Weeks after Transplanting				
Treatment	4	6	8	10	12
Lime t/ha)					
0	9.85c	12.19c	26.04c	40.88b	48.65b
1.12	10.54b	14.50b	28.67bc	43.00ab	54.88ab
2.24	12.31a	17.44a	32.94ab	48.29a	55.67a
4.48	11.52b	16.91a	35.52a	49.42a	55.35a
8.96	11.81b	14.42bc	21.23c	39.21b	47.52b
SE±	0.30	0.47	1.47	1.75	2.21
Nitrogen Sources					
Urea	11.20	15.53	28.38	44.17	52.01
CAN	11.22	15.03	29.38	44.15	52.97
SE±	0.19	0.30	0.93	1.11	1.40
Varieties					
TI 221	11.13	15.53	33.83a	52.74a	65.94a
TI 106	11.38	14.50	27.14b	39.81b	42.26b
TI 539	11.13	15.24	25.68b	39.93b	44.27b
SE±	0.28	0.36	1.14	1.35	1.72
Interactions					
L X N	*	*	NS	NS	*
L X V	NS	*	NS	NS	NS
N X V	NS	NS	NS	NS	NS
L X N X V	NS	NS	NS	NS	NS

Meams followed by the same letter(s) within a treatment group are not significantly different at 5% level of significance using DMRT. NS = Not significant * = Significant

Table 36: Interaction effect of lime and N sources on plant height at 4 WAT

Treatment	Nitrogen Sources		
	Urea		CAN
Lime (t/ha)			
0	9.29b		10.42bc
1.12	11.29b		9.74c
2.24	11.88a		12.75a
4.48	11.58a		11.46ab
8.96	11.96a		11.67a
SE±		0.42	

Table 37. Interaction effect of lime and N Sources on Plant height at 6 WAT.

Treatment	Nitrogen Sources		
	Urea		CAN
Lime (t/ha)			
0	11.00c		13.83b
1.12	15.46b		13.54bc
2.24	17.67a		17.21a
4.48	17.69a		16.12ab
8.96	13.06c		14.92b
SE±		0.66	

Means followed by the same letter(s) within a treatment group are not significantly Different at 5% level of Significance using DMRT.

Table 38. Interaction effect of lime and N Sources on Plant height at 12 WAT.

Treatment	Nitrogen Souruces	
	Urea	CAN
Lime (t/ha)		
0	44.46b	52.83a
1.12	54.92a	54.83a
2.24	52.00a	59.33a
4.48	57.46a	53.25a
8.96	51.21ab	44.62b
SE±	3.13	

Table 39: Interaction effect of lime and Varieties on Plant height at 6 WAT.

Treatment	Varieties		
	TI221	TI106	TI539
Lime (t/ha)			
0	12.56c	11.19c	12.81c
1.12	14.88b	14.44b	14.19bc
2.24	17.69a	17.56a	17.06ab
4.48	19.44a	14.69b	16.60b
8.96	13.06c	14.63b	15.56b
SE±		0.81	

Means followed by the same letter(s) within a treatment group are not Significantly Different at 5% level of Significance using DMRT.

4.48t/ha rates were significantly higher than the control and other rates. With variety 106, value was significant at 4.48t/ha, for TI 539, values between 1.12 to 8.96t/ha rates were not significantly different.

4.4.2 *Effect of lime and N sources on the number of leaves per plant*

Number of leaves per plant at 6, 8, 10 and 12 WAT (Table 40), were significantly increased with the application of lime upto 4.48t/ha after which application of more lime at 8.96t/ha tended to reduce the number of leaves per plant.

Nitrogen source did not significantly affect the number of leaves per plant throughout the sampling periods. With respect to varieties, variety TI 221, had significantly more number of leaves per plant than the other two varieties at all the stages of sampling. A significant interaction effect between lime and N sources was observed at 6 and 12 WAT (Tables 41 and 42). At 6 WAT, the highest lime rate of 8.96t/ha, gave significantly lower number of leaves than the control and other rates for both urea and CAN. At 12 WAT, higher values were obtained at 2.24 and 4.48t/ha for both sources of N, while the control, 1.12 and 8.96t/ha were significantly lower.

4.4.3 *Effect of lime and N sources on the number of branches per plant*

The effect of lime and N sources on the number of branches per plant is shown in Table 43. Number of branches increased, with increasing lime rates upto 4.48t/ha, after which it tended to drop. At 10 WAT, values between 1.12 to 4.48t/ha, were significantly higher than the control and 8.96t/ha. While at 12 WAT, value was only significant at 2.24t/ha. Higher number of branches were produced when CAN

Table 40. Effect of lime and N Sources on the number of leaves per plant in the dry season.

	Number of leaves			
	Weeks after Transplanting			
Treatment	6	8	10	12
Lime (t/ha)				
0	9.90b	22.92c	35.02b	34.10c
1.12	10.27a	22.25c	38.40a	43.90b
2.24	13.17a	31.25b	46.23a	55.60a
4.48	12.15a	40.50a	38.33ab	53.30ab
8.96	8.21b	16.96b	35.54b	41.80bc
SE±	0.79	1.45	2.00	2.41
Nitrogen Sources				
Urea	10.15	24.40	39.03	43.30
CAN	11.32	29.15	38.38	48.20
SE±	0.50	0.92	1.27	1.50
Varieties				
TI221	11.66	30.04a	47.54a	55.50a
TI106	10.48	24.00b	34.44b	40.80b
TI539	10.07	26.29ab	34.14b	41.00b
SE±	0.62	1.12	1.56	1.89
Interactions				
LXN	*	NS	NS	*
L X V	NS	NS	NS	NS
N X V	NS	NS	NS	NS
L X N X V	NS	NS	NS	NS

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of Significance using DMRT>
NS = Not significant * = Significant

Table 41. Interaction effect of lime and N Sources on Plant height at 6 WAT.

Treatment	Nitrogen Sources	
	Urea	CAN
Lime (t/ha)		
0	9.00b	10.79b
1.12	11.75b	8.79bc
2.24	9.71b	16.63a
4.48	12.29b	12.00b
8.96	8.00c	8.42c
SE±	1.12	

Table 42. Interaction effect of lime and N Sources on the number of leaves per Plant at 12 WAT.

