EFFECTS OF NITROGEN SOURCES AND RATES ON SOIL PROPERTIES, TISSUE NUTRIENT CONCENTRATION AND YIELD OF COTTON (*GOSSYPIUM HIRSUTUM* L.) IN SOILS OF THE UNIVERSITY FARM, MOROGORO.

By

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DECLARATION

I, THOBIAS K. MWAGANICHA, do hereby declare to the Senate of the Sokoine University of Agriculture that this dissertation is my original work and has not been submitted for a degree in any other University.

Signature: Mwaganicha

Date: 06.07.1989

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DEDICATION

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ABSCTRACT

Pot and field experiments were carried out to investigate the effects of different rates and sources of N in soils with different initial pH on soil chemical properties, tissue nutrient concentration, growth and yield of cotton at the University Farm, Morogoro. Nitrogen rates applied were 0, 50, 100 and 150 kg N/ha and the N sources were SA, urea and CAN. The soils used had initial pH values of 4.8, 6.1 and 6.9 and were designated as strongly acid soil (SAS), moderately acid soil (MAS) and almost neutral soil (ANS), respectively. The experimental design was a split-plot with N rates as main plots and N sources as subplots.

Soil chemical properties assessed were pH, exchangeable acidity, Al, bases and Mn. Concentration of N, P, Ca and Mn were determined in leaf tissues at flowering in the pot study and at flowering and boll stages of cotton development in the field experiment. Shoot dry weight, plant heights, number of fruiting branches, number of flowers, number of bolls, number of early maturing bolls, as well as seedcotton yield and one thousand seeds weight were also determined.

Nitrogen application above the control significantly increased exchangeable acidity and aluminium in the SAS, the effects being mainly due to different rates of SA. Other soil chemical properties in SAS and all measured properties in MAS and ANS were not significantly affected by the rates and sources of N. Nitrogen application significantly increased N concentration in leaf tissues except that of leaf blades at flowering in SAS and in both petioles and leaf blades at boll development stage in ANS. The N concentration at flowering associated with maximum seedcotton yield was 2.0% for petiole N and 4.4% for leaf blades N. While P and Ca concentrations in leaf tissues at flowering were significantly increased due to different rates of CAN, Ca concentration was significantly decreased at 150 kg N/ha applied as SA and urea in the SAS. Manganese concentration in leaf tissues at flowering was significantly increased due to various rates of SA in the SAS, and in leaf blades at flowering and boll stages of cotton development in the ANS.

Shoot dry weight, plant heights, number of fruiting branches, number of flowers and number of bolls were significantly increased by N application. Early maturing bolls were not significantly affected by N application. Nitrogen sources did not significantly affect the growth and reproductive characters of cotton, except shoot dry weight in the field experiment at flowering which was significantly increased by SA. Seedcotton yield and one thousand seeds weight were significantly increased by N application, with maximum responses being at 100 kg N/ha. Nitrogen sources had no significant effects on the yield components of cotton in the ANS. Nitrogen concentration in leaf tissues was significantly correlated with shoot dry weight and yield of seedcotton.

It was therefore concluded that (i) consideration of N sources was necessary in the SAS but was appearing irrelevant in the MAS and ANS, (ii) the agronomic optimum N rate was close to 100 kg/ha for these soils and (iii) concentration of N in petioles and leaf blades at flowering could be used to assess the N status of cotton plants with values of 2.0% and 4.4% respectively, being tentatively suggested as optimum.

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1. INTRODUCTION

Cotton is one of the most important export crops in Tanzania. It is grown on a large variety of soils, but it does best on deep friable soils with medium content of humus, well drained and average moisture-holding capacity. Sandy loams, loams and well-granulated clay loams are considered best (Berger, 1969). Cotton prefers a slightly acid to neutral soil reaction. The optimum soil pH lies between pH 5.5 and 7.0 (Fink, 1982). Strong soil acidity is injurious to cotton as a result of excess soluble aluminium and manganese ions, which are toxic to cotton roots. In addition, such soils are deficient in calcium. Calcium is an important cation in cation-anion balance in cotton nutrition (Adams and Wear, 1957; Le Mare, 1971; Adams and Moore, 1983; Adams and Hathcock, 1984).

Most of the cotton in Tanzania is grown on Oxisols[1] and Alfisols[2] derived from acid, coarse-grained granite and a small portion on Ultisols[3] and Vertisols[4] (Le Mare, 1971; 1974). Most of these soils are inherently low in organic matter (less than 3%) and hence low in nitrogen content (less than 0.2%). However, nitrogen is required by cotton plants in relatively large quantities. The above-ground parts of cotton plants yielding an average of 600 kg of lint and 1100 kg of seed per hectare remove about 73 kg of N, 28 kg of P, 56 kg of K, 8 kg of Ca, 6 kg of Mg and 3 kg of S per hectare

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[1] Ferralsols, [2] Luvisols, [3] Acrisols and [4] Vertisols; equivalent names in the FAO-UNESCO Soil Classification System (FAO-UNESCO, 1974).

(Berger, 1969). These figures reveal the extent of nitrogen requirement and uptake by cotton, as compared to other nutrients.

Cotton responds well to N fertilizers and by using adequate amounts of fertiliser N, high yields can be obtained. In various trials conducted at Ukiriguru and Ilonga Research Institutes and other nearby areas, yields between 1200 and 3100 kg/ha of seed cotton have been obtained with N fertilizers at rates of 30 to 60 kg N/ha (Le Mare, 1974; Acland, 1977; Fielding, 1976; 1977). Also yields reported from a Fertilizer Demonstration Programme started in 1964/65 in the Western Tanzania cotton areas increased from a level of 225-280 kg to 785-900 kg of seedcotton/ha following applications of 125 kg of sulphate of ammonia (SA)/ha (26 kg N/ha) together with 40 kg P (as doublesuperphosphate)/ha (Le Mare, 1972).

The scarcity and exorbitant rise in the cost of fertilizers during recent years have also necessitated designing a rational use of N fertilizers. The present fertilizer recommendations for cotton are based primarily on the results of work by the Agricultural Research Institutes at Ukiriguru and Ilonga. Currently, a recommendation is available only for the Western Tanzania cotton areas, which is 26 kg N/ha as SA together with 40 kg P/ha and applied prior to ridging (Fielding, 1977). However, there are no recommendations on any N source and rate of application for the Eastern cotton growing areas of Tanzania. The presently held view that these areas have more fertile soils and therefore do not need fertilizer application requires thorough evaluation. Cotton is grown over a very wide range of soil conditions, and such a general statement can not hold true. In addition, continued cultivation has increased the drain of nutrients from these traditional cotton-producing areas, particularly during recent years, when heavier population pressure has forced peasants to abandon shifting cultivation and to establish permanent villages. Also the government is putting a lot of emphasis on cotton production in these areas which have a high potential for the crop (Ministry of Agriculture, 1983). One of the most important inputs in this effort will be fertilizer use, particularly N fertilizer. There is a need, therefore, for intensive research to determine the optimum rate of N application for cotton in the Eastern cotton growing areas of Tanzania.

The appropriate source of N for different soils continues to hold a place of prominence, in considerations related to cotton production. This interest is due primarily with obtaining a form of N fertilizer which possesses N availability characteristics that coincide with the desired absorption, growth pattern and yield level of cotton (Grimes _et al_., 1969a; 1969b; Smithson and Heathcote, 1977; Sonar _et al_., 1984).

Different sources and forms of nitrogenous fertilizers are available in the country, with different N contents. The most available and commonly used N fertilizers are sulphate of ammonia (SA), urea and calcium ammonium nitrate (CAN). Some of these fertilizers contain other nutrients along with N and this is advantageous. While some N sources like SA and urea have acidifying effects on soils, others like CAN are neutral in their effects. These differences in fertilizer carrier material have been found to affect various soil chemical properties when used continuously, especially the soil reaction, exchangeable acidity, exchangeable aluminium, exchangeable manganese and exchangeable bases (Abruna et al., 1958; Peat and Brown, 1962; Stephens, 1969; Le Mare, 1972; Singh and Balasubramanian, 1979).

Knowledge of the suitability of different N sources relative to the soil and crop in question is important to maximize return per unit of investment. This knowledge may also help avoid mistakes made earlier in the other cotton-growing areas of Tanzania. For example, it has been reported that some areas of Sukumaland have already been damaged by injudicious use of agro-chemicals, especially the continued use of SA in already acid soils (Le Mare, 1972; Ministry of Agriculture, 1983). Such information is also of value to the government, for it to arrive at a technically sound fertilizer policy. In view of the above considerations, this study was conducted with the following main objectives:

(i) To assess the effects of rates and sources of N on growth, tissue nutrient concentration and yield of cotton in soils of the University farm, Morogoro.

(ii) To evaluate the effects of rates and sources of N on a number of soil chemical properties in soils of different pH values from the farm.

2. REVIEW OF LITERATURE

2.1 Importance and requirement of N for cotton.

2.1.1 Effects of N on cotton growth and yield.

Nitrogen is deficient in most soils and is the nutrient that most frequently limits crop production. Deficiency of nitrogen results in poor plant growth and a uniform yellowing of leaves. Application of nitrogen enhances vegetative growth and imparts dark green colour to the foliage. If applied too near to harvest, the increased leaf area may not have time to make an economic contribution to the yield, and indeed may reduce yield by encouraging greater vegetative growth rather than seedcotton production. Such a leafy plant can also be "attractive" to insect pests, ultimately ripening fewer bolls and resulting in low yield (Wrigley, 1982).

Consistently nitrogen has been reported to affect almost all the growth processes of the cotton plant. The height of plants increases with additions of nitrogen, as does the number of vegetative branches, flowers and mature open bolls. It also affects boll number, seedweight and final yield of seedcotton (Berger, 1969). Gardner and Tucker (1967a) observed plant heights of 44 and 90 cm, vegetative branches of 0.68 and 1.29 per plant, total flowers of 177 and 420 per plot, total bolls of 84 and 206 per plot and yield of seedcotton of 3.2 and 8.7 g per plot; for the control and 112 kg N/ha, respectively. The differences between the two N levels were found to be highly significant. Similarly, Amer and Abuamin (1969), reported a significant increase in seedcotton yield from 2010 to 4540 kg/ha in three experiments from the application of 150 kg N/ha.

Experimental results obtained over a period of eight years at five locations in Georgia (USA), showed that of every dollar profit resulting from the application of N, P and K on cotton, 76 ct were due to N, 8 ct due to P and 16 ct due to K (De Geus, 1973). Generally, large increases in yields and economic return resulting from the application of N have been reported in most cotton growing areas (Wahhab and Ahmad, 1961; Le Mare, 1972; 1974; De Geus, 1973; Kairon et al. (1980).

The major essential roles of nitrogen as reported by Gardner and Tucker (1967a) and Berger (1969) are (i) to initiate meristematic activity (ii) to stimulate shoot and root development and activity and (iii) to enhance the uptake of nutrients from the soil through the above processes. Grunes (1959) observed markedly increased absorption of soil and fertilizer P by cotton plants with addition of nitrogen. These effects of N were related to increased root growth and foraging capacity of the roots.

An experiment conducted in South Arabia, resulted in a positive response to N application of 58% in the first year and 51% the following year at the rate of 112 kg N/ha applied at flowering (Mawly, 1967). When the same experiment was repeated for P and K, no significant responses were observed.

Similarly, in experiments conducted in Malawi over eight sites, covering a wide range of soil conditions, to assess the effects of applying different rates of N and P fertilizers on cotton yield, good responses to N were obtained at 6 sites, while P gave significant increases in yield only at one site. Nitrogen was applied as CAN at rates of 0, 45, and 90 kg N/ha and P at rates of 0 and 15 kg P/ha, on soils with pH (H_2O) range of 6.1 to 6.2 (Matthews, 1972). Likewise, Burhan (1971) obtained a highly significant response of cotton yield to N application. The addition of P and K even at higher levels of N, did not affect yield significantly. According to Burhan (1971; 1972), a curvilinear relationship was shown to exist between yield and the rate of N application. Such a function permitted the estimation of the expected increments in yield due to N levels and could be used to determine the economically optimum rate of N fertilizer. The optimum rate from this study was 134.5 kg N/ha, applied as urea rather than the earlier recommended rate of 89.7 kg N/ha, in the Gezira Scheme.

MacKenzie and van Schaik (1963) and Grimes et.al. (1969a; 1969b), reported N to be an important factor influencing plant characteristics, boll properties and yield in different varieties of cotton. Most varieties tested responded positively with rates of N upto 107 kg N/ha, as SA. It is therefore, evident that the soils where the bulk of the cotton crop is grown are deficient mainly in N, but are not deficient in P and K and hence emphasizing the importance of N in cotton production (Bartholomew and Clark, 1965; Stephens, 1967; 1968; Stevenson, 1982)

2.1.2 Nitrogen requirement, uptake and time of application.

Yields of cotton reported in the literature vary between 500 and 5000 kg/ha of seedcotton, depending on the level of N fertilizer and supply in the soil. Rates of N application depend on the yield level required and N supply in the soil and have been reported to range between 20 and 200 kg N/ha (Finck, 1982; Sonar _et_ _al_., 1984). Low N rates have been found to correspond to abundant N supply in the soil (a rare case), while large doses are required for high yields on soils poor in N. In the coastal areas of Peru, the magnitude of cotton response to fertilizer N and the N requirements at different soil analysis levels have been used to categorize the soils into three major fertility classes. These were low, medium and high, corresponding to soil total N of less than 0.1%, 0.1 to 0.15% and above 0.15%, respectively. The N requirements in the respective soil groups were classified as high, fairly high to normal and moderate to none (De Geus, 1973). Similar N-fertility classes of soils based on total N have been reported in Morogoro region for maize (Singh and Uriyo, 1980). These workers observed that the magnitude of response increased significantly with increasing doses of fertilizer N upto 200 kg N/ha on low N and upto 150 kg N/ha on medium N soils. Relationships between soil N level to cotton yield and response to added N fertilizer have also been reported by Gardner and Tucker (1967b). When soil NO_3-N was 0.45 ppm, yield following N application of 112 kg/ha was 6.4 bales/ha compated to 8.4 bales/ha with soil NO_3-N of 11.29 ppm. At the respective soil NO_3-N levels, yields in the controls were 2.0 and 6.9 bales/ha. The increases due to N application therefore, were 4.4 and 1.5 bales/ha or 68.8 and 19.9%, respectively.

According to Finck (1982), a harvest of 1,500 kg fibre and 3000kg seeds/ha required about 200 kg N/ha. While at 500 to 1000kg fibre and 1000 to 2000 kg seeds/ha, N requirement was 35 to 70 kg N/ha. De Geus (1973), reported that the amount of N fertilizer to use must be determined by the grower himself taking into account the soil type, its fertility level, cropping and fertilizer application history, soil management practices, yield levels and climatic conditions. In various N fertilizer trials conducted in Malawi to assess the effects of applying different N rates on growth and yield of cotton, applications of 30 to 50 kg N/ha were considered adequate, depending on the N status in the soil, and a mean yield of 2300 kg/ha seedcotton was obtained (Matthews, 1972).

Cotton plants show outstanding differences in N requirements and uptake at different stages of growth. The peak uptake was observed between the 20th and 60th days after planting. However, it was highest during square and early boll stages, and a secondary peak was observed between the 20th and 50th days after these stages, corresponding to full boll and seed development stages (Gardner and Tucker, 1967b). This trend was also true for all other nutrients. In an experiment on a sandy loam soil in Georgia, the uptake of N at different stages of cotton growth as a percentage of total uptake was as follows: planting to seedling 4.4%, seedling to early square 12.8%, early square to early boll 43.3% and early boll to maturity 39.5%. In a similar experiment conducted in Israel, the N uptake as percentage of the total uptake was 20% from emergence to flowering, 26% at 65 to 80 days after emergence, 43% at 80 to 110 days after emergence and 11% at 110 days to final harvest. The pattern of growth and N uptake by cotton in both experiments showed an initially slow N uptake and growth until first flowering, followed by a rapid increase in both dry matter production and N uptake during fruiting and seed development (Mackenzie _et_._al_., 1963; Berger, 1969; De Geus, 1973).

Basset et al. (1970) observed that the amounts of N,P,K, Ca, Mg and Na accumulated in the above ground parts of cotton at first flowering were less than 15% of the total uptake. Of the total seasonal uptake, 45% of N and P and 67% K occurred between flowering and boll formation stages. During these peak absorption periods, daily uptake per hectare was 1.5 to 2.0 kg N, 0.17 to 0.34 kg P and 2.1 to 3.4 kg K. Dry matter production of cotton plants was also slow for 40 to 80 days following seeding, with 2-4% of the total seasonal aerial dry matter present at the time of first square and 7-10% at the time of first flowering. Most of the N, therefore was used from the time of squaring to boll formation and smaller amounts were used before squaring and later in the season. Of practical importance is the fact that the optimum time of N application should be guided by N requirements of the cotton plants (Ashley _et_ _al_. 1974).

According to Chokhey et al. (1972), the yield of cotton was lowest when N (at rates of 30 to 60 kg N/ha) as SA was applied at sowing or at square or boll formation stages or in split applications at both these stages. Application of a larger dose of N at sowing and the remaining at the square stage resulted in balanced vegetative growth, better fruiting, more and bigger bolls and higher yield of seedcotton. Likewise, split application of half at sowing and other half at the square or boll formation stage gave the same effects. However, starvation of the cotton crop till the square or boll formation stages and then supplying plenty of N at these stages did not improve yield.

In Northern Nigeria, trials to determine the optimum rate and time of N application to cotton indicated that N is used most efficiently when applied at relatively low rates, with at least half the application delayed until the flowering (Smithson and Heathcote, 1977). According to these results, early application caused the incorporation of a greater proportion of the N into the vegetative structures which, at low rates, may leave insufficient N for fruit development. With late application, a greater proportion of the N was utilized in reproductive growth and therefore full utilization may not be achieved at higher rates.

Burhan (1972) conducted an investigation at the Gezira Research Station in the Sudan to determine the effects of post-sowing application of urea on the yield of cotton. Yields were slightly, but consistently increased when the fertilizer was applied 6-10 weeks after sowing. Similarly, Jones et al. (1973) concluded from experiments in Uganda that N application could be delayed until 80 days after sowing without reducing yield responses. Post-sowing N fertilizer application tended to minimize N loss and rendered it available at a time when it could be most efficiently used by the plants. Likewise, Peat and Brown (1962) and Tollervey (1972) in Tanzania, observed that SA gave smaller yield increases when incorporated into the ridges before sowing than when applied as a topdressing at flowering time. According to Reed's (1969) work in the Western Tanzania cotton zone, N is best utilized when applied in two splits, with the first immediately after thinning or 6 weeks after planting and the second split at the square or flower stages.

The knowledge of N requirement and time of application has been found important in relation to effective N supply and availability in the soils on the one hand, and the pattern of N uptake and utilization on the other hand (Aldrich, 1980; Cooke, 1982; Earl, 1982; Keeney, 1982; Olson and Kurtz, 1982). According to Sanchez (1976), and Wrigley (1982), the N level in the soil builds up very rapidly at the start of the rain season, but is then rapidly leached out. The Most effective time of N application therefore, would be early in the rains when the crop has developed sufficient roots to take the applied N before it is leached away and/or denitrified, rather than at planting (Brown, 1962; Smith and Brown, 1963; Percy, 1975; Donald and MacDonald, 1978a; 1978b; Stevenson, 1982).

2.1.3 Optimum rate of nitrogen application

Adequate supply of N is associated with vigorous vegetative growth and deep green colour. Deficiency of N results in poor cotton growth and reduced yield. Oversupply, on the other hand, may result in detrimental effects (Wrigley, 1982). According to results from Arkansas, high N rates increased yield but delayed maturity. In these results, the total yield of cotton was 1642 kg/ha in the control, and 2010 and 2020 kg/ha seedcotton at 67 and 101 kg N/ha, respectively. The amount of seedcotton at first picking as a percentage of the total was 71% in the control and 63 and 58% at 67 and 101 kg N/ha, respectively (Tisdale and Nelson, 1970). Thus a carefully regulated N supply regime may be of extreme importance in controlling the vegetative and fruiting performance of the cotton plant.

Basinski _et_ _al_. (1971) observed that the effect of N applications on plant characteristics and yield of cotton was also dependent on the initial N fertility of the soil and yield level desired. Dry matter production increased from 1205 kg/ha in the control to 2734 kg/ha at 450 kg N/ha. At the respective N rates, plant heights were 71 and 107 cm, fruiting points were 256 and 542, number of bolls were 70 and 167, number of squares and flowers were 86 and 141, and seedcotton yields were 1903 and 3316 kg/ha. Le Mare (1972) obtained 2000 kg seedcotton/ha as the best recorded yield in an experiment at Ukiriguru at a rate of 112 kg N/ha as SA. While in 92 field experiments conducted in east of Lake Victoria in Tanzania, mean yield in the controls was nearly 900 kg/ha of seedcotton compared to mean yields of 1275 and 1800 kg/ha of seedcotton at rates of 42 and 84 kg N/ha, respectively, applied as SA. However, Matthews (1972), and Singh and Balasubramanian (1983) reported that high N application rates resulted in too much vegetative growth at the expenses of lint formation, and application of 30 to 50 kg N/ha was considered adequate for cotton under continuous cultivation. At the reported rates, a mean yield of 2300 kg/ha of seedcotton was obtained (Matthews, 1972).

