DYNAMICS OF SOIL NITROGEN IN CEREAL-BASED CROPPING SYSTEMS IN THE NIGERIAN SAVANNA

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by

SYLVESTER OJO OIKEH
B. AGRIC (Hort.), UNN
PG Dip. Irrig. Eng., Belgium
M.Sc Vegetable Crops, UNN

1996

DECLARATION

I hereby declare that this dissertation has been written by me and that it is a record of my own research work. It has not been presented before in any previous application for a higher degree.

Sylvester Ojo Oikeh

Name and Signature of Candidate

Prof. V. O. Chude

Name and Signature of Chairman
Supervisory Committee

CERTIFICATION

This dissertation titled **'DYNAMICS OF SOIL NITROGEN IN CEREAL-BASED CROPPING SYSTEMS IN THE NIGERIAN SAVANNA'** meets the regulations governing the award of the degree of Doctor of Philosophy (Soil Science) of Ahmadu Bello University, and is approved for its contribution to knowledge and literacy presentation.

Prof. V. O. Chude
Chairman, Supervisory Committee — 24-12-96 — Date

Prof. J. J. Owonubi
Member, Supervisory Committee — 6/1/97 — Date

Dr. G. K. Weber
Member, Supervisory Committee — 18-07-96 — Date

Prof. V. O. Chude
Head of Department
Head, Department of Soil Science — 24-12-96 — Date

Dean, Postgraduate School — 30/3/97 — Date

DEDICATION

"To the small-holder farmers of the

Northern Guinea Savanna of Nigeria"

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Abstract

Two field trials were conducted in the 1993 and 1994 cropping seasons to develop strategies for efficient use of nitrogen in cereal-based cropping systems of the Northern Guinea Savanna of Nigeria. The objective of the first trial was to evaluate the contribution of root morphology to N use efficiency (kg grain per kg available soil N) and yield of five maize cultivars and one local sorghum cultivar planted early in the season at five levels of applied nitrogen.

Root length density and root dry matter at 35 DAP in 1994 were significantly increased in 0-15 cm soil layer when N was increased from 0 to 60 kg ha" . Application of 120 kg N ha in splits of 60:60 at 2 and 5 WAP stimulated lateral root development in the 0-15cm soil layer at silking (64-69 DAP). In the subsoil £45cm root length density was lower (P<0.01) by 47 and 63 percent at 0 and 120 than at 30 kg N ha . Root length density, root dry matter, and N uptake were highest in Mokwa 87TZPB-SR in both in 1993 and 1994.. The most widely grown maize, cultivar TZB-SR had the least root development. All the maize cultivars rooted to 90cm depth, but 30-45cm layer was the most active rooting depth for nutrients uptake, because it had the highest concentration of fine root system. Sorghum root production was higher, but more superficially located within the topsoil (0-30cm), than maize roots. Screening maize cultivars for improved root development in the subsoil (>30cm depth) late in the season was a better indicator of N uptake efficiency than screening for rapid early root growth.

The hybrid maize cultivar 8644-27 gave the highest grain yield of 5.8 t ha and was the most N-use (18-30 kg grain per kg available soil N) efficient cultivar. It had higher sink capacities, including extended grain filling period, harvest index and 1000-kernel weight than the other cultivars. The most widely grown cultivar TZB-SR was the least efficient in utilizing available soil N for grain production (15-28 kg grain per kg available soil N), although it had the highest source capacity. The efficiency of local sorghum to convert available soil N to grain yield was relatively low, being only 9 as against 17-27 kg grain per kg available N, average for maize.

Marginal analyses showed that 60 kg N ha applied at 2 WAP was the most profitable rate under the conditions of the experiment. A farmer planning to invest on improved maize technology will receive higher return for his investment by growing an N-use efficient hybrid, cultivar 8644-27, than growing his popular open pollinated maize, cultivar TZB-SR. But, he will be better off growing the N-use efficient open pollinated cultivars than growing an N-use efficient hydrid, cultivar 8644-27.

The second trial was conducted to evaluate the hypothesis that the contributions of an N-use efficient maize and legumes to N use efficiency can be improved by matching legume residue decomposition rate with soil nitrate release. Soybean *(Glycine max* cv. TGx 923-2E) and stylo *(Stylosanthes hamata* cv. Verano, a forage legume), and a control (maize cv. TZB-SR) were grown in four farmers' fields of different native fertility in Tsibiri village in 1993. At the end of the season, soybean grain and stover were harvested and stylo biomass was removed for fodder.

Total available soil N in the 0-3 0cm layer at the beginning of 1994 season was 75, 52 and 44 kg ha" following previous soybean, stylo and maize, respectively. Total N uptake of maize was over 25 percent higher following legumes than following maize. A combination of legume rotation, 60 kg ha applied at 2 WAP, and an N-use efficient cultivar 8644-27 gave a yield advantage of 1.3t ha over a two-year sole crop maize, cultivar TZB-SR supplied with 60 kg N ha at 2 WAP. There was no effect of previous crops on sorghum yield Losses of N probably due to leaching, were lowest in plots previously planted with stylo.

Soybean rotation system reduced *Striga hermonthica* incidence and severity compared to a two-year sole crop maize or a stylo rotation system.The highest incidence of *Striga hermonthica* was found in stylo rotation system. There was less *Striga* emergence in the N-use efficient cv. 8644-27 plots than in plots planted with cv. TZB-SR.

Results indicate opportunities to integrate appropriate legume-based technologies into savanna farming system based on an identification of soil and legume N-release patterns.

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CHAPTER ONE

INTRODUCTION

The main agricultural soils of the savanna agroecological zone are generally low in organic matter, buffering and cation exchange capacities, and in some cases these soils are sandy and acidic. Nitrogen is the most limiting plant nutrient in the savanna soils. It has therefore, become mandatory with land use intensification and with agricultural development to fertilize farmlands, especially with nitrogenous fertilizers for satisfactory yields (Oikeh and Asiegbu, 1993). However, due to high energy cost, chemical fertilizers have become very expensive and are also scarce (William and Haris, 1986). The situation could further be compounded if the Nigerian government finally respond to international pressure through the structural adjustment reforms to remove the present 80 percent subsidy on fertilizers to save foreign exchange.

Besides these economic problems confronting the farmers in this zone, there are agroecological problems associated with the use of N-fertilizers to increase and sustain high crop production. Nitrogen is prone to leaching especially in the more sandy soils commonly found in the savanna, resulting in the contamination of ground water with nitrates (Chinwo *et al.*, unpublished). Moreover, high rates of nitrogen fertilizers, in particular, ammonium sulphate, have been shown to acidify the soils (Jones, 1976; Pieri, 1990; Juo *et al.*, 1995), thus resulting in undesirable effects on soil physical and chemical properties (Kang and van der Heide, 1985 Juo *et al.*, 1995). One possible solution to these problems would be through an efficient use of available nitrogen in the soil, minimizing and optimizing input nitrogen and transforming nitrogen most efficiently into agricultural products by using N efficient cultivars.

Nitrogen flush caused by the moistening of soil after the dry season has been shown to increase nitrate-N in the top soil (Wild, 1972). This phenomenon of increase of nitrate-N in the surface soil at the commencement of the wet season has long been

widely reported in other tropical soils (Greenland, 1958; Birch, 1958; 1960). However, the real value of this NO_3-N to crop production is not clear (Ahmad, 1985) and as such has not been used for programming fertilizer recommendation.

Recent studies conducted in Northern Guinea Savanna have shown at least 5-fold and often 10-fold differences in NO_3- availability between farmers' fields at the beginning of the season, irrespective of fertilizer rates (Weber *et al.*, 1995c). Soil nitrate-N concentrations at 2-8 weeks after planting (WAP) had significant correlation with maize yields, but were not associated with soil organic carbon or total nitrogen content. Two major scenarios were identified from the studies:

i. Fields with high NO_3-N release pattern.
ii. Fields with low NO_3-N release pattern.

A greater understanding of the amount, rate and duration of the release of nitrate-N in farmers' field will allow an appropriate targeting of N-saving, N-enriching or N-using technology into the system.

The cropping system of the Nigerian savanna was dominated by cereals like millet and sorghum which are the traditional crops. Improved maize varieties were introduced in the zone in the 1970s. Maize cropping has transformed agriculture in the zone during the last decade (Smith *et al.*, 1994). Unlike the traditional sorghum adapted to poor soils of low N availability, maize responds well to higher soil fertility, especially high N availability (Jones and Wild, 1975). Due to the problem of fertilizer distribution and the increasing prices, it is a common practise for farmers to reduce the land area under maize in favour of sorghum production, if at planting time they are not sure of procuring fertilizers. It is therefore, important to analyse the productivity of maize and sorghum in the farming system under the scenarios of high and low NO_3-release. To sustain maize production in the zone would therefore, require better uptake and utilization of N by the plants for grain production. The introduction of N-use efficient cultivar at the farmers' level to minimize and optimize input N will be an

attractive proposition.

There are differences in root morphological characteristics, particularly total root length density, which play an important role in determining N-use efficiency (grain yield per available soil N) in maize (Heuberger *et al.*, 1994; Wiesler and Horst *et al.*, 1994). This might even allow some reduction in fertilizer rates, thereby minimizing input N (Atkinson, 1990). The identification of maize cultivars with such improved root growth characteristics to capture the initial flush of NO_3-N, and which later in the season can extract NO_3^- from the subsoil to prevent NO_3^- from accumulating in the subsoil will be highly desirable in improving N-use efficiency.

Legumes currently present the best potential to contribute significantly to maintain nitrogen levels, organic matter, and physical properties of soils for intensifying cereal-based cropping systems (COMBS, 1993). The removal of above-ground parts from the fields for animal feed and for domestic purposes (fencing, firewood, etc.) is a common practise among the small-holder farmers of the Northern Guinea savanna. On-station trials based on researchers' perception of what farmers should do have shown that legumes would contribute higher to the production systems if the above-ground parts are left on the field and if they are incorporated into the soil. But with the present farmers' practise, the questions are, how much, under what conditions and with which technology will legumes contribute more to soil fertility in farmers' fields in the savanna? Beyond the fact that N supply will be enhanced by legumes in rotation with maize, there may also be a scope to fine tune the system by using legumes whose residues have different decomposition rates. A low N-release field can benefit most from fast decomposing legume residues; and a moderate to high N-release field might benefit more from residues which decompose slowly. A legume-based system will also provide fodder for the farmers, in addition to improving soil properties.

Research Objectives:

1. To identify which maize and/or sorghum cultivar most efficiently utilizes available N resources for grain production.
2. To evaluate the contribution of genetic differences in maize root morphology to N use efficiency under savanna conditions.
3. To evaluate the contribution legumes and an N-use efficient cereal variety in legume/cereal rotation in the savanna.

These objectives are based on the following:

1. Maize and sorghum have different N uptake and utilization patterns and their productivity depend on the amount of soil N content.
2. Differences in NO_3-N release patterns in the savanna soil can be exploited through varieties with improved root morphological characteristics.
3. Contributions of legumes to nitrogen availability can be improved by matching legume residue decomposition rates with soil NO_3-N release.

CHAPTER TWO

REVIEW OF LITERATURE

2.1. GENERAL

2.1.1. Importance of Maize

Maize (*Zea mays* L.) is an annual plant of the grass Gramineae family. It is an out-pollinated plant which matures usually in 100-120 days, although some variation exists. The male flowers called tassels emerge 50-60 days after planting (DAP) at the apex of the plant. At about the same time, the female flowers are formed in the axils of the lower leaves. But the stigmatic surfaces of the female flower called silk only emerge from the leaf axils shortly after tasseling (Williams and Chew, 1980).

Maize is one of the most important cereal crops grown in Nigeria. It serves as a major food and cash crop of the savanna. In the last decade through the introduction of fertilizer responsive improved cultivars and the adoption of fertilizer use, maize cropping has dramatically transformed agriculture in the Northern Guinea Savanna (NGS) from a subsistence to a cash oriented system (Smith *et al.*, 1994). The crop is being utilized as a staple food, feed for livestock, and in brewery and confectionery industries in Nigeria.

2.1.2. Climatic and Soil Requirements of Maize

Maize is grown over a wide range of climatic conditions. In Nigeria maize is grown in areas where annual rainfall ranges from 500mm in the Sudan/Sahel savanna to 3,500mm in the mangrove forest. Excessive rainfall and soil moisture however, decrease yields. Moisture stress especially at flowering has similar effect on yield. The solar radiation and mean daily temperature of maize growing zones in Nigeria range from 350-400 cal cm^{-2} day^{-1} and 27°C in the north and about 250 cal cm^{-2} day^{-1} and 24.8°C in the south (FAO, 1984). High temperatures above 32°C at tasseling and pollination speed up differentiation process of the reproductive organs resulting in higher kernel abortion. When many kernels are aborted, the total sink size could limit

yield (IITA, 1986).

Maize is grown on a wide range of soils. But it grows best in deep, well drained, medium to moderately heavy-textured soil, with adequate organic matter. It yields poorly on shallow, sandy soils because of higher susceptibility to moisture and nutrient stress. Maize does best on soils with pH of 5.5-7.0, and strongly acid soils with pH<5.0 are unsuitable except when limed. It can also be grown in alkaline soils but deficiencies of iron and manganese must be corrected (William and Chew, 1980).