Treatment	Nitrogen Sources	
	Urea	CAN
Lime t/ha)		
0	28.90c	39.40bc
1.12	38.00c	49.70b
2.24	50.40a	60.70a
4.48	53.10a	53.50a
8.96	45.90ab	37.70c
SE±	3.40	

Means followed by the same letter(s) within a treatment group are not significantly Different at 5% level of Significance using DMRT.

Table 43. Effect of lime and N Sources on the number of branches per plant in the dry season.

	Number of branches	
	Weeks after Transplanting	
Treatment	10	12
Lime (t/ha)		
0	6.56c	7.83c
1.12	8.13a	9.42b
2.24	8.03a	10.67a
4.48	7.79a	9.15b
8.96	7.29b	8.94b
SE±	0.93	0.76
Nitrogen Sources		
Urea	7.15b	8.68b
CAN	7.99a	9.72a
SE±	0.59	0.48
Varieties		
TI221	9.55a	12.51a
TI106	7.25ab	7.89b
TI539	5.91b	7.20b
SE±	0.72	0.59
Interactions		
L X N	NS	NS
L X V	NS	NS
N X V	NS	NS
L X N X V	NS	NS

Means followed by the same letter(s) within a treatment group are not Significantly Different at 5% level Significance using DMRT.
NS = Not Significant

was applied. Varietal differences were also significant. At all stages of measurement, TI 221 had significantly more number of branches per plant. Interaction effects were not significant.

4.4.4 Effect of lime and N sources on the number of flowers per plant

Number of flowers per plant as influenced by lime and N sources at 10 and 12 WAT is shown in Table 44. At 10 WAT, liming and N sources did not significantly affect number of flowers per plant. There were also no significant difference among the varieties. At 12 WAT, liming significantly increased number of flowers per plant, though at the highest rate of 8.96t/ha, the difference with the control was not significant. Nitrogen source did not significantly affect the number of flowers per plant. While TI 221 variety significantly produced more flowers than the other two varieties. Interaction effects were not significant.

4.4.5 Effect of lime and N sources on the number of fruits per plant

At all stages of sampling, number of fruits per plant increased with liming upto 4.48t/ha, beyond which there were decreases (Table 45). At 10 WAT, values at 2.24 and 4.48t/ha were significantly higher than the control, 1.12 and 8.96t/ha. At 12 WAT, value at 2.24t/ha was significantly higher than at other rates. At 14 WAT, values generally tended to increase with increasing lime rates upto 2.24t/ha, beyond which values slightly decreased, the control, 4.48 and 8.96t/ha rates were not significantly different. At harvest values at 2.24 and 4.48t/ha rates were significantly higher than the control, 1.12 and 8.96t/ha.

The number of fruits per plant obtained with the application of CAN throughout the sampling periods were significantly higher than with urea, except at

Table 44. Effect of lime and N Sources on the number of flowers per plant in the dry season.

	Number of Flowers	
	Weeks after Transplanting	
Treatment	10	12
Lime (t/ha)		
0	11.63	13.92b
1.12	11.50	17.54a
2.24	17.08	17.69a
4.48	13.31	17.56a
8.96	12.21	16.31ab
SE±	1.78	0.77
Nitrogen Sources		
Urea	13.09	16.34
CAN	12.20	16.87
SE±	1.05	0.49
Varieties		
TI221	12.30	19.55a
TI106	13.32	15.87b
TI539	13.81	14.39b
SE±	1.28	0.59
Interactions		
L X N	NS	NS
L X V	NS	NS
N X V	NS	NS
L X N X V	NS	NS

Means followed by the same letter(s) within a treatment group are not Significantly Different at 5% level Significance using DMRT.
NS = Not Significant

Table 45: Effect of lime and N sources on the number of fruits per plant in the dry season.

	Number of fruits			
	Weeks after Transplanting			
Treatment	10	12	14	At Harvest
Lime (t/ha)				
0	18.33b	27.85b	32.85b	24.97ab
1.12	20.65b	35.20ab	36.77a	23.32b
2.24	32.50a	39.69a	40.23a	29.54a
4.48	31.50a	31.83b	36.44ab	25.96a
8.96	16.88b	27.63b	31.29b	23.26b
SE±	1.90	1.65	1.84	1.19
Nitrogen Sources				
Urea	24.22	30.77b	33.38b	24.08b
CAN	23.72	34.11a	37.47a	26.74a
SE±	1.20	1.04	1.60	0.75
Varieties				
TI 221	24.44	31.35	35.79a	26.29a
TI 106	23.01	33.20	36.92a	28.37a
TI 539	24.46	32.48	33.56b	21.57b
SE±	1.48	1.27	1.42	0.92
Interactions				
L x N	NS	NS	NS	*
L x V	NS	NS	NS	*
N x V	NS	NS	NS	NS
L x N x V	NS	NS	NS	NS

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of significance using DMRT.
NS = Not significant.
* = Significant.

10 WAT. Varietal differences were significant only at 14 WAT and at harvest with TI 539 having values significantly lower.

Interaction effects of lime and N source, and lime and varieties were significant (Tables 46 and 47). At harvest, significant number of fruits was obtained with the application of CAN and lime at 2.24t/ha, while the highest lime rate and CAN gave a significantly lower value. With the application of urea, the control and other rates were not significantly different. Interaction between lime and varieties, indicated that variety TI 221 was not significantly affected, while with variety TI 106, values at 2.24 and 4.48t/ha were significantly higher than the control and other rates. For variety TI 539, value at 2.24t/ha was significantly higher than others.

4.4.6 Effect of lime and N sources on mean fruit diameter and weight

The effect of lime and N sources on mean fruit diameter and weight are shown in Table 48. Plots receiving 2.24 and 4.48t/ha lime gave significantly higher values than the control, 1.12, and 8.96t/ha which were not significantly different. With the application of CAN, values were significantly higher than with urea. Varietal differences were noticed, mean fruit diameter and weight were significantly higher with variety TI 221. Interaction effects were not significant.

4.4.7 Effect of lime and N sources on total fruit yield (t/ha)

Generally total fruit yield tended to increase with increasing lime rates upto 4.48t/ha (Table 49), beyond which value slightly decreased, though not significant. Values obtained for the control and 1.12t/ha were not significantly different, but significantly lower than other rates. CAN gave total fruit yield significantly higher than with urea. Variety TI 221, had total fruit yield significantly, higher than others.