Kairon et al. (1980) evaluated the response and economic analysis of cotton at different N rates in India. Results showed that the average response of cotton per kg N at at 50, 100 and 150 kg N/ha, was 6.72, 5.28 and 3.91 kg seedcotton, respectively, during 1952-56 at one location (Hansi). When a similar experiment was repeated in 1963-77 at another site (Hissar), the response at 40,80 and 120 kg N/ha was 5.50, 4.24 and 3.36 kg seedcotton, respectively. Thus, N application at higher doses reduced the efficiency of N utilization. Similar results were reported by Burhan (1971), and Singh and Balasubramania (1983). In a number of field fertilizer trials conducted at the Ukiriguru Research Institute, the best response was obtained by applying 60 kg N/ha as CAN, at 6 weeks after sowing, giving a record harvest of 2235 kg/ha seedcotton (Fielding, 1976). The current recommended rate in the Western Tanzania cotton zone is about 30 kg N/ha applied as SA (Reed, 1969; Fielding, 1977; Acland, 1977).

2.1.4 Effects of N on nutrient uptake by cotton

Nutrient absorption by cotton plants has been reported to be more directly related to supply of the nutrients in the soil and was sensitive to changes in availability than is yield response (Gardner and Tucker, 1967a). In India, Pundarikakshudu et al. (1972) conducted an experiment to assess the relation between N content in plants at maturity against dry matter- and seedcotton-yield. Significant correlations(r) were obtained between dry matter and N content (r = 0.96; p = 0.01) and between seedcotton yield and N content (r = 0.711; P = 0.01). In field experiments conducted for four seasons from 1964 to 1967 in India (Sambandam et al. 1971), the concentrations of N in the plant at different stages of growth were correlated with yield of seedcotton. The calculated "r" values were found significant at seedling stage (r = 0.739; P = 0.01) and at first picking stage (r = 0.703; P=0.01).

MacKenzie et al. (1963), and Gardner and Tucker (1967b) reported that the level of N in petioles during certain bloom stages of growth was a good indicator of N nutrition of cotton plants. It was, therefore, concluded that the N requirements of cotton plants could be determined precisely throughout the growing season by utilizing soil and petiole analysis. Likewise, Sabbe and MacKenzie (1973) have reported that leaf blade analysis can also be used to judge the efficiency of a fertilizer source and practice. Petioles and leaf blades located along the main stem were found satisfactory for tissue analysis and the analytical results were found to be related to total yield. Workers in Puerto Rico and India have used leaf blades to evaluate nutrient sources, and levels of N, P and K in cotton plants. Nutrient concentrations in petioles and leaf blades of the youngest, fully expanded leaves have been recorded in the literature for use in th diagnosis of nutrient deficiencies for cotton in South America, Africa, India and the U.S.A. Joham (1951) thus obtained positive and significant correlations in cotton plants at 30 and 90 days after planting when petiole N, P, K, Ca and Mg were compared with their respective concentrations in the soil.

Sufficiency ranges of various nutrients in cotton plants based on studies conducted in Arkansas and Georgia have been reported by Sabbe and MacKenzie (1973). The average value for selected nutrients in cotton leaves of 70 to 110 day old plants as a fraction of dry matter were 3.0 to 4.5% N, 0.30 to 0.65% P, 1.90 to 3.50% Ca, and 30 to 350 ppm Mn. For the same nutrients, Bache and Heathcote (1969) in Nigeria obtained values of 2.79 to 3.15% N, 0.296 to 0.265% p, 1.64 yo 1.30% Ca and 122 to 226 ppm Mn, when N was applied at rates of 0 and 45 kg N/ha, respectively as SA. Similarly, Le Mare (1972) in Tanzania obtained values of 2.59-3.69% N, 0.683-0.586% P, and 1.20-1.87% Ca, when N was applied at 0 and 112 kg N/ha, respectively, from SA. Generally, nutrient levels in cotton petioles or leaf blades were found to be high during early stages of growth, but decreased during fruiting and maturation and uptake was related to supply in the soil. Plant tissue analysis can thus play an important part in determining the nutritional status of cotton plants. Indications of deficiencies by plant tissue analysis can be advantageous, as corrections can be made in advance of the appearance of typical deficiency symptoms (Sabbe and MacKenzie, 1973).

2.2 Nitrogen sources and their effects on cotton production.

Sources of nitrogen are chemical substances or carriers that contain the element N in absorbable forms, chiefly as NO_3^- or NH_4^+ cr those which yield these forms after conversion such as amides like urea. Ammonium sulphate (SA), urea and calcium ammonium nitrate (CAN) are the most commonly used N sources in Tanzania (Samki, 1975; Samki _et_ _al_., 1980; Uriyo _et_ _al_., 1979).

2.2.1 Effects of N sources on growth and yield of cotton.

The determination of suitable source and form of fertilizer N for cotton is necessary for increased yields. Various sources and forms of N have been found to influence the availability of N and other nutrients to cotton. In several experiments conducted in the USA, Australia and Chad, lower responses were obtained with urea than with other sources. For instance in studies conducted in the USA, the response from urea was 70-80% of that from SA. The difference in response was attributed to volatilization losses due to surface application, since these could be decreased from 36% for surface spread urea to 2% when urea was banded at 5 cm deep (De Geus, 1973). Similar results were obtained when NH_4-N and NO_3-N were compared in the heavy soils of the Gezira in Sudan (Musa, 1968a; 1968b). The NO_3-N was found to be more effecient than NH_4-N. Ammonium-nitrogen from SA showed a loss of about 22 kg N/ha at rates upto 130 kg N/Ha. The loss and difference in efficiency did not occur when SA was placed 15 cm deep. Reduction of N losses by deep placement, implies that the method of application also affects the effectiveness of N fertilizers as reported elsewhere (Gard, 1965; Parr, 1967; Terman, 1979; Engelstad and Russel, 1979; Smith and Chalk, 1980; Follett et al., 1981; Hans and Vehtras, 1982).

In a pot experiment conducted under tropical conditions, urea and SA were reported to give consistently similar responses in dry matter production at the various rates tried. The rates tested were 1400, 2800 and 4200 mg N/pot, resulting in respective increases in dry matter of 11.2, 16.0 and 22.9 g/pot for urea and 12.4, 15.3 and 22.9 g/pot for SA (Enyi, 1965). In another pot experiment, Radin and Sell (1975) evaluated the effects of NO_3-N and NH_4-N on the growth and yield of cotton at rates of 0, 5, 10 and 20 m.e. N/litre. A nitrification inhibitor (N-serve) was included in all treatments. Both N sources supported vegetative growth although there was little responses to increments of NO_3-N above 5 m.e./litre. However, growth responses were observed in the NH_4-N treatments upto the highest rate (20 m.e./litre) tested. Nitrate-N was found less effeective than NH_4-N in promoting fruitfulness and N accumulation relative to the vegetative parts. Thus plants with high NO_3-N treatments were less efficient in supporting reproductive growth relative to vegetative growth than that of NH_4-N. This occurred because vegetative growth was much greater in NO_3-N treatments than in the NH_4-N treatments. Amer and Abuamin (1969) found NO_3-N to increase petiole N content more than urea and NH_4-N but no differences in seedcotton yield due to N sources were observed. The calculated availability coefficients of N in NH_4-N and urea as a fraction of that of NO_3-N were 0.714 and 0.511, respectively. Differences in the effects of the fertilizers on the N content of petioles (NO_3-N > NH_4-4 > urea) were due to volatilization losses as NH_3 from NH_4-N and urea hydrolysis on a calcareous clay loam soil. Similar results were reported in India and USA and showed that the effects of N sources were related to differences in uptake of NO_3-N and NH_4-4 by cotton plants grown in soils of different pH values (Rajendra and Thomas, 1982). Mengel and Kirkby (1982) reported that the uptake of NO_3-N by plant roots was greater in low pH soil, while high pH values favoured the uptake of NH_4-N. For instance NH_4-N uptake was 34.9 mg/pot while NO_3-N uptake was 33.6 mg/pot at pH 6.8. At pH 4.0, the uptake of NH_4-N and NO_3-N was 26.9 and 43.0 mg/pot, respectively.

Soil pH can markedly affect the uptake of nutrient elements by plants. This is because the availability of nutrients to most crops is optimum in the pH range 6 to 7.5 (Rios and Pearson, 1964). In a pot experiment with maize plants, Miller _et al._ (1971) observed that the addition of sulphate of ammonia (SA) to a fertilizer P band lowered pH of the soil-root interface by 0.65 units compared to that of the control and increased P absorption. They also noted that the ratio of $H_2PO_4^-/HPO_4^=$ ions at pH 7.3 was 0.8 compared to 3.2 at pH 6.7. The higher proportion of P in the H_2PO_4- form at the lower pH increased P absorption by the roots due to a greater rate of absorption of H_2PO_4- compared to that of HPO_4= ions. Phosphorus concentration in the shoots of the maize plant was double by the addition of potassium sulphate (K_2SO_4) and tripled due to SA compared to that of the control. Thus they concluded that the lowered pH was responsible for the large increase in P uptake. In field experiments with a near-neutral soil conducted at the Central Rice Research Institute at Cuttack, India, the performances of urea, SA and CAN over the control were 30, 21 and 7% respectively (De Geus, 1973) and hence emphasizing the importance of soil reaction.

2.2.2 Effects of N sources on soil chemical properties.

Nitrogen sources may contain **certain materials and** properties which may be both advantageous and disadvantageous in relation to soil chemical properties, cotton growth and yield. Sulphate of ammonia (SA) increases the soil acidity, resulting in a loss in nutrient cations and increased phosphorus fixation by aluminium and iron. The increased acidity also increases the amount of soluble aluminimum and manganese ions which at high levels are toxic to cotton roots, thus lowering crop yields (Rios and Pearson, 1964; Bache and Heathcote, 1969; Stephens, 1969; Le Mare, 1972; Adams and Moore, 1983; Adams and Heathcock, 1984). Urea like SA has an acidic reaction in the soil and will have effects similar to SA, although the acidity produced is only 2/3 of that produced by SA (Roy et al., 1980). Urea in high concentration has been reported to be injurious to plant roots. This has been attributed to toxic intermediate mineralization products, especially free ammonia and nitrite, which may sometimes accumulate in the soil due to delayed nitrification (Court et al., 1964a; 1964b; Alexander, 1977).

Sulphate of ammonia (SA) and urea are therefore classified as acid-forming N fertilizers. The major acidifying effect of these fertilizers is exerted when the ammonia or ammonium ions are nitrified. The simplified equation for nitrification is as follows;

$$NH_4^+ + 2O_2 \longrightarrow 2H^+ + NO_3^- + H_2O$$

The reaction produces hydrogen ions (H^+) which result in the acidification of the soil. Thus frequent use of ammonium-containing fertilizers or those which produce ammonium upon reaction with soils will increase soil acidity, unless their use is accompanied by a suitable programme of corrective liming (Finck, 1982).

Calcium ammonium nitrate (CAN) does not affect soil pH.. Commercial CAN contains 25-28% N, half of it in the ammoniacal form and half in the nitrate form. It also contains limestone or dolomite in sufficient quantities to neutralize the acidity produced by the ammonium component. The supply of calcium (10% CaO) and magnesium (7% MgO) from CAN (Tisdale and Nelson, 1970) has been found to be advantageous in acid soils probably due to slight liming effect (Le Mare, 1972; Roy et al. 1979) and an increase in the supply of these nutrients (Adams and Hathcock, 1984).

Pearson et al. (1962), and Jones and Stockinger (1976) reported that the use of high rates of acid-forming N fertilizers like SA and urea caused an appreciable downward transfer of Ca and Mg in the soil profile. This trend was increased with increasing N application. The amounts of Ca and Mg moved from the surface into the 30-60 cm zone were equivalent to as much as 6.6 tons/ha. Bache and Heathcote (1969) reported that exchangeable Ca, by far the greater nutrient observed to be lost from soil, decreased from a level of 1.03 m.e./100g soil in the control to 0.93 and 0.83 m.e./100g soil at 56 and 112 kg N/ha applied as SA respectively. While the loss may have been in part due to removal by crops, the increased leaching by the acidifying N fertilizer must have accounted for much of the decrease.

Wolcott et al. (1965) compared the effects of N sources on exchangeable bases to a depth of 38 cm from 1959 to 1963. Total exchangeable CA found at the end of the experiment was 1577 kg/ha in the control compared to 918 and 1546 kg/ha due to application of 336 kg N/ha annually as SA and urea, respectively. The amounts of exchangeable Mg was 216 kg/ha in the control as compared to 96 and 152 kg/ha for SA and urea treated plots, respectively. All these changes were statistically significant. Exchangeable K was not significantly changed by these treatments. Likewise, Le Mare (1972; 1974) and Fielding (1977) reported that

SA was much responsible for loss of cations, especially Ca, in the Western Tanzania cotton zone. Lack of response of cotton to N applications as SA in these areas was attributed to the loss of Ca. Most N is taken up as NO_3^-, so Ca seems very important to maintain a suitable cation-anion balance (Le Mare, 1974). Experimental trials at Ukiriguru with urea and CAN as alternative N sources, have obtained better responses (Fielding, 1976; 1977). According to Smithson and Heathcote (1977), CAN and urea have replaced SA as N sources on account of the latter's acidifying properties in Northern Nigeria.

Yearly applications of SA resulted in greater reduction in soil pH than urea (0.8 and 0.3 pH units, respectively) when all were applied at the rate of 140-318 kg N/ha (Peat and Brown, 1962). Similarly, Abruna et al. (1958) observed a greater **reduction of** soil pH in the 0-15cm zone, resulting in final values of 5.2 and 4.2 due to SA at 450 and 1800 kg N/ha, respectively, compared to 5.6 in the control. At the same respective rates, the final pH in the 15-30 cm zone was 4.7 in the control compared to 4.6 and 4.2 in the treated soil. Also Wolcott et al. (1965) found that the final pH to a depth of 0-38 cm was 5.9 in the control, compared to 4.0 and 4.8 in the soils treated with SA and urea, respectively, at an annual rate of 336 kg N/ha. Cummulative effects of N fertilizers for 15 years at Ukiriguru (Le Mare, 1972) showed soil pH in the control to be 4.9 compared to 4.1 with annual dressing of SA at a rate of 112 kg N/ha. After compost alone was incorporated as a treatment at a rate of 15 tons/ha, pH was raised from 4.9 to 5.9 during the period, but it went down to 4.6 when compost at 15 tons/ha and SA at 112 kg N/ha were combined.

An experiment was conducted in Nigeria to assess the effects of N sources on soil and leaves of cotton. The results showed that application of SA was noted for the large increase in soil acidity, associated with higher exchangeable Al and Mn concentrations. While soil pH (1:5, H_2O) was reduced from 5.96 in the control to 5.36 at 112 kg N/ha, Al and Mn increased from 0.07 to 0.78 and 0.1 to 0.4 me/100g soil, respectively (Bache and Heathcote, 1969). Likewise, Le Mare (1972) observed an increase in exchangeable Mn from 0.05 m.e/100g soil in the control to 0.15 m.e/100g in the soil in which 112 kg N/ha as SA was applied for one season. After the next 14 years of continuous use, it increased from 0.09 in the control to 0.214 m.e./100g at 112 kg N/ha.

A relationship between the ability of SA to acidify the soil and the plant tissue concentration of P, Ca and Mn was noted too (Bache and Heathcote, 1969). When soil pH was reduced from 5.95 in the control to 5.36 at 112 kg N/ha, P and Ca were decreased from 0.296 to 0.265%, and 1.64 to 1.30%, respectively. On the other hand, Mn increased from 122 ppm to 226 ppm. The changes in these nutrients must have been due to the acidifying effects of SA in the soil. These workers thus speculated that cotton grown in the more acid soil may have been affected by Al and Mn toxicity and calcium deficiency. Aluminium and Mn toxicity, and Ca deficiency to cotton were reported to be prevalent in soils where pH was below 4.5 with 40 ppm of water-soluble Mn (Adams and Wear, 1957; Foy and Brown, 1963; Rios and Pearson, 1964; Wolcott *et al.*, 1965; Adams and Moore, 1983; Adams and Hathcock, 1984). These workers reported that soil solution containing 11 ppm Mn or more caused severe crinkle symptoms in cotton leaves. However, cotton plants grown in solution containing 0.5 ppm Mn had normal growth as contrasted to the crinkle leaf symptoms on the cotton grown in solution containing 10 ppm Mn (Adams and Wear, 1957; Foy and Brown, 1963; Foy *et al.*, 1968; Foth and Turk, 1972). The choice of a suitable source of N fertilizer for cotton is thus necessary, not only for increased yields, but also to avoid the undesirable effects of some N sources, as well as associated changes in soil chemical properties and nutritional problems of cotton plants as reviewed above.

3. MATERIALS AND METHODS

The study consisted of pot and field experiments and was carried out during the 1983/84 cropping season at Sokoine University of Agriculture (SUA), Morogoro. The University area is located on latitude 6°50 'South and longitude 37°38' East, with an elevation of 525 metres above sea-level.

3.1 Pot experiment

3.1.1 Soil data

Three different soil types from the University farm were collected from the 0-30 cm depth, air-dried and ground to pass through a 2mm sieve. The samples were analysed for selected physical and chemical properties using the following procedures: Soil pH (1:1 soil-water ratio) was determined by Beckman pH-meter, organic carbon by the wet digestion method of Walkley and Black (Allison, 1965), total nitrogen by Kjeldahl method (Bremer, 1965), exchangeable bases were measured by atomic absorption spectro-photometry from leachate of the soils with I$\underline{N}$ ammonium acetate (pH 7.0). Exchangeable acidity was determinec by titration of I$\underline{N}$ KCL soil extract with 0.05$\underline{N}$ HCl after addition of I$\underline{N}$ NaF (10 mls) to the I$\underline{N}$ KCl soil extract initially titrated with 0.05$\underline{N}$ NaOH. Cation exchange capacity was taken as the sum of the exchangeable cations and exchangeable acidity (Jackson, 1962; Black *et al.*, 1965; Dewis and Freitas, 1970; Hesse, 1971; U.S. Soil Conservation Services, 1972). Soil available phosphorus was extracted according to Bray No.1 method (Bray and Kurtz, 1945) and colorimetrically determined by the ascorbic acid method (Juo, 1975). Percentage base saturation (P.B.S.) was calculated as:

$$\text{P.B.S.} = \frac{(\text{Ca}^{++} + \text{Mg}^{++} + \text{K}^{+} + \text{Na}^{+}) \times 100\%}{\text{Cation exchange capacity by summation}}$$

Particle size distribution of the soils was carried out by Hydrometer method and textural class obtained using U.S.D.A. textural triangle (Dewis and Freitas, 1970; U.S. Soil Conservation Service, 1972). Data of the physico-chemical properties of the three soils are presented in Table 1. Based on pH values as determined in water (1:1 soil-water ratio), the three soil types were characterized as strongly acid, moderately acid and almost neutral (Roy et al. 1979; Finck, 1982), and to facilitate presentation, they were designated as SAS, MAS and ANS, respectively.

3.1.2 Experimental procedures and agronomic practices

Four kilograms of air-dry sieved soil of each type were placed in four-litre plastic pots. Triplesuperphosphate (20% P) at a rate of 40 kg P/ha (320 mg/pot) and ground into a powder, was mixed up with soil before planting. Then four cotton seeds (variety IL74) were planted in each pot and later (18 days after planting) thinned to two seedlings or plants per pot. The treatments tested were three N sources each at four rates of application. The N sources used were calcium ammonium nitrate (CAN), sulphate of ammonia (SA) and urea, which will subsequently be designated as CAN, SA and Urea, respectively. Each N source was tested in each soil at four rates, viz; 0, 50, 100 and 150 kg N/ha. The layout of the experiment was a split-plot design, with N rates as main plots and N sources as subplots for each soil and replicated three times. The N sources were applied in solution after thinning (18 days after sowing). Other nutrients were not applied since their deficiencies have not been diagnosed.

The experiment was conducted for 75 days (upto early flowering stage) and the data collected included plant heights, number of flowers, dry matter yield of the shoot and the concentrations of N,P, Ca and Mn in the petioles and leaf blades. Some selected soil chemical properties were also determined at the end of the experiment to assess the treatment effects. These included soil pH, exchangeable acidity, exchangeable aluminium, exchangeable manganese and exchangeable bases. The methods used have been described in section 3.1.1.

Prior to determination of nutrient concentrations in plant materials, all the vegetative parts of the two plants from each pot were washed twice in tap-water and in distilled water and dried in an oven at 65°C to constant weight. Due to the small size of the samples, it was impossible to adopt standard sampling for the plant tissues of interest. Thus, all the petioles from each pot were taken as one sample for this tissue, while all leaf blades also constituted a sample

Table 1: Selected properties of the three soil types used for the pot experiment (0-30 cm).