2.1.3. Agricultural Systems of the Northern Guinea Savanna and Their Constraints

The agricultural systems of the Northern Guinea Savanna (NGS) are based mainly on cereals such as maize, sorghum, millet and rice which are well adapted to the ecological conditions prevailing in the zone. Traditional systems are based on sorghum and millet with occasional fallow periods. These are rapidly changing to more intensive land-use systems with reduced fallow periods (Weber *et al.*, 1995a). In areas where agricultural inputs are rarely available and soil fertility is low, sorghum and millet still continue to dominate the system. But, in other areas where there is good access to market, availability of fertilizers and improved maize varieties, the production system is changing to a maize-based system (Weber *et al.*, 1995a). The most common non-cereal crops in the savanna systems include cotton, groundnut, cowpea and soybean (Ogungbile *et al.*, 1991). Cultivation of forage crops is rare, in spite of increasing animal husbandry.

However, with increasing population density, marketing infrastructure and the need for food, the demand for agricultural products has increased. This in turn has resulted in the opening of new frontiers and/or intensification of cropping on the same land (de Ridder and van Keulen, 1990; Weber *et al.*, 1995b). This process of intensification has led to a decline in soil fertility, soil compaction, soil acidification resulting from misuse of chemical N fertilizers, and a build-up of pest problems

affecting the productivity of the land (Weber *et al.*, 1996).

There are some socio-economic constraints to the expansion of the maize-based cropping system. The structural adjustment reforms introduced in the country in the mid-eighties has led to an increase in fertilizer/grain price ratios in spite of the 80 percent subsidy on fertilizers. Fertilizers have become very expensive and most farmers who cannot purchase them abandon maize production for sorghum which is adapted to poor soils and relatively non-responsive to nitrogen fertilization. In order to sustain the maize-based system, strategies are therefore required for efficient use of native nitrogen and for a judicious application of inorganic nitrogen.

This review is in two parts. The first part discusses management strategies for the use of native soil nitrogen and development of organic input nitrogen from legume-based technology with emphasis on N-cycle, organic matter and mineral N dynamics. The second part focuses on nitrogen requirement of maize, response of maize to N fertilization, and variety differences in N-use efficiency, mechanisms and also indicators of N-use efficiency.

2.2. NITROGEN CYCLE IN SOIL

The pathways of nitrogen movement in plants, animals, soil and in nature which are inter-related to form a cycle of event is known as nitrogen cycle. The major focus however, will be on internal nitrogen cycle that is operative in soil, and distinct from the overall cycle of nitrogen in nature, but which interfaces with it (Fig. 2.01). The internal nitrogen cycle also referred to as nitrogen cycle in soil, has two components: gains in soil nitrogen and losses from the soil.

The gains in soil nitrogen occur through biological nitrogen fixation (NF), from synthetic fertilizers and from return of nitrate (NO_3) and ammonium

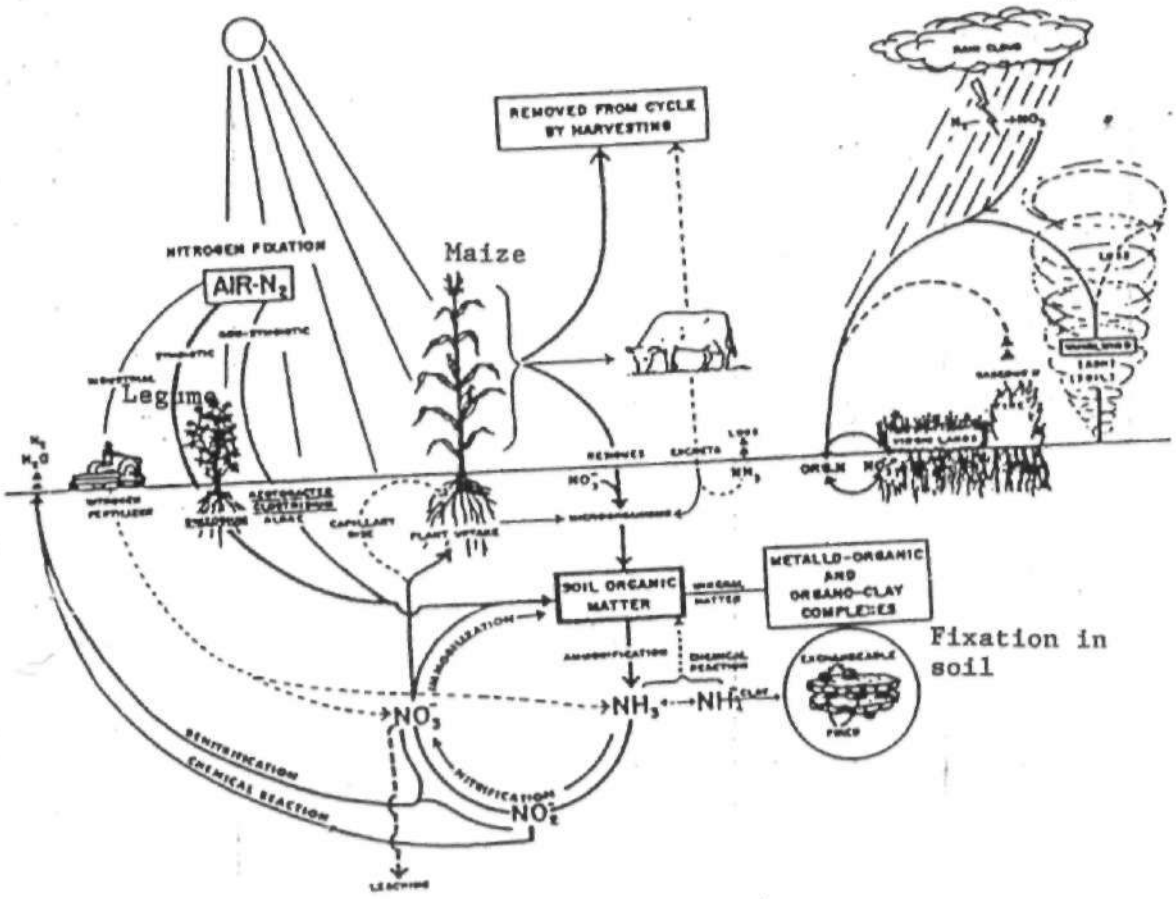


Fig.2.01: The nitrogen cycle in soil (Courtesy of Frank J. Stevenson, 1965).

(NH_4) in rain water. The latter is very insignificant and will not form part of this review. Losses occur through plant uptake and consumption of plant products by animals, although part of this is later returned to the soil through organic matter when plants or animals die. Losses also occur through leaching and volatilization. Regardless of the ways N may be added to the soil it often undergoes many transformations before it is removed.

A good understanding of these transformation processes will facilitate adequate management of agricultural inputs in order to sustain the maize-based cropping systems of the Northern Guinea Savanna.

2.3. SOIL ORGANIC MATTER DYNAMICS

Soil organic matter refers to the partial or complete transformation of organic inputs in the soil, and it is located below the surface (Fernandes and Sanchez, 1990). Fernandes and Sanchez (1990) defined organic inputs as the above-and the below-ground litter, crop residues, mulches, green manures and animal manures, which constitute an external source of nutrients and organic carbon. Soil organic matter (SOM) plays a significant role in chemical, physical, and micro biological aspects of soil fertility and productivity (Allison, 1973).

2.3.1. Importance of Soil Organic Matter in Soil Fertility and Productivity

The importance of SOM lies more on its potential benefits to soil productivity. Below are some of the potential benefits:

(i) SOM serves as a major reservoir or source of inorganic nutrients for plants. During its oxidation, N, P, and S are released which may become plant available during the growing season of crops. Details on the release of N has been discussed under section 2.4.

(ii) SOM is a substrate for the growth of microorganisms.

(iii) It serves as an ion - exchange material, chelating agent and buffer. Pichot (1975)

pointed out that in tropical soils, particularly savanna soils where clay fraction is dominated by kaolinite and Fe and Al oxides and hydroxides, SOM content is a major factor influencing cation exchange capacity (CEC). This conclusion could be based on results from various studies conducted in West and Central Africa in which significant positive correlations were observed between organic matter content and CEC (de Ridder and van Keulen, 1990). The complexing of Al by SOM reduces exchangeable Al levels which is very important in alleviating Al toxicity, a common problem in oxisols and ultisols. The strong complexation of SOM with Al and Fe could probably be the reason why the oxisols and ultisols have good physical structure (Coleman *et al.*, 1989).

(iv) SOM is a factor in soil aggregation thereby maintaining soil structural stability. The improvement in structural stability of the soil occurs because the biological agents in the SOM increase both the degree of aggregation of the primary mineral particles and the strength of the bonds between the mineral particles.

(v) SOM serves as a factor in plant disease control. The amount and type of organic matter in soils plays a role in the extent to which a crop is affected by certain plant diseases which are caused by fungi, bacteria, actinomycetes, viruses, nematodes, and in some cases parasitic weeds. The energy source of soil borne pathogens mostly comes from their hosts, organic matter in the soil, or sometimes from both living and dead tissues. When SOM serves as a direct source of food for the disease organism, it may increase the disease organism, and, if it increases the growth of the competing organisms, it may suppress the disease, while if it acts as a source of nutrients for the host, the host may grow and build up a resistance to the disease organism.

(vi) It plays a role in pesticide movement via runoff, soil erosion and leaching thereby reducing environmental pollution. SOM directly influences soil adsorption of pesticides.

On application of pesticides to such soil, the downward percolation and leaching of the

soluble pesticides are reduced, while the structural stability reduces erosion and loss of particles of pesticides in runoff.

(vii) Application of organic inputs increases SOM which leads to increases in water holding

capacity and structural stability of the soil.

2.3.2. Constituents of Soil Organic Matter

In a recent review, Wallace (1994) divided SOM into five different fractions; two representing litter and the others representing materials fully incorporated into the soil, thus:

(i) The structural litter fraction

This consists of fragments of straw, wood, stems and related plant parts. It has a turnover time of about three years. The C:N ratio varies around 150:1. Products are high in lignin, and decompose rather slowly with loss of carbon dioxide and usually with microbial uptake of mineral-nitrogen (immobilization).

(ii) The metabolic litter fraction

It comprises particles of leaves, bark, flowers, fruit and animal manure. The turnover time is short, about one-half year or even less. C:N ratios range from 10:1 - 25:1. These products decompose with loss of carbon dioxide and become incorporated in other fractions with more narrower C:N ratios. The transformation requires that most of the residual organics become part of the bodies of microorganisms, which is discussed in the next fraction. On decomposition of this fraction there is a loss of carbon dioxide and mineral nitrogen is given up as explained in section 2.4. Most annual legume residues fall within this fraction.

(iii) The active soil fraction

This consists of microbial bodies living or dead and their metabolites. It has an average turnover time of 1.5 years. The C:N ratio is around 5-15:1. This fraction receives N from other pools and also gives up mineral - N. It is often said to give life

to the soil. Swain (1992) reported that about 5g of soil may contain as many as five billion bacteria, 20 million of various fungi, one million protozoa, and even some larger organisms. The microbes within this ecosystem variously function to create better soil and to keep in balance other organisms that could destroy crops. The living microbes build their bodies mostly from either the stable soil organic matter or from non-stable organic matter in soil.

(iv) The slow or decomposable soil fraction

This fraction is much like a mature compost. It has a turnover time of about 2.5 years and C:N ratio of 10:1 to 20:1. Composts have C:N ratios around 20:1. They have been made more or less stable due to long period of biological digestion. The digestion process will continue in the soil because the ratio is higher than that of the stable SOM and will continue until the ratio of 10:1 is reached. This is the fraction of SOM that readily decomposes with cultivation of soil and cropping to release its N that can be used by the crops. The fraction has a considerable influence on favourable physical properties of soil.

(v) The passive soil organic fraction

This is the highly stable recalcitrant organic matter with turnover time of around 1,000 years. It has a C:N ratio of 7:1 to 9:1 with fairly well defined characteristics. Paustian *et al.* (1992) reported that this fraction is resistant to oxidation even after the slow fraction has been depleted. It is not readily in dynamic equilibrium with other organics in soil, but it can be added to and taken from, and some microbes can use it as a source of energy. It can be replenished from both the active and slow fractions. It has a fairly constant C:S but not C:P ratio. The fraction has a function analogous to cement which binds with soil particles, and mostly bridges with calcium.

2.3.3. Break Down of Soil Organic Matter and Organic Inputs

2.3.3.1. Mineralization/immobilization of SOM and organic inputs

The conversion of organic complexes to inorganic state brought about by the activities of micro-organisms is referred to as mineralization. Some of the products of mineralization particularly ammonium (NH_4+) is incorporated into the cells of the micro-organisms in a process known as immobilization. Details of these processes have been discussed under mineral nitrogen dynamics in section 2.4.

2.3.3.2. Modeling SOM dynamics in soil

Due to the absence of correlation between total SOM and crop growth or soil productivity, the various fractions/pools of organic matter discussed above have been used to simulate changes in SOM as a result of addition of organic inputs in various agricultural systems. Many models have been used for these simulations, but of particular note is the CENTURY MODEL developed by Parton *et al.* (1987). This model incorporates most of the recent improvement in the understanding of SOM dynamics and the interaction of C, N, P and S in soil-plant systems (Swift, 1987). Detailed description of the model has been presented by Coleman *et al.*, (1989). Modeling SOM will not form part of the present study.

Due to the important role SOM plays in soil fertility and productivity and considering the fragile nature, and low organic matter content of savanna soils (Jones 1976), there is an urgent need for proper residue management. One option is through integration of legumes into the farming system, which will supply organic matter in addition to nutrients from the residues. This is further discussed in section 2.5.