Table 46: Interaction effect of lime and N sources on total number of fruits per plant at harvest

Treatment	Nitrogen sources	
	Urea	CAN
Lime (t/ha)		
0	24.33b	25.62b
1.12	21.67bc	24.98b
2.24	23.55b	35.53a
4.48	25.19b	26.73b
8.96	25.61b	20.86c
SE±	1.68	

Table 47: Interaction effect of lime and varieties on the total number of fruits per plant at harvest.

Treatment	Varieties		
	TI 221	TI 106	TI 539
Lime (t/ha)			
0	28.49ab	24.90b	21.53bc
1.12	24.22b	27.07ab	18.68c
2.24	27.06b	31.00a	30.55a
4.48	24.40b	33.84a	19.64c
8.96	27.28b	25.03b	17.48c
SE±		2.04	

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of significance using DMRT.

Table 48: Effect of lime and N sources on mean fruit diameter and weight in the dry season.

Treatment	Mean diameter(cm)	Mean weight(g)
Lime (t/ha)		
0	4.47b	45.45c
1.12	4.66b	48.50b
2.24	5.08a	51.92a
4.48	5.25a	52.29a
8.96	4.67b	50.61b
SE±	0.06	1.02
Nitrogen Sources		
Urea	4.73b	48.44b
CAN	4.93a	51.07a
SE±	0.04	1.06
Varieties		
TI 221	5.25a	50.26a
TI 106	4.35c	45.92b
TI 539	4.86b	46.76b
SE±	0.48	0.49
Interactions		
L x N	NS	NS
L x V	NS	NS
N x V	NS	NS
L x N x V	NS	NS

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of significance using DMRT.
NS = Not significant

Table 49: Effect of lime and N sources on the total fruit yield(t/ha) in the dry season.

Treatment	Total fruit yield (t/ha)
Lime (t/ha)	
0	9.92d
1.12	11.67c
2.24	14.77a
4.48	13.04ab
8.96	12.25b
SE±	2.27
Nitrogen Sources	
Urea	11.69b
CAN	12.97a
SE±	0.40
Varieties	
TI 221	13.61a
TI 106	13.06b
TI 539	10.31c
SE±	0.49
Interactions	
L x N	*
L x V	NS
N x V	*
L x N x V	NS

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of significance using DMRT.
NS = Not significant
* = Significant.

The interaction effects of lime and N sources and lime and varieties were significant (Tables 50 and 51). With the application of urea, yield was significantly higher at the two highest lime rates, while with CAN, the effect of lime was significantly higher at 1.12 and 2.24t/ha. Interaction between N sources and varieties, showed that application of CAN, significantly increased yield in varieties TI 106 and TI 539.

4.4.8 Effect of lime and N sources on the macronutrient concentration in tomato leaves

The effect of lime and N source on the concentrations of N, P, K, Ca and Mg is shown in Table 52. The concentration of N in the leaves tended to increase with increasing lime rates, values at 2.24, 4.48 and 8.96t/ha rates were significantly higher than values at 1.12t/ha and the control which were not significantly different. Phosphorus concentration was significantly higher at 4.48 and 8.96t/ha rates, than the control, 1.12 and 2.24t/ha rates which were not significantly different. Liming did not significantly affect K concentration. While values for Ca and Mg were significantly higher at 2.24 and 4.48t/ha rates. Except for N concentration where CAN gave significantly higher value than urea, N source did not affect the other elements.

4.4.9 Effect of lime and N sources on the micronutrient concentration in tomato leaves

Changes in the concentrations of micronutrient elements in tomato leaves is presented in Table 52. Liming had a depressing effects on Zn, Mn, Fe and Cu levels in the leaves. With the application of lime upto 2.24t/ha, values for Zn and Mn were significantly higher than at 4.48 and 8.96t/ha. Similar trend was also observed for

Table 50: Interaction effect of lime and N sources on the total yield fruit

	Nitrogen sources	
Treatment	Urea	CAN
Lime (t/ha)		
0	8.16c	11.68b
1.12	10.09bc	13.27a
2.24	12.59b	16.94a
4.48	13.41a	12.66b
8.96	14.24a	10.28b
SE±	0.89	

Table 51: Interaction effect of lime and varieties on the total fruit yield.

	Varieties		
Nitrogen Sources	TI221	TI 106	TI 523
Urea	14.59ab	11.39b	9.11b
CAN	12.04b	14.74a	11.52b
SE±	0.67		

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of significance using DMRT.

Table 52: Effect of lime and N sources on Nutrient concentrations in tomato leaves during the dry season.

Treatment	Nutrient element concentrations								
	N	P	K	Ca	Mg	Zn	Mn	Fe	Cu
	%					$Mgkg^{-1}$			
Lime (t/ha)									
0	3.30bc	0.52b	3.87	3.09c	0.95b	110.40a	84.70a	161.70a	15.27a
1.12	3.12c	0.59b	3.80	5.14b	1.39ab	106.10a	83.70a	153.50b	15.04a
2.24	3.72ab	0.58b	3.82	4.78b	0.95b	107.40a	73.30b	131.60c	11.63b
4.48	4.18a	0.66a	3.94	5.20a	1.29ab	85.50b	63.30c	106.10d	9.83c
8.96	3.94a	0.69a	3.92	5.90a	1.63a	88.10b	59.50c	90.40e	7.65d
SE ±	0.42	0.09	0.19	0.52	0.39	6.11	2.24	5.79	1.20
Nitrogen Sources									
Urea	3.47b	0.61	3.92	4.90	1.11	100.00	73.60a	131.20a	12.02a
CAN	3.84a	0.60	3.82	5.14	1.38	99.00	72.30b	126.10b	11.75b
SE ±	0.42	0.06	0.12	0.52	0.39	3.87	1.42	3.66	0.76
Interaction									
L x N	NS	NS	NS	NS	NS	NS	NS	NS	NS
L x V	NS	NS	NS	NS	NS	NS	NS	NS	NS
N x V	NS	NS	NS	NS	NS	NS	NS	NS	NS
L x N x V	NS	NS	NS	NS	NS	NS	NS	NS	NS

Means followed by the same letter(s) within a treatment group are not significantly different at 0.05 level of significance using DMRT. NS = Not Significant.

Fe and Cu. The concentrations of Mn, Fe and Cu were significantly higher with the application of urea, while Zn was not affected by N source.

4.4.10 Effect of lime and N sources on soil pH at flowering and at harvest and exchangeable cations

Increasing lime rates significantly increased soil pH (Table 53). Values at 4.48 and 8.96t/ha were significantly higher than that obtained at the other lime rates. The effect of N source was not significant, though values were slightly higher where CAN was applied.