Soil property	Soil type		
	SAS	MAS	ANS
Soil pH (1:1 soil-water ratio)	4.80	6.10	6.90
Organic carbon (%)	1.61	1.52	1.65
Organic matter (%)	2.78	2.63	2.85
Total Nitrogen (%)	0.15	0.11	0.14
Carbon:Nitrogen ratio	11:1	14:1	12:1
Available phosphorus (ppm)	8.33	10.00	12.00
Exchangeable bases (m.e/100g soil):			
Ca^{++}	3.74	6.64	6.65
Mg^{++}	2.61	5.14	5.39
K^{+}	0.75	0.93	0.56
Na^{+}	0.18	0.09	0.08
Percentage base saturation	45.70	81.53	85.22
Exchangeable manganese (ppm)	9.00	5.5	6.50
Exchangeable aluminium (m.e/100g soil)	6.83	da	da
Exchangeable acidity (me/100g soil)	9.10	2.90	2.20
Cation Exchange capacity (m.e/100g soil)	15.93	15.70	14.88
Particle size analysis: Sand (%)	67	62	72
Silt (%)	6	7	4
Clay (%)	27	31	24
Textural class (U.S.D.A. triangle)	SCL	SCL	SCL

All units expressed on air-dry weight basis.
da: determined but not available.
SCL: Sandy Clay Loam.

for this tissue. Samples were ground in a mortar to pass through a 1.0 mm sieve. Total nitrogen was determined by the Kjeldahl method, while P, Ca and Mn were carried out on the acid extract of ash, following ignition at 500°C. Phosphorus was then determined colorimetrically by the Vanado-molybdate method, while Ca and Mn were determined by atomic absorption spectrophotometry. The methods and procedures used for plant analysis are those outlined by Juo (1975).

3.2 Field experiment

3.2.1. Site details and soil data

The experiment was located in Magadu area of the Sokoine University of Agriculture Farm. This was the site from which the almost neutral soil (ANS) used in the pot experiment was taken. Relevant phsico-chemical properties are given in Table 1 above. Meteorological data for the area during the growing season are given in Appendix 1. The University Farm is a typical rain shadow area which receives relatively less rainfall compared to other surrounding area. The rainfall pattern is bimodal, the first season being between October- December and the second and more reliable season being March-May. The total annual rainfall for 1983/84 was 1009.7 mm, while the mean annual rainfal for 42 years is 837 mm. Average mean monthly maximum and mean minimum temperatures for the year were 29.7 and 18.7°C, respectively, with average mean monthly maximum temperatures occurring between November and March and average mean minimum monthly temperature between June and September.

3.2.2 Experimental procedures and agronomic practices

A field experiment was conducted to test the effects of rates and sources of nitrogen on soil chemical properties, tissue nutrient concentration and yield of cotton. The design of the experiment, as well as the rates and sources of N used were the same as those in the pot experiment and replicated four times. The cotton cultivar IL74 was used as a test crop.

The plot size was 5.4 x 5.4 m^2 with 4.8 x 3.6 m^2 as harvested area. Each plot had seven rows of cotton plants at a spacing of 90 cm between rows and 30 cm between plants and a stand of one plant per hill; equivalent to 37,000 plants/ha as recommended by Reed (1969) and Acland (1977). Phosphorus fertilizer as triplesuperphosphate (20% P) at a rate of 40 kg P/ha was applied in all plots by banding at 5-8 cm below the seeds at the time of planting. Nitrogen fertilizer was applied in two splits. One-third of the amount was at six weeks from the date of planting and the remaining two-thirds at the time of flowering (eleven weeks from date of planting) as recommended by Reed (1969), Tollervey (1972), Acland (1977) and Smithson and Heathcote (1977). All N fertilizers were applied in rings, 8-10 cm away from the seedlings and at a depth of 5 cm, and then immediately covered with soil. Other nutrients were not applied since their deficiencies have not been diagnosed in the University Farm.

The field was planted on March 16th when the long rains had started and thinned four weeks later. Recommended plant protection measures were followed at all stages of growth and development of the cotton plants. Four weedings and four sprayings using ULV sprayer were carried out during the whole growing period. The pests commonly observed in the field were termites (*Microtermes spp.*), aphids (*Aphis gossypii*), cutworms (*Spodoptera exigua* and *Agrotis ypsilon*) and cotton stainers (*Dysdercus spp.*). but they did very little damage to the crop due to effective control measures. Aphids and cotton stainers were controlled by spraying with decis, a broad spectrum insecticide at a rate of 12.5 g/ha (active ingredient/ha), while termites and cutworms were controlled by soil application of toxadrin 40.

The crop was harvested 170 days after planting. Only the five centre rows were harvested in each plot while one row was left on each side in order to avoid broder effects. Harvesting and delinting for the one thousand seeds weight were done by hand.

3.2.3 Data recorded

Plant heights and number of fruiting branches were recorded at 75 and 120 days after planting. These dates corresponded approximately to 50% flowering and 50% full boll development stages, respectively. Ten plants, randomly selected in each plot (two from each of the centre five rows) and tagged with white plastic sheets were used. The same plants were also used for counting the number of flowers at 75 days, number of bolls at 120 days and number of early maturing bolls at 160 days. At 75 days, shoot dry weight was determined using five plants from each plot taken at random (one plant from each of the centre five rows). The dry matter was recorded after drying the plants in the oven at 70^{0}C.

3.2.4 Plant samples

Leaf samples for the determination of nutrient contentration were taken at 75 and 120 days after planting. Sampling was carried out according to procedures and recommendations outlined by Joham (1951), MacKenzie et al. (1963), MacKenzie (1969), Gardner and Tucker (1967a; 1967b), Ulrich and Hills (1967), Amer and Abuamin (1969), and Sabbe and MacKenzie (1973). Briefly, the sampling was done as follows: Thirty leaves from the third and fourth nodes from the apex on the main stems were collected from each plot and were immediately washed twice in tap-water, and then in distilled water. The samples were then dried at 65^{o}C, separated into petioles and leaf blades and ground to pass 1.0 mm sieve. Determinations of N, P, Ca, and Mn concentrations in the petioles and leaf blades were carried out in accordance with methods and procedures described in section 3.1.2.

3.2.5 Yield data

The data taken after harvest included seed cotton and one thousand seed weight. Seed cotton yields were then converted to tons/ha to facilitate comparison with results reported elsewhere. One thousand cotton seeds were randomly delinted from each treatment and weighed.

3.2.6 Soil samples after harvest

Soon after harvest, soil samples were taken to a depth of 0-30 cm to assess the treatment effects on soil chemical properties. Each sample was a composite of four subsamples collected from each plot. These were air-dried and ground to pass through a 2 mm sieve and different determinations as described in section 3.1.1 were made.

3.3 Statistical analysis of data

The results obtained from the pot and field experiments were analysed statistically using procedures described by Little and Hills (1975; 1978) and Snedecor and Cochran (1980). The treatment effects on soil chemical properties, various growth components, nutrient concentrations in petioles and leaf blades, reproductive parts, shoot dry weight, yield of seed-cotton and one thousand seeds weight were assessed by the analysis of variance method using a computer. Where significant effects were observed, comparisons of the treatment means were carried out by Duncan's new multiple range test as described by Steel and Torrie (1960), and Little and Hills (1975; 1978). Where significant interaction effects were also observed, a comparison of the simple effects of the N sources at each N rate was made again using Duncan's new multiple range test. Correlation relationships were determined between selected variables.

4. RESULTS AND DISCUSSION

4.1 Pot Experiment

The general characteristics of the soils used in the pot experiment are given in Table 1 above. The major soil characteristic used to differentiate the three soils was pH. It was 4.8 for the strongly acid soil (SAS), 6.1 for the moderately acid soil (MAS) and 6.9 for the almost neutral soil (ANS). Organic carbon and organic matter for all soils were in the medium category (Nandra, 1976; Marshall et al. 1976), while total N content and available P were considered medium and low on the basis of N and P fertility rating, respectively by Robison (1968), Scaife (1969) and Singh and Uriyo (1980). Exchangeable bases, especially Ca and Mg were classified as low to medium in all soils, while exchangeable K was between 0.5 and 1.0 m.e./100g soil and was considered moderate to high (Marshall et al., 1976; Legger and van der Pouw, 1980). Exchangeable acidity, aluminium and manganese were rated as moderate to high for the strongly acid soil, while it was low in the other two soils (Adams and Wear, 1957; Foy and Brown, 1963; Adams and Hathcock, 1984). Aluminium saturation in the strongly acid soil was 43%. The base saturation was 46% for the SAS, 82% for MAS and 85% for AMS, with Ca and Mg as the dominant cations. The soil texture was sandy clay loam in all soils.

4.1.1 Effects of rates and sources of N on soil chemical properties.

The treatment effects were assessed on soil pH, exchangeable acidity, exchangeable aluminium, exchangeable bases and exchangeable manganese, and the results are presented in different tables below.

4.1.1.1 Soil pH.

The changes in soil pH due to rates and sources of N were not significantly different in all soils (Table 2). However, N rates decreased soil pH by 0.3 units in the SAS at 100 kg N/ha. Soil pH was decreased by 0.2 and 0.1 units in the MAS and ANS, respectively at 150 kg N/ha. The decrease in soil pH in the SAS was slightly larger than in the other two soils. Nitrogen sources affected soil pH differently in the different soils. Sulphate of ammonia gave slightly lower pH values in SAS and ANS than the other two sources but the three sources had similar effects in MAS. The interactions between rates and sources of N indicated that the decrease in pH observed due to N rates was mainly due to SA which decreased soil pH by 0.5 units in the SAS and 0.3 units for each of the other two soils at 150 kg N/ha. Calcium ammonium nitrate and urea had almost no effect on soil pH at all N rates and in all soils.

Table 2. Effects of rates and sources of N on soil pH in three soils with different initial pH.

SOIL TYPE	Nitrogen source	Nitrogen rates (kg/ha)				Mean
		0	50	100	150	
		pH (H_2O)				
SAS	CAN	5.1	5.0	5.7	5.2	5.1x
	SA	5.1	4.8	4.7	4.6	4.8x
	UREA	5.1	5.0	4.9	4.9	5.0x
	Mean	5.1x	4.9x	4.8x	4.9x	
ANS	CAN	6.9	6.8	6.7	6.9	6.8x
	SA	6.9	6.7	6.7	6.6	6.7x
	UREA	6.9	6.9	6.8	6.8	6.8x
	Mean	6.9x	6.8x	6.7x	6.8x	
MAS	CAN	6.1	6.1	6.0	6.0	6.0x
	SA	6.1	6.0	6.0	5.8	6.0x
	UREA	6.1	6.1	6.0	6.0	6.0x
	Mean	6.1x	6.1x	6.0x	5.9x	

Values followed by a common letter in the same column or row for the same soil type are not significantly different at 5% level by Duncan's new multiple range test. Note that body means and overall means were compared separately.

The effects of rates and sources of N observed in this investigation are for one season and hence the insignificant change observed. But the trend is clear and indicates that strong acid-producing N fertilizers like SA are more detrimental in soils which are already acid (Stephens, 1969). Peat and Brown (1962) observed similar but significant changes in soil pH after seven years of continuous use of SA in the field with initial soil pH of 5.73. The decrease in pH reported ranged between 0.2 to 0.48 units at the rates of 140 to 300 kg N/ha. The pH data for the control in this study shows that the pH in the SAS was higher than when initial soil properties were determined (5.1 compared to 4.8). This was probably due to the effect of added P fertilizer which may have reduced the aluminium and iron activity, hence increased pH. No change in soil pH was observed in the controls of the other soils in which no exchangeable Al was extracted.

4.1.1.2 Exchangeable acidity

Exchangeable acidity was increased significantly by rates and sources of N only in the strongly acid soil. The treatments did not significantly affect exchangeable acidity in the other two soils (Table 3 and Appendix 2).

All N rates above the control significantly increased exchangeable acidity, but the differences among them were not significant. Nitrogen sources significantly increased exchangeable acidity, their effect being mainly due to SA and urea.

A strong interaction ($P < 0.01$) between rates and sources of N was observed in the SAS. This was attributed to differences in the simple effects of the different N sources. Sulphate of ammonia (SA) caused a greater increase in exchangeable acidity than CAN and urea. The latter two N sources had no significant effects on exchangeable acidity.

These results indicate that SA had a stronger acidifying effect in the SAS than the other two N sources. Grunes (1959) and Bache and Heathcote (1969) observed the greater ability of SA to acidify the soil as shown by various soil properties. They observed that N application at 112 kg N/ha reduced pH from 5.95 in the control to 5.36 and increased exchangeable Al from 0.07 to 0.78 M.

A comparison of the effects of N sources between the three different soils indicated that the effect was greatest in the SAS. The overall mean increase in exchangeable acidity over the controls were 0.32 m.e./100g soil for the SAS and 0.02 m.e./100g soil for the other two soils. These results indicate that exchangeable acidity is greatly increased in soils with low pH and supports the commonly held view that acidifying fertilizers are more detrimental in soils which are already acidic (Wolcott _et_ _al_., 1965;Bache and Heathcote, 1969).

4.1.1.3 Exchangeable aluminium

Exchangeable Al was only determined in the SAS (Table 4). It was increased significantly by rates and sources of N. All N

Table 3. Effects of rates and sources of N on exchangeable acidity in the strongly acid soil.

SOIL TYPE	Nitrogen source	Nitrogen rates (kg/ha)				Mean
		0	50	100	150	
		Exchangeable acidity (m.e/100g soil)				
SAS	CAN	9.13a	9.43a	9.43a	9.40a	9.35x
	SA	9.13a	9.63b	9.77b	9.63b	9.54y
	UREA	9.13a	9.40a	9.43a	9.47a	9.45xy
	Mean	9.13x	9.49y	9.54y	9.50y	

Values followed by a common letter in the same column or row are not significantly different at 5% level by Duncan's new multiple range test. Note that body means and overall means were compared separately.

Table 4. Effects of rates and sources of N on exchangeable aluminium in the strongly acid soil.

SOIL TYPE	Nitrogen source	Nitrogen rates (kg/ha)				Mean
		0	50	100	150	
		Exchangeable Al (m.e/100 g soil)				
SAS	CAN	6.73a	6.83a	6.93a	6.75a	6.81x
	SA	6.73a	7.10b	7.20b	7.20b	7.06y
	UREA	6.73a	7.00ab	7.00ab	7.00ab	6.93xy
	Mean	6.73x	7.00y	7.04y	6.98y	

Values followed by a common letter in the same column or row are not significantly different at 5% level by Duncan's new multiple range test. Note that body means and overall means were compared separately.

rates above the control significantly increased exchangeable Al ($P<0.05$) but the differences among them were not significant. When N sources were compared, SA was found to increase exchangeable Al more than the other two sources. Urea caused a slightly higher increase in exchangeable Al than CAN, but the difference was not significant. A strong interaction ($P<0.01$) between rates and sources of N was observed. This was due to differences in the simple effects of the different N sources in the SAS. Sulphate of ammonia (SA) caused a greater increase in exchangeable Al than CAN and urea. Urea caused a slightly higher increase in exchangeable Al than CAN but the effect was not significant.

These results indicate that SA had a stronger acidifying effect in the SAS, thus increased the activity and solubility of exchangeable Al, hence acidity. Bache and Heathcote (1969) observed an increase in exchangeable Al from 0.07M in the control to 0.78M at 112 kg N/ha applied as SA. No exchangeable Al was extracted from the other two soils, even in treatments in which N was applied. Generally, little or no exchangeable Al is extracted from soils with pH greater than 5.5 (Singh, 1984).

4.1.1.4 Exchangeable bases

Exchangeable bases were not affected significantly by rates and sources of N in all soils (Appendix 3). However, exchangeable bases were decreased slightly with increasing N rates in all soils, probably due to increased crop uptake, especially of Ca and Mg favoured by N application. Nitrogen sources also affected exchangeable bases, but the effects were different. In the strongly acid soil CAN increased exchangeable bases slightly while SA and urea decreased the bases slightly. The increase in exchangeable bases due to CAN was probably due to added calcium as it contains 10% CaO, equivalent to 14 kg Ca/ha at the rate of 50 kg N/ha from CAN. The slight decrease due to SA and urea is possibly due to the acidifying effects of these fertilizers, causing a loss of cations by replacement with acidic cations followed by leaching. For example when SA is added to the soil, the first reaction is the cation exchange, in which ammonium (NH_4^+) ions displace some other cations, usually calcium, on the exchange site. The reaction can be represented as follows (FAO, 1984);

$$\text{Ca-Soil} + (NH_4)_2SO_4 \longrightarrow (NH_4)_2\text{-- Soil} + CaSO_4$$

Calcium sulphate ($CaSO_4$) so formed may be leached and lost in drainage water, particularly during rain season, thus resulting in a loss of soil calcium (Le Mare, 1972; Finck, 1982). Such losses caused by acidifying effects of applied SA Have been reported in Southern and Western Uganda (Stephens, 1969) and in the Western cotton growing zone of Tanzania (Le Mare, 1974). Pearson et al., (1962) observed that the amounts of Ca and Mg moved from the surface soil layer into the 15-30 cm zone were equivalent to as much as 6.6 tons of $CaCO_3$/ha. The rate of observed downward movement of Ca and Mg increased with increasing residual acidity of the source ($SA > Urea$). For the other two soils, the effects of N sources on exchangeable bases were identical (Appendix 3).

4.1.1.5 Exchangeable manganese

Both rates and sources of N had no significant effects on exchangeable Mn in all the three soils (Appendix 4). Manganese level in the soils as intially determined was 9.0 ppm in the SAS, while it was 5.5 and 6.5 ppm in the MAS and ANS, respectively. Lack of significant increase in exchangeable Mn in the SAS is probably due to an increase in pH caused by P application as discussed in section 4.1.1.1 and that the treatment had minimum effects on soil pH. Subsequent wetting and drying cycles of the soil have also been observed to reduce exchangeable Mn (Sillanpaa, 1972; Foth and Turk, 1972).

For the MAS and ANS, exchangeable Mn was low and an increase was not expected in such high pH values. However, when the effects of N sources on exchangeable Mn were compared among the three different soils, it was found that the effect was slightly greater in the SAS than in the other two soils. The overall mean exchangeable Mn values were 0.063, 0.057 and 0.037 m.e./100g soil for the SAS, ANS and MAS, respectively. In a longterm experiment conducted at Ukiriguru, Le Mare (1972) observed an increase in exchangeable Mn from 0.05 in the control to 0.15 m.e./100g soil in a soil treated with SA at a rate of 45 kg N/ha. Bache and Heathcote (1969) observed an increase in Mn concentration from 0.1M in the control (Soil pH 5.95) to 0.4M in the soil treated with N at 112 kg/ha from SA for 15 years and with a pH of 5.36. Manganese solubility is strongly related to soil pH and increases with decreasing pH (Chapman, 1968; Davies, 1980).

4.1.2 Effects of rates and Sources of N on nutrient concentration in petioles and leaf blades

The nutrients considered were N, P, Ca and Mn and were determined at flowering stage of cotton development. It is important to note that standard sampling of the leaves was not possible due to insufficient plant material. Therefore, all the petioles and leaf blades from the two plants in each pot were used for the determination of nutrient concentration. The data for the different nutrients are presented in different tables below.

4.1.2.1 Nitrogen

Analysis of cotton petioles indicated significant differences in N concentration due to N rates in all the three soils and increased as N rates were increased (Table 5). Significant increases were observed in all soils when N rates above 50 kg/ha were applied. Nitrogen application at 150 kg/ha increased N concentration in petioles from 1.3 to 1.7%, 1.4 to 2.4 and 1.6 to 2.3%, representing increases of 23.5%, 30.4% and 42%, for the SAS, ANS and MAS, respectively, when compared to the control. Nitrogen sources in all the soils had no significant effects on N concentration in petioles. However, there was an interaction between rates and sources of N which was in all soils, but more explicit in the SAS. In this soil, CAN differed from the other two sources at the highest two rates in that it caused significantly higher petiole N than the other two sources. The mean effects of the treatments on N concentration in petioles were 1.53%, 1.92% and 2.03% for SAS, ANS and MAS, respectively, with N concentration in SAS being significantly lower than in the other two soils (Table 15).

When these results are compared with those reported by Sabbe and MacKenzie (1973), N concentrations in petioles below 100 kg N/ha in the SAS and below 50 kg N/ha for the other two soils were below sufficiency levels, indicating that N was limiting. The general poorer performance of all treatments in the SAS compared to that in the MAS and ANS is probably due to high exchangeable Al reported in section 4.1.1.3 above. High Al concentration possibly resulted into restricted root growth and hence reduced N uptake as reported by Rios and Pearson (1964), Adams and Moore (1983) and Adams and Hathcock (1984).

Analysis of data for N concentration in leaf blades indicated no significant differences among rates and sources of N in the SAS (Table 6). Low pH and high exchangeable Al probably restricted root growth and thus N uptake, resulting into little or no response to applied N. However, N rates significantly increased N concentration in leaf blades over the control in the other two soils (Table 6). The increase was not significantly different for all N rates above the control and also between the control and the 50 kg N/ha. Nitrogen sources had no significant effects on N concentration in leaf blades in the other two soils.

Table 5. Effects of rates and sources of N on nitrogen concentration in cotton petioles at flowering in three soils with different initial pH.

SOIL TYPE	Nitrogen source	Nitrogen rates (kg/ha)				Mean
		0	50	100	150	
		Nitrogen concentration in DM(%)				
	CAN	1.3a	1.5ab	1.8c	1.9c	1.6x
SAS	SA	1.3a	1.5ab	1.5b	1.6b	1.5x
	UREA	1.3a	1.4ab	1.5ab	1.6b	1.5x
	Mean	1.3x	1.5xy	1.6y	1.7y	
	CAN	1.4a	1.5a	2.0ab	2.4b	1.8x
ANS	SA	1.4a	1.9ab	2.2b	2.5b	2.0x
	UREA	1.4a	1.9ab	2.2b	2.2b	1.9x
	Mean	1.4x	1.8xy	2.1y	2.4y	
	CAN	1.6a	1.9ab	2.2b	2.4b	2.0x
MAS	SA	1.6a	1.9ab	2.3b	2.3b	2.0x
	UREA	1.6a	1.9ab	2.3b	2.3b	2.0x
	Mean	1.6x	1.9xy	2.3y	2.3y	

Values followed by a common letter in the same column or row for the same soil type are not significantly different at 5% level by Duncan's new multiple range test. Note that body means and overall means were compared separately.