2.4. MINERAL-NITROGEN DYNAMICS

Mineral nitrogen also referred to as available soil N, is the summation of ammonium and nitrate ions in the soil derived from the process of mineralization. During mineralization, soil organic nitrogen is broken down to release amino-N through a

process known as proteolysis or aminization by the activity of heterotrophic organisms. Amino-N is further reduced to NH_4^+ by the process of ammonification brought about by general purpose organisms - bacteria, fungi and actynomycetes. Part of the ammonia is absorbed directly by higher plants, some amount is fixed by clay minerals in the soil, some is immobilized by the micro-organisms and small proportion is lost to the atmosphere through volatilization (Fig. 2.01). A major proportion of the NH_4^+ is converted to nitrate in a two-phase reaction known as nitrification, by the activity of autotrophic soil bacteria. In the first phase NH_4^+ is converted to nitrite by nitrosomonas (bacteria). The reaction is represented thus:

$$2\,NH_4^+ + 3O_2 \xrightarrow{\text{Nitrosomonas}} 2\,NO_2 + 2H_2O + 4H^+ + \text{Energy}$$

ammonia oxygen nitrite water hydrogen ion

The second phase involves the conversion of nitrite to nitrate by nitrobacter. The reaction is as follows:

$$2\,NO_2 + O_2 \xrightarrow{\text{Nitrobacter}} 2NO_3^- + \text{Energy}$$

nitrite oxygen nitrate

The nitrification process is more rapid in neutral to slightly acid soil condition under which these bacteria thrive best.

2.4.1. Mineral-N Flush

The increase in available soil N in the surface soil at the commencement of the wet season is referred to as mineral-N flush. This phenomenon has been widely reported in tropical soils (Greenland, 1958; Birch, 1958; 1960). Several factors may contribute to N flush following rewetting of dry soil. A significant proportion of soil microorganisms can die during drying of the soil (van Gestel *et al.*, 1991) and rewetting soil (Kieft *et al.* 1987), and the dead microbial cells available for

decomposition may cause part of the N flush (Marumoto *et al.*, 1977). The boost in microbial population that develops after rewetting of dry soil can also be responsible for part of the N flush (Birch, 1958). Furthermore, N flush may also be explained by an increase in the availability of organic substrates through desorption from soil surfaces (Seneviratne and Wild 1985), and through an increase in organic surfaces exposed (Birch, 1960). Wild (1972) in on-station studies conducted in Samaru, Zaria also observed high nitrogen flush in the top soil caused by the moistening of soil after the dry season. The real value of this mineral-N is not well known in the savanna (Ahmad, 1985), and hence has not been considered in formulating fertilizer recommendations for crop production.

In Germany for instance, nitrogen fertilizer requirement of crops is based on a method referred to as "the N_{min}-method" (Wehrmann and Scharpf, 1986). It involves measuring the quantity of mineral nitrogen in the rootable soil layer of a particular crop at the time of fertilizer application (N_{min}-supply). The N fertilizer rate to be applied is calculated as the difference between optimum N quantity and N_{min}-supply of the soil. Wehrmann and Scharpf (1986) gave the advantages of "the N_{min} -method" to include high yield at the lowest possible fertilizer rates, high quality products example, low nitrate content in vegetables, and minimum nitrate leaching into ground water. To adopt this method for programming fertilizer requirement for the savanna soils, detailed investigation of the pattern of mineral N release, particularly on farmers' fields and simple tools for quick determination are required.

In recent studies covering 57 farmers' fields in the Northern Guinea Savanna, Weber *et al.* (1995c) found that differences in nitrate-nitrogen availability between fields were at least five-fold and often 10-fold differences in absolute terms, independent of the fertilizer rates applied by the farmers. Four patterns of N release were identified (Fig. 2.02). Temporal differences were observed, the first pattern (FG 4) consists of fields with high nitrate release at 0-5 weeks after planting (WAP) with a

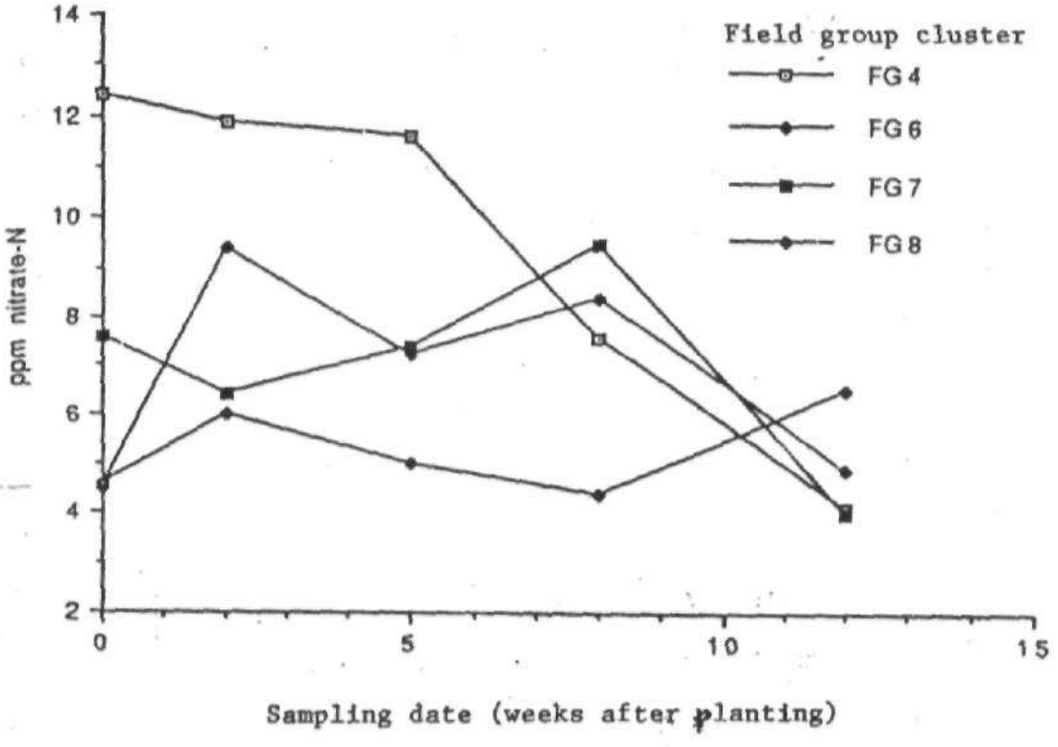


Fig.2.02: Patterns of nitrate N concentrations over the seasons at 0-30 cm soil depth in four field groups formed through clustering 35 farmers field. From Weber et al, (1995c).

subsequent decline at 8-12 WAP. The second and third group (FG 6 and FG 7) have fields with delayed N-peak at 2-8 and 5-8 WAP, respectively. The last pattern (FG 8) showed fields which maintained low nitrate-N all through the season. Maize grain yield was found to be positively correlated with nitrate-N release in the soil, although no correlation between nitrate-N and soil organic matter or total soil nitrogen content was found.

The first and last patterns of nitrate-N release will form the major thrust of the present study. Appropriate legume-based technology is required to save N or to enrich the soil with N based on these patterns of nitrate-N release. This has been discussed in detail under the benefits of legume-N to cereal-based cropping systems, section 2.5.2. Also, N using technology such as N-efficient maize could best be targeted into the low-input systems taking advantage of these soil-inherent nitrate releasing patterns existing on farmers' fields, but it could also be used on fertile fields. This is further discussed in section 2.6.

Different simulation models exist that describe N dynamics in soil. These have been well reviewed by Frissel and van Veen (1981); Haith (1982). Modeling N dynamics or validation of existing models will not form part of this study.

2.5. LEGUME INTEGRATION INTO CEREAL-BASED SYSTEMS

Legumes play a major role in farming systems because in addition to being a good source of protein, they provide an alternative and inexpensive source of nitrogen for soil fertility maintenance, and dry or green matter for soil conservation and weed suppression (Muyinda *et al.*, 1988; Kang, 1992; Danso, 1992; COMBS, 1993). Legumes can fulfill a major part of their N requirement through N_2 fixation, and contribute N to the soil and the companion or subsequent crops.

2.5.1. Biological Nitrogen Fixation

This is a major input of N to the soil. It is the conversion of dinitrogen (N_2) from the soil air to ammonia by micro-organisms. The process could be non-symbiotic or symbiotic. In non-symbiotic or free fixation, some specific micro-organisms exist independently in soil and in the presence of moisture convert N_2 into body tissue nitrogen forms. When they die and decompose, the nitrogen is released for plant uptake. However, the amount of N fixed by this process is very small. Miller and Donahue (1990) gave an average range of 5-8 kg ha^{-1} $year^{-1}$. It therefore, plays very little role in agriculture.

In symbiotic fixation, bacteria from *Bradyrhizobium* and *Rhizobium* genera, and actinomycetes (fungi) cause the formation of root nodules in leguminous plants and then inhabit the nodules where they fix nitrogen by symbiosis with the legumes and obtain their carbohydrates need from their host. The amount of N fixed by these microorganisms vary greatly with the rhizobial strains, the legume species and the fertility level of the soil among others.

Grain legumes for instance, fix large amounts of N_2. Danso (1992) showed that out of the six grain legumes examined, faba beans (*Vicia faba*) had, on the average, the highest nitrogen fixation capacity, while phaseolus beans (*Phaseolus vulgaris*) had the least. Whereas faba beans derived about 70 percent of its N from N_2 fixation, cowpea and soybean derived about 50 percent of their N and phaseolus beans only about 25 percent of its N from fixation. Giller and Wilson (1991) gave estimates of N_2 fixation for soybean and cowpea in the tropics ranging from 26-188 kg ha^{-1} and 9-201 kg ha^{-1}.

In soybean, the amount of N_2 fixed is determined by plant growth duration, vigour, nodulation, physiology of N_2 fixation and soil or fertilizer N use (Giller and Wilson, 1991). The long duration soybean would therefore, fix more N_2 than the short duration cultivars. Similarly, Eaglesham *et al.* (1982) found that N_2 fixation by

cowpea increased in the order of: determinate < semi-determinate < indeterminate.

Under conditions of high soil fertility, legumes may utilize mineral N in preference to forming nodules and fixing N_2 (Allos and Bartholomew, 1959). But when soil N is limiting starter-N may be applied to stimulate early growth, nodulation, and N fixation.

There is paucity of literature on the amount of N_2 fixed by annual fodder legumes in the tropics. However, whatever amount of N_2 fixed by legumes the benefits to the farming systems would largely depend on how their residues are managed either in intercropping or in sequential (rotation) cropping.

2.5.2. Benefits of Legumes to the Farming Systems

2.5.2.1. Nitrogen benefit to non-legumes in intercrop

Legumes can supply N to cereal through current transfer of N by excretion to the associated non-legume (cereal) in intercropping system. There are conflicting reports however, on the N benefit to the cereal crop in this system. Some greenhouse and field studies have shown possible N excretion by the inter cropped legume which benefited the cereal particularly under low soil mineral N (Agboola and Fayemi, 1972; Eaglesham *et al.*, 1981; Patra *et al.* 1986). However, Eaglesham *et al.* (1981) stressed that this process of N excretion is difficult to demonstrate and the conditions conducive for significant N transfer are also difficult to adequately define. Some of the benefits of inter cropped legumes to the non-legume (cereal) have also been attributed to the sparing effect of the legumes on the availability of N for the associated crop (Henzell and Vallis, 1977). They explained that the nodulated legume will usually take up N less rapidly from the soil than the non-nodulated plants, and therefore in a given planted area, a cereal intercrop will have access to a larger pool of N than when grown as a sole-crop. The depletion of mineral N by the inter cropped cereal would also enhance the rate of N fixation by the legumes.

Most other results on intercropping have been summarised by Kang (1982) as follows:

i. When N was not applied, the yields of sole and inter cropped cereal were similar. This gives little support to the speculation that grain legumes in intercropping might benefit the associated cereal during the growing season.

ii. Intercropping tended to reduce the yield and N uptake of legumes, particularly with increased N rates;

iii. Sole and inter cropped cereal responded similarly to applied N; and

iv. Land equivalent ratios decreased with increased N rates.

A multilocational study by Ahmed and Rao (1982) showed that the yield advantage of maize/soybean intercropping varied with N fertilizer level, ranging from 64 percent at zero N rate to 42 percent at 100 percent of the recommended rate (50-120 kg ha^{-1}) of N applied to maize. They concluded that intercropping seemed particularly suited for subsistence farmers who use little or no fertilizers.

2.5.2.2. Nitrogen benefit to non-legumes in sequential (rotation) cropping

The highest N benefit to non-legumes is derived from residual N supply. Nitrogen fixed by the legume integrated into the system as a relay intercrop or in sequential (rotation) cropping is available to the non-legume after senescence of the legume and the decomposition of its residues. The potential N available to the cereal under rotation system depends mainly on:

(a) the total amount of N fixed and accumulated in the legume residues left in the field after harvest;

(b) the quality of the residues;

(c) soil inherent characteristics.

(a) Total amount of N fixed and accumulated in residues after harvest.

The potential N contributed to a succeeding crop can be estimated from the total N content of the legume, the N removed in the harvest and the percent of total N which is derived from atmospheric N_2 fixation (% Ndfa) usually from ^{15}N dilution technique. Large amounts of N may be derived from legume - *Rhizobium* symbiosis, but if the legume is grown for grains most of the N may be sequestered to the grains and exported out of the field (high nitrogen harvest index-NHI). This will leave little N in the residues left on the field for the subsequent crop. When the product of % Ndfa and the total N content of the legume is greater than NHI, the legume will contribute N to the soil and a subsequent crop. But when NHI is greater than the total N content derived from atmospheric N_2 fixation, soil N will be depleted by the legume and very little N will be contributed to a succeeding non-legume crop. Also, if the legume is grown for fodder all the residues may be exported from the field leaving only leaf and root litter.