The exchangeable cations of the soil were significantly improved by liming, values were significant at 4.48 and 8.96t/ha rates. Application of CAN significantly increased exchangeable Mg, while the other exchangeable cations were not significantly affected.

Interaction effect of lime and N sources on exchangeable K is shown in Table 54. Exchangeable K was higher with control than other rates when urea was applied, while with CAN values were significant between 1.12 to 4.48t/ha lime rates.

4.4.11 Correlation coefficient (r) between yield and yield-related parameters

The correlation coefficient among the various yield-related parameters and fruit yield is shown in Table 55. Total fruit yield was positively and significantly (at $p = 0.01$ and 0.05) correlated with plant height ($r = 0.478^{**}$ and $r = 0.478^{**}$), number of leaves ($r = 418^{**}$ and $r = 0.526^{**}$), branches ($r = 0.270^{*}$ and $r = 0.409^{**}$), flowers ($r = 0.339^{**}$ and $r = 0.486^{**}$), fruits ($r = 0.538^{**}$, $r = 0.646^{**}$ and $r = 0.738^{**}$), mean fruit diameter ($r = 0.326^{**}$ and $r = 0.250^{*}$) and weight ($r = 0.294^{*}$ and $r = 0.457^{**}$).

Table 53: Effect of lime and N sources on soil pH at flowering and at harvest and exchangeable cations in the dry season

Treatment	Flowering		Harvesting		Exchangeable cations (Cmol kg^{-1})			
	pH 1:2.5(H_2O)	pH 1:2.5(0.01mcaCl$_2$)	pH 1:2.5(H_2O)	pH 1:2.5(0.01MCaCl$_2$)	Ca	Mg	Na	K
Lime (t/ha)								
0	4.70d	4.60d	5.10e	4.50e	2.16d	0.34c	0.19c	0.53
1.12	6.00c	5.40c	5.50d	5.00d	2.88c	0.44bc	0.23c	0.48
2.24	6.40b	5.80b	5.80c	5.60c	3.93b	0.38bc	0.26ab	0.48
0.48	6.70a	6.30a	6.50b	6.10b	3.95b	0.52a	0.39a	0.55
8.96	6.90a	6.20a	6.90a	6.40a	4.60a	0.51a	0.40a	0.43
SE±	0.13	0.16	0.21	0.10	0.16	0.09	0.14	0.09
Nitrogen Sources								
Urea	6.20	5.60	5.90	5.40	3.78	0.33b	0.22	0.47
CAN	6.20	5.70	6.10	5.60	3.05	0.41a	0.30	0.39
SE ±	0.13	0.16	0.21	0.81	0.16	0.09	0.14	0.09
Interaction								
L x N	NS	NS	NS	NS	NS	NS	NS	*
L x V	NS	NS	NS	NS	NS	NS	NS	NS
N x V	NS	NS	NS	NS	NS	NS	NS	NS
L x N x V	NS	NS	NS	NS	NS	NS	NS	NS

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of significance using DMRT. NS = Not Significant. * = Significant

Table 54. Interaction effect of lime and N Sources on soil Exchangeable K.

Treatment	Nitrogen Sources	
	Urea	CAN
Lime(t/ha)		
0.	0.49a	0.36b
0.12	0.31b	0.46a
2.24	0.32b	0.43ab
4.48	0.32b	0.58a
8.96	0.39b	0.28b
SE±	0.16	

Means followed by the same letter(s) within a treatment group are not significantly different at 5% level of Significance using DMRT.

Table 55: Matrix of Correlation coefficients (r) between tomato fruit yield (t/ha) and yield-related parameters in the dry season.

Variables	Variables															
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}
X_1	1.000															
X_2	0.294**	1.000														
X_3	0.457**	0.422**	1.000													
X_4	0.326**	0.205	0.583**	1.000												
X_5	0.250*	0.305**	0.672**	0.790**	1.000											
X_6	0.538**	0.215	0.422**	0.117**	0.121	1.000										
X_7	0.646**	0.258*	0.451**	0.218	0.116	0.502**	1.000									
X_8	0.738**	0.215	0.328**	0.072	0.051	0.455**	0.471**	1.000								
X_9	0.334**	0.263*	0.245*	0.053	0.185	0.172**	0.330**	0.273**	1.000							
X_{10}	0.486**	0.034	0.485**	0.428**	0.379	0.204**	0.472**	0.240	0.256*	1.000						
X_{11}	0.479**	0.002	0.458**	0.628**	0.593	0.260*	0.402**	0.328*	0.173	0.540**	1.000					
X_{12}	0.477**	0.039	0.488**	0.619**	0.569*	0.142	0.324**	0.304*	0.156	0.650*	0.721**	1.000				
X_{13}	0.418**	0.010	0.508**	0.617**	0.536**	0.280*	0.287*	0.253*	0.184	0.647**	0.569**	0.610**	1.000			
X_{14}	0.526**	0.282*	0.298**	0.668**	0.663**	0.317*	0.471**	0.270*	0.171	0.600**	0.501**	0.688**	0.652**	1.000		
X_{15}	0.270**	0.045	0.523**	0.394**	0.254*	0.069	0.367**	0.175	0.008	0.503**	0.373**	0.402**	0.440**	0.509**	1.000	
X_{16}	0.409**	0.092	0.732**	0.614**	0.551**	0.281*	0.250*	0.223	0.056	0.550**	0.519**	0.597**	0.636**	0.536**	0.503**	1.000

* = Significant at 0.05 level of significance ** = Significant at 0.01 level of level of significance

X_1 = fruit yield (t/ha)
X_2 = Mean fruit weight 1st & 2nd harvest
X_3 = Mean fruit weight 3rd & 4th harvest
X_4 = Mean fruit diameter 1st & 2nd harvest
X_5 = Mean fruit diameter 3rd & 4th harvest
X_6 = Number of fruits per plant at 12 WAT
X_7 = Number of fruits per plant at 14 WAT
X_8 = Total number of fruits per plant at harvest
X_9 = Number of flowers per plant at 10 WAT
X_{10} = Number of flowers per plant at 12 WAT
X_{11} = Plant height at 10 at 11 WAT
X_{12} = Plant height at 12 WAT
X_{13} = Number of leaves per plant at 12 WAT
X_{14} = Number of leaves per plant at 10 WAT
X_{15} = Number of branches per plant at 10 WAT
X_{16} = Number of branches per plant at 12 WAT.