Table 6. Effects of rates and sources of N on nitrogen concentration in cotton leaf blades at flowering in three soils with different initial pH.

SOIL TYPE	Nitrogen source	Nitrogen rates (kg/ha)				Mean
		0	50	100	150	
		Nitrogen concentration in DM(%)				
SAS	CAN	2.8	2.8	2.9	2.9	2.9x
	SA	2.8	2.9	2.9	2.9	2.9x
	UREA	2.8	3.2	3.0	3.0	3.0x
	Mean	2.8x	3.0xy	2.9x	2.9x	
ANS	CAN	2.8a	3.6ab	4.2b	4.6b	3.8x
	SA	2.8a	3.9ab	4.1b	4.5b	3.8x
	UREA	2.8a	3.8ab	4.0b	4.4b	3.8x
	Mean	2.8x	3.8xy	4.1y	4.5y	
MAS	CAN	2.8a	3.8ab	4.7b	4.9b	4.0x
	SA	2.8a	3.2ab	4.5b	4.8b	3.9x
	UREA	2.8a	3.6ab	4.1b	4.5b	3.8x
	Mean	2.8x	3.5xy	4.4y	4.7y	

Values followed by a common letter in the same column or row for the same soil type are not significantly different at 5% level by Duncan's new multiple range test. Note that body means and overall means were compared separately.

These results suggest that N concentration in leaf blades was not responsive to rates and sources of N in the SAS and the values were below sufficiency levels when compared with those reported by Sabbe and MacKenzie (1973). Nitrogen concentration in leaf blades was greatly increased in the MAS and ANS and the values above the control were in the adequate range. Lack of significant effect among N rates in the SAS is probably due to the unfavourable soil conditions discussed above. For the other two soils, lack of significant differences among N rates occurred because N concentration was already in the sufficiency range so that higher rates caused relatively small increases in N concentration.

4.1.2.2 Phosphorus

The concentration of P in both petioles and leaf blades were significantly affected by rates and sources of N in the SAS (Table 7 and 8). Nitrogen rates above 50 kg N/ha significantly increased P concentration in petioles and leaf blades relative to lower N rates. Nitrogen sources also significantly increased phosphorus concentration in both petioles and leaf blades. The effect of CAN being significantly greater than that of the other two sources. A strong interation effect ($P<0.01$) between rates and sources of N was observed in the SAS. This was due to differences in the simple effects of the different N sources. Calcium ammonium nitrate (CAN) significantly increased P concentration in leaf tissues. Urea and SA had no significant effects in P concentration in the leaf tissues.

Table 7. Effects of rates and sources of N on phosphorus concentration in petioles at flowering in the strongly acid soil.

SOIL TYPE	Nitrogen source	Nitrogen rates (kg/ha)				Mean
		0	50	100	150	
		Phosphorus concentration in DM(%)				
	CAN	0.12a	0.20b	0.24bc	0.30c	0.22y
SAS	SA	0.12a	0.11a	0.10a	0.10a	0.11x
	UREA	0.12a	0.12a	0.12a	0.11a	0.12x
	Mean	0.12x	0.14xy	0.15yz	0.17z	

Values followed by a common letter in the column or row are not significantly different at 5% level by Duncan's new multiple range test. Note that body means and overall means were compared separately.

Table 8. Effects of rates and sources of N on phosphorus concentration in leaf blades at flowering in the strongly acid soil.

SOIL TYPE	Nitrogen source	Nitrogen rates (kg/ha)				Mean
		0	50	100	150	
		Phosphorus concentration in DM(%)				
	CAN	0.21a	0.25b	0.30b	0.29b	0.26y
SAS	SA	0.21a	0.20a	0.21a	0.20a	0.21x
	UREA	0.21a	0.24ab	0.27b	0.24ab	0.23x
	Mean	0.21x	0.23xy	0.26y	0.24y	

Values followed by a common letter in the same column or row are not significantly different at 5% level by Duncan's new multiple range test. Note that body means and overall means were compared separately.

The favourable effect from CAN in the SAS is thought to be due to the lime contained in this material which may have neutralized some of the acidity and probably caused better root growth. Also acid subsoil horizons have been reported deficient in Ca and its addition has been found to enhance the uptake of anions including phosphates (Le Mare, 1972; Adams and Hathcock, 1984). However, SA and Urea do not have such beneficial effects and are known to aggravate soil acidity (Grunes, 1959; Wolcott et al. 1965).

Phosphorus concentration in both petioles and leaf blades in the other two soils was not significantly affected by rates and sources of N (Appendices 5 and 6). However, P concentration was slightly increased with increasing N rates and in most cases SA and Urea had slightly higher P concentration than CAN.

These results indicate that the treatments had little effects on P uptake in the MAS and ANS because soil conditions were already favourable and none of the sources had advantages over the other in influencing P uptake. The P concentration values observed in the leaves are comparable to those reported by Sabbe and MacKenzie (1973) as being within the adequate range.

4.1.2.3 Calcium

The concentration of Ca in petioles was only slightly affected by rates and sources of N in all the three soils (Appendix 7). Calcium was slightly decreased by increasing N rates of SA and Urea in the SAS. However, it was slightly increased by increasing N rates of CAN. For the other two soils, Ca concentration in petioles was slightly increased by increasing N rates. The concentration of Ca in plants grown in these soils was almost double that of plants grown in the SAS. The concentrations of Ca values in the SAS were below adequate levels, those in the other two soils were within the sufficiency range (Sabbe and MacKenzie, 1973).

The concentration of Ca in leaf blades was significantly affected by rates and sources of N in the strongly acid soil (Table 9). Al N rates decreased Ca concentration in leaf blades but N application at 150 kg/ha significantly decreased Ca concentration in leaf blades. Nitrogen sources affected Ca concentration in leaf blades differently. Plants treated with CAN had higher values than those treated with SA and Urea. An interaction effect between rates and sources of N was also observed. This is explained by the fact that while different rates of SA and Urea significantly decreased Ca concentration in leaves, N rates from CAN had slight positive but non significant effect on Ca concentration. The favourable effect from CAN in the SAS was attributed to the lime contained in this material which may have neutralized some of the acidity and caused better root growth and more Ca uptake. Sulphate of ammonia and Urea contain no Ca and are known to aggravate the acidity problem which can lead to loss of Ca by leaching (Abruna et al. 1958; Pearson et al. 1962).

Calcium concentration in leaf blades in the other two soils was not affected by both rates and sources of N (Appendix 8). Lack of significant treatment effects on Ca concentration in leaf blades for the MAS and ANS is probable due to high initial Ca in these soils. Calcium uptake and translocation in plants has been reported as a passive process and thus influenced by its concentration in the soils. Therefore, high Ca content in the soils will be reflected by high concentration in plant tissues (Mengel and Kirkby, 1982). A comparison of the Ca concentration data in petioles against that in leaf blades indicates that the latter is higher. Calcium has been observed to be deposited mainly in the vacuoles of leaf blades and this can possibly be the explanation for its high concentration in leaf blades (Mengele and Kirkby, 1982).

4.1.2.4 Manganese

Manganese concentration in petioles and leaf blades was significantly affected by rates and souces of N in the SAS (Table 10 and 11). All N rates above the control significantly increased Mn concentration in petioles and leaf blades, but the differences among them were not significant. Nitrogen sources also significantly increased Mn concentration in petioles and leaf blades. Plants treated with SA and Urea had significantly higher Mn concentration in petioles than those treated with CAN, while only those treated with SA had significantly higher Mn concentration in leaf blades. A strong interation ($P<0.01$) between rates and sources of N was observed.

Table 9. Effects of rates and sources of N on calcium concentration in leaf blades at flowering in the strongly acid soil.

SOIL TYPE	Nitrogen source	Nitrogen rates (kg/ha)				
		0	50	100	150	Mean
		Calcium concentration in DM (%)				
	CAN	1.43b	1.54b	1.56b	1.42b	1.49y
SAS	SA	1.43b	1.28ab	1.24ab	0.97a	1.23x
	UREA	1.43b	1.29ab	1.23ab	1.22ab	1.29x
	Mean	1.43y	1.37y	1.34y	1.20x	

Values followed by a common letter in the same column or row are not significantly different at 5% level by Duncan's new multiple range test. Note that body means and overall means were compared separately.

Table 10. Effects of rates and sources of N on manganese concentration in petioles at flowering in the strongly acid soil.

SOIL TYPE	Nitrogen source	Nitrogen rates (kg/ha)				
		0	50	100	150	Mean
		Manganese concentration in DM(ppm)				
	CAN	140.0a	143.3a	140.0a	143.3a	141.7x
SAS	SA	140.0a	163.3b	173.3b	176.7b	163.3y
	UREA	140.0a	155.0ab	155.0ab	170.0b	155.0y
	Mean	140.0x	153.0y	156.1y	163.3y	

Values followed by a common letter in the same column or row are not significantly different at 5% level by Duncan's new multiple range test. Note that body means and overall means were compared separately.

Table 11. Effects of rates and sources of N on manganese concentration in leaf blades at flowering in the strongly acid soil.

SOIL TYPE	Nitrogen source	Nitrogen rates (kg/ha)				Mean
		0	50	100	150	
		Manganese concentration in DM(ppm)				
	CAN	180.0a	181.7a	175.0a	176.7a	178.4x
SAS	SA	180.0a	201.7b	220.0c	226.7c	207.1y
	UREA	180.0a	188.0ab	189.0ab	188.3ab	186.3x
	Mean	180.0x	190.5y	194.7y	197.2y	

Values followed by a common letter in the same column or row are not significantly different at 5% level by Duncan's new multiple range test. Note that body means and overall means were compared separately.

This was due to differences in the simple effects of the different N sources. In the SAS, SA caused a greater increase in Mn concentration in both petioles and leaf blades. Urea significantly increased Mn concentration in petioles only, while CAN had no significant effect in both tissues.

These results suggest that the increase in Mn concentration in leaf tissues due to SA and Urea was possibly due to soil acidification which might have increased Mn concentration in the soil and thus increased uptake, although soil Mn was not affected; suggesting tissue analysis was more sensitive in detecting Mn changes than soil analysis. Bache and Heathcote (1969) observed an increase in Mn concentration in cotton leaves from 122 ppm in the control to 226 ppm at 112 kg N/ha applied as SA. These values compare well with those obtained in this investigation and especially those in leaf blades. Manganese concentration in petioles was lower than in leaf blades. This probabley is due to higher Mn requirements of leaves as compared to other tissues as suggested by Mengel and Kirkby (1982).

Manganese concentration in petioles and leaf blades for the other two soils were not significantly affected by rates and sources of N (Appendices 9 and 10). It was also lower when compared with Mn concentration in leaf tissues in the SAS; supporting the commonly held view that Mn concentration in the soils is much related to soil pH and is reflected in tissue composition as reported by Adams and Wear (1957), Camberlain and Searle (1963), Sillanpaa (1972) and Davies (1980). The lack of significant increase in Mn concentration in plant tissues in the MAS and ANS is likely to be a result of high soil pH since Mn in the soils decreases 100 fold for each unit increase in pH (Gheesling and Perkins, 1970). Sillanpaa (1972) also noted that soil pH markedly affected the availability and consequently the plant uptake of Mn. Reducing acidity reduces the solubility and uptake of manganese.

4.1.3 Effects of rates and sources of N on selected growth characters of cotton.

The characters considered were plant height, number of flowers and shoot dry weight. The results are given in different tables below.

4.1.3.1 Plant height

The cotton height was significantly increased by rates of N in the strongly acid soil (Table 12). All N rates above the control significantly increased cotton height, but the differences among them were not significant. The effects of N sources on plant height was not significant except that a slight increase occurred due to CAN as compared to SA and Urea. A significant interation effect ($P<0.05$) between rates and sources of N was observed in the SAS. This was due to differences in the simple effects of the different N sources. Urea and CAN caused a greater increase on cotton height than SA, while the latter N source had no significant effect.

These results indicate the strong acidifying effects of SA and Urea in the SAS and the associated negative effects on cotton growth and also the superiority of CAN in acid soils

Table 12, Effects of rates and sources of N on cotton height at flowering in the strongly acid soil

SOIL TYPE	Nitrogen source	Nitrogen rates (kg/ha)				Mean
		0	50	100	150	
		Cotton height (cm)				
	CAN	21.7a	28.7a	32.7b	38.0b	30.3x
SAS	SA	21.7a	24.0ab	30.0b	31.0b	26.7x
	UREA	21.7a	27.7b	36.0b	30.0b	28.9x
	Mean	21.7x	26.8xy	32.9y	33.1y	

Values followed by a common letter in the same column or row are not significantly different at 5% level by Duncan's new multiple range test. Note that body means and overall means were compared separately.

as observed and discussed earlier.

The effects of rates and sources of N in the other two soils were not significantly different, although there was a slight increase in cotton height with increasing N rates (Appendix 11). Lack of significant treatment effects on cotton height in these soils suggest that the treatments had little effects on cotton height in these soils because soil conditions were already favourable and none of the sources had advantages over the other in influencing cotton height. Plant height is affected mainly through internode elongation and has been reported to be increased by N application (Gardner and Tucker, 1967a) which is contrary to this observation probably due to differences in soil conditions. When cotton height was compared in the different soils, the SAS significantly decreased the growth of cotton in height (Table 15). However, no significant difference in cotton height was observed between the other two soils. The unfavourable effects in the strongly acid soil as discussed above are therefore emphasized.

4.1.3.2 Number of flowers.

The effects of rates and sources of N on number of flowers are given in Table 13. All N rates above the control significantly increased the number of flowers in all soils, but the differences among them were not significant in most cases. Nitrogen sources had no effects on cotton flowers in all soils. A strong interaction effect ($P<0.01$) was observed in all soils between rates and sources of N. This was attributed to differences in the simple effects of the different N sources. In the SAS, CAN caused a greater increase in the number of flowers than SA and Urea. In the ANS and MAS, SA and Urea perofrmed slightly better than CAN, but the effect was not significant.

These results indicate that CAN performed better than the other two sources in the SAS, probably due to the liming effect of added Ca which favoured root growth and more nutrient uptake and number of flowers per plant. For the other two sources, the residual acidity discussed above is probably responsible for the decreased number of flowers per plant. However, the performances of all N sources in the other two soils were in most cases the same at all N rates above the control, with slightly higher values for SA and Urea than CAN. This was possibly due to slight reduction in pH caused by SA and Urea application compared to the neutral effects of CAN in these soils.

The three soils differed on the effects on the number of flowers. The number of flowers per plant were 4.8, 6.1 and 8.2 for the SAS, ANS and MAS, respectively, with significant differences among them (Table 15). The poor performance of cotton in the SAS is probably due to the effects of some chemical factors on cotton roots. Aluminium toxicity and calcium deficiency in acid subsoil horizons have been reported the most important chemical factors affecting root growth. Reduced growth rate of cotton taproots and visual symptoms of Al toxicity and Ca deficiency on roots were noted by others (Rios and Pearson, 1964; Adams and Moore, 1983; Adams and Hathcock, 1984). No

Table 13. Effects of rates and sources of N on number of flowers per plant at flowering in three soils with different initial pH.

SOIL TYPE	Nitrogen source	Nitrogen rates (kg/ha)				
		0	50	100	150	Mean
		- Number of flowers/plant -				
	CAN	1.0a	5.0bc	7.0de	8.0e	5.3x
SAS	SA	1.0a	4.0b	6.0cd	6.0cd	4.3x
	UREA	1.0a	5.0bc	6.0cd	7.0de	4.8x
	Mean	1.0x	4.7y	6.3y	7.0y	
	CAN	3.0a	4.0ab	6.0cd	8.0e	5.3x
ANS	SA	3.0a	6.0cd	9.0ef	10.0f	7.0x
	UREA	3.0a	5.0bc	7.0d	9.0ef	6.0x
	Mean	3.0x	5.0xy	7.3y	9.0y	
	CAN	3.0a	7.0b	8.0b	11.0bc	7.3x
MAS	SA	3.0a	8.0b	9.0b	12.0bc	8.0x
	UREA	3.0a	9.0b	11.0bc	14.0c	9.3x
	Mean	3.0x	8.0y	9.3yz	12.3z	

Values followed by a common letter in the same column or row for the same soil type are not significantly different at 5% level by Duncan's new multiple range test. Note that body means and overall means were compared separately.

exchangeable Al was extracted from the other two soils and the level of exchangeable Ca was in the medium category supporting that these soils had some favourable conditions for root growth and thus better effects on the number of flowers.

4.1.3.3 Shoot dry weight

The shoot dry weight of cotton was significantly increased by N application in all soils (Table 14). All N rates above the control significantly increased shoot dry weight, but the differences among them were not significant in most cases. Nitrogen rate at 100 kg N/ha increased shoot dry weight by more than twice of that of the control in all soils. The highest rate of N (150 kg N/ha) increased shoot dry weight, but the increase was not significantly different from that obtained at 100 kg N/ha. This suggests that the agronomic optimum rate is probably close to 100 kg N/ha. Nitrogen sources in all soils had no significant effects on shoot dry weight. A significant interaction ($P<0.05$) between rates and sources of N was observed in all soils. This was due to differences in the simple effects of the different N sources. In the SAS, Urea and CAN caused a greater increase in shoot dry weight than SA, whereas in the ANS and MAS, Urea and SA gave slightly higher values than CAN, but the differences were not significant.

These results indicate that there were different effects of N sources in different soil pH as discussed above. The effects of soils on shoot dry weight are compared in Table 15, and indicate that the SAS had a significantly lower value than

Table 14. Effects of rates and sources of N on dry matter production at flowering in three soils of different initial pH.

SOIL TYPE	Nitrogen source	Nitrogen rates (kg/ha)				Mean
		0	50	100	150	
		Dry matter yield (g/plant)				
SAS	CAN	3.0a	5.9b	8.2bc	12.5d	7.4x
	SA	3.0a	5.1b	7.0b	9.2c	6.1x
	UREA	3.0a	7.0b	9.5c	10.9c	7.6x
	Mean	3.0x	6.0y	8.2yz	10.9z	
ANS	CAN	5.5a	8.7b	11.2bc	11.4bc	9.2x
	SA	5.5a	6.8ab	12.0c	12.8c	9.3x
	UREA	5.5a	9.3b	14.0c	14.5c	10.8x
	Mean	5.5x	8.3y	12.4z	12.9z	
MAS	CAN	5.0a	9.6b	10.7b	11.2b	9.1x
	SA	5.0a	10.7b	12.1b	13.6bc	10.4x
	UREA	5.0a	11.9b	14.8c	14.7c	11.6x
	Mean	5.0x	10.7y	12.5y	13.2y	

Values followed by a common letter in the same column or row for the same soil type are not significantly different at 5% level by Duncan's new multiple range test. Note that bod means and overall means were compared separately.

Table 15. Effects of soils of different initial soil pH on N concentration in petioles, dry matter yield, plant height and number of cotton flowers at flowering stage of development.

SOIL TYPE	N. concentration in petioles (%DM)	Dry matter yield (g/plant)	Plant height (cm)	Number of flowers/ plant
SAS	1.53a	7.03a	28.60a	4.80a
ANS	1.92b	9.78b	31.20b	6.10b
MAS	2.03b	10.35b	31.20b	8.20c

Values followed by the same letter in the same column are not significantly different at 5% level by Duncan's new multiple range test.

the other two soils, but there was no significant difference between them. Low pH, high exchangeable acidity and Al together with low exchangeable bases in the SAS are possible factors that reduced the total top growth of the cotton plants, probably through their direct effects on root growth and reduced nutrient uptake. These effects were also aggravated by application of SA and urea in the SAS. Soil conditions in the other two soils were already favourable and the application of N sources, especially SA and Urea had some added beneficial effects. Similar observations were noted by Wolcott _et_ _al_. (1965) when soil effects were assessed on SA and Urea application.

4.1.4 Correlation relationships between selected data

The data on N concentration in petioles at flowering in the three soils were correlated with shoot dry weight. The resulting relationships are shown in Figures 1,2 and 3. These results indicate that N concentration in petioles is highly correlated with shoot dry weight and that N is an important nutrient in dry matter production in these soils. The relationships also indicate that N concentration in petioles can be a useful indicator of the N status of cotton plants. The calculated "r" values were 0.844, 0.864 and 0.869 for the SAS, MAS and ANS, respectively. Similar results have been reported by Sambandan _et_ _al_. (1971) and Pundarikakshudu _et_ _al_. (1972). The slightly lower "r" value in the SAS than in the other two soils is probably due to the unfavourable soil conditions observed above, especially the high exchangeable Al and low base status.