(b) The quality of residues

The potential N availability to the soil and subsequent non-legume depends also on the rate of release of N from the residues. This is governed by the quality of the legume residues left on the field after harvest. There is a general consensus that net N release (mineralization) occurs if the N concentration of the residues is above a critical value of 15-25 g kg^{-1} and immobilization occurs below this concentration (Stevenson 1986), and the lower the C/N ratio the more rapidly mineral N will be released from the soil, so long as lignin and polyphenol contents are low (Allison, 1973; Pieri, 1990; Tian *et al.*, 1992). When legume residues contain high concentration of lignin or polyphenols, little release of N may take place in spite of having N concentration greater than the critical level (Mellilo *et al.*, 1982; Palm and Sanchez, 1991). Fox *et al.* (1990) compared N mineralization in six legumes on the basis of lignin, polyphenol and N contents in a 12-week greenhouse study. They found that two of the legumes, Fitzroy

Stylo (*Stylosanthes scabra* Vog., Var. *Fitzroy*) and round leaf Cassia (*Cassia rotundifolia* Pers., var. Wynn) which contained less than 20 g kg^{-1} of N (C:N ratio approximately 30:1) for the first six weeks of the study showed net immobilization. The lignin+ polyphenol: N ratio was a better predictor of N mineralization rates of the legume residues in their experiment.

Furthermore, the amount of N added to the soil from legumes will also, depend on the N content and mass of the legume roots. Considering the below ground legume residue quality, Nnadi and Balasubramanian (1978) compared root N content and transformation in five grain legumes in Samaru, Zaria and found higher root N content in Bambaranuts (*Vigna subterranea*) compared with the other legumes. Consequently faster mineralization of added root N was observed in this legume suggesting that it will add significant amounts of mineral N to the soil compared to the other legumes. Recently, Wardle and Greenfield (1991), reported that mineral N released from the nodules was not significantly related to the C/N ratio or organic N content of the nodules. However, it was strongly associated with concentration of NH_4-N and hexosamine-N in the nodules. The contribution of this factor still needs further research.

(c) Inherent soil characteristics

The potential available N from legume residues also depends on soil microbial activity. It will be higher in fields having inherently higher microbial population than in dormant fields, with low microbial activity. In a recent review, Wani *et al.* (1995) reported an increase in microbial biomass-carbon, microbial-nitrogen, and microbial activity in an agroecological eight-year rotation (AER) system compared with continuous barley (CB) system. Wani *et al.* (1991) had earlier observed that in the AER system containing fababeans and forage, mycorrhizal colonization of barley roots was increased as compared to a CB system. The increased mycorrhizal colonization was positively related to K, Ca, Mg, Zn, S and Fe in the legume rotations than in the barley

system (Wani *et al.*, 1995). However, not much has been done on the role of microbial activity on N availability following a legume rotation in the savanna.

Based on the factors discussed above, the potential availability of N in legume residues left in the field after harvest to a subsequent non-legume crop is variable. Wild (1972) and Jones (1974) found that the amounts of mineral N in Samaru top soils were higher after groundnuts than after cotton, cowpea or sorghum. Giri and De (1980) and Nnadi *et al.* (1981) estimated that groundnuts, bambaranuts and cowpea contributed 50-60 kg N ha^{-1} to subsequent pearl millet and sorghum crops. In Northern Ghana, Dakora *et al.* (1987) found that sole crops of groundnuts and cowpeas contributed approximately 60 kg N ha^{-1} to a subsequent maize crop. More recently, Horst and Hardter (1994) estimated a contribution of 80 kg N ha^{-1} from two crops of cowpea grown in the first year followed by a maize in the second year in Nyankpala, Ghana. However, Eaglesham *et al.* (1982) calculated very low N contribution of 0-25 kg N ha^{-1} from previous nitrogen fertilized soybean. A definite depletion of soil N was found in their studies when 100 kg N ha^{-1} was applied to the soybean.

Information is lacking on the contribution of forage legume rotation to available soil N. Most studies available are on forage legumes used as green manure (Carsky *et al.*, 1990; Lathwell,1990). The reported positive contribution of forage legumes to available soil nitrogen.

2.5.2.3. Benefits of legume rotation to other soil properties

In addition to the enhancement of available soil N, legume residues also influenced soil physical and chemical properties to the benefit of the subsequent non-legume crop. According to de Ridder and van Keulen (1990) the application of crop residues leads to higher water holding capacity, more favourable soil pH, higher organic C, total P, CEC, and base saturation. These benefits however, do not often manifest in the first year following a legume rotation. But some studies on short-term rotation have shown

better soil physical properties including bulk density, aggregate stability, buffering and water holding capacities, and infiltration rate in legume rotation system than in monocropping (Buresh and De Datta, 1991; Raimbault and Vyn, 1991; Latifi *et al.*, 1992; Horst and Hardter, 1994; Wani *et al.*, 1994). Improvement in soil biological characteristics has also been reported (Thomas, 1995).

2.5.2.4. Pest and disease control benefits of legumes in rotation

Legume rotations break the cycles of cereal pests and diseases, and the allelopathic and phytotoxic effects of different crop residues. Francis and Clegg (1990) summarized the effect of crop rotation on pest pressure thus, "the greater the differences between crops in a rotation sequence, the better cultural control of pests can be expected". Crop rotation is an effective tool for control of certain pests. For instance, crop rotation using non-host such as soybean and *Aeschynomene histrix* (fodder legume) was found to reduce the incidence and severity of *Striga hermonthica* (Del.) Benth., a parasitic weed of cereal and the severity of cereal nematodes in the NGS of Nigeria (Weber *et al.*, 1995a; Weber *et al.*, 1995d).

However, legume rotation does not control all pests and diseases. For example, Johanson *et al.* (1984) reported a more severe problem of black cutworms (*Agrotis ipsilon*) when maize was rotated with either wheat or soybean than in maize monocrop.

Furthermore, phytotoxic (allelopathic) substances such as phenolics are released during the decomposition of maize crop-residues (Yankle and Cruse, 1984; Martin *et al.*, 1990; Horst and Hardter, 1994). The persistence of these substances in the soil has been shown to have more deleterious effects on maize in a monocrop system than in legume rotation system (Hardter *et al.*, 1991). However, some other studies have shown that substances produced during decomposition of maize residues are not toxic to maize in monocrop system (Breakwell and Turco, 1989).

2.5.2.5. Dry matter and nitrogen accumulation in cereal succeeding legumes in rotation

Higher dry matter and nitrogen accumulation in cereal have been associated with legume rotation than monocropping (Jones, 1974; Giri and De, 1980); Ner *et al.*, 1981; Dakora *et al.*, 1987; Horst and Hardter, 1994; Carsky and Berner, 1995). This positive effect on dry matter and N accumulation was explained in terms of N release from the legume residues, improvement on soil properties and better pest and disease control.

As discussed in section 2.5.2.2a, when the crop is harvested for grain or forage, only small proportions of fixed N_2 is returned to the soil; nevertheless, the additional earnings from the harvest are often higher than the cost of replacing the N with chemical fertilizers because of the additional benefits not related to legume N, called rotation effects (Parè *et al.*, 1992). In terms of yield, the total rotation effect is the yield differential under zero-N, the rotation effect is yield differential at the highest N rate, while the N-rotation effect is the total minus the rotation effect.

The uptake of N by the non-legume in a legume rotation system can be optimized when the release of N from the above-ground and roots of legume residues is synchronized with the non-legume growth demands (Swift, 1987). That is, a concurrence in time, when the rate of release of available soil N from the legume residues is closely related to the rate at which it is demanded by the non-legume crop. Factors affecting this synchronization have been discussed in section 2.5.2.2.

Low use efficiency of legume N by cereal has been reported (Peoples *et al.*, 1995). Some legume residues because of their low litter quality (low N, high lignin and/or polyphenol content) may release available soil N more slowly than is demanded by the succeeding cereal and consequently lead to N deficiency in the cereal (Swift, 1987). While some other legumes with high-litter quality (high N, low lignin and polyphenol content) may release N more rapidly in excess of N demand by the

succeeding cereal, resulting in N being lost from the system through leaching or denitrification. This can reduce the use efficiency of the legume N.

In the high-quality litter scenario, synchrony could be achieved by rotating the legume with cereal having rapid root development early in the season (example, maize) to capture the N release before it is lost from the system. Better synchrony could also be achieved by integrating such high-quality legume residues into fields with low inherent N releasing pattern described in section 2.4.1, and by growing an N-use efficient maize genotype. Similarly, better synchrony can be accomplished by integrating low-quality legume residues into fields with high inherent N releasing pattern also described in section 2.4.1.

In the savanna of Nigeria, it is a common practice for farmers to remove the above ground residues from the field as fodder (examples, groundnuts and cowpeas) or in the grain harvesting process (example, soybean). It is not known under such conditions how much available soil N is contributed by a sole crop of legume to a succeeding cereal crop. And how best legumes should be integrated in the farming system. The present study will address this gap.

In conclusion therefore, strategies are required to develop a sustainable legume-based technology for the low-input farmers of the NGS. These strategies should combine the quality of legume residues with soil N release characteristics in combination with N-use efficient maize cultivars considering that farmers remove residues from their fields.

2.6. NITROGEN REQUIREMENT OF MAIZE

Crop nitrogen requirement is the minimum crop N uptake required to obtain maximum yield. It is used in the determination of N fertilizer need of a crop. The N requirement of maize for instance, can be measured by investigating maize yields at different levels of N fertilization, and/ or by determining the correlation between tissue N

concentration or N content and maize yield performance. Often crops which produce large amounts of dry matter require more N than those producing less dry matter. This means that the potential dry matter production is an important factor in determining the N need of a given crop.

Another important factor is the internal crop N requirement, defined as the N concentration in the total above-ground dry matter at near maximum yield (Liu, 1991). The N concentration in the crop tissue is only slightly affected by the N supply, and remains fairly stable over a wide range of environmental and cultural conditions (Binford *et al.*,1990). It is essential therefore, to maintain an adequate concentration of N in the photosynthetic organs in order to obtain high dry matter production.

Based on these two factors, the N requirement can be estimated. A multiplication of the internal crop N concentration with dry matter will give an estimate of how much N the crop will need to produce a given yield. For instance, assuming a maize crop will yield 5000 kg ha^{-1}, and assuming the harvest index (HI) is 0.5, the total above-ground dry matter production can therefore, be estimated as 10000 kg ha^{-1}. If for instance, the N concentration of the above-ground tissue is 30mg g^{-1}, the N requirement of the maize crop will be 300 kg ha^{-1}. Part of this amount will come from soil mineral N and the other part from input N. Of all the known approaches/methods, nitrogen fertilizer requirement can best be estimated from N response curve, and is dependent on the soil productivity of the field.

2.6.1 Response of Maize to N Fertilization in NGS

Maize responds well to soil fertility especially to high N availability (Jones and Wild, 1975), probably because of its shorter growth period and hence greater intensity of nutrient demand (Stockinger, 1971). Early fertilizer work on maize gave a recommended rate of 66 kg N

ha^{-1} as optimal for an expected average yield of about 2.0-2.8 t ha^{-1} grain

(i.e., 30-42 kg grain kg N^{-1}) in the NGS (Goldworthy, 1967). Jones (1972) tested

three rates of N applied as Calcium Ammonium Nitrate (CAN) and found that the responses of maize were generally high and significant to rates of 56 kg and 112 kg N ha^{-1}; and on the average, these rates increased yields by 2.0 and 1.0 t ha^{-1}, respectively. Higher application rates resulted in further increases of only 0.6t grain ha^{-1}. With intensification of cultivation, development of improved varieties, improved management practices and skills over the years, greater responses to N fertilizers and much higher yields than hitherto have been achieved (Lombin, 1987).

The current N fertilizer recommendation for the NGS therefore, is 120 kg N ha^{-1} for open pollinated (OP) maize and 150 kg N ha^{-1} for hybrid; with grain yields ranging from 3.5-5.0 t ha^{-1} for OP and an average of 5.0 t ha^{-1} for hybrid, under adequate P and K (Enwezor *et al.*, 1989). This gives grain/N ratio of 29-42 for OP and 33 for hybrid.

This grain to N ratio is quite low considering that maize in the NGS has a potential to yield 7-8 t ha^{-1} grains. The grain/N ratio is even lower under farmers conditions. Farmers' maize yields vary widely between 0.2- 2.0 t ha^{-1} (Enwezor *et al.*, 1989). And N fertilizer rates also vary widely from 85 to over 200 kg ha^{-1} (Lekan, 1992, unpublished HND thesis). The grain/N ratio is currently very low. There is therefore, a need to improve on the grain to N ratio of maize in the NGS.

In general, maize response to nitrogen fertilizer shows that grain yield at first increases linearly with N and further additional increase in N gives only a smaller increase in yield (declining rate of return) until a maximum yield is attained, beyond which yield declines. However, it is theoretically known that economic efficiency is attained at a lower rate than the optimum N. In a recent study Smith *et al.*, (in press), hypothesized that maximum yield advantage in hybrid maize is attained at a moderate rate of 50-60 kg ha^{-1} as opposed to recommended rate of 120 kg ha^{-1}. This can best be achieved at the small holder level by improving nitrogen use efficiency in maize.