4.3.12 *Correlation coefficient (r)* between yield-related parameters and nutrient element concentrations in leaves

Correlation coefficient between plant height, number of leaves, branches, flowers, fruits per plant, mean fruit diameter and weight with nutrient concentration is shown in Table 56. Nitrogen concentration was positively and significantly correlated to plant height (r =0.272*) number of leaves (r = 0.445*), branches (r = 0.250*) fruits (r = 0.261* and r = 0.302*), mean fruit diameter (r = 0.349*) and fruit weight (r = 0.466**). Phosphorus concentration was positively and significantly correlated with total number of fruits (r = 0.263*), mean fruit diameter (r = 0.323**) and fruit weight (r = 0.250*), while K concentration was positively and significantly correlated only mean fruit diameter (r = 0.316*). Similarly Ca concentration was positively and significantly correlated with mean fruit weight (r = 0.370**). Magnesium concentration was positively and significantly correlated to plant height (r = 0.246*).

Correlation between Zn concentrations and number of branches (r = -0.257*), flowers (r = -0.377**), fruits (r = -0.328**) and mean fruit diameter (r = -0.296*) were found to be negative and significant. Manganese concentration was negatively and significantly correlated with total number of fruits (r = -0.238*) and mean fruit weight (r = -0.336**). Similarly mean fruit diameter (r = -0.271*) and weight (r = -0.280*) were negatively and significantly correlated with Fe concentration. And Cu concentration was negatively and significantly correlated with total number of fruits (r = -0.253*) and mean fruit weight (r =-0.322**).

Table 56: Correlation between tomato performance and nutrient element concentrations in tomato leaves in the dry season.

Nutrient	Plant Performance												
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}
N	0.203	0.272*	0.118	0.445**	0.146	0.250*	0.026	0.213	0.115	0.261*	0.302*	0.349**	0.466*
P	0.222	0.221	0.061	0.234	0.067	0.217	0.001	0.039	0.093	0.016	0.263*	0.323**	0.250*
K	0.077	0.087	0.138	0.015	0.105	0.062	0.211	0.195	0.148	0.061	0.104	0.316*	0.034
Ca	0.219	0.158	0.061	0.088	0.144	0.098	0.139	0.123	0.081	0.027	0.137	0.026	0.370**
Mg	0.246*	0.068	0.179	0.032	0.052	0.052	0.183	0.189	0.033	0.003	0.141	0.058	0.013
Zn	-0.041	-0.064	-0.047	-0.117	-0.135	-0.257*	0.226	-0.377**	-0.063	0.200	-0.328**	-0.298**	-0.190
Mn	-0.068	-0.022	-0.091	-0.120	-0.165	-0.114	-0.085	-0.017	-0.018	-0.018	-0.238	-0.051	-0.336**
Fe	-0.091	-0.013	-0.042	-0.102	0.021	-0.167	-0.132	-0.058	-0.055	-0.109	-0.079	-0.271*	-0.280*
Cu	-0.150	-0.143	-0.194	-0.044	0.076	-0.005	-0.082	0.233	-0.137	-0.018	-0.253*	-0.086	-0.322**

* = Significant at 0.05 level of significance ** = Significant at 0.01 level of significance.
X_1 = Plant height at 10 WAT
x_2 = Plant height at 12 WAT
x_3 = Number of leaves per plant at 10 WAT
x_4 = Number of leaves per plant at 12 WAT
x_5 = Number of branches per plant at 10 WAT
X_6 = Number of branches per plant at 12 WAT
X_7 = Number of flowers per plant at 10 WAT
x_8 = Number of flowers per plant at 12 WAT
x_9 = Number of fruits per plant at 10 WAT
x_{10} = Number of fruits per plant at 12 WAT
x_{11} = Total number of fruits per plant at harvest
x_{12} = Mean fruit diameter
x_{13} = Mean fruit weight

CHAPTER FIVE

DISCUSSION

5.1 Effect of lime and N Sources on vegetative growth of tomato

The result from this study indicated that, in general liming this soil significantly increased plant height, number of leaves and branches per plant at all the growth stages.

In the greenhouse study, taller plants, more leaves and branches per plant were produced when lime was applied at 0.40 and 0.55 t/ha. Similar results were obtained in the wet season, where higher lime rates of 0.40 and 0.55 t/ha were applied. Values for plant height, number of leaves and branches per plant were significantly higher. In the dry season, plant height, number of leaves and branches per plant were significant at 2.24 and 4.48 t/ha rates. This result is expected as the soil of the study area (Table 1) is acid in reaction and liming reduced the acidity and therefore improved nutrient availability. Liming contributes to maintaining and improving fertility of an acid soil (Martini and Mutters, 1983).

Vegetative growth is generally enhanced by the application of lime as it provides a more favorable environment for plant growth due to improved root growth, reduction in toxic concentrations of plant Al and Mn and increase in the Microbial activity and availability of major plant nutrients (Okigbo, 1972; Amarasiri and Olsen, 1973; Phillips, 1977; Mendoza, 1983; Olvera and Blue, 1985; Akinsola and Obi, 1987). The increase in plant height, number of leaves and branches per plant with lime application, confirms the views expressed by Doss *et al.* (1977), Fageria *et al.* (1981), Asiegbu and Uzo (1983), Fuleky and Hassan (1988) that application

of lime increased shoot and root growth, root concentration weight and dry matter yield.

There was also an increase in the tissue concentrations of N, P, Ca and Mg with lime application, while Zn, Mn, Fe and Cu concentrations, were decreased. This is also reflected in the increase in growth parameters. This also confirms the findings of Kehoe and Curnow (1963), Noborg and Hoyt (1978), Narottama (1974), Mathur and Levesque (1983) Kowalenko *et al.* (1980) Patiran (1990) and Umesh (1972) who reported that lime application might increase macronutrient uptake by improving physiological conditions of the plant and also decrease the amount of micronutrient uptake by plants.

There was a slight decrease in growth parameters when lime was applied at 8.96 t/ha. This is expected since excessive amount of lime is unfavourable to plant growth. High soil pH reduces the availability of nutrients and causes imbalance in the uptake of K, Mn and Zn. These observations confirm the views expressed by Juo and Uzu (1977), Black and Cameroon (1984) and Duguma *et al.* (1980) who reported that over liming Tropical soils is known to have detrimental effect on plant growth.