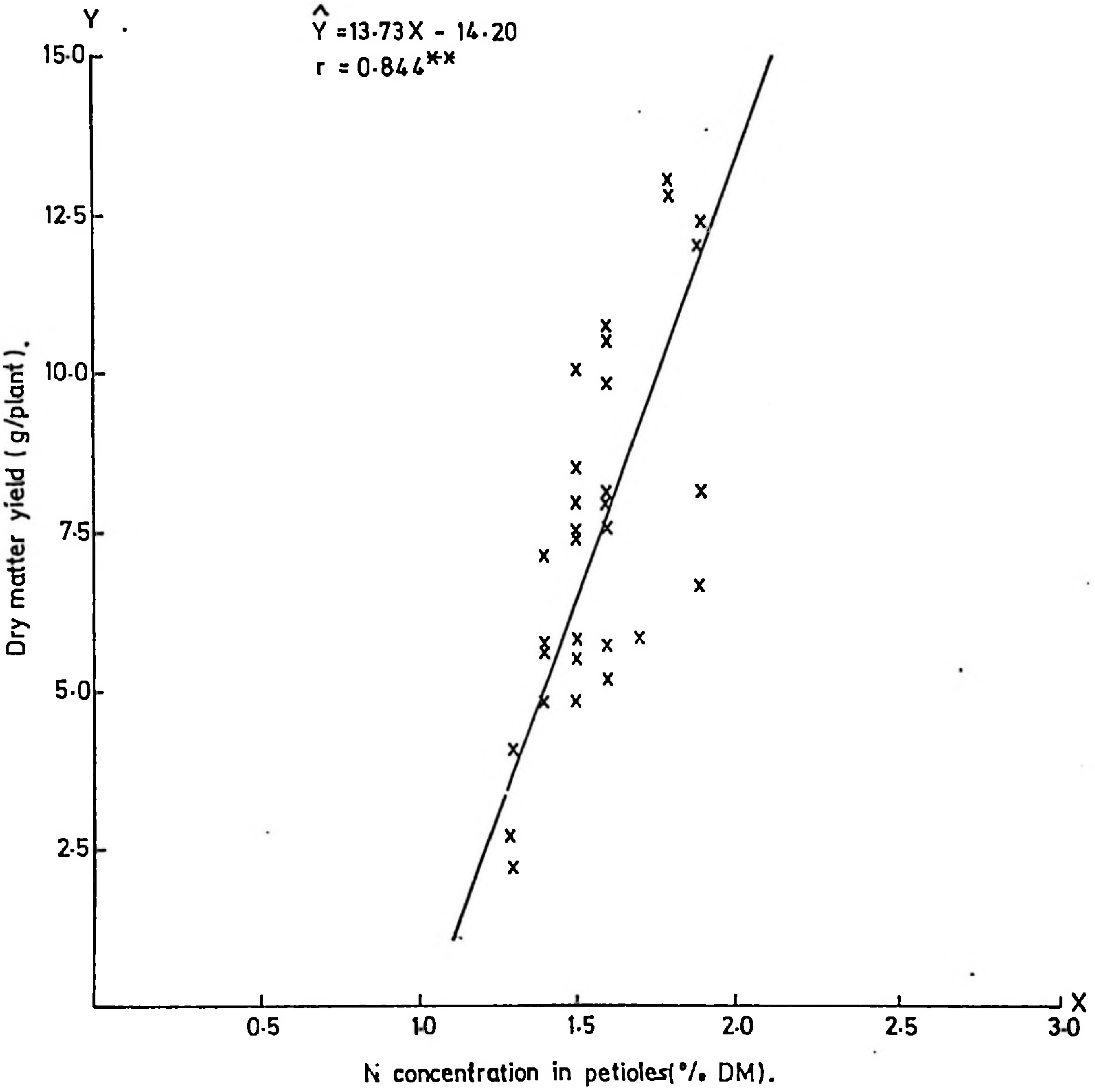

Fig.1. Relationship between N concentration in petioles and dry matter yield at flowering in the strongly acid soil.

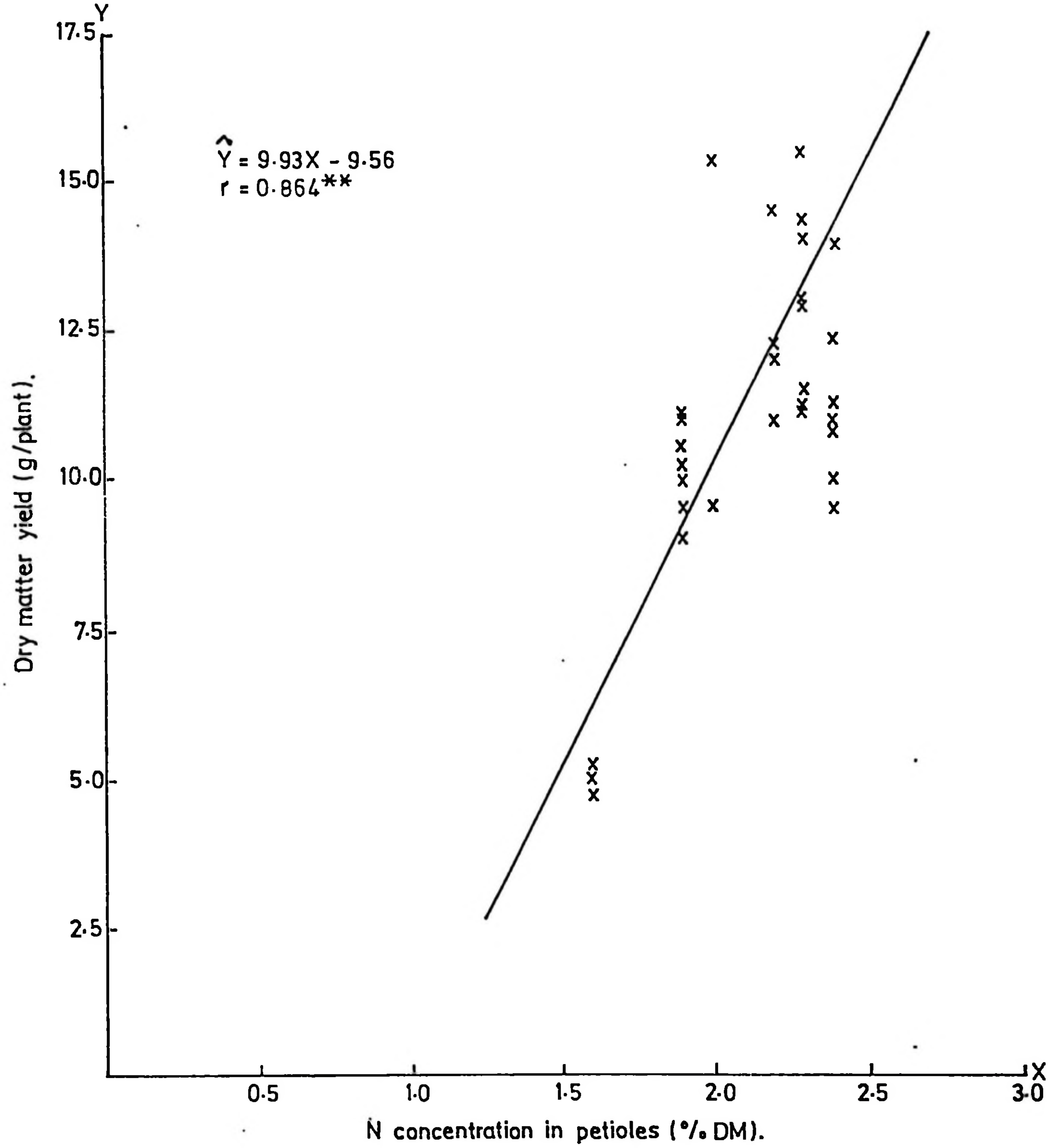

Fig. 2. Relationship between N concentration in petioles and dry matter yield at flowering in the moderately acid soil.

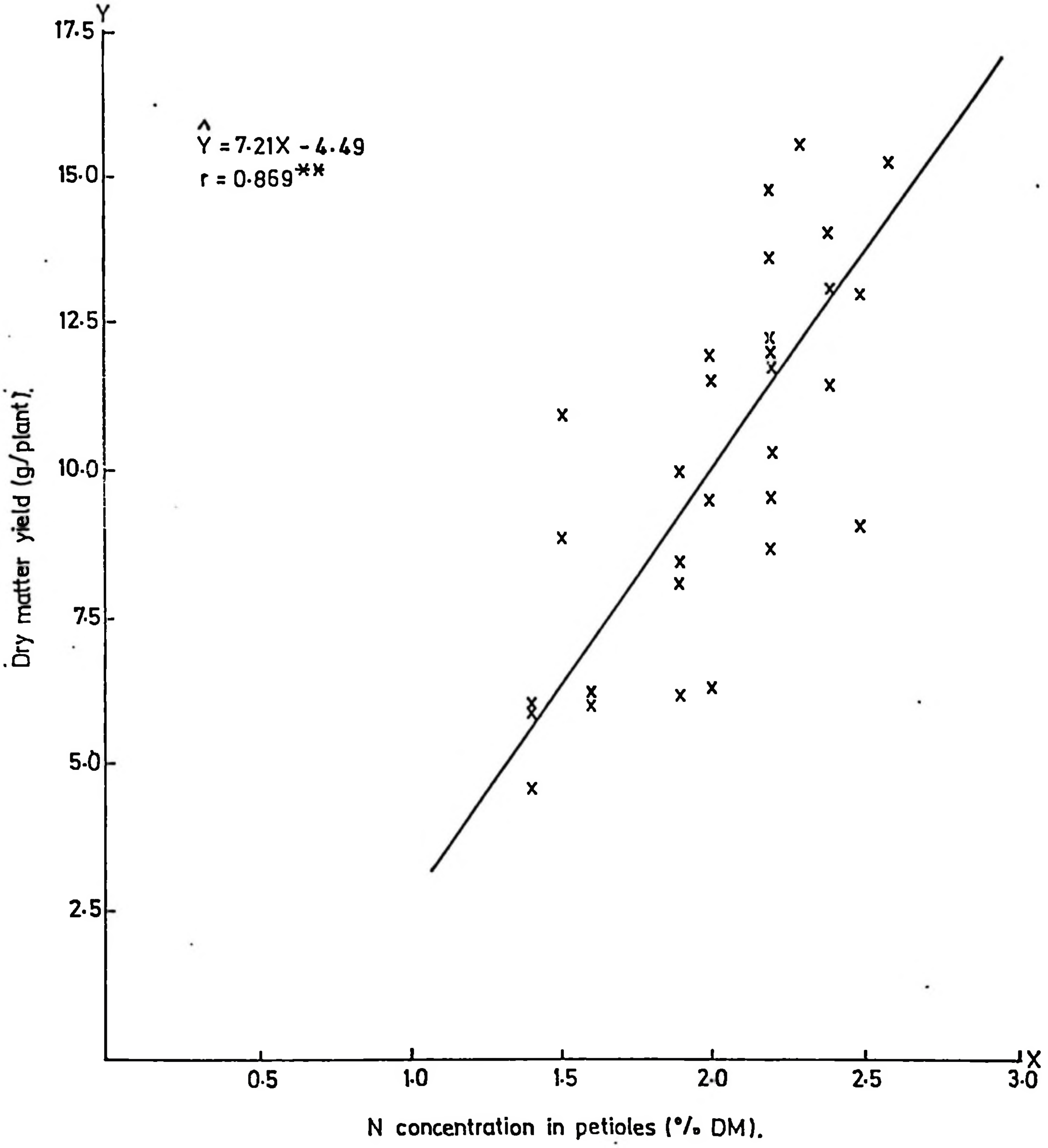

Fig.3. Relationship between N concentration in petioles and dry matter yield at flowering in the almost neutral soil.

4.2 Field Experiment

4.2.1 Effects of rates and sources of N on soil chemical properties

Treatment effects on the chemical properties of the surface soil (0-30 cm) taken after harvest of seedcotton were assessed. The properties considered were soil pH, exchangeable acidity, exchangeable bases and exchangeable manganese. Soil analysis indicated no significant treatment effects on the soil chemical properties (Appendix 12). Nitrogen rates caused only slight changes in the measured soil properties. Soil pH decreased by 0.1 unit, exchangeable acidity increased from 0.13 to 0.17 m.e./100g soil, exchangeable bases decreased by 0.7 m.e./100g soil, while exchangeable manganese was increased by 0.01 m.e./100g soil. Nitrogen sources also caused slight changes in soil chemical properties. Sulphate of ammonia decreased soil pH by 0.1 unit and exchangeable bases by 0.8 m.e./100g soil. It increased exchangeable acidity and exchangeable manganese by 0.04 and 0.01 m.e./100g soil. **respectively.** Calcium ammonium nitrate increased exchangeable bases by 0.2 m.e./100g soil. The slight changes in the soil chemical properties due to urea were in most cases similar to those made by SA. The interaction between rates and sources of N indicates that SA and urea were responsible for the slight increase in exchangeable acidity and manganese and the slight decrease in soil pH and exchangeable bases at different rates of N application. Calcium ammonium nitrate at rates of 100 and 150 kg N/ha caused a slight increase in exchangeable bases, but had no effect on the other soil properties assessed.

These results, although not significant, suggest some trends that can be expected from the continued use of strong acid producing N fertilizers on some soil chemical properties. However, the slight decrease in exchangeable bases due to SA and urea may also be due to increased nutrient uptake, especially of Ca, Mg and K brought about by heavier cotton uptake favoured by N application. The slight increase in exchangeable bases due to CAN is probably due to added Ca contained in the fertilizer material. Lack of significant increase in exchangeable Mn was expected due to low soil Mn and high pH (6.9). Adams and Wear (1957) and Mengel and Kirkby (1982) reported that exchangeable Mn level in the soil was very low in soil with pH above 6.5. This is because soil pH is one of the main factors influencing the Mn status in the soil and its solubility has been found to decrease 100 fold for each unit increase in pH as reported by Camberlain and Searle (1963) and Sillanpaa (1972).

4.2.2 Effects of rates and sources of N on nutrient concentration in petioles and leaf blades

The nutrients considered were N, P, Ca and Mn and the data is given in various tables below.

4.2.2.1 Nitrogen

Analysis of petioles and leaf blades at flowering indicated significant differences due to N rates, but the differences among all N rates below 150 kg N/ha were not significant (Table 16). Only the 150 kg N/ha significantly increased N concentration in leaf tissues over the control with 80% increase in petioles and 25% increase in the leaf blades. Nitrogen sources had no significant effects on N concentration in the leaf tissues at flowering.

These results indicate that N concentration in leaf tissues at flowering responded to N application but not to N sources. Lack of significant effect among N rates above the control suggest that the soil used in this study had relatively high N as indicated by the medium level of soil N observed. Also no N source had advantage over the other due to favourable soil conditions.

Nitrogen concentrations in petioles and leaf blades at boll development stage were not significantly affected by rates and sources of N (Table 16). But there was a slight increase in N concentration with increasing N rates and also due to SA and Urea. Generally, N concentrations were higher at flowering in leaf tissues than at boll development stage, suggesting a higher uptake and accumulation of N in the vegetative parts upto flowering. At the latter stage, most of the N was required for the reproductive parts like flowers, bolls and seeds, thus causing a translocation of N from the vegetative to reproductive parts and lowering the N concentration

Table 16: Effects of rates and sources of N on nitrogen concentration in petioles and leaf blades at flowering and boll stages of cotton development in the ANS.

Plant part and stage of development	Nitrogen source	Nitrogen rates (kg/ha)				Mean
		0	50	100	150	
		N concentration in DM(%)				
Petiole at flowering	CAN	1.5a	1.6a	2.2ab	2.5b	2.0x
	SA	1.5a	2.0ab	2.1ab	2.7b	2.1x
	UREA	1.5a	1.7a	2.0ab	2.8b	2.0x
	Mean	1.5x	1.8xy	2.1xy	2.7y	
Petiole at boll formation	CAN	1.4	1.4	1.6	1.6	1.5x
	SA	1.4	1.5	1.6	1.7	1.6x
	UREA	1.4	1.6	1.6	1.6	1.6x
	Mean	1.4x	1.5x	1.6x	1.6x	
Blade at flowering	CAN	3.9a	4.6ab	4.6ab	5.3b	4.6x
	SA	3.9a	4.4ab	4.6ab	5.6b	4.6x
	UREA	3.9a	4.4ab	4.6ab	5.1b	4.8x
	Mean	3.9x	4.5xy	4.6xy	5.3y	
Blade at boll formation	CAN	1.8	1.8	1.8	2.0	1.8x
	SA	1.8	2.0	1.9	2.2	1.9x
	UREA	1.8	2.1	2.2	2.2	2.1x
	Mean	1.8x	2.0x	2.0x	2.1x	

Values followed by a common letter in the same column or row for the same plant part and stage of development are not significantly different at 5% level by Duncan's new multiple range test. Note that body means and overall means were compared separately.

in both tissues. A similar trend has been observed for NO_3-N in petioles by Gardner and Tucker (1967a; 1967b), Wahhab (1963), Burhan and Babiker (1968), and Basinski et al. (1971).

4.2.2.2 Phosphorus

Phosphorus concentration in petioles and leaf blades at both flowering and boll development stages was not significantly affected by rates and sources of N (Appendix 13). However, P concentration in both tissues increased slightly with increasing N rates, and there was little variation between plant parts and sampling periods. Also the values observed in both tissues and sampling periods are comparable to those reported to be in the sufficiency range by Sabbe and MacKenzie (1973) except for those in the control. The results indicate that rates and sources of N fertilizers had little influence on P uptake and thus concentration in cotton leaf tissues, possibly due to the favourable soil conditions observed and discussed above. Also P concentration was already in the sufficiency range so that higher N rates caused relatively small increases in P concentration.

4.2.2.3 Calcium

The concentration of Ca in both petioles and leaf blades at both stages of development was not significantly affected by rates and sources of nitrogen (Appendix 14). Calcium concentration increased slightly with increasing N rates and was slightly lower in petioles than in leaf blades. However, all values in leaf tissues were within the adequate range, except for those of the control in petioles at flowering, which were in the low range when compared with those reported by Sabbe and MacKenzie (1973).

The slightly higher Ca concentration at boll stage of cotton development than at flowering in both tissues is due to Ca accumulation with age of tissues. Lack of significant effect among N rates is probably due to favourable soil conditions observed and especially medium exchangeable Ca observed when determining initial soil properties.

4.2.2.4 Manganese

Nirogen application increased Mn concentration in petioles at both sampling dates, but the increase was not significantly different among rates and sources of N (Table 17). Petioles at flowering contained less Mn than at boll development stage. Manganese concentration in leaf blades was significantly affected by both rates and sources of N at flowering, but only affected by N rates at the boll development stage. All N rates above the control significantly increased Mn concentration in leaf blades at both stages, but the differences among them were not significant. Of the N sources, SA resulted in significantly higher Mn concentration in leaf blades at both stages, but the differences among them were not significant. Of the N sources, SA resulted in significantly higher Mn concentration in leaf blades at flowering than urea and CAN. A strong interaction ($P<0.01$) between rates and sources of N was observed. This was attributed to differences in the simple effects of the different N sources. It was found that SA caused a greater increase in Mn concentration in leaf blades than CAN and urea at flowering, while urea and CAN had no significant effects.

Table 17: Effects of rates and sources of N on manganese concentration in petioles and leaf blades at flowering and boll development stages of cotton in the ANS.

Plant part and stage of development	Nitrogen source	Nitrogen rates (Kg/ha)				Mean
		0	50	100	150	
		Mn concentration in DM (ppm)				
Petiole at flowering	CAN	50.0	48.8	47.5	48.8	48.8x
	SA	50.0	56.3	60.0	58.8	56.3x
	UREA	50.0	50.0	50.0	53.8	50.9x
	Mean	50.0x	51.7x	52.5x	53.8x	
Petiole at boll formation	CAN	64.5	58.8	71.8	65.8	65.2x
	SA	64.5	53.8	70.0	71.8	65.0x
	UREA	64.5	67.3	70.0	67.5	67.3x
	Mean	64.5x	60.0x	70.6x	68.4x	
Blade at flowering	CAN	83.8a	85.0a	80.0a	85.8a	83.6x
	SA	83.8a	138.8b	160.0c	162.5c	136.3y
	UREA	83.8a	88.0a	75.8a	87.5a	83.8x
	Mean	83.8x	102.9y	106.3y	111.9y	
Blade at boll formation	CAN	118.8a	161.3b	155.0b	145.0b	145.0x
	SA	118.8a	151.3b	156.3b	165.0b	147.8x
	UREA	118.8a	138.8b	147.5b	156.3b	140.4x
	Mean	118.8x	150.5y	152.9y	155.4y	

Values followed by a common letter in the same column or row for the same plant part and stage of development are not significantly different at 5% level by Duncan's new multiple range test. Note that body means and overall means were compared separately.

The different results obtained for petioles and leaf blades indicate that the latter (leaf blades) are more sensitive to Mn changes in the soil than petioles as reported by Gheesling and Perkins (1970). The significant increase in Mn concentration in leaf blades at flowering due to SA has been reported by others (Grunes, 1959; Bache and Heathcote, 1969; Le Mare, 1972) and is due to increased solubility of soil Mn with decreasing soil pH. High plant Mn concentration in this soil is not supported by soil Mn data (Appendix 12); suggesting tissue analysis was more sensitive in detecting Mn changes than soil analysis. Probably greater changes are occuring around the root-zone due to ring N application method, while soil samples are taken from inter-row zones. The slightly higher Mn concentration at boll development stage than at flowering in both tissues is due to Mn accumulation with age of tissues (Mengel and Kirkby, 1982).

4.2.3 Effects of rates and sources of N on selected growth components of cotton

The components considered were plant height at flowering and boll development stages and shoot dry weight at flowering.

4.2.3.1 Plant height

Cotton height was significantly increased by N rates at both development stages, but was not affected by N sources (Table 18). All N rates above the control significantly increased cotton height, but in most cases the differences among them were not significant at both stages of cotton development. A highly significant interaction effect ($P<0.01$) on cotton height was observed between rates and sources of N. This was attributed to differences in the simple effects of the different N sources. The significant increase in cotton height at both stages of development was due to SA and urea, while CAN had no significant effect.