2.7 NITROGEN USE EFFICIENCY DEFINED

Nitrogen use efficiency (NUE) can be defined in many ways. For cereal crops it is often defined as grain production per unit of N available in the soil (Moll *et al.*, 1982; Kamprath *et al.*, 1982). And an N efficient genotype can be characterized in accordance with Graham (1984) as a genotype that is capable of realizing a yield above average under conditions of sub optimal N supply. Often because of the difficulties in measuring N that is available for crop use in the soil , NUE is usually presented in terms of the amount of N fertilizer supplied to the crop. In this case, the term fertilizer N use efficiency or agronomic efficiency is applied. It is defined as yield per unit of N fertilizer applied.

There are two primary components of NUE. The efficiency of absorbing N from the soil, known as N uptake efficiency, and the efficiency with which the N absorbed is utilized to produce yield, referred to as utilization efficiency. The corresponding terms when dealing with fertilizer N use efficiency, suggested by Bock (1984) are recovery efficiency and physiological efficiency.

Crop species respond differently to soil and fertilizer N (Sinclair and de Wit, 1975). These differences could be seen even in different cultivars of the same crop species (Messmer *et al.*, 1984). Moll *et al.*, (1982) reported that when N supply was high, variation in the NUE of maize hybrids was due mainly to variation in N uptake efficiency, but at a low N supply differences were due mainly to variation in the utilization of N. It is therefore necessary to consider varietal responses to N regimes when seeking cultivars with a high NUE. It may also be important to identify which of the components best contribute to NUE of tropical maize under the savanna conditions.

2.8. VARIETAL DIFFERENCES IN N UPTAKE AND UTILIZATION EFFICIENCIES

Genotypic variation exists in the efficiency of maize to absorb nutrients from the soil. This variation could be explained on the basis of the mechanisms of absorption. Baligar and Duncan (1990) in their review identified three mechanisms in N uptake, namely physiological, morphological and biological. In this review, emphasis will be on differences in root morphological characteristics in relation to soil nitrate utilization by maize and how this could be influenced by N application.

2.8.1. Differences in root morphological characteristics in relation to N uptake efficiency

Root length density defined as root length per unit volume of soil is a major factor in the acquisition of nutrients from the soil (Robinson, 1986). According to Wiesler and Horst (1994a), a wide range of variation in root length density can influence N absorption in maize. In field experiments, Wiesler and Horst (1992 and 1994a) found significant differences in root length density at various soil horizons. They also found close positive correlations between genetic variation in root length densities and nitrate depletion in the subsoil, and a negative correlation with nitrate depletion in the surface 0-30 cm soil layer. Earlier studies of Mackay and Barber (1986) however, indicated that maize cultivars may differ in root length exclusively in the top soil. In sorghum, Jordan and Miller (1980) reported significant differences in root length density between cultivars below 100 cm soil depth. Wiesler and Horst (1994a) showed that cultivar differences were relatively largest in soil layers between 0.60-1.20 m depth. The increased root growth in this zone was found to have a marked effect on nitrate utilization (Wiesler and Horst, 1994b). In an earlier work, they reported a significant negative correlation between root length density in the subsoil and NO_3^- leaching in suction probes under maize (Wiesler and Horst, 1993). This may imply that nitrate uptake efficiency and the ability of a maize genotype to minimize ground water

pollution by nitrate would largely depend on its ability to develop a deep root system to extract nitrate from deeper soil layers later in the season (Greenwood, 1986).

A better understanding of the relationship between shoot and root characteristics may facilitate the identification of cultivars with superior root development (Wiesler and Horst, 1994a). However, literature on this relationship is not conclusive. MacKey (1973) found a close relationship between shoot biomass and rooting depth, while Saddiq *et al.* (1990) reported a significant positive relationship between shoot biomass and root dry matter. In their studies, Wiesler and Horst (1994a) found a positive association between vegetative yield of maize cultivars used in their experiment with total root length in one of the years. In another year, the relationship was negative. This suggests that shoot/root relationship may be site and year specific. The nature of the relationship under savanna soil conditions is not known.

Another important parameter that has been used to differentiate cultivars in nutrient uptake efficiency is the root diameter. Due to the difficulties in measuring root diameter, it is often expressed in terms of specific root length, defined as root length per unit root weight. It is based on the assumption that fine root systems (small diameter) will have lower dry weight compared with roots of bigger diameter. Cultivars with fine root system or higher specific root length will have a larger surface area and per unit length a larger soil volume which will supply nutrients to the root, and this will increase the uptake rate (Sattelmacher *et al.*, 1994). Large genetic differences in specific root length between cultivars have been reported in field and pot experiments (Fitter, 1991; Sattelmacher *et al.*, 1994). Sattelmacher *et al.* (1994) showed that specific root length was generally higher at limited P supply than when P was not limiting. They found that this larger specific root length contributed to a higher P-use efficiency in wheat. This may be applicable to N. The identification of a maize cultivar with a large specific root length early in the growth of the crop may

enhance uptake of mineral N released early in the season before it is leached to the subsoil.

Nitrogen availability affects root development in maize. Increase in N supply has been reported to increase root length and root biomass in maize especially in the zone of application (Maizlish *et al.*, 1980; Granato and Raper, 1989; Durieux *et al.*, 1994). Some other studies have shown a reduction in root surface area due to increased N supply (Barber, 1979; Fusseder, 1984; Feil *et al.*, 1990). The reduction is based mainly on partitioning of dry matter within the plant. At low N a higher proportion of dry matter is allocated to the root system, while at high N supply greater dry matter is allocated to the shoot at the expense of the root system (Sattlemacher *et al.*, 1994). There may be an optimal N rate that will give a balance in shoot and root development.

2.8.2 Nitrogen Utilization Efficiency

There are two aspects of N utilization efficiency: partitioning of N within the plant and utilization at the cellular level (Sattelmacher *et al.*, 1994). This discussion will centre on the former. Some indicators of N utilization efficiency will also be highlighted.

2.8.2.1 Partitioning of N within the plant

The partitioning of N towards the harvested organs (grains) is expressed as nitrogen harvest index (NHI). Genotypic variation exists in NHI. Also, there is a positive correlation between NHI and soil fertility (Sattelmacher *et al.*, 1994). This implies that under the conditions were soil fertility is relatively high, selection of cultivars for high NHI could be used to increase N utilization efficiency. An alternative approach to increase N utilization efficiency could be through selecting cultivars with a low N concentration in the harvested organs (Lippsett, 1964). This has its demerits. Low N concentration in the organs would mean a reduction in the nutritive value of the crop. Moreover, low N concentration in the seeds can impede early seedling establishment (Sattelmacher *et al.*, 1994).

2.8.2.2 Indicators of N utilization efficiency.

Since the emphasis is on identifying cultivars that can realize yield above average under a sub optimal N supply, indicators of N utilization under low N will be addressed. The major indicators include:

(a) Preservation of photosynthetic longevity

During the reproductive growth of maize, there are two sources of N, from the vegetative tissues and the concurrently absorbed N from the soil (Ta and Weiland, 1992). Under low N fertility, available soil N would be in short supply at grain-filling period. Therefore, the remobilization of N from the vegetative tissue will be more important for kernel growth. Since the leaves provide photosynthates for plant metabolism and kernel growth, delayed remobilization of N from the stalk and root tissues can preserve photosynthetic longevity, a characteristic also known as 'stay-green', thus resulting in higher yield (Ta and Weiland, 1992; Lafitte and Edmeades, 1994). Grain yield under low N has been positively associated with the duration of grain- filling (Muchow, 1988b). Duration of grain-filling depends in part on delayed foliar senescence and the maintenance of a healthy green leaf area- 'stay-green' characteristic (Wolfe *et al.*, 1988).

(b) Ability to absorb exogenous N after mid-silk stage

The special ability of a cultivar to absorb additional N from the soil after mid-silk stage is an important indicator for N utilization efficiency. Weiland (1989), Ta and Weiland (1992) showed that the later N is absorbed by maize during the growth period the more likely it would be translocated to the kernels. They concluded that early absorbed N becomes more a part of the structural system and less a part of the enzymatic/storage/mobilization pool.

(c) Kernel N sink capacity

Kernel N sink or the rate of zein synthesis in the kernel is a primary determinant of dry matter accumulation and grain yield in maize (Tsai *et al.*, 1984). And by measuring the

N sink accumulation rate as described by Tsai *et al.* (1984) , it is possible to determine the maximum yield potential of the cultivar. Kernel size is closely related to kernel N sink capacity.

(d) Other indicators

In correlation studies, Lafitte and Edmeades (1994) enumerated the following traits as important indicators of utilization of nitrogen under low N: ear-leaf chlorophyll concentration, ear-leaf area, plant height, anthesis-silking interval (ASI), and radiation use efficiency. All traits except ASI, have positive relationship with yield.

In conclusion, varietal differences exist in both N uptake and utilization efficiencies, two components of N use efficiency in maize. If a maize cultivar with improved root growth characteristics early in the season could be identified, it may capture the initial nitrate flush commonly experienced in the savanna soils. This will improve N uptake efficiency and reduced the amount of nitrate being leached to the subsoil. Also, if a cultivar with deep root systems later in the season to exploit the subsoil nitrate could be identified, it may improve N uptake and reduce environmental pollution of ground water. Furthermore, a maize cultivar with high efficiency to convert the absorbed N to grain formation, especially under low N, may discourage farmers from switching to sorghum production when they have little chemical N fertilizer. However, because some farmers have competing needs for maize stover as hay for their animals, improving N utilization efficiency would mean a reduction in the fodder value of the stover. Therefore, there is a need for integrating legumes into the system to increase the amount of N available, at the same time as introducing N-use efficient maize.

CHAPTER THREE

MATERIALS AND METHODS

Two field experiments were conducted on-station and on-farm in 1993 and 1994.

3.1 EXPERIMENT I - ON-STATION:

Response of Five Maize Culitivars plus One Sorghum Cultivar to Different Rates of Nitrogen Application.

3.1.1 Location and Climate

The experiment was conducted for two years in 1993 and 1994, at the experimental farm of the Institute of Agricultural Research (IAR), Samaru, Zaria. Samaru is located at an altitude of 686 m, 11^{o} 11'N and 7^{o} 38'E, in the Northern Guinea Savanna (Fig. 3.01). The Northern Guinea Savanna is characterized by a subhumid climate, covering about 50 percent of the land area of Nigeria. It has a monomodal rainfall of 800-1200 mm with mean of 1100 mm. It has a growing period varying between 150 and 180 days per year. The rainfall distribution at Samaru in 1993 and 1994 are presented in Fig. 3.02. The total rainfall was higher (1049 mm) in 1993 than in 1994 (909 mm), but was less uniformly distributed. There was a brief drought in the second decade of June in 1993. The rainy season ceased much earlier in 1993 than in 1994. The total rainfall in both years was below the long-term mean of 1100 mm. Description of the vegetation and geology of the sites is contained in Appendix 1.



Fig. 3.01: Nigeria: Location map of study area showing Samaru and Tsibiri villages.

Dynamics of soil nitrogen in cereal-based cropping systems of the Savanna (S. O. Oikeh)
Resource Information System, Agroecological Studies, IITA, FAX:(INMARSAT) 874 177 2276

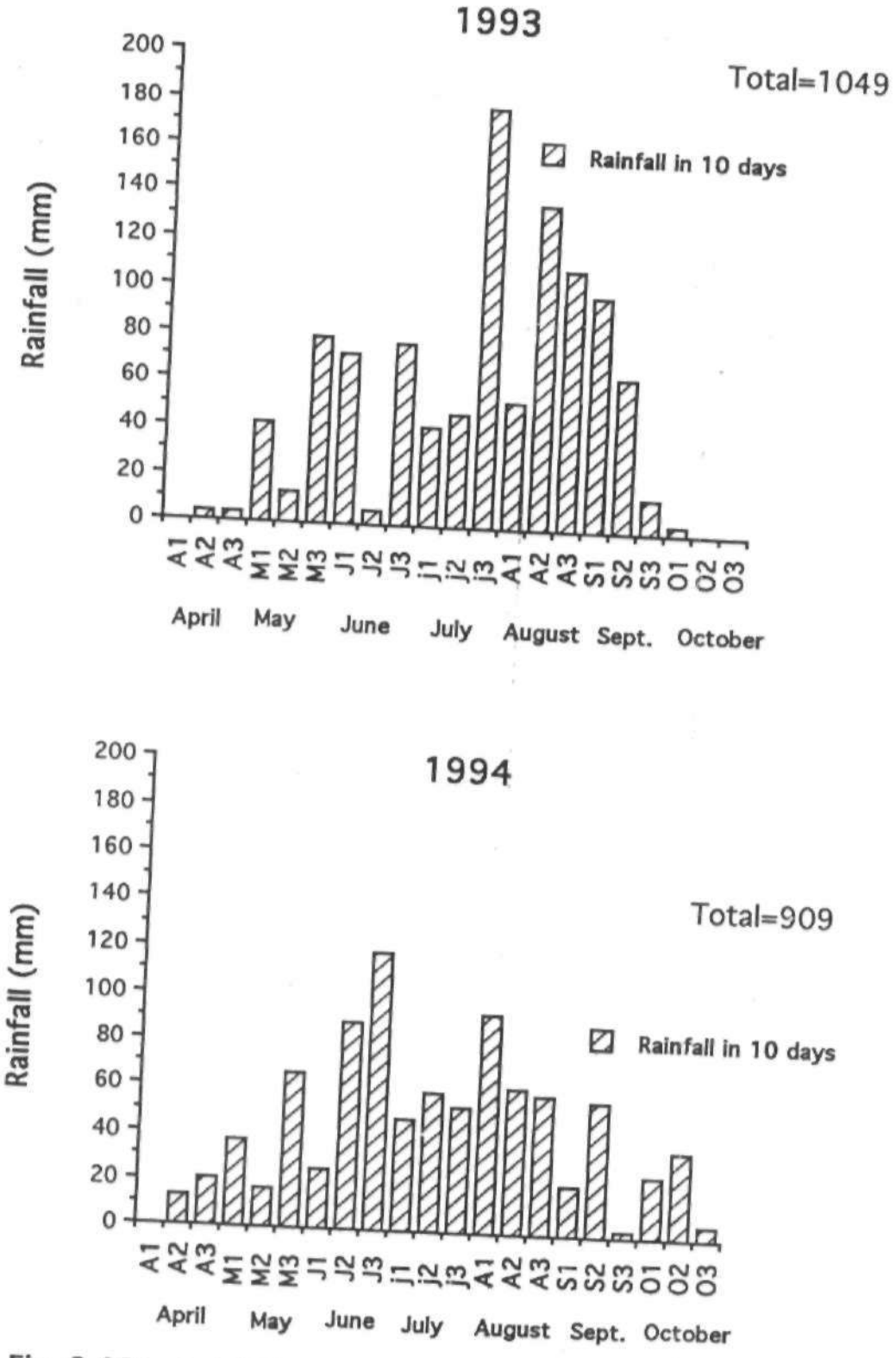


Fig. 3.02: Rainfall patterns in Samaru in 1993 and 1994

3.1.2 Experimental Materials

Five maize and one sorghum cultivars were used. Maize was obtained from Maize Improvement Programme (MIP) of the International Institute for Tropical Agriculture (IITA), Ibadan and sorghum was obtained from a local farmer at Tsibiri village. Four of the maize cultivars were improved cultivars selected on the basis of having higher initial root growth parameters from greenhouse studies (Heuberger, unpublished), and with similar growth cycle. The characteristics of the cultivars are presented in Table 3.01.