Use of CAN instead of urea fertilizer significantly favoured most of the growth parameters during the greenhouse, wet and dry seasons. For example plant height, number of leaves and branches per plant were significantly higher when CAN was applied. Such enhanced plant performance may be attributed to the lower acidifying effects of CAN. Jone (1976) and Okpon (1987) stated that CAN had enough $CaCO_3$ to neutralize 80-83% of potential residual acidity of its ammonium nitrate content. There was also an increase in tissue N, P, Mg and Ca

concentrations with CAN application, which might also be attributed to increase in growth parameters.

In the greenhouse and during the wet and dry seasons, varietal response to lime and N sources indicated that variety TI 221, responded significantly to the treatments as it had taller plants, higher number of leaves and branches per plant at sampling periods. Foy and Brown (1964) stated that crop response to lime varies considerably even among varieties of the same species.

There was a significant interaction effect in the greenhouse between N sources and varieties, with variety TI 221 producing taller plants and more leaves with the application of CAN. In the dry season, a significant interaction effect between lime and N sources was observed. Taller plants were observed when lime was applied at 2.24 and 4.48t/ha with both sources of N.

5.2 Effect of lime and N sources on yield- elated parameters of tomato

Growth parameters generally increased with liming. This may be due to its activity in promoting growth of plants, which enhanced efficient photosynthetic activity, resulting into increased yield-related parameters such as number of flowers, fruits, mean fruit diameter and weight.

In the greenhouse and wet season studies, yield-related parameters were significantly higher when lime was applied at 0.40 and 0.55t/ha, while in the dry season, yield-related parameters were significantly increased with liming rates upto 4.48t/ha, beyond which there was a decrease only in number of fruits, fruit mean diameter and weight. This is expected as lime enhances the release of nutrients in such an acidic soil, in addition to improving some physical properties of the soil (Russel, 1932; Eades *et al.*, 1962; Badanur and Ventata, 1975).

Increase in yield-related parameters can also be tied down to an increase in nutrient concentrations in the leaves with liming. This confirms the findings of Winsor *et al.* (1967), Doss *et al.* (1977), Rhue and Everrett (1987), who stated that weight per fruit and size increased with liming. Overliming is reported to depress growth, reduce number of fruits per plant and fruit quality (Winsor and Long, 1968; Juo and Uzo, 1977).

For most of the yield-related parameters assessed, it was observed that maximum values were obtained with the application of CAN. This could be due to the less acidifying effect of CAN on these soils that are also acidic (Jones, 1976 and Okpon, 1987). Similarly CAN stimulated the uptake of nutrients by plants which in turn increased nutrient concentrations in the leaves resulting in to an increase in yield-related parameters.

The varieties responded differently in terms of number of flowers, fruits, mean fruit diameter and weight. Variety TI 221 gave highest values compared to the other two. It produced more fruits larger and heavier fruits in the greenhouse, wet and dry seasons. Similar observations were made by Foy and Brown (1964).

A significant interaction effect between N sources and varieties was observed in the greenhouse, application of CAN resulted into higher number of fruits in variety TI 221 at 6 WAT. While on the field in the wet season, interaction was between lime and varieties, lime applied at 0.55t/ha produced higher number of flowers in variety TI 221 at 6 and 8 WAT. In the dry season interaction between lime and N sources, and lime and varieties were observed. Higher number of fruits were obtained when CAN was applied with lime at 2.24t/ha. The favorable interaction between lime and CAN on the number of fruits corresponds to a work

by Okigbo (1972), who found that 2.24t/ha lime in combination with N, P, K and Mg gave high maize yield. Interaction between lime and varieties indicated that highest number of fruits were obtained in varieties TI 106 and TI 539, when lime was applied at 2.24 and 4.48t/ha. This differences responses in the various varieties confirms the observations made by Bohn *et al.* (1964) and Foy and Brown (1964).

5.3 Effect of lime and N sources on total fruit yield

Liming generally increased plant growth and yield-related parameters, which also resulted in an increase in the total fruit yield. Maximum fruit yield in the greenhouse and wet season was obtained at 0.40 and 0.55t/ha. In the dry season, there was also an increase in fruit yield with increasing lime rates upto 4.48t/ha, beyond which values slightly decreased. This increase in fruit yield is expected, since there were increases in growth and yield-related parameters, which will contribute to the total fruit yield. Doss *et al.* (1977), Worley (1977), Asiegbu and Uzo (1983), Pombo and Smith (1986), Rhue and Everret (1987) reported increase in tomato yields with lime application. The significant increase in yield with liming on this soil, indicates the inherent low fertility and acidic nature of the savanna soils as reported by Jones and wild (1975) and Lombin (1982). Thomas and Hangrove (1984) and Doerge *et al.* (1985) reported that when lime was applied to acidic soils many chemical changes occurred which were responsible for improved crop growth.

Higher fruit yields were also obtained with the application of CAN rather than urea in the greenhouse, wet and dry seasons. This is expected since CAN has less acidifying effects than urea (Jones, 1976 and Opkon, 1987).

All the varieties responded to the treatments differently. Variety TI 221 produced significantly more fruits than varieties TI 106 and TI 539. Foy and Brown

(1964) indicated that crop response to lime varies considerably even among varieties of the same species.

Interaction effect on total fruit yield was only significant in the dry season experiment. Evidently the individual lime rates, N sources and varieties resulted in an increased fruit yield, but the effect is more pronounced when they are used in combination with one another. Lime and N source interaction, indicated that higher fruit yield were obtained at 4.48 and 8.96t/ha with urea while with CAN yields were higher at 2.24 and 4.48t/ha. Interaction between N sources and varieties, indicated a significant increase in yield with the application of CAN in variety TI 106.

The results from the study, indicates that if lime is supplemented with CAN, reasonable improvement in performance and yield of tomato may be expected.

5.4 Effect of lime and N sources on the macronutrient concentrations in tomato leaves

The nutrient concentrations in plant tissue is the integral effects of all the factors that acted upon plant during its growth. Liming acid soils reduces toxic concentration of plant available Al and Mn and increases the availability of major plant nutrients.