These results suggest that all N rates above the control were almost equally effective on cotton height. Cotton height is increased through internode elongation and this has been found to be greatly increased by N application (Gardner and Tucker, 1967a; 1967b). Lack of significant effect among N rates above the control on cotton height is probably due to favourable soil conditions observed, especially the medium level of soil N and high base status. The results also suggest that SA and urea were slightly better than CAN. The acidic effects of SA and urea possibly had slightly reduced soil pH in the plant vicinity close to the optimum pH (6-6.5) for most nutrient uptake compared to the neutral effect of CAN, resulting in slightly better effects.

4.2.3.2 Shoot dry weight

Nitrogen application significantly increased shoot dry weight, from 46.9g/plant in the control to 56.7g/plant at 100 kg N/ha (Table 18). All N rates above the control significantly increased shoot dry weight, but the differences among them were not significant. Also there was no significant difference between the control and the 50 kg N/ha. Nitrogen sources affected shoot dry weight differently with the effect of SA being

Table 18: Effects of rates and sources of N on selected growth components of cotton at flowering and boll development stages in the almost neutral soils.

Growth component	Nitrogen source	Nitrogen rates (kg/ha)				Mean
		0	50	100	150	
Plant height at flowering (cm)	CAN	74.0a	86.5b	75.4a	78.6ab	78.6x
	SA	74.0a	81.8ab	90.8bc	90.1bc	84.2x
	UREA	74.0a	84.0b	88.8bc	93.9c	85.2x
	Mean	74.0x	84.1y	85.0y	87.5y	
Plant height at boll formation (cm)	CAN	114.9a	136.6bc	137.7bc	133.9b	130.8x
	SA	114.9a	131.4b	143.5c	142.4c	133.0x
	UREA	114.9a	139.0bc	144.4c	145.0c	135.9x
	Mean	114.9x	135.7y	141.9z	140.6z	
Dry matter production at flowering (g/plant)	CAN	46.9a	47.6ab	52.6bc	50.2ab	49.3x
	SA	46.9a	51.1ab	63.8c	62.1c	56.0y
	UREA	46.9a	53.6bc	53.8bc	56.4bc	52.7xy
	Mean	46.9x	50.8xy	56.7y	56.2y	

Values followed by a common letter in the same column or row for the same growth component and stage of development are not significantly different at 5% level by Duncan's new multiple range test. Note that body means and overall means were compared separately.

significantly greater than that of CAN. Urea had intermediate effect. A strong interaction ($P<0.01$) between rates and sources of N was observed, indicating that N sources behaved differently as the rates were changed. Sulphate of ammonia (SA) caused a greater increase in shoot dry weight (63.8g/plant) than CAN (52.6g/plant), while urea was in most cases intermediate (56.4g/plant) in its effect. These values were obtained at rates 100 kg N/ha for SA and CAN, and at 150 kg N/ha for urea.

The results reported suggest that optimum N application was probably close to 100 kg N/ha, since a higher rate did not significantly affect shoot dry weight. Also SA and Urea seemed better N sources than CAN in this soil due to their acidic reaction. Enyi (1965) also found SA and Urea to give comparable responses on shoot dry matter production of cotton in a soil with initial pH between 5 and 6 under tropical conditions.

4.2.4 Effect of rates and sources of N on selected reproductive parts of cotton plants.

The parts considered were number of fruiting branches, number of flowers, number of bolls and number of early maturing bolls at different development stages and the data is given in the tables below.

4.2.4.1 Number of fruiting branches

Fruiting branches per plant at flowering were not significantly affected by rates and sources of nitrogen (Appendix 15).

However, there was a slight increase with N application and also due to SA and urea than CAN. Fruiting branches at the boll development stage were significantly increased by N rates, from 18.9 branches per plant in the control to 23.9 branches per plant at 150 kg N/ha, representing an increase of 26.5%, with no significant differences among all N rates above the control (Table 19). Nitrogen sources did not significantly affect fruiting branches at boll development stage. A strong interaction between rates and sources of N was observed. On further analysis, it was found that the significant effects observed due to N rates were mainly due to SA and urea.

These results suggest that at flowering, fruiting branches possibly had just started to form so that the effects of applied N were not yet experienced, thus resulting into insignificant increase among N rates. The slightly better effects with SA and urea than CAN are expected in this type of soil with a high pH. Physiologically acid N fertilizers have been found beneficial in soils with pH above 6.5, while neutral fertilizers like CAN are better in soils with pH below 6.5 (Wolcott _et al_., 1965; Samki, 1975; Samki _et al_.. 1980).

4.2.4.2 Number of flowers

Nitrogen application significantly increased the number of flowers over the control (Table 19). Also N applications at 50 and 100 kg/ha were not significantly different, but were significantly lower than the 150 kg N/ha. Nitrogen sources had no significant effects on the number of flowers, but SA and urea had slightly higher values than CAN. A strong interaction effect ($P<0.01$) was observed between rates and sources of N. This was due to differences in the simple effects of the different N sources. Urea and SA caused a greater increase on the number of cotton flowers per plant than CAN, while the latter N source had no significant effect. These results indicate that N application increased the number of flowers per plant, probably through the increased number of fruiting branches observed above.

4.2.4.3 Number of bolls

Nitrogen application significantly increased the number of bolls per plant (Table 19). All N rates above the control significantly increased the number of bolls per plant and that the 150 kg N/ha was significantly higher than others. Nitrogen sources had no significant effects on the number of bolls, but SA and urea had slightly higher values than CAN. A strong interaction ($P<0.01$) between rates and sources of N was observed. This was attributed to differences in the simple effects of the different N sources.Urea and SA caused a greater increase on the number of cotton bolls per plant than CAN, while the latter had no significant effect. These results suggest that the number of bolls per plant can be increased by N application and that SA and urea were slightly more beneficial than CAN in this particular soil.

4.2.4.4 Number of early maturing bolls.

Number of early maturing bolls were not significantly increased by rates and sources of nitrogen (Appendix 15). A slight

Table 19: Effects of rates and sources of N on selected reproductive parts of cotton at flowering and boll development stages in the almost neutral soil.

Reproductive plant part	Nitrogen source	Nitrogen rates (kg/ha)				Mean
		0	50	100	150	
Fruiting branches at 50% boll formation (per plant)	CAN	18.9a	23.0b	20.9ab	23.3b	21.3x
	SA	18.9a	25.0bc	25.7bc	26.0c	23.9x
	UREA	18.9a	23.7bc	23.6bc	23.5bc	22.4x
	Mean	18.9x	23.9y	23.4y	23.9y	
Flowers per plant at 75 days or 50% flowering	CAN	37.0a	51.4b	48.0b	50.9b	46.8x
	SA	37.0a	44.8ab	55.1c	60.0c	50.6x
	UREA	37.0a	54.3c	50.7b	55.3c	49.4x
	Mean	37.0x	50.2y	51.3y	57.3z	
Bolls per plant at 120 days or 50% boll formation	CAN	45.1a	52.8ab	54.1ab	63.3bc	53.8x
	SA	45.1a	62.3bc	61.8bc	70.0c	59.8x
	UREA	45.1a	70.4c	70.9c	73.7c	65.0x
	Mean	45.1x	61.8y	62.3y	69.0z	

Values followed by a common letter in the same column or row for the same reproductive plant part are not significantly different at 5% level by Duncan's new multiple range test. Note that body means and overall means were compared separately.

increase with increasing N rates was observed. Also SA and Urea had slightly better effects than CAN. Looking at the data in Table 19 on number of bolls per plant, the number of early maturing bolls as percentage of the number of bolls were 32.2% in the control and 24.5% at 150 kg N/ha.

These results indicate that N application significantly increased the number of bolls per plant, but delayed maturity so that relatively fewer bolls matured early on N treated plots. Nitrogen application at higher rates has been observed to induce greater vegetative growth and under some conditions prolong the growing period, resulting into delay in crop maturity (Tisdale and Nelson, 1970; Ashley et al, 1971).

4.2.5 Effects of rates and sources of N on selected yield components of cotton

The yield components considered were seedcotton and one thousand seedweight.

4.2.5.1 Yield of seedcotton

The yield of seedcotton was significantly increased by N application, but was not sensitive to N sources (Table 20). All N rates above the control significantly increased yield of seedcotton, but there were no significant differences among them. Yield of seedcotton increased by about 45%, from 1.6 tons/ha in the control to 2.3 tons/ha at 100 kg N/ha. The yield of the control plot was fairly high when compared with yield obtained in other parts of Tanzania, especially on soils where cotton has been grown for a number of years. For instance, in 92 field experiments conducted in the Western Tanzania cotton growing area, mean yield of the control plots was round 900 kg/ha of seedcotton under different climatic and soil conditions (Le Mare, 1972).

These results together with the medium level of soil N and high base status observed, suggest that the soil used in this study was relatively high in fertility. The climate was also favourable during the year of study (Appendix 1). Nevertheless, it is beneficial to apply N fertilizers and the results suggest that the agronomic optimum rate is close to 100 kg N/ha. Tollervey (1972) obtained an optimum N rate (112 kg N/ha) close to this one in various experiments conducted at Ilonga Research Institute.

Nitrogen sources were found to have comparable effects on seedcotton yield although SA and urea gave slightly better yield than CAN. Lack of significant effects among N sources is probably due to the favourable soil conditions of this soil, especially the pH (6.9) and high base status as reported above (Section 4.1). Similar results have been reported by Tiwari and Bisen (1972) who observed that the form of N had no significant effect on the yield of seedcotton. The N sources used were SA, urea and ammonium sulphate nitrate. Wahhab and Ahmad (1960) observed similar increases in yield of seedcotton when SA and urea were applied at the same rates in West Pakistan.

4.2.5.2 One thousand seeds weight

Nitrogen application significantly increased weight of one thousand cottonseeds (Table 20). Seedweight increased with increasing N rates upto 100 kg N/ha, but decreased thereafter. Nitrogen sources had no significant effects on one thousand seeds weight. These results suggest that 100 kg N/ha is probably close to the agronomic optimum rate for seed weight and that no N source was better than the other under the conditions of the study. The results for N rates are comparable to those of Tollervey (1972) who observed maximum seedweight and yield of seedcotton at 112 kg N/ha at Ilonga in Tanzania.

4.2.6 Correlation relationships between selected data

The data on shoot dry weight and yield of seedcotton were correlated with N concentration in petioles and leaf blades at flowering. The resulting relationships are given in Figures 4, 5, 6 and 7. Also shoot dry weight at flowering was correlated with yield of seedcotton and the resulting relationship is given in Figure 8. Relationships in Figures 9,10 and 11 are correlations between yield of seedcotton and the number of fruiting branches, number of flowers and number of bolls, respectively. All the relationships were linear and highly significant ($P<0.01$).

The highly significant correlation between N concentration in petioles and leaf blades with dry matter and seedcotton yield indicate that the N status of plants is an important factor affecting yield. Similar results were observed by Sambandam

Table 20: Effects of rates and sources of N on selected yield components of cotton in the almost neutral soil.

Yield component	Nitrogen source	Nitrogen rates (kg/ha)				Mean
		0	50	100	150	
Seedcotton (tons/ha)	CAN	1.6a	2.0b	2.1b	1.9b	1.9x
	SA	1.6a	1.9ab	2.4b	2.3b	2.0x
	UREA	1.6a	1.8ab	2.3b	2.2b	2.0x
	Mean	1.6x	1.9xy	2.3y	2.1y	
1000 cotton seed weight (g)	CAN	91.4a	92.5ab	96.0bc	92.0ab	93.0x
	SA	91.4a	93.4ab	97.8c	93.6ab	94.0x
	UREA	91.4a	95.2b	99.3c	96.2bc	95.5x
	Mean	91.4x	93.7x	97.7y	93.9x	

Values followed by a common letter in the same column or row for the same yield component are not significantly different at 5% level by Duncan's new multiple range test. Note that body means and overall means were compared separately.

et al. (1971) and Pundarikakshudu *et al* (1972). In addition, the correlation coefficients observed in this study were higher for petiole N than leaf blade N suggesting that the former tissue was a better indicator of the N status of cotton plants than the latter. These results are similar to those reported by MacKenzie *et al*. (1973), Gardner and Tucker (1967b), and Sabbe and MacKenzie (1973).

The correlation relationships presented also indicated that seedcotton yield was significantly related to a number of components of the cotton plant, namely the shoot dry weight, number of fruiting branches, number cf flowers and number of bolls. Thus any factor influencing these components, such as N supply, will also influence cotton yield.

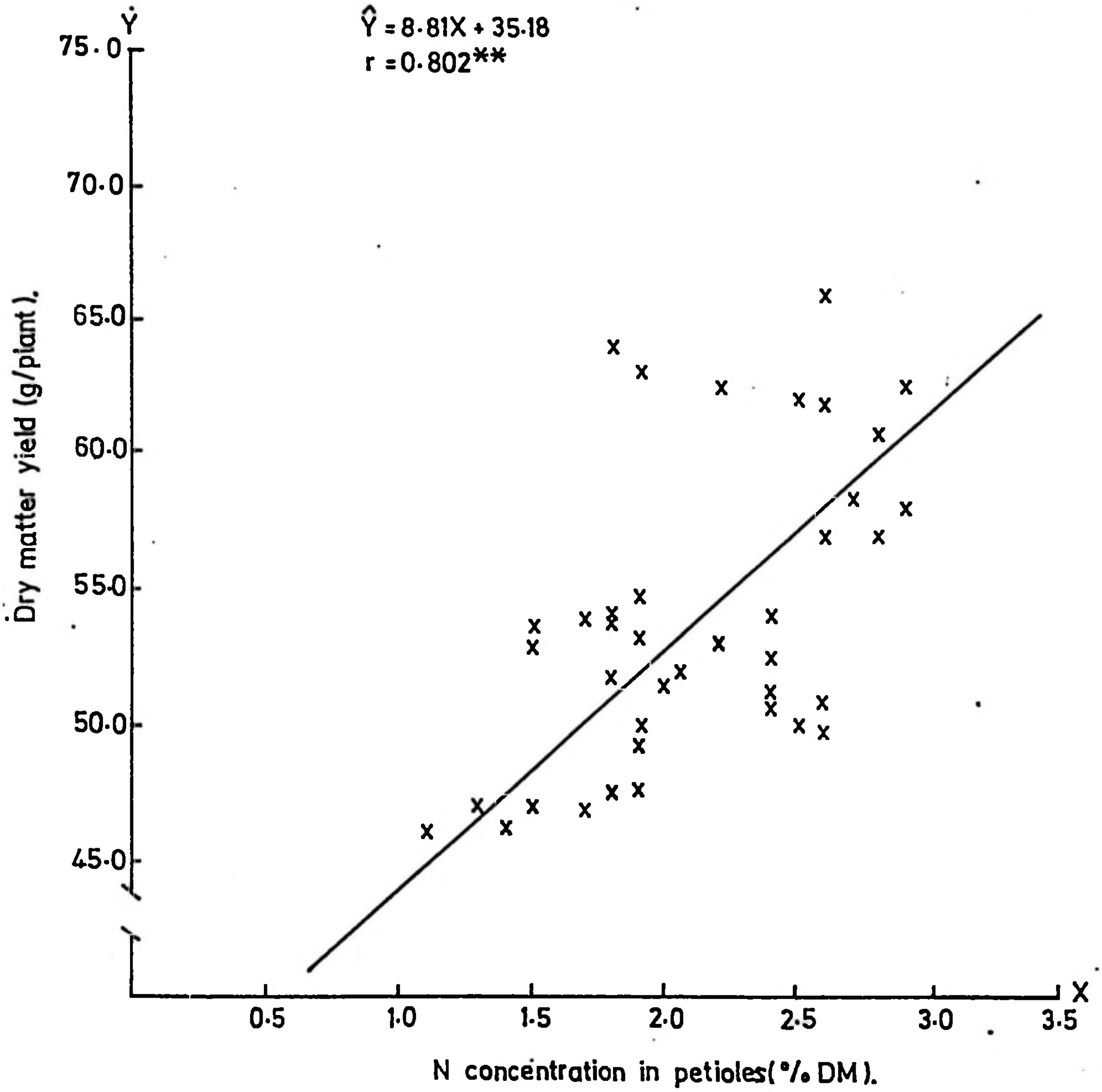

Fig. 4. Relationship between N concentration in petioles at flowering and dry matter yield at flowering in the almost neutral soil.

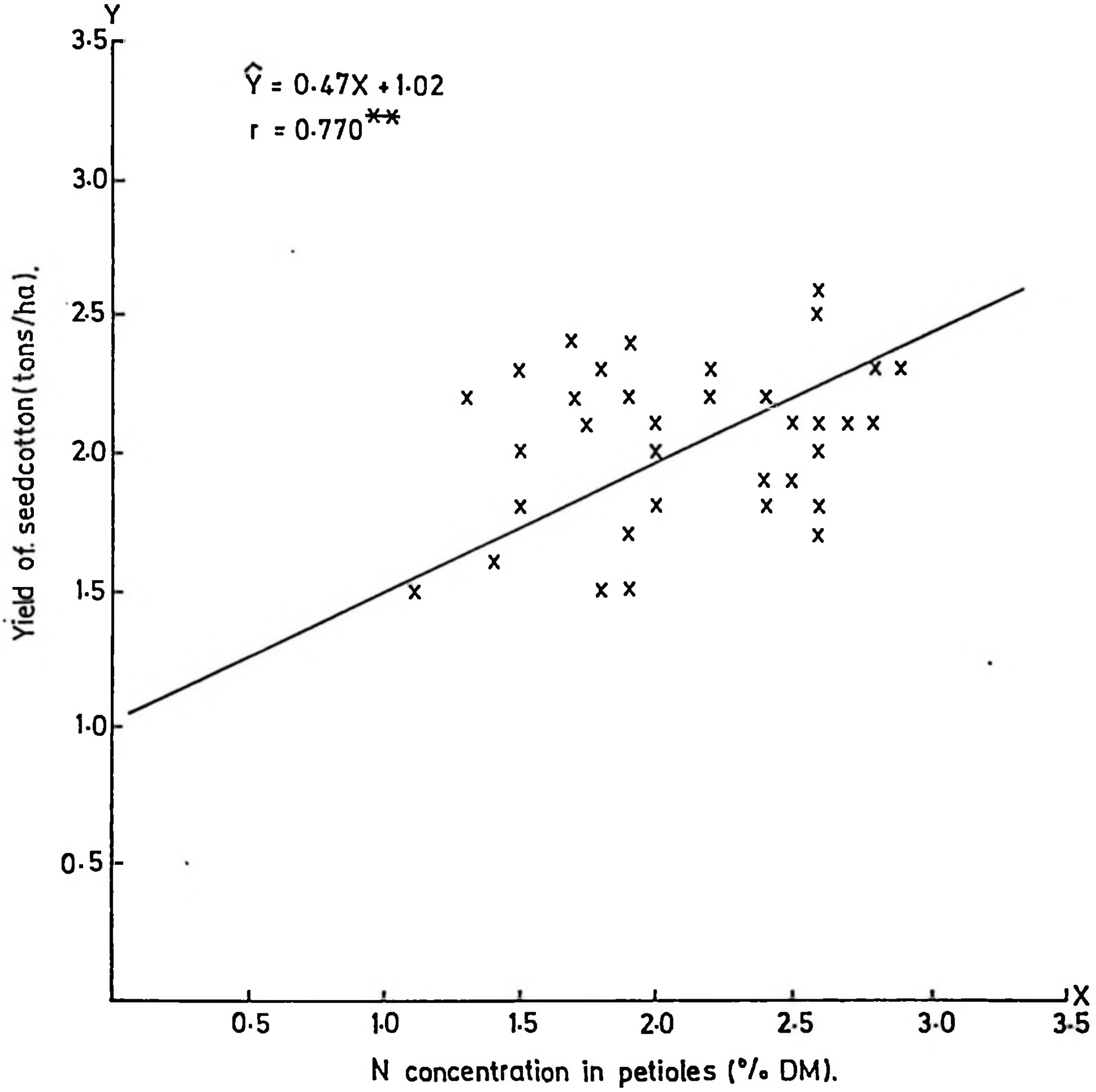

Fig.5. Relationship between N concentration in petioles at flowering and yield of seedcotton in the almost neutral soil.