3.1.3 Experimental Methods

3.1.3.1 Design of experiment

The experimental design was a split-plot in randomized complete block design with four replications. The main plots of size 31.5 m x 6 m, consisted of the N fertilizer rates, while the subplots of size 6 m x 5.25 m consisted of the cultivars. The N rates were 0, 30:0, 60:0, 30:60, 60:60 and 120:0 kg N per hectare, in two splits applied at 2 and 5 WAP, respectively. The nitrogen source was calcium ammonium nitrate (CAN) with 27 percent N. The lower rates were selected to study the performance of the different cultivars at early growth stage with some expected available N from the soil. The high rate of 120 kg/ha applied once could enhance leaching and was included to allow identification of the cultivars with extended root system to extract the leached nitrate later in the season thereby reducing nitrate pollution of the aquifer. Split applications of high N rates were used to ensure non-limiting N uptake despite soil-related losses. The cultivars have been described in section 3.1.2.

Table 3.01: Description of cultivars used in 1993 and 1994, on-station experiments.

Cultivars	Origin	Grain type	Remark
Improved:			
EV8728-SR	CIMMYT/IITA	Yellow flint/dent	Good for N use, but has potential for improvement
Mokwa 87 TZPB-SR	IITA	White dent	High yield, high kernel weight
SPL (semi prolific)	CIMMYT/IITA	White flint	Susceptible to root lodging
8644-27 (Oba Super 2)	IITA/Pioneer	Yellow flint	Hybrid, single cross (TZi 18 x TZi 35)
Widely grown maize			
TZB-SR	Nigeria/IITA	White flint/dent	Widely grown by farmers in moist savanna but susceptible to low fertility and low yield potential
Local sorghum ('Mori')	Local	White	Photosensitive sorghum, locally grown

The experiment was repeated in a nearby field and slightly modified in 1994, but the design was not changed. The N rates were reduced to five: 0, 30:0, 60:0, 30:60(split), and 60:60(split) kg N ha^{-1}. The result of the previous season indicated no difference in grain yield between 60:60(split) and 120:0 kg N ha^{-1}, hence the latter was dropped. The number of replications was increased to five to improve on the precision of the experiment so as to adequately evaluate the contribution of root growth characteristics of the different cultivars to N-use efficiency. Plot sizes and number of cultivars were unaffected.

3.1.3.2 Agronomic observations and soil management practices

In both years the land was ploughed and harrowed 2-3 times before ridging. In 1993, P, K and Zn were applied as basal dressing based on soil content of low to medium class P of 12.54 mg kg^{-1} soil, low class K of 0.10 $Cmol^{+}$ kg^{-1} soil, and medium class Zn of 2.8 mg kg^{-1} soil. The rates were 26.2 kg P, 49.8 kg K and 1 kg Zn per hectare as single super phosphate, muriate of potash and zinc sulphate, as recommended by Enwezor *et al.*, (1989). The soil content of 1994 site also showed low to medium class P of 13.0 mg

kg^{-1} soil , but medium class K of 0.27 $Cmol^{+}$ kg^{-1} soil, and high class Zn of 5.6 mg kg^{-1} soil. The rates were 26.2 kg P, 24.9 kg K and 0 kg Zn per hectare, from the same sources as in 1993. The Zn level was higher than the critical 3.6 mg kg^{-1} soil level, below which response to Zn fertilization has been observed in the savanna (V.O. Chude, personal communication). In both years, the fertilizer mixtures were broadcast uniformly on the soil and incorporated using a disc plough before ridging.

Nitrogen fertilizer was applied at 3 WAP in 1993 and 2 WAP in 1994. The delay in the first year was due to some management problems and lack of rains. Method of application was by single band about 5cm deep made along the ridge 5-10 cm away from the plant stands. The fertilizer was incorporated. The second application for 30:60 and 60:60 kg per hectare treatments was made after weeding/remoulding of

ridges at 5-6 WAP in both years. The method of application was the same as in the first application.

High bunds of about 0.75m were made to separate the main plots, and in addition, to harvest rain in the furrow, thereby conserving moisture needed by the crops for early establishment. This strategy was adopted to prevent crop failure due to uneven rain fall distribution often experienced early in the season. Later in the season when rain had fully established, the bunds were opened slightly to allow runoff and to prevent water logging.

All seeds were first treated with Apron plus (a.i 10 percent metalaxyl, 6 percent carboxin and 34 percent furathiocarb) at the rate of 5g per 2 kg seeds before planting. Four to five maize seeds and ten to fifteen sorghum seeds were sown per hill. Seeds were hand sown on 28/5/93 and 16/6/94 in their respective plots at 75 cm x 50 cm between- and within- row spacing (sole crop). The maize was later thinned to two plants per stand to give a population of 53,333 plants per hectare, while the sorghum plants were established at 26,666 hills per hectare with an average of five plants per hill, as generally practiced by the farmers. Sorghum was planted only in mainplots supplied with 90 and 120 kg N ha^{-1} in 1993, and 0, 30, 120 kg N ha^{-1} in 1994. There were 120 subplots with maize and 8 with sorghum in the first year, and in the second year the figures were 125 and 15. Planting was delayed in 1994 due to late establishment of rains.

In both years weeding was done twice, at 2 and 5 WAP. The first weeding was done with small hand hoe, and involved weeding up the ridge. The operation combined removal of weeds and addition of more soil to the ridges, to conserve moisture. The second weeding was also done with hand hoe. The operation involved remoulding of ridges by incorporating weeds with the soil from the furrow to the ridge, as commonly practiced by the farmers.

3.1.3.3 Plant growth and yield analysis

(a) Total dry matter production and sample preparation

Plant height and rate of leaf elongation were measured at 25-28 DAP for maize and 42-45 DAP for sorghum, to determine the cultivars with rapid growth rate at the period of maximum plant elongation or primodium development. Height of four plants per plot was measured from the soil level to the ligule of the upper-most fully expanded leaf and the average height was calculated. Using the same plants, leaf length measurements were taken from soil level to the tip of the youngest unfolded leaf, about 3-5 cm opened. The leaf was marked and the length was measured three days later. The difference in measurements gave the elongation. Rate of leaf elongation was calculated by dividing the elongation by three.

Dry matter production was determined to monitor plant growth during the growing period. This will be related to N use efficiency, and to soil nitrogen depletion as an indicator of N uptake by the different cultivars.

The dry matter yield was determined at 5 WAP, 50 percent silking, and at harvest. The first two samplings were taken from main plots with 30:60 and 120:0 kg N ha^{-1} in 1993, and zero, 30:0, and 60:60 kg N ha^{-1} in 1994 to limit the samples to a manageable size. A maximum of twelve plants were harvested. Total fresh weights were taken and the stalks and leaves were cut into pieces, mixed thoroughly, and sub samples were taken for fresh weight The dry weight of these sub samples was taken after oven-drying at 80°C for at least three days. The total dry matter yield of each plot was estimated from the sub sample dry weight by simple proportion. The sub samples were then milled and stored for total-N analysis.

At 50 percent silking, in addition to total dry matter determination, another four plants were separated into ear leaves, other leaves, and stems, and dried in the oven at 80°C for at least three days to determine dry matter partitioning. Samples were milled and stored for total-N analysis. The same plants were also used for estimation of root

length (see below).

At harvest, after removing the ears, all the stalks in the net plot of 7.5 m^2 including the husks were weighed and cut into pieces, mixed and sub sampled for dry matter yield. The samples were also milled and stored for total-N analysis to estimate total N uptake and for N balance calculations. The difference between N uptake at 50 percent silking and at harvest will determine if N-uptake continued after silking.

(b) Estimation of root length and root distribution

In order to identify a cultivar with improved root growth characteristics to capture the initial nitrate flush, and to relate this uptake with N-use efficiency, root samples were taken at 5 WAP in 1994 in main plots with zero and 60:60 kg N ha^{-1}. At this stage the crop had only received the first dose of nitrogen. Due to the delay in nitrogen application in the first year, root sampling was not done at this stage. Using the same plants selected for the determination of total dry matter production, core samples were taken from five stands per plot at 12.25 cm from the stand along the ridge. Sampling was done to a depth of 60 cm in 15 cm increments, using a root auger (Eijkelkamp) of 8 cm diameter and 15 cm length.

At 50 percent silking, root samples were taken to estimate root length and maximum rooting depth. In 1993, samples were taken from mainplots which received 30:60 and 120:0 kg N ha^{-1}. Four cores per plot at 25 cm away from the plant stand were taken. Sampling was limited to 60 cm in 15 cm increments, because of the presence of laterite or petroplinthite which made sampling difficult beyond this depth. In 1994 samples were taken to a depth of 90 cm in 15 cm increments and 12.25 cm away from plant stand along the ridge in mainplots which received 0, 30:0, and 60:60 kg N ha^{-1}. Five cores were sampled per plot. Also, sorghum root sampling was done only to 60 cm in both years due to the dry nature of the soil at heading. Rain had ceased at sampling time.

In both years, soil cores with root samples were stored for a maximum of 6

days in polyethylene bags in a cold store before washing. Core samples were soaked with water in plastic buckets and the soil clods with roots were thoroughly dissolved with hands. The suspension was poured over a 0.5 mm sieve. Roots were separated from soil using a jet of water from an over head tap. When water pressure was low, water was poured directly from a bucket. Debris, weeds and dead roots were sorted out from the 'live' roots during washing. Root length was determined in 1993 using a line intersect method (Tennant, 1975). But in 1994, an image analyzer (Delta-T Area Meter) was used because of the large sample size. The instrument was first calibrated using a known length of string. The data was fitted with a non-linear regression to estimate the constants for computing the length of the roots from the Delta-T counts using the equation developed by Harris and Campbell (1989):

$$C = pL \exp^{(-qL)}$$

where, C = counts displayed on the monitor and L = root length, p and q were determined from non-linear least square fit on the calibration data as 135.9782 and 0.0046. With this equation, root length was calculated from the count by iterative procedure using a FORTRAN programme. Root length densities were calculated by dividing the root length by the volume of soil core. Root dry matter was determined after oven-drying samples at 80^{o}C for at least three days using a metler balance accurate to 4 decimal places.

In order to compare the data from both years, twenty samples from 1994 were randomly selected and root length was determined by both methods. A correction factor was derived from the relationship between root length density (RLD) measured by both methods, expressed by the following regression equation:

$$\text{Delta-T} = 25.0285 + 1.612T \quad R^2 = 0.90 \quad P<0.001$$

where, Delta-T=RLD measured with Delta-T and T=RLD measured with Tennant (1975) method. The 1993 data were corrected using the equation.

(c) Nitrogen deficiency symptom rating

To evaluate yield loss due to N deficiency, a scoring system was developed using a scale of 1-9. Each plot was scored accordingly. Photographs of plants in the different scoring scale were taken (Plate 1). The scale was simplified into five (1,3,5,7,9) digits for easy adoption by other researchers and farmers for assessing yield loss due to N deficiency on farmers' fields, and for programming of fertilizer application (Table 3.02).

(d) Yield and yield components

From the border rows four ears of maize or panicles of sorghum were randomly harvested at two days intervals to study days to physiological maturity, when plants were showing signs of maturity as from 105 DAP. Twenty grains were removed progressively along the ears or panicles to score the development of black layer (Daynard and Duncan, 1969; Muchow, 1988a). Days to physiological maturity of each genotype was recorded when 75 percent of the ears or panicles have 80 percent of the grains with black layer.