In the green house, wet and dry season experiments, increasing lime rates tended to increase N concentrations. Higher N content was obtained at 0.40 and 0.55t/ha lime rates for the greenhouse and wet season while for the dry season N concentration was significantly higher at 4.48 and 8.96t/ha lime rates. This increase in N concentration is expected as lime increases N content of plants (Marousky and Wohz, 1977, Bouton *et al.* 1981, Walworth and Summer, 1990). Patel (1969) also stated that total N content of leaf increased with increase in Ca concentration.

Similarly Blue *et al.* (1980), reported that lime treatments stimulate nitrification ($NH^+_4 \rightarrow NO^-_3$) allowing the NO^-_3) to be utilized in biological cycles and in the absorption and storage of N. Application of CAN, resulted into a significant increase in N concentration in the leaves.

Phosphorus concentration in the leaves tended to increase with increasing lime rates, values were significantly higher with higher rates of lime in the green house, wet and dry season experiments. Such an increase in P concentration in the leaves may be attributed to the increase in P solubility due to liming. Abdul (1964) reported that liming liberated P locked in the organic form and increased efficiency of applied P for crops, while Kehoe and Curnow (1963) and Friensen *et al.* (1980) suggested that lime application might increase P uptake by improving the physiological conditions of the plant.

There was no measurable effects of lime on plant K concentration. There was no significant difference between the control and other rates in the whole experiment. This lack of effect was possibly caused by different mechanisms operating for divalent and monovalent cation uptake by plants (Mengel and Kirkby, 1978). Non significant increase in tissue K concentration with liming was also observed by Martini and Mutters (1985) and Rhue and Everret (1987), while Amarari and Olsen (1973) reported an increase in Ca concentration in plant resulting into a decrease in the K/Ca ratio. Similarly K and lime interaction resulted into a decrease in K uptake (Aderson 1970).

Lime increased leaf Ca and Mg. Values tended in increase with increasing lime rates. Highest values were obtained at 0.40 and 0.55t/ha lime rates for the green house and wet season, while concentration were highest with 4.48 and 8.96t/ha rates

for the dry season. This is expected as lime increased exchangeable Ca and Mg contents of the soil, making then readily available for plant uptake. The Ca:Mg ratio in plants increased with liming (Mathur and Levesque, 1983). Similar result was reported by Chriesten *et al.* (1973), who reported that liming increased Ca and Mg content of plants.

The application of CAN, significantly increased N, Ca and Mg concentrations in the green house, while on the field (wet and dry seasons), N, K and Mg were significantly increased. There was an increase in P and Ca, but values were not significant. This is in agreement with the findings of Pill and Lambert (1977) who stated that fertilization of tomato with NH_4 - N reduced shoot concentration of Ca, Mg, K, P and NO_3, compared to NO^-_3 - N. While Hamid and Sarwar (1976) stated that ammonium nitrate had about 50% more stimulating effect on the uptake of N than urea. This decrease in tissue Ca and Mg with NH_4 nutrition has been well documented (Kirkby and Mengel, 1967; Blair *et al.* 1970; Barker and Maynard, 1972; Haynes and Goh, 1978).

There was a significant interaction effect between lime and N source on Ca concentration in the green house . Higher Ca concentration was obtained in pots limed at 0.40 and 0.55t/ha rates, for both sources of N. Similar result was also obtained by Winsor *et al.* (1967), who reported a significant interaction between lime and N. Interaction effect between lime and varieties, indicated a significant increase in Ca concentration in all the varieties with lime applied at 0.40 and 0.55t/ha.

5.5 Effect of lime and N sources on micronutrient concentrations in tomato leaves

There was an obvious decrease in micronutrient concentrations with increasing lime rates. The concentrations of Zn and Mn were significantly lower with lime applied at 0.25 to 0.55t/ha for the green house and wet season, and at 4.48t/ha and 8.96t/ha for the dry season. The decrease in nutrient concentration in the leaves were related to changes in soil pH due to lime application. This supports the findings of Moraghan and Mascagni (1991) who stated that increasing the pH of a soil by liming usually decreases the plant available Zn and Mn. This decrease in tissue Zn and Mn is expected as extractable Zn and Mn taken up by plant decreases with increasing lime rates (Sims, 1986; Yli-Halla, 1993; Forno *et al.* 1975; Doger and Van Hai, 1980). Juo and Uzo (1977), found that liming soil can reduce water soluble Zn and Mn to an undetectable values.

Similar trend was also observed with Fe and Cu. Increasing lime rates, resulted in a decrease in Fe and Cu concentrations in the leaves. Values were more significant with the higher rates of lime 0.40 and 0.55t/ha for greenhouse and wet season, and 4.48 and 8.96t/ha for the dry season experiments. This is expected as liming resulted in an increase in soil pH and decreases in Fe and Cu concentrations in plants. This collaborates findings of Fuleky and Hassan (1988). Mahendra and Dahiya (1976), Lambert and Grant (1980) and Patiran (1990), reported that Fe and Cu concentration and uptake decreased with increase in $CaCO_3$.

Application of urea resulted in a significantly increase in Fe and Cu in the greenhouse, while in the wet season there was an increase in Zn, Fe and Cu. Similarly Mn, Fe and Cu content were significantly increased with the application of urea in the dry season. This is due to the tendency for the soil to become acidic

when N was supplied as NH^+_4. Similar observation was made by Haynes and Goh (1978).

Interaction effect between lime and N source on Zn concentration in the greenhouse indicated that highest Zn concentration in the leaves was obtained at 0.25t/ha lime with the application of urea. In the wet season the interaction between lime and N source resulted in a significant increase in Mn concentration with the application of urea. Interaction effects between lime and varieties were not consistent in the greenhouse, while on the field, Zn concentration was significantly higher at 0.10t/ha lime in varieties TI 106 and TI 539. Such variations confirms the findings of Foy and Brown (1964), Bohn *et al.* (1964), Bear and Prince (1945).

5.6 Effect of lime and N sources on soil pH and exchangeable cations

The pH of the soil generally increased with, application of lime the increase being linear with increasing rates of lime.

The pH values varied little among the rates in the wet season. Values were significant at 0.55t/ha, though there was a slight difference between the control and other rates. For the dry season, values were significantly higher at 4.48 and 8.96t/ha rates. The change in soil pH is expected due to the acidic nature of the savanna soils (Lombin, 1983). Liming this soil, neutralized its acidity and increased base saturation. Levesque and Mathur (1983) made similar observations and reported that the average soil pH increased linearly with liming. So also the base saturation, thus ameliorating the soil acidity.