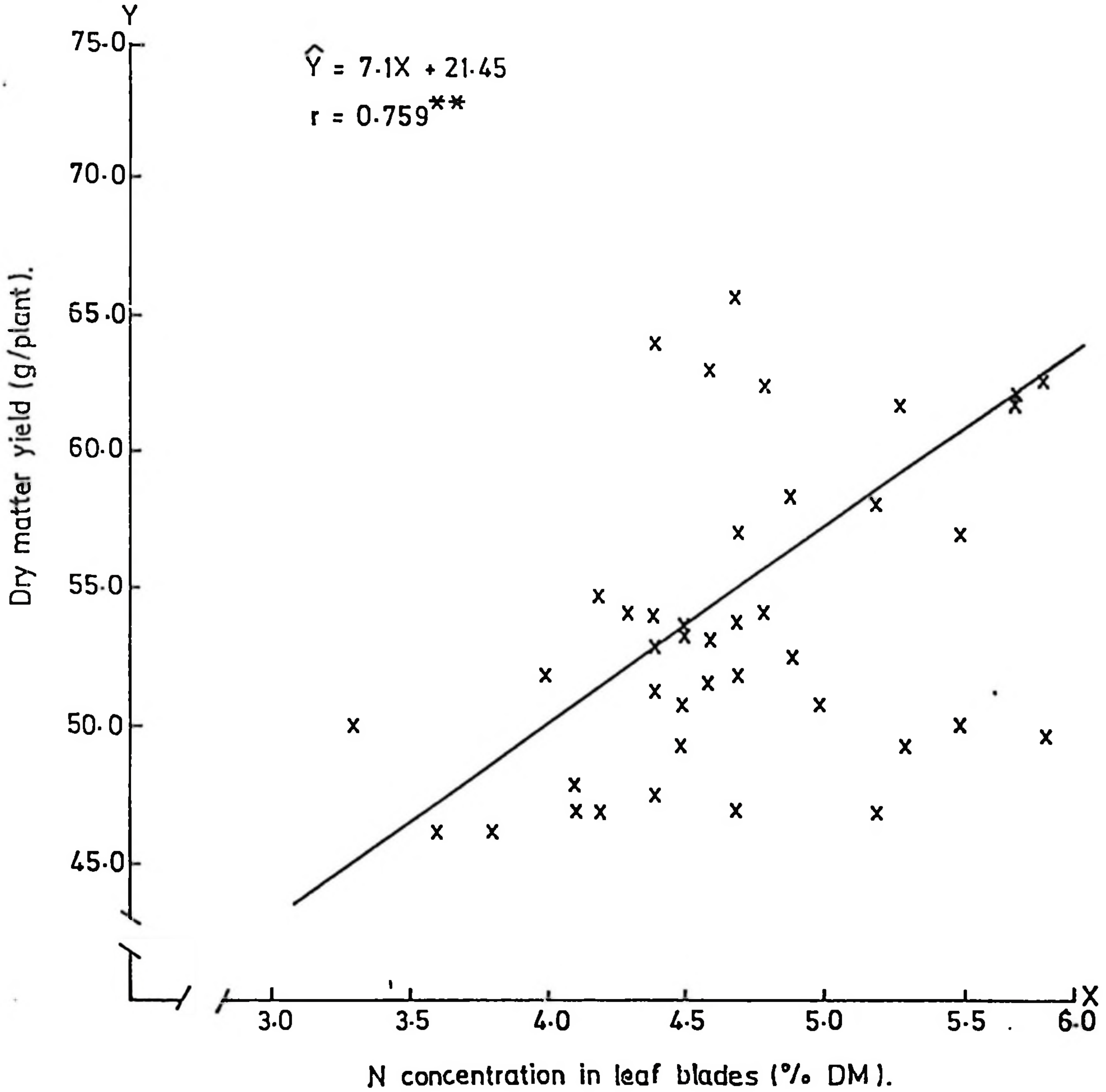

Fig. 6. Relationship between N concentration in leaf blades at flowering and dry matter yield at flowering in the almost neutral soil.

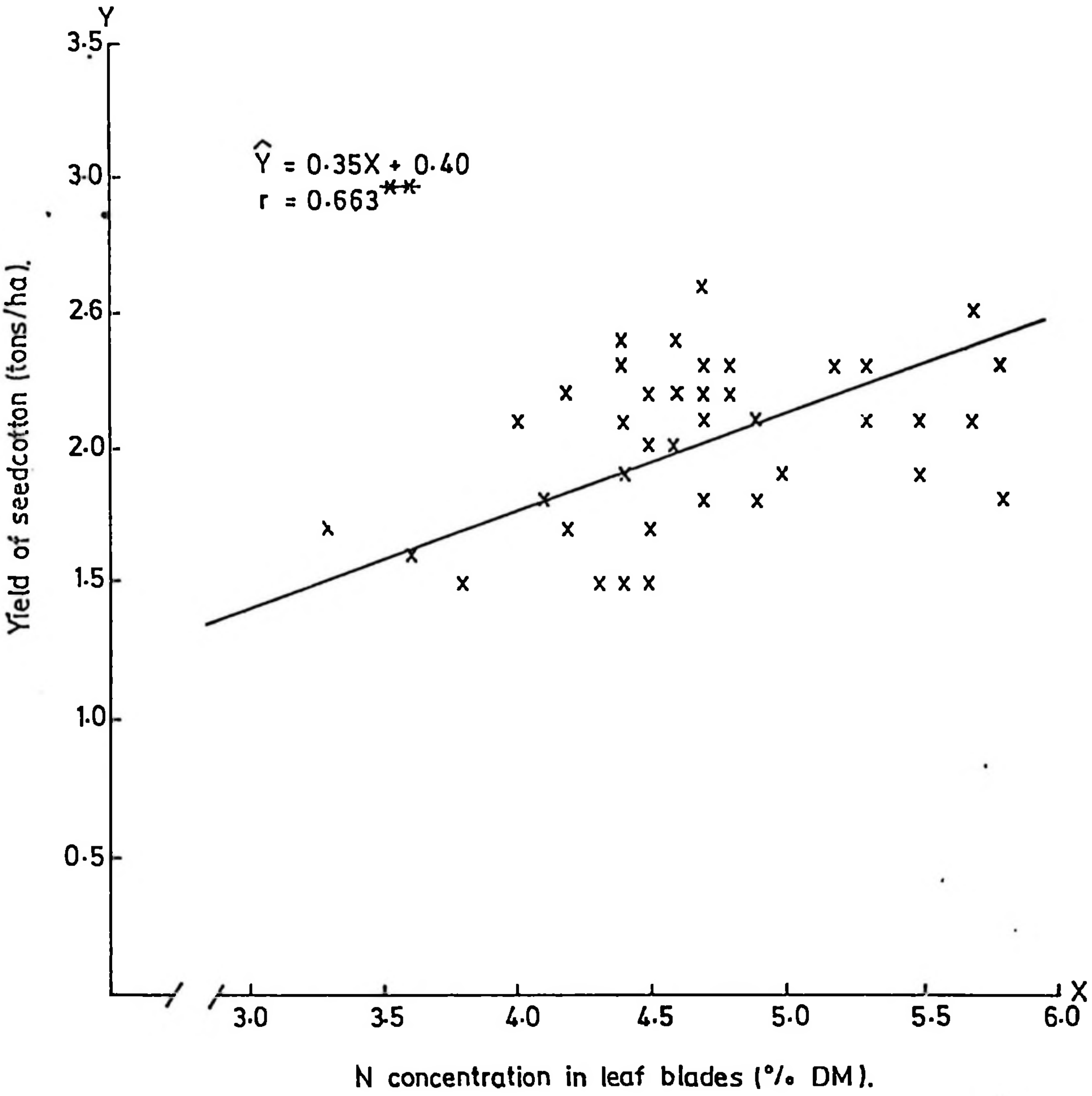

Fig. 7. Relationship between N concentration in leaf blades at flowering and yield of seedcotton in the almost neutral soil.

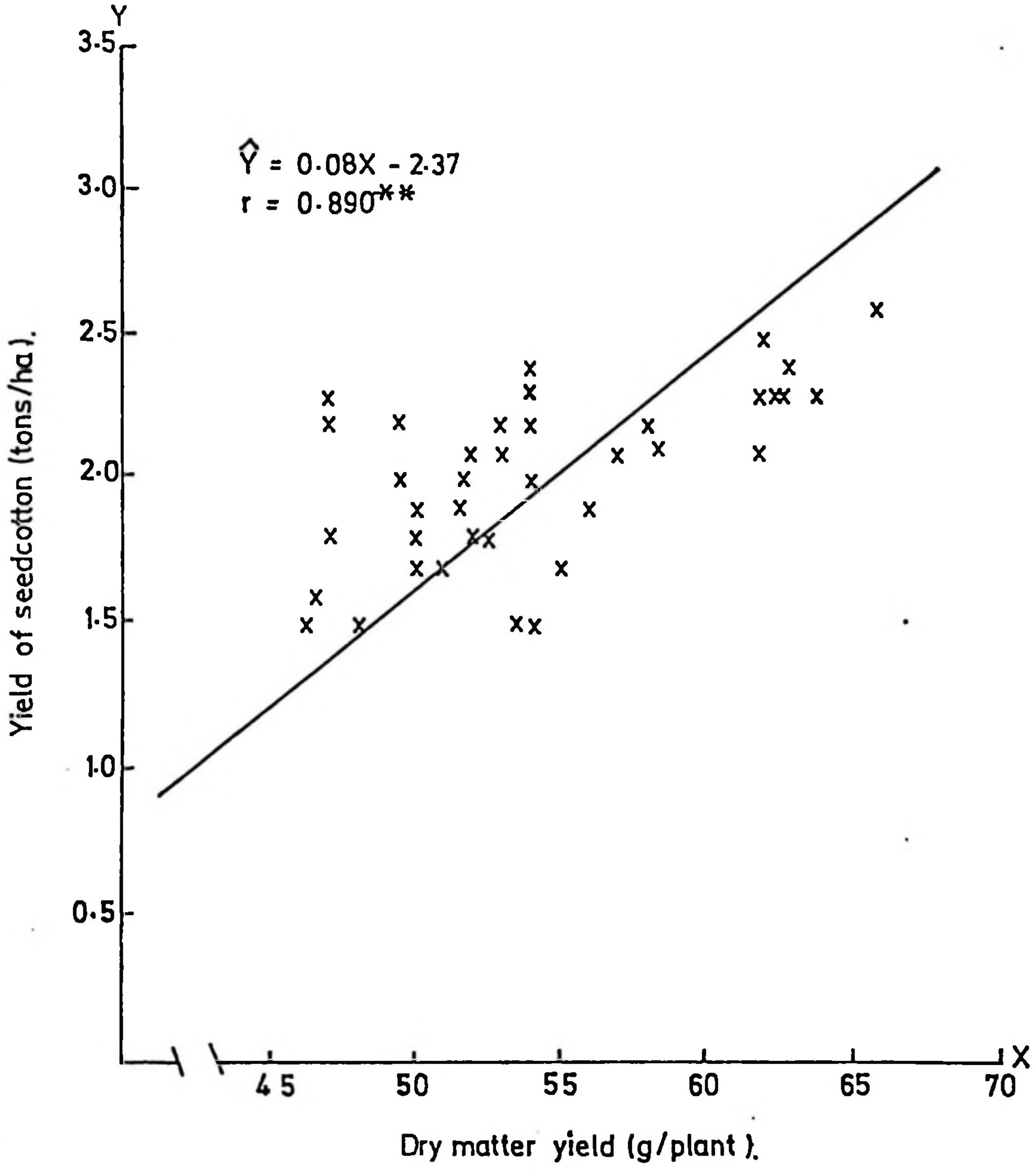

Fig.8. Relationship between dry matter yield at flowering and yield of seedcotton in the almost neutral soil.

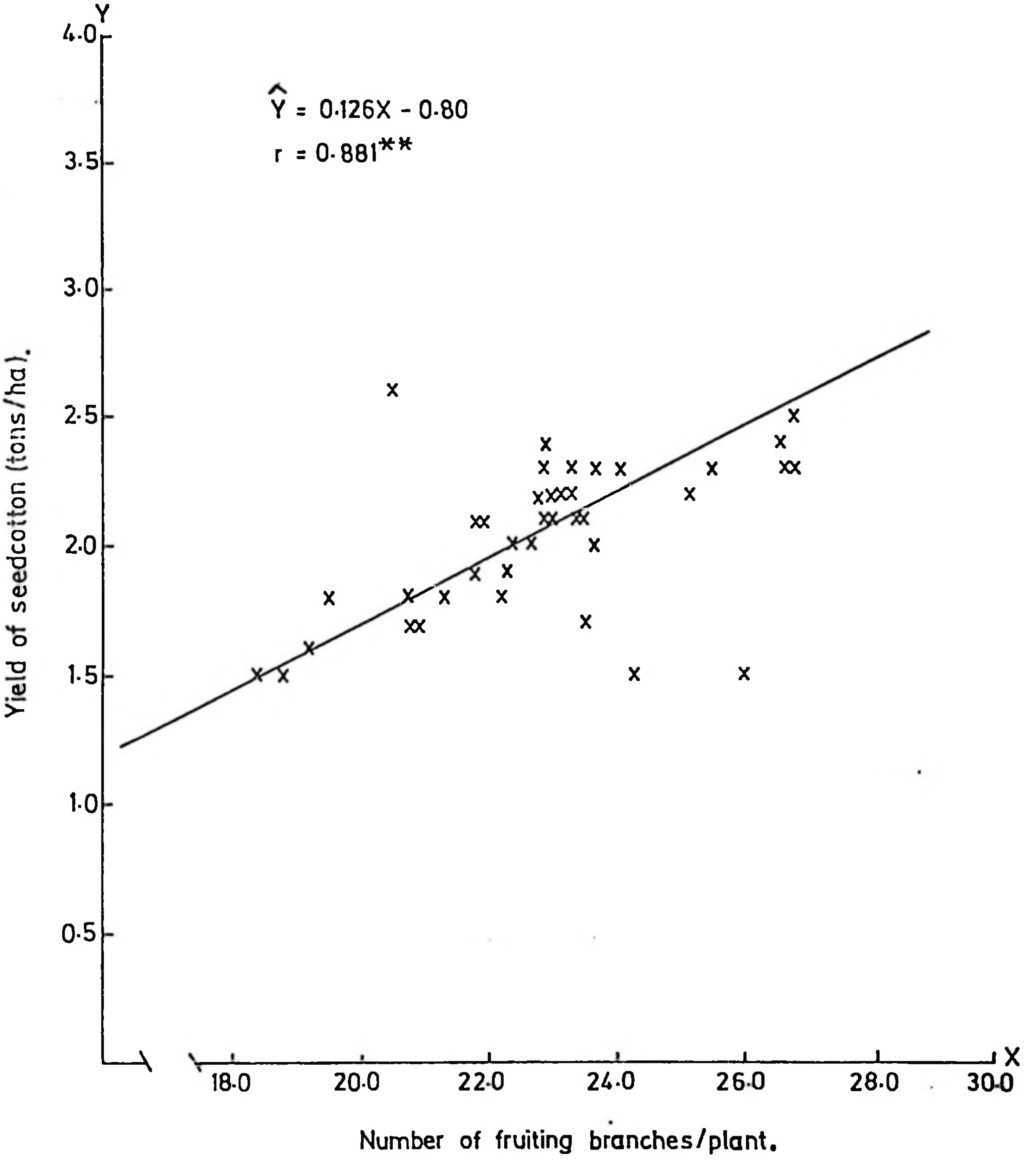

Fig.9. Relationship between number of fruiting branches at boll development stage and yield of seedcotton in the almost neutral soil.

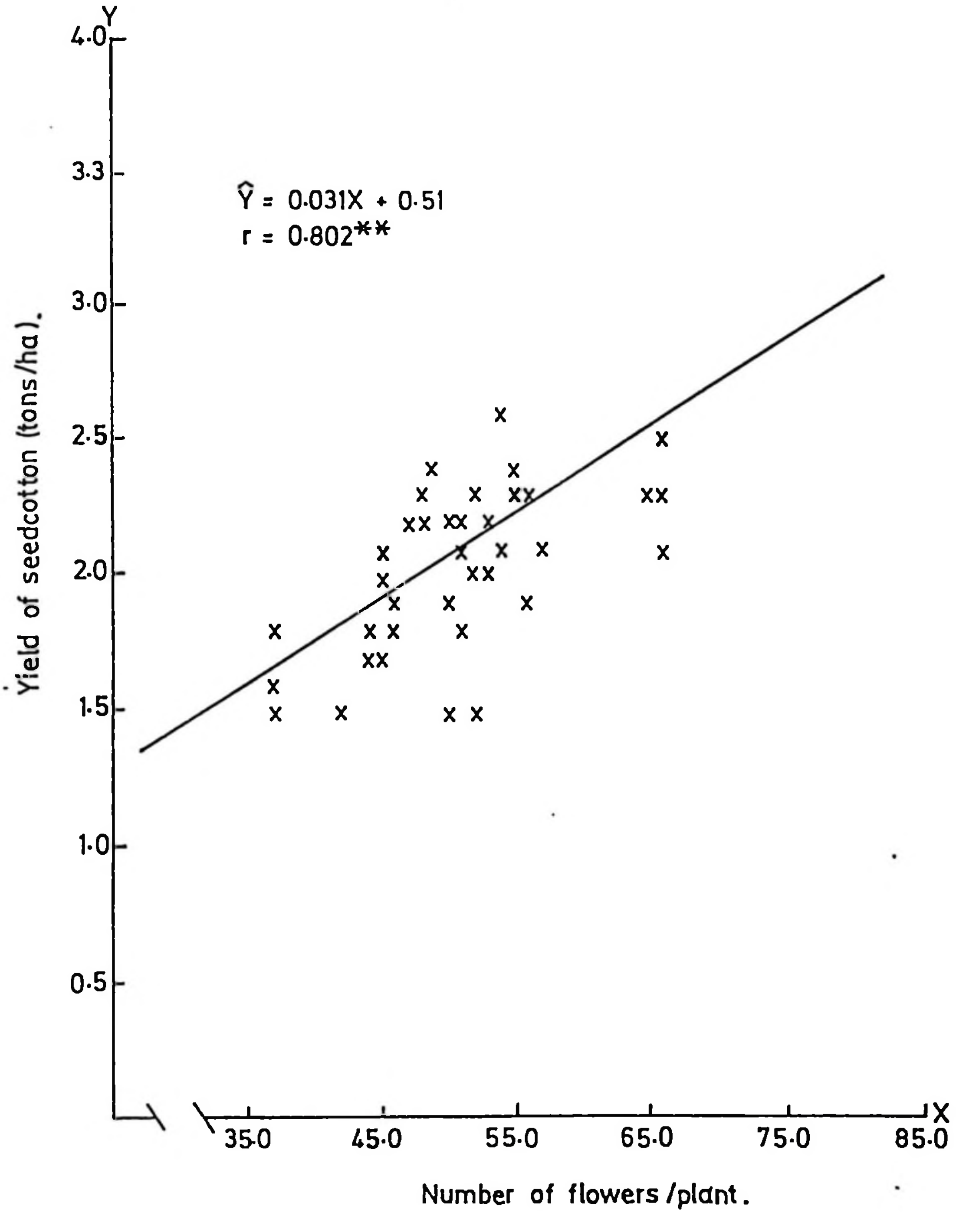

Fig.10. Relationship between number of flowers and yield of seedcotton in the almost neutral soil.

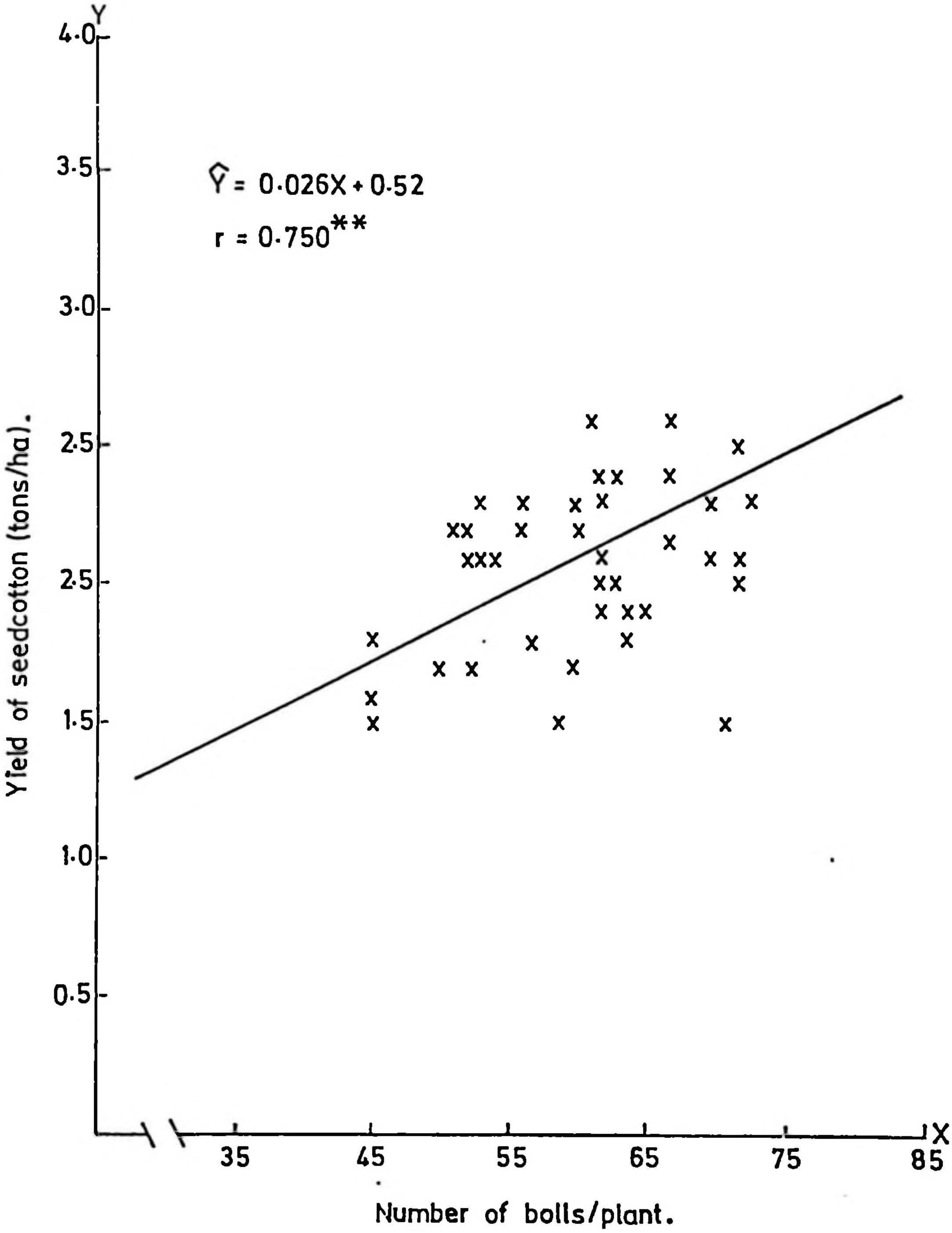

Fig.11. Relationship between number of bolls and yield of seedcotton in the almost neutral soil.

5. SUMMARY AND CONCLUSION

An experiment involving a pot and field study was conducted at Sokoine University of Agriculture Farm, Morogoro, to study the effects of rates and sources of N applied to soils with different initial pH, on soil chemical properties, tissue nutrient concentration, growth and yield of seedcotton. Treatments in a split-plot design consisted of four levels of N (0, 50, 100 and 150 kg N/ha) as main plots and three N carriers (CAN, SA and Urea) as subplots. Three soils characterized as strongly acid soil (SAS), moderately acid soil (MAS) and almost neutral soil (ANS) with initial pH of 4.8, 6.1 and 6.9 (pH in water), respectively, were used in the pot study. The almost neutral soil (ANS) was also used for the field study.

Soil pH, exchangeable acidity, Al, bases and Mn were determined at flowering in the pot study and after harvest of seedcotton in the field experiment. Plant samples for the determination of N, P, Ca and Mn concentrations were taken at flowering for the pot study and at flowering and boll development stages in the field experiment. Shoot dry weight, plant heights, number of fruiting branches, number of flowers, number of bolls and number of early maturing bolls were determined at different stages of cotton growth and development, in addition to the seedcotton yield and the one thousand seeds weight.

Nitrogen application above the control significantly increased exchangeable acidity and Al in the SAS, the effects being mainly due to different rates of SA. Other soil chemical properties in the SAS and all measured properties in the MAS and ANS were not significantly affected by rates and sources of N. Slightly higher changes due to SA and urea than CAN were observed in all soils and were more pronounced in the SAS than in the other two soils. The uniquely greater residual acidity from SA in the SAS may have been due to greater exchange affinity and displacement of bases by Al ions.

Nitrogen concentration in leaf tissues was significantly increased by N application in most cases, while N sources had no significant effects in all soils. Phosphorus and Ca concentrations in leaf tissue at flowering were significantly increased by N application in the SAS, the effect being mainly due to CAN. Calcium concentration in leaf blades at flowering was significantly decreased by SA and urea at 150 kg N/ha in the SAS. Manganese concentration in leaf tissues at flowering was significantly increased by SA in the SAS, and in leaf blades at flowering and boll development stages in the almost neutral soil (ANS). These soils had slightly higher initial exchangeable Mn than the MAS. Leaf blades were found to be more sensitive to Mn changes in the soil than petioles.

Nutrient concentrations in leaf tissues were found to be adequate at all N rates above 50 kg N/ha in the MAS and ANS. It was below sufficiency levels in the SAS for all N rates below 100 kg N/ha, except that of Mn which was high at all N rates. Tissue analysis indicated that per cent N in petioles and leaf blades should be approximately 2.0 and 4.4% at flowering, for good vegetative growth and maximum production of seedcotton. These results were achieved when N was applied at the rate of 100 kg/ha suggesting that this was the agronomic optimum rate for these soils.

Shoot dry weight, plant heights, number of fruiting branches, number of flowers and number of bolls were significantly increased by N application. Number of early maturing bolls were not significantly increased by N application, probably due to delayed maturity where N was applied. Nitrogen sources had no significant effects on growth and reproductive characters of cotton, except that of shoot dry weight in the field experiment which was significantly increased by SA. This is probably due to a slight reduction in pH observed with this N source. The increase in shoot dry weight in the different soils ranked in the order MAS > ANS > SAS. Shoot dry weight increase in the field study due to N rates ranked in the order 100 > 150 > 50 > 0, and due to N sources it was SA > Urea > CAN.

Nitrogen application significantly increased seedcotton yield and one thousand seeds weight. Maximum responses for both values were observed at 100 kg N/ha. Slight decreased responses at 150 kg N/ha was probably due to inadequate supply of other nutrients or to an imbalance brought about by excessive N. Nitrogen sources had no significant effects on the yield components of cotton. Generally, SA and urea had slightly better effects than CAN on MAS and ANS due to their acidifying effects in these soils with high pH, while CAN was more suitable on the SAS, possibly due to the liming effect of this fertilizer material (Tisdale and Nelson, 1970).

Significant correlations were observed between N concentration in leaf tissues at flowering, and shoot dry weight and yield of seedcotton; and between shoot dry weight, number of fruiting branches, number of flowers and number of bolls, and the yield of seedcotton. The high positive and significant correlation coefficients between the various growth, reproductive and yield attributes of cotton indicate their inter-dependence and the dependence of cotton on N nutrition. The calculated "r" values between N concentration in petioles, and shoot dry weight and seedcotton yield were slightly higher than those for leaf blades (0.802 and 0.770 vs 0.759 and 0.663, respectively) suggesting that petiole N was a slightly better indicator of the N status of cotton than leaf blade N.

In view of the above results, it was concluded that:

1. Consideration of N sources is necessary in strongly acid soils but appears to be irrelevant in moderately acid and almost neutral soils. Calcium ammonium nitrate was better than urea and SA in the former soil.
2. The optimum agronomic rate of N for these soils is around 100 kg N/ha.
3. Analysis of leaf tissues at flowering provides a useful indicator of the N status of cotton plants in the area and optimum concentration values of 2.0 and 4.4% for petiole N and leaf blade N, respectively, are tentatively suggested.
4. These findings need to be confirmed by including more soils and by repeating the experiment over several seasons.

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APPENDICES

Appendix 1: Rainfall and temperature data for the year 1984 at Sokoine University of Agriculture, Morogoro.

Month	Rainfall (mm)	Average temperature (^{o}C)	
		Maximum	Minimum
JANUARY	186.10	30.40	20.90
FEBRUARY	101.40	32.10	20.60
MARCH	110.80	31.50	20.20
APRIL	297.60	29.50	20.20
MAY	63.30	27.90	18.50
JUNE	22.90	27.20	15.90
JULY	5.90	26.90	16.80
AUGUST	2.00	27.30	15.90
SEPTEMBER	5.60	30.31	15.99
OCTOBER	30.50	31.70	17.90
NOVEMBER	127.40	29.70	20.10
DECEMBER	56.20	31.70	21.00

Source: Meteorological station, Sokoine University of Agriculture, Morogoro.

Appendix 2 : Effects of rates and sources of N on exchangeable acidity in three soils with different initial pH.

Soil Type	Nitrogen source	Nitrogen rates (kg/ha)				Mean
		Exchangeable acidity (m.e./100g soil)				
SAS	CAN	9.13a	9.43a	9.43a	9.40a	9.40x
	SA	9.13a	9.63b	9.77b	9.63b	9.59x
	UREA	9.13a	9.40a	9.43a	9.47a	9.41x
	Mean	9.13x	9.49y	9.54y	9.50y	
ANS	CAN	1.19	0.21	0.21	0.23	0.21x
	SA	0.19	0.23	0.21	0.24	0.22x
	UREA	0.19	0.17	0.23	0.26	0.21x
	Mean	0.19x	0.20x	0.22x	0.24x	
MAS	CAN	0.31	0.24	0.33	0.29	0.29x
	SA	0.31	0.27	0.31	0.27	0.29x
	UREA	0.31	0.26	0.25	0.29	0.28x
	Mean	0.31x	0.26x	0.30x	0.28x	

The values followed by a common letter in the same column or row for the same soil type are not significantly different at 5% level by Duncan's new multiple ranges test. Note that body means and overall means were compared separately.

Appendix 3: Effects of rates and sources of N on exchangeable bases in three soils with different initial pH.

Soil Type	Nitrogen source	Nitrogen rates (kg/ha) 0	50	100	150	Mean
		Exchangeable bases (m.e/100g soil)				
SAS	CAN	6.18	6.31	6.48	6.60	6.39
	SA	6.18	6.00	5.78	5.87	5.96
	UREA	6.18	6.03	5.93	5.69	5.96
	Mean	6.18x	6.11x	6.06x	6.05x	
ANS	CAN	11.14	11.00	10.68	10.10	10.73x
	SA	11.14	11.00	10.48	10.70	10.83x
	UREA	11.14	10.90	10.23	10.62	10.72x
	Mean	11.14x	10.97x	10.46x	10.47x	
MAS	CAN	11.28	10.92	10.10	9.92	10.56x
	SA	11.28	10.12	10.05	10.13	10.40x
	UREA	11.28	10.70	9.82	9.53	10.33x
	Mean	11.28x	10.58x	9.99x	9.86x	

Values followed by a common letter in the same column or row for the same soil type are not significantly different at 5% level by Duncan's new multiple range test. Note that body means and overall means were compared separately.

Appendix 4: Effects of rates and sources of N on exchangeable manganese in three soils with different initial pH.

Soil Type	Nitrogen source	Nitrogen rates (kg/ha)				Mean
		0	50	100	150	
		Exchangeable Mn (m.e/100g soil)				
SAS	CAN	0.06	0.06	0.06	0.06	0.06x
	SA	0.06	0.08	0.07	0.07	0.07x
	UREA	0.06	0.06	0.07	0.06	0.06x
	Mean	0.06x	0.07x	0.07x	0.06x	
ANS	CAN	0.05	0.07	0.07	0.06	0.06x
	SA	0.05	0.05	0.07	0.08	0.06x
	UREA	0.05	0.05	0.05	0.05	0.05x
	Mean	0.05x	0.06x	0.06x	0.06x	
MAS	CAN	0.03	0.03	0.03	0.04	0.03x
	SA	0.03	0.04	0.05	0.07	0.04x
	UREA	0.03	0.03	0.04	0.04	0.04x
	Mean	0.03x	0.03x	0.04x	0.05x	

Values followed by a common letter in the same column or row for the same soil type are not significantly different at 5% level by Duncan's new multiple range test. Note that body means and overall means were compared separately.

Appendix 5: Effects of rates and sources of N on phosphorus concentration in petioles at flowering in two soils with different initial pH.

Soil Type	Nitrogen source	Nitrogen rates (kg/ha) 0	50	100	150	Mean
		Phosphorus concentration in DM (%)				
ANS	CAN	0.29	0.29	0.36	0.38	0.33x
	SA	0.29	0.35	0.39	0.42	0.36x
	UREA	0.29	0.31	0.53	0.34	0.38x
	Mean	0.29x	0.32x	0.43x	0.39x	
MAS	CAN	0.27	0.29	0.33	0.36	0.31x
	SA	0.27	0.35	0.38	0.39	0.35x
	UREA	0.27	0.31	0.38	0.36	0.32x
	Mean	0.27x	0.32x	0.36x	0.37x	

Values followed by a common letter in the same column or row for the same soil type are not significantly different at 5% level by Duncan's new multiple range test. Note that body means and overall means were compared separately.

Appendix 6: Effects of rates and sources of N on phosphorus concentration in leaf blades at flowering in two soils with different initial pH.

Soil Type	Nitrogen source	Nitrogen rates (kg/ha)				Mean
		0	50	100	150	
		Phosphorus concentration in DM (%)				
ANS	CAN	0.33	0.37	0.39	0.38	0.37x
	SA	0.33	0.40	0.43	0.41	0.39x
	UREA	0.33	0.33	0.44	0.38	0.37x
	Mean	0.33x	0.37x	0.42x	0.39x	
MAS	CAN	0.30	0.32	0.37	0.40	0.35x
	SA	0.30	0.42	0.48	0.41	0.40x
	UREA	0.30	0.34	0.49	0.43	0.39x
	Mean	0.30x	0.36x	0.45x	0.41x	

Values followed by a common letter in the same column or row for the same soil type are not significantly different at 5% level by Duncan's new multiple range test. Note that body means and overall means were compared separately.

Appendix 7: Effects of rates and sources of N on calcium concentration in petioles at flowering in three soils with different initial pH.

Soil Type	Nitrogen source	Nitrogen rates (kg/ha)				Mean
		0	50	100	150	
		Calcium concentration in DM (%)				
SAS	CAN	0.74	0.84	0.79	0.76	0.78x
	SA	0.74	0.74	0.67	0.64	0.70x
	UREA	0.74	0.63	0.65	0.63	0.66x
	Mean	0.74x	0.74x	0.70x	0.68x	
ANS	CAN	1.45	1.71	1.63	1.51	1.57x
	SA	1.45	1.55	1.67	1.53	1.55x
	UREA	1.45	1.58	1.63	1.55	1.55x
	Mean	1.45x	1.61x	1.64x	1.53x	
MAS	CAN	1.71	1.79	1.86	1.77	1.78x
	SA	1.71	1.73	1.83	1.64	1.73x
	UREA	1.71	1.74	1.84	1.64	1.64x
	Mean	1.71x	1.75x	1.84x	1.68x	

Values followed by a common letter in the same column or row for the same soil type are not significantly different at 5% level by Duncan's new multiple range test. Note that body means and overall means were compared separately.

Appendix 8: Effects of rates and sources of N on calcium concentration in leaf blades at flowering in two soils with different initial pH.

Soil Type	Nitrogen source	Nitrogen rates (kg/ha)				Mean
		0	50	100	150	
		Calcium concentration in DM (%)				
ANS	CAN	2.78	2.85	2.90	2.80	2.83x
	SA	2.78	2.76	2.81	2.63	2.75x
	UREA	2.78	2.81	2.94	2.60	2.65x
	Mean	2.78x	2.81x	2.88x	2.68x	
MAS	CAN	2.66	2.67	2.94	2.90	2.79x
	SA	2.66	2.73	2.76	2.70	2.71x
	UREA	2.66	2.86	2.94	2.80	2.81x
	Mean	2.66x	2.76x	2.88x	2.80x	

Values followed by a common letter in the same column or row for the same soil type are not significantly different at 5% level by Duncan's new multiple range test. Note that body means and overall means were compared separately.

Appendix 9: Effects of rates and source of N on manganese concentration in petioles at flowering in two soils with different initial pH.

Soil Type	Nitrogen source	Nitrogen rates (kg/ha)				Mean
		0	50	100	150	
		Manganese concentration in DM (ppm)				
ANS	CAN	81.7	81.7	81.7	83.3	82.1x
	SA	81.7	83.3	93.3	95.0	88.3x
	UREA	81.7	83.3	83.3	83.3	82.9x
	Mean	81.7x	82.8x	86.1x	87.2x	
MAS	CAN	79.0	80.0	83.3	81.7	81.0x
	SA	79.0	85.0	85.0	83.3	83.1x
	UREA	79.0	83.3	80.0	80.0	80.6x
	Mean	79.0x	82.8x	82.8x	81.7x	

Values followed by a common letter in the same column or row for the same soil type are not significantly different at 5% level by Duncan's new multiple range test. Note that body means and overall means were compared separately.

Appendix 10: Effects of rates and sources of N on manganese concentration in leaf blades at flowering in two soils with different initial pH.

Soil Type	Nitrogen source	Nitrogen rates (kg/ha) 0	50	100	150	Mean
		Manganese concentration in DM (ppm)				
ANS	CAN	79.0	80.7	82.7	86.7	83.3x
	SA	79.0	84.7	88.3	91.7	85.9x
	UREA	79.0	83.3	85.0	88.3	83.9x
	Mean	79.0x	82.9x	85.3x	88.9x	
MAS	CAN	78.0	83.3	80.0	83.3	81.2x
	SA	78.0	83.3	83.3	85.7	82.6x
	UREA	78.0	82.0	80.0	83.3	81.6x
	Mean	78.0x	82.9x	81.1x	84.1x	

Values followed by a common letter in the same column or row for the same soil type are not significantly different at 5% level by Duncan's new multiple range test. Note that body means and overall means were compared separately.

Appendix 12: Effects of rates and sources of N on selected soil chemical properties in the almost neutral soil.

Soil Property	Nitrogen source	Nitrogen rates (kg/ha)				Mean
		0	50	100	150	
pH(H_2O)	CAN	6.9	6.9	6.8	6.9	6.9x
	SA	6.9	6.8	6.8	6.6	6.8x
	UREA	6.9	6.8	6.7	6.8	6.8x
	Mean	6.9x	6.8x	6.8x	6.8x	
Exchangeable acidity (m.e/100g soil)	CAN	0.13	0.13	0.12	0.13	0.13x
	SA	0.13	0.17	0.17	0.21	0.17x
	UREA	0.13	0.20	0.13	0.17	0.16x
	Mean	0.13x	0.17x	0.14x	0.17x	
Exchangeable bases (m.e/100g soil)	CAN	10.6	10.6	10.9	10.9	10.8x
	SA	10.6	9.8	9.4	9.5	9.8x
	UREA	10.6	9.8	9.6	9.3	9.8x
	Mean	10.6x	10.1x	10.0x	9.9x	
Exchangeable manganese (m.e/100g soil)	CAN	0.05	0.05	0.04	0.04	0.05x
	SA	0.05	0.06	0.06	0.07	0.06x
	UREA	0.05	0.05	0.06	0.06	0.06x
	Mean	0.05x	0.05x	0.05x	0.06x	

Values followed by a common letter in the same column or row for the same soil property are not significantly different at 5% level by Duncan's new multiple range test. Note that body means and overall means were compared separately.

Appendix 13: Effects of rates and sources of N on phosphorus concentration in petioles and leaf blades at flowering and boll development stages of cotton in the almost neutral soil.

Plant part and stage of development	Nitrogen source	Nitrogen rates (kg/ha)				
		0	50	100	150	Mean
		Phosphorus concentration in DM (%)				
Petioles at flowering	CAN	0.29	0.31	0.41	0.40	0.35x
	SA	0.29	0.40	0.40	0.40	0.37x
	UREA	0.29	0.32	0.40	0.32	0.33x
	Mean	0.29x	0.34x	0.40x	0.37x	
Petioles at boll formation	CAN	0.25	0.26	0.31	0.32	0.28x
	SA	0.25	0.30	0.30	0.33	0.29x
	UREA	0.25	0.30	0.32	0.31	0.29x
	Mean	0.25x	0.29x	0.31x	0.32x	
Leaf blades at flowering	CAN	0.37	0.40	0.40	0.40	0.39x
	SA	0.37	0.40	0.40	0.40	0.39x
	UREA	0.37	0.40	0.40	0.40	0.39x
	Mean	0.37x	0.40x	0.40x	0.40x	
Leaf blades at boll formation	CAN	0.26	0.27	0.30	0.31	0.28x
	SA	0.26	0.31	0.35	0.33	0.31x
	UREA	0.26	0.30	0.32	0.32	0.30x
	Mean	0.26x	0.29x	0.32x	0.32x	

Values followed by a common letter in the same column or ror for the same plant part and stage of development are not significantly different at 5% level by Duncan's new multiple range test. Note that body means and overall means were compared separately.

Appendix 14: Effects of rates and sources of N on calcium concentration in petioles and leaf blades at flowering and boll development stages of cotton in the almost neutral soil.

Plant part and stage of development	Nitrogen source	Nitrogen rates (kg/ha)				Mean
		0	50	100	150	
		Calcium concentration in DM (%)				
Petioles at flowering	CAN	1.9	1.9	2.0	1.9	1.9x
	SA	1.9	1.8	1.9	1.9	1.9x
	UREA	1.9	2.0	2.0	2.0	2.0x
	Mean	1.9x	1.9x	2.0x	1.9x	
Petioles at boll formation	CAN	2.3	2.4	2.5	2.4	2.4x
	SA	2.3	2.3	2.6	2.5	2.4x
	UREA	2.3	2.4	2.6	2.5	2.4x
	Mean	2.3x	2.4x	1.6x	2.5x	
Leaf blades at flowering	CAN	2.2	2.4	2.3	2.4	2.3x
	SA	2.2	2.3	2.3	2.4	2.3x
	UREA	2.2	2.3	2.4	2.3	2.3x
	Mean	2.2x	2.3x	2.3x	2.4x	
Leaf blades at boll formation	CAN	3.2	3.6	3.7	3.6	3.5x
	SA	3.2	3.4	3.4	3.3	3.3x
	UREA	3.2	3.5	3.4	3.5	3.4x
	Mean	3.2x	3.5x	3.5x	3.5x	

Values followed by a common letter in the same column or row for the same plant part and stage of development are not significantly different at 5% level by Duncan's new multiple range test. Note that body means and overall means were compared separately.

Appendix 15: Effects of rates and Sources of N on selected reproductive parts of cotton at flowering and boll development stages in the almost neutral soil.

Reproductive plant part	Nitrogen source	Nitrogen rates (Kg/ha)				Mean
		0	50	100	150	
Fruiting branches per plant at flowering	CAN	11.7	13.0	12.7	11.9	12.3x
	SA	11.7	12.7	13.0	13.7	12.8x
	UREA	11.7	12.8	13.2	13.4	12.8x
	Mean	11.7x	12.8x	13.0x	13.1x	
Early maturing bolls at 160 days after Sowing	CAN	14.5	15.5	15.9	15.6	15.4x
	SA	14.5	16.3	17.7	17.2	16.4x
	UREA	14.5	17.2	19.0	18.0	17.2x
	Mean	14.5x	16.3x	17.5x	16.9x	

Values followed by a common letter in the same column or row for the same reproductive plant part are not significantly different at 5% level by Duncan's new multiple range test. Note that body means and overall means were compared separately.