In each subplot, the central 7.5 m^2 area was used for yield determination. Total number of maize plants and number of plants with root lodging were recorded. The ears were harvested and dehusked. Number of ears and ear weight were taken. Ten ears were randomly selected, and number of kernels per ear (KPE) was determined from the number of kernels (G_j) in two opposite rows and number of rows (R_j) from the mid-point of the ear using the formula:

$$KPE = \Sigma (G_i * R_i)/10$$

where, G_i = mean number of kernels per row.

The ears were shelled and kernel weight recorded. Grain humidity was determined in two sub samples using Dickey-john grain moisture tester. Percent grain moisture content was read from the chart. Also, one thousand kernels were counted and weighed from each plot for 1000-kernel weight. This sample was milled and stored for kernel-N analysis. Furthermore, the cobs were oven-dried at 80°C for at least three days to estimate cob dry matter. From the dry samples, 15 cobs were selected, crushed, milled and stored for cob-N analysis.

In the case of sorghum, the number of hills and plants in the sampling area (7.5 m^2) was recorded. The panicles were cut with a knife, and the number and weight were taken. Panicles were later sun-dried for five days and threshed in a mortar, winnowed to separate the chaff. Grains were weighed and the moisture content was measured as in maize. The panicle residue was chopped into pieces, oven-dried and weighed. Sub samples were milled and stored for panicle residue-N (pan-res-N) determination. Also, one thousand grains were counted and weighed for 1000-grain weight. The grain samples were milled and stored for grain-N.

In 1993 the 'pan-res'-N was not determined because samples were mixed up after threshing. Number of grains per panicle was not determined because of the difficulties of getting accurate counts.



Plate 1: Nitrogen deficiency symptom rating on maize showing score 1-9 at mid silking.

Table 3,02:Scoring system for evaluating nitrogen deficiency symptoms at silking

Score		Symptom description
1	Nil	Normal maize growth, plants looking healthy and vigorous.
3	Slight	Very slight deficiency symptoms of slight pale yellowing of lower leaves; plants have normal height but slightly reduced vigour.
5	Moderate	Mild deficiency symptoms, 10-15% lower leaves looking pale yellow with V-shape from the tip ; plants have slightly reduced height.
7	Severe	High deficiency symptoms, 50% of lower leaves are pale yellow with V-shape from the tip, extending half the leaf lamina; slightly spindle growth of plants.
9	Very severe	Very severe deficiency symptoms with over 50% of leaves pale yellow; plants are weak and stunted in growth with reduced internode.

3.1.4. Economic Analysis of Maize Yield

Partial budget and marginal analyses were done to determine the recommended level of investment if farmers are considering investing on the improved cultivars and on nitrogen

fertilizer and the labour to apply it. The results however, may not represent a real farming situation considering the conversion of data from micro plots to hectrage, and hence, should to be taken with caution. Marginal analysis involves calculating the marginal rates of return between treatments, and comparing the rates of return to the minimum rate of

return acceptable to farmers.

The following assumptions were made:

(a) a minimum rate of return of 100 percent. Farmers should be willing to change from one treatment to another if the marginal rate of return of that change is greater than the minimum rate of return (CIMMYT, 1988).

(b) since farmers' yields are always far below yields obtained in on-station, yield adjustment of 40 percent was made based on experience.

(c) due to the fluctuations in prices, calculations were based in U.S dollars using an exchange of $1.00=80 naira. Prevailing (May, 1996) farm gate prices in Zaria were used (V. Manyong and K. Makinde, IITA, Ibadan, personal discussion), thus:

Price of nitrogen=$ 0.926 kg^{-1}

Price of maize=$ 0.175 kg^{-1}

Cost of one fertilizer application (12 man-day ha^{-1} and $ 0.875 man-day^{-1})=$ 10.50 ha^{-1}

Price of OP seeds (seed rate of 48 kg ha^{-1})= $ 0.313 kg^{-1}

Price of hybrid seeds (seed rate of 48 kg ha^{-1})= $ 0.938 kg^{-1}

3.2 EXPERIMENT II - ON-FARM:

On-Farm Evaluation of an N-use Efficient Maize Cultivar in Legume/Cereal Rotation under the Scenarios of High and Low NO_3- Release Patterns.

3.2.1 Location and Climate

The experiment was conducted for two years, in 1993 and 1994 in four farmers' fields selected in Tsibiri village (11° 32'N and 7° 32'E, Fig. 3.01) based on previous on-farm evaluation of nitrate-nitrogen dynamics under maize in the NGS of Nigeria (Weber *et al.*, 1995c). The fields represent: (i) two fields with high (8.0-12.5 ug ml^{-1}) NO_3- release pattern in 1992, and (ii) two fields with low (<6.0 ug ml^{-1}) NO_3- release pattern in 1992.

Tsibiri is located about 20 km from Samaru (on-station site) in the NGS (Fig. 3.01). The rainfall distribution for Tsibiri for 1993 and 1994 was similar to that of Samaru (Fig. 3.03). Description of vegetation and geology of the experimental sites is presented in Appendix 1.

3.2.2 Experimental Materials

The seeds of long duration soybean (*Glycine max* cv.TGx923-2E) were collected from the Grain Legume Improvement Programme (GLIP), IITA, Ibadan, while the forage legume (stylo) seeds (*Stylosanthes hamata* cv.verano) were collected from the National Animal Production Research Institute (NAPRI), Shika, Zaria. Seeds of a standard commercial maize cultivar, TZB-SR and a hybrid, Oba Super 2 (cv. 8644-27), an improved, N-use efficient maize were obtained from MIP/IITA, Ibadan. The seeds of sorghum cultivar 'mori' were collected from a farmer in Tsibiri village.

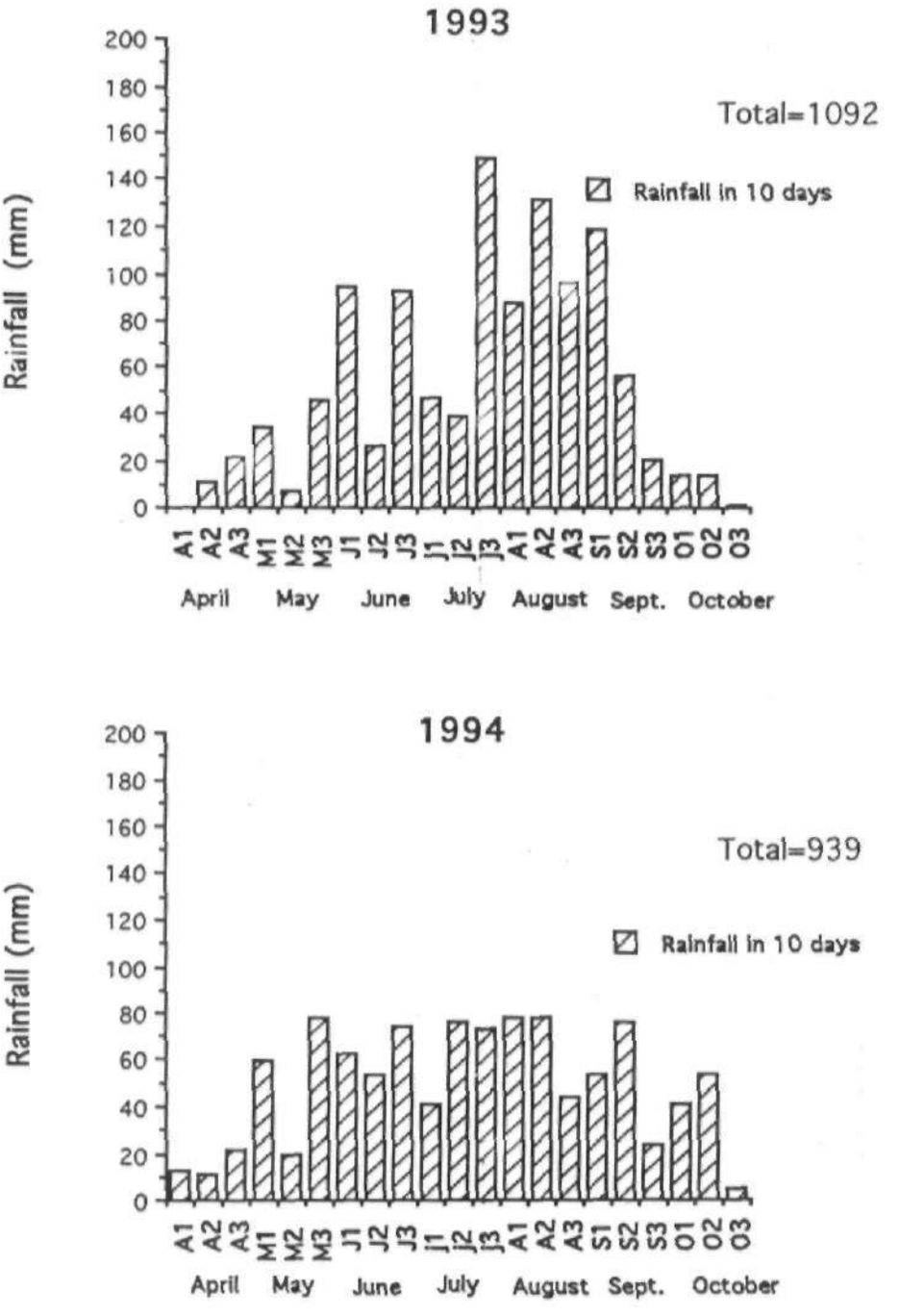


Fig. 3.03: Rainfall patterns in Tsibiri in 1993 and 1994

3.2.3 Experimental Methods

3.2.3.1 Design of experiment

In 1993, the treatments were three N regenerating sources and two NO_3^- release patterns (ie. the two soil scenarios). The first treatment comprised two different legume species, a fast decomposing legume (soybean,) and stylo, a slow decomposing forage legume species, and a chech-maize variety (cv. TZB-SR). This legume classification is based on their above-ground qualities, soybean had 48g kg^{-1} lignin and stylo had 67g kg^{-1} lignin (Fox *et al.*, 1990; Vigil and Kissel, 1991). The experiment was laid out in each field in a randomized complete block design (RCBD) with three replications. Each crop was planted as a sole crop on a different plot size 67.5 m^2. There were three plots of each crop in each of the four fields

The second year experiment was to assess the effects of the different previous legume crops, maize and sorghum on soil N, test crop N, and test crop yield and N use efficiency in a system were the above-ground residues are removed from the field after harvest, except leaf and root litter. The experiment was conducted in a split-plot in a randomized complete block design. In each field, the three main plots planted with legumes or maize (check) in 1993 were divided into three subplots and planted with a local sorghum variety (cv.'mori'), maize cv. TZB-SR, and an N-use efficient maize (cv.8644-27) selected from 1993 on-station experiment. Each subplot measured 6 m * 3.75 m.

3.2.3.2 Agronomic observations and soil management practices

The time schedule for agronomic observations, soil management practices and sampling dates are presented in Table 3.03. The experiment was researcher managed. In both years land preparation (ridging) was done with hand hoe except Site 4 which was prepared with animal traction by the farmer.

A basal dressing of P, K and Zn was applied at the rate of 26.2 kg P from SSP, 24.9 kg K from MOP and 1 kg Zn from $ZnSO_4$ per hectare, based on soil test

results. In 1993, only the check-maize plots received N fertilizer from CAN at an optimum rate of 30 and 60 kg ha^{-1} applied at 2 and 5 WAP. In 1994 all subplots received 60 kg N ha^{-1}, the most efficient rate identified from on-station experiment in 1993, in addition to the P and K applied at planting, at the same rate as in 1993. Zn was not applied in 1994 because the soil test showed high level of 5.6 mg kg^{-1}, adequate for the crops.

Bunds were made to separate the main plots and to harvest rain in the furrows in order to overcome the effect of dry spell at the beginning of the season. They were later opened slightly to allow runoff and prevent water logging in the furrows.

The maize, sorghum and soybean seeds were treated with Apron plus for pest control before planting. The stylo seeds were first scarified using hot ($100^{o}C$) water treatment for three minutes before planting. The seeds were planted by broadcasting at 10-15 kg viable seeds per hectare. Soybean seeds were drilled along the ridges. Maize was established at two plants per stand to give a plant population of 53,333 plants per hectare, while sorghum was established at 26,666 hills per hectare with an average of five plants per hill, as generally practiced by the farmers.

The stylo plots were hand weeded four times in each field. Maize, sorghum and soybean were weeded twice with hand hoe. The second weeding combined weed removal and remoulding of ridges, a weed control and soil conservation method. Time schedule for weeding is shown in Table 3.03.

Table 3.03: Time schedule for the agronomic observations, soil management practices and soil sampling in 1993 and1994 for on-farm experimentation.

Years	1993	1994	Remark
Profile description and soil sampling for characterization	30/5	11/5	
Soil microbial biomass/mineral-N sampling to 30/90cm in 15 and 30cm increments			
Before sowing	-	11/5	
At sowing	-	27/5	
5 WAP	-	1/7	
Silking/heading	-	28/7(14/10)	
At harvest	-	20/9(23/11)	
Sowing	1/6	28/5	
Fertilizer application:			
At sowing			
SSP, MOP and $ZnSO_4$	31/5	27/5	
At 2 WAP, CAN	15/6	11/6	CAN apllication was restricted to maize only in year
At 5 WAP, CAN	7/6	-	$ZnSO_4$ was not applied in year 2
Weeding:			
Stylo			
1st weeding	14/6	-	
2nd weeding	25/6	-	
3rd weeding	11-14/7	-	
4th weeding	11-13/8	-	
Soybean and maize			
1st weeding (weeding up)	14/6	10/6	
2nd weeding (remoulding)	6/7	28/6	
Harvesting:			
Year 1			
legumes	18/10	-	
maize	22/10	-	
Year 2			
maize	-	20/9	
sorghum	-	23/11	

3.2.3.3 Plant growth and yield analysis

The following agronomic data were collected following the procedures described in section 3.1.3.3:

i. Plant height at 25, 42 DAP;

ii. Leaf area of ear leaf using procedure described by Muchow (1988a) and leaf senescence at mid-silking and mid-grain filling;

iii. Total dry matter production, and yield and yield components as in Trial 1.

3.2.3.4 Crop pest evaluation

During crop observations at silking in 1994, it was observed that all the four fields were infested by the maize parasite, witch weed (*Striga hemonthica* Benth.). Evaluation of its density (number of *Striga*/plant), and severity on the crops was done using a modified scoring system developed by Kim (1991). The percent severity indicates the proportion of plants showing *Striga* damage symptoms, and was calculated using the following equation:

$$\% \text{ severity} = (p_3 + p_5 + p_7 + p_9) * 100 \qquad (1)$$

$$p_i = n_i / n \qquad (2)$$

where, p_i is the proportion of plants with *Striga* damage score from 3 to 9, n_i the number of plants in the sampling area with symptom score ranging from 3 to 9, and n the total number of plants in the sampling area.

3.3 PLANT AND SOIL ANALYSIS

3.3.1 Plant total-N analysis

Total nitrogen analysis of plant samples was done to assess differences in N uptake by the different cultivars under different N availability (N fertilizer and legume N), and for N balance studies. The micro-kjeldahl method was used as described in IITA (1982). The concentration of N was determined with a Technicon AA11, Autoanalyzer.

Nitrogen uptake was calculated as the product of N concentration in the given plant fraction and its dry matter content. The rate of N uptake per metre of root per day was calculated in Experiment I using the following equation as used by Warncke and Barber (1974).

$$I = [(U_2-U_1)/(t_2-t_1)]\ [(\ln L_2/L_1)/(L_2-L_1)]$$

where I is the uptake rate (g per metre day^{-1}), U is the amount of nutrient in the plant (g), t is the time (days), and L is the root length in the profile. Subscripts 1 and 2 refer to the 5 WAP and 50 percent silking harvests. The equation reflects the exponential nature of plant growth.

3.3.2 Soil analysis

(a) Field sampling and sample preparation

For general soil characterization of the experimental sites, soil samples were collected from a soil profile pit sunk beside each site. The samples were air-dried and passed through a 2 mm sieve. For the analysis of total N a sub sample was ground with a mortar and passed through a 0.5 mm sieve. All samples were stored for analysis.

(b) Soil physical characterization

Particle size distribution was determined by the hydrometer method according to Bouyoucos (1951). **Soil water release characteristic:** The procedure was according to the method described by Reeve and Carter (1991). The **saturated hydraulic**

conductivity was determined from fresh soil core samples in the laboratory with the aid of a constant head permeameter described by Youngs (1991). Samples collected from the 1994 site could not be determined because the permeameter was faulty. **Soil bulk density:** This was determined by oven-drying the soil core samples at 105°C for three days, and expressed as mass of dry soil per unit volume of moist soil (Campbell and Henshall, 1991). The bulk densities were used to convert mineral nitrogen from concentration (ug ml^{-1}) to kg per hectare and to study the state of compaction of the soil with depth.

(c) Soil chemical characterization

Soil chemical analyses were carried out on the air-dried sieved soil using procedures described by IITA (1982).

Soil pH: Soil pH was determined in water and in 0.01M $CaCl_2$ with a pH glass electrode using a soil:solution ratio of 1:2.5. **Organic carbon:** The soil organic carbon was determined by the Walkley-Black wet combustion method (Walkley and Black, 1934 and Black, 1965). **Exchangeable bases** (Ca, Mg, K, and Na): The analysis was done by 1*N* NH_4OAc extraction method. **Cation exchange capacity (CEC)** was determined by the 1N NH_4OAc (pH7.0) method. **Exchangeable acidity** was determined by the 1*N* KCl extraction method. **Base saturation percentage (% B.S)** was calculated by dividing the total exchangeable bases by exchangeable cation exchange capacity (ECEC) and expressed in percentage. **Soil available P** was determined by the method of (Bray and Kurtz, 1945). **Total nitrogen:** The procedure followed that of Kjeldahl outlined by Bremner (1960) for soils. Total N concentration was determined with a Technicon AA11, autoanaylser.

Mineral nitrogen: Mineral nitrogen (N_{min}) determinations were carried out periodically during the growing period to monitor the distribution and movement of mineral nitrogen in the soil profile in order to estimate (a) the changes in the N availability with time, and (b) the uptake or losses from the soil through leaching.

Composite samples of four borings were taken with a soil auger from depths of 0-15, 15-30, 30-60, and 60-90 cm at planting and 5 WAP, 50 percent silking/heading and at physiological maturity for determination of mineral nitrogen. Sampling at 5 WAP and silking were restricted to subplots used to assess dry matter production. For Experiment II, monitoring of mineral N was done only in 1994. Sampling at 0 and 5 WAP was from the main plots of 1993, planted with legumes amd maize; while sampling at the other periods were on all the subplots. Samples were stored deep frozen, in sealed polyethylene bags (Whirlpak) until analyzed. Hardter (1989) found that deep freezing led to a decrease of mineral N by 6 percent compared with freshly analyzed samples. This had to be tolerated however, because of the large number of samples, which could not be analyzed immediately and therefore had to be frozen.

Fifteen gram sub samples of the moist frozen soil samples were extracted with 30 ml of 1*N* KCl on a mechanical shaker for 1 hr. The suspension was thereafter filtered through a Whatman No.1 filter paper, discarding the first few drops. The filtrate was stored in vials in a deep freezer until the nitrate and ammonium concentrations were read in a Tecnicon AA11, autoanalyser. Mineral-N samples were sub sampled for gravimetric moisture. The nitrate- and ammonium-N content was calculated with the formula:

$$NO_3\text{-}N/NH_4\text{-}N\ (kg/ha) = C * T * B.D * D * 10$$

where,

C= concentration of NO_3/NH_4 in wet soil (ug ml^{-1})

DW= oven-dry weight of soil sample (g)

B.D= bulk density of soil in the profile (g cm^{-1})

D= depth of soil sampled (0.15 m or 0.30 m)

T= total amount of extract used (ie. ml of extract solution + moisture content in the soil sample).

10= conversion factor to kg ha^{-1}

The summation of NO_3-N and NH_4-N content gave the content of N_{min} or available soil N in kg per hectare.

Available-Zn Cu Mn and Fe were extracted with 0.1*N* HCl. The elements were determined by atomic absorption as described in IITA-manual (1982).

3.3.3 Estimation of Nitrogen Balance

In order to compare the different cultivars and cropping systems with regard to N loss or gain during the test crop, N balance in 0-90cm soil profile over the 1994 season was estimated using the following equation:

$$N_{l/g} = (N_{up(t2)} + N_{min(t2)}) - (N_{fert} + N_{min(t1)})$$

where,

$N_{l/g}$=Nitrogen loss or gain in the system;

$N_{up(t2)}$=Net above ground N uptake at harvest;

$N_{min(t2)}$=Mineral nitrogen in 0-90cm soil profile at harvest in 1994;

N_{fert}=Nitrogen fertilizer added to the system (60 kg ha^{-1});

$N_{min(t1)}$=Mineral nitrogen in 0-90cm soil profile at planting In 1994.

3.3.4 Statistical Analysis

Data were subjected to analysis of variance using the SAS statistical programme (SAS, 1985). Maize and sorghum data were analysed separately. In tables and figures, results of the F-test (***, **, *, and + indicate significance at the $P<$ 0.001, 0.01, 0.05, and 0.1 level), in some cases standard error of the means (S.E) and the coefficients of variation (CV%) are given.

CHAPTER FOUR

RESULTS

4.1. SOIL CHARACTERIZATION AND CLASSIFICATION OF EXPERIMENTAL SITES

4.1.1. On-Station Sites

The soil of the experimental site used in 1993 was described and classified according to the US Soil Taxonomy System, as Plinthustalfs, fine loamy, Isohyperthemic (Plinthic Alisols-FAO 1988). The main soil characteristics are presented in Table 4.01 and Appendix 1. It occupies a gentle (2-4 percent) slope. It is gravelly in the subsoil and underlain by hardened plinthite (laterite or petroplintite) at a depth of 82cm. The surface horizon was dark brown (7.5YR 4/4), while the subsoils were yellowish red (5YR 5/6) to reddish yellow (7.5YR 6/8) in colour. The Ap horizon was loam, dominated by sand while the subsurface horizon had clay loam texture. The structure is moderately developed and sub angular. The soil is also well drained, friable, porous and strongly acidic (pH 4.8) in the surface horizon. The pH appeared to increase slightly with depth which suggests that the soil parent material is less acidic than the soil formed from it. The soil is commonly concretional derived from basement complex rocks.

Furthermore, the soil was low in organic carbon, total N, available P, exchangeable acidity, base saturation and moisture holding capacity. Exchangeable calcium (Ca), magnesium (Mg), and potassium (K) were low to medium. The effective cation exchange capacity (E.C.E.C) was also low. The value of cationic micronutrients manganese (Mn), iron (Fe), zinc (Zn), and copper (Cu) were however, high.

In 1994, the experimental site was located adjacent to the 1993 site, and had similar site characteristics (Table 4.01) except, it occupied the mid-slope, level or

Table 4.01: Soil characteristics of on-station sites

A. Physical properties

Depth (cm)	Horizon	Particle size distribution (%) Sand (50-2000μm)	Silt (2-50μm)	Clay (<2μm)	Bulk density (g cm^{-3})	AWHC (%)	Ks (mm hr^{-1})	Soil texture
1993 site: Plinthustalfs, fine-loamy, isohyperthermic (Plinthic Luvisols - FAO)								
0-17	Ap	48	38	14	1.49	23.1	8172	L
17-31	B/A	38	34	28	1.51	24.0	2460	CL
31-82	Bt	34	32	34	1.37	16.3	157	CL
>82	Bt_{cv}	42	28	30	-	-	-	CL
1994 site: Typic haplustalfs, fine-clay, isohyperthemic (Chromic Luvisols - FAO)								
0-20	Ap	39	46	15	1.29	26.8	-	L
20-57	Bt_1	33	36	31	1.42	18.5	-	CL
57-80	Bt_2	24	35	41	1.53	11.0	-	CL
80-185	C	29	32	39	1.67	9.0	-	CL

B. Chemical properties

Depth (cm)	Horizon	Org. C ($g\ kg^{-1}$)	Total N ($g\ kg^{-1}$)	P Bray 1 ($mg\ kg^{-1}$)	pH H_2O	pH 1N KCl	ECEC	Exch. acidity (H^+, Al^{3+})	Base saturation (%)
							$Cmol^+\ kg^{-1}$		
1993 site:									
0-17	Ap	6.44	0.56	6.39	4.8	4.3	3.46	0.30	70.5
17-31	B/A	3.19	0.43	3.77	4.6	4.6	4.66	0.90	80.7
31-82	Bt	1.18	0.24	1.23	5.0	4.8	5.25	0.70	86.7
>82	Bt_{cv}	1.18	0.28	0.67	5.1	5.0	5.84	0.70	88.0
1994 site:									
0-20	Ap	3.83	0.65	2.50	5.5	4.9	4.2	0.5	87.8
20-57	Bt_1	2.20	0.52	0.30	5.2	5.0	8.5	0.9	89.4
57-80	Bt_2	1.39	0.49	0.10	5.8	4.7	11.4	0.9	92.1
80-185	C	1.00	0.32	0.10	5.6	4.7	12.6	0.9	92.9

Depth (cm)	Horizon	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	Mn^{2+}	Fe^{2+}	Zn^{2+}	Cu^{2+}
		Cmol+ kg^{-1}				mg kg^{-1}			
1993 site:									
0-17	Ap	1.50	0.43	0.26	0.25	18.0	9.6	6.2	1.44
17-31	B/A	2.45	0.93	0.14	0.24	16.4	7.2	6.8	1.36
31-82	Bt	2.50	1.50	0.27	0.28	8.8	7.2	6.6	1.36
>82	Bt_{cv}	2.62	1.62	0.62	0.28	13.2	16.0	6.6	1.44
1994 site:									
0-20	Ap	2.2	1.0	0.2	0.2	19.2	20.0	5.6	0.55
20-57	Bt_1	4.6	2.6	0.2	0.2	14.0	8.0	5.8	1.00
57-80	Bt_2	6.6	3.3	0.3	0.3	10.0	11.2	6.4	0.68
80-185	C	7.4	3.5	0.4	0.4	8.0	12.0	6.2	0.70

nearly level (0-2 percent) slope. Due to higher depost of leached materials from the upper slope the soil was moderately acid (pH 5.9) in the surface horizon. The soil has higher clay content, organic carbon, effective cation exchange capacity and depth than the 1993 site. It was classified according to the US Soil Taxonomy System as Typic Haplustalfs, fine loamy, isohyperthermic (Chromic Luvisols - FAO, 1988). Both sites had no problem of soil pests or water logging.

4.1.2. On-Farm Sites

The soils of the four experimental fields were described and classified in 1993 according to the US Soil Taxonomy System, as Typic Haplustalfs, fine-loamy, isohyperthemic (Chromic Luvisols - FAO, 1988). The main soil characteristics are presented in Table 4.02.

Low nitrate fields (Profiles TBR1 and TBR2)

The two low nitrate fields occupy gentle (2-4 percent) slope. The soils were moderately well drained with