Liming the soil generally increased the exchangeable cations. Values were slightly increased in the wet season. In the dry season, liming at 4.48 and 8.96t/ha significantly increased Ca, Mg and Na contents of the soil, while K was not

significantly increased with liming. This increase in exchangeable cations is expected due to the acidic and low fertility nature of the savanna soil, confirming the view expressed by Edmeade (1982), that liming increased exchangeable Ca, Mg, Na and (to lesser extent) K.

There was an increase in soil pH with the application of CAN, though values were non-significant in both seasons. Only exchangeable Mg was significant with the application of CAN in the dry season. Such an increase in soil pH and exchangeable cations may be due to the neutralizing effects of CAN on the soil. This collaborates the findings of Jones (1976) and Okpon (1987) which stated that CAN contains enough Ca to neutralize about 80 - 83% of the potential residual acidity from the ammonium nitrate.

5.7 Correlation coefficient between yield and yield-related parameters

The positive and significant correlation that existed between total fruit yield and plant height, number of leaves and branches per plant in the greenhouse, wet and dry seasons studies, signifies the degree of the importance of these growth parameters as assimilatory organs that produce the materials, or assimilates which form the basis of yield. The reason why plant height was directly correlated with increased fruit yield was probably because taller plants exposes the crop canopy for more and efficient utilization of sunlight. Taller plants often have more vegetative growth and more flowers and higher fruit set, leading to higher fruit number and yield. This is in agreement with the findings of Nandpuri (1969) who observed that yield per plant was positively correlated with plant height, number of branches and number of fruits. Similarly Hoffman (1971) and Doss (1977) reported that total fruit yield and yield-related parameters were positively and strongly correlated.

5.8 Correlation coefficient between yield-related parameters and nutrient concentrations in tomato leaves

In the greenhouse, wet and dry seasons, plant height, number of leaves, branches, fruit, mean fruit diameter and weight were significantly and positively correlated to N concentrations. Nitrogen availability and uptake are known to be enhanced by liming. Blue *et al.* (1980) stated that liming stimulates the release and uptake of N. Nitrogen itself, is a very important element for vegetable production, hence there is a strong correlation with these growth parameters. Phosphorus concentration was positively and significantly correlated to all the parameters in the greenhouse, with the number of leaves, branches and mean fruit diameter in the wet season. While in the dry season correlation was with number of fruits, mean fruit diameter and weight only. For the dry season, only mean fruit weight was correlated to K concentration. Calcium concentration was positively and significantly correlated with all the yield-related parameters except number of leaves and branches in the greenhouse. All yield-related parameters in the wet season were significantly correlated to Ca concentration except number of branches per plant. In the dry season, only mean fruit weight was significantly correlated to Ca concentration. These positive and significant correlations are expected as lime improves soil conditions and availability of exchangeable cations (Edmeade 1982). Magnesium was positively and significantly correlated to all the yield-related parameters in the greenhouse. In the wet season correlation was only significant with plant height and number of leaves per plant, while in the dry season only plant height was significantly correlated with Mg concentration.

All micronutrient element concentrations (except Zn) were negatively and significantly correlated to all the yield-related parameters in the greenhouse. In the wet season, plant height number of leaves, flower and mean fruit weight were significantly correlated with micronutrient concentrations. For the dry season, Zn

concentration was only significantly correlated to plant height and mean fruit weight, while the concentrations of Mn, Fe and Cu were negatively correlated to all the yield-related parameters, except values for number of fruits, mean fruit diameter and weight were significant. This is attributed to the effect of liming on micronutrient availability in plants. Liming is reported to decrease micronutrient availability in the soil (Mcleod and Quin 1979, Fuleky and Hassan 1988, Moraghan and Mascagni 1991).

CHAPTER SIX

SUMMARY AND CONCLUSION

The serious acidifying effect of nitrogenous fertilizer on the poorly buffered savanna soils, is a major factor limiting food production. For successful crop production, liming is important in combating fertilizer-induced acidification.

The emphasis of this study was to ascertain the effects of two nitrogen sources, urea and calcium ammonium nitrate in combination with different rates of lime on tomato yield and yield-related parameters, changes in soil pH and exchangeable cations. Sequal to this a greenhouse and two field (wet and dry seasons) studies were carried out at the Institute for Agricultural Research (IAR) irrigation site Samaru Northern guinea savanna zone of Nigeria.

The treatments consisted of two nitrogen sources (urea and CAN), five rates of lime (0, 0.10, 0.25, 0.40 and 0.55t/ha, for green house and wet season, while for dry season lime rates were increased, 0, 1.12, 2.24, 4.48 and (8.96t/ha) and tomato varieties namely TI 221 TI 106 TI 539. All the possible combinations of the factors were arranged in a complete randomized design and replicated three times. Soil, plant and lime samples were analysed for nutrient contents. Observations were made on performance, yield and yield-related parameters.

The results from the green house and wet season, showed that tomato performance as measured by total fruit yield, plant height number of leaves, branches fruits mean fruit diameter and weight were generally better when lime was applied at 0.40 and 0.55t/ha than the other rates. Results from the dry season studies showed that yield and yield-related parameters generally increased with increasing lime rates upto 4.48t/ha and decreased slightly at 8.96t/ha.

Yield and yield-related parameters were significantly higher with the application of CAN than urea throughout the whole trials.

Variety TI 221 showed a significantly higher response to lime and N sources than varieties TI 106 and 539. Taller plants have higher number of leaves, branches, fruits, mean fruit diameter, weight and total fruit yield were obtained in variety TI 221.

Liming generally increased soil pH. The pH values varied slightly in the wet season, value was only significant at 0.55t/ha. For the dry season, values were slightly higher at 4.48 and 8.96t/ha rates. Similar trend was also observed with the exchangeable cations, values were slightly increased in the wet season, with the highest values obtained at 0.55t/ha. While in the dry season exchangeable Ca, Mg and Na content of the soil were significantly increased at 4.48 and 8.96t/ha rate.

From the study, the following conclusions can be drawn.

1. Tomato performance with CAN was generally superior, higher fruit yield and yield-related parameters were produced with the application of CAN than Urea.
2. Variety TI 221 was more responsive to lime and N sources than varieties TI 106 and 539.

Conclusively, the soils of this area requires liming at 2.24 and 4.48t/ha supplemented with CAN, for improvement in performance and yield of tomato, particularly variety TI 221.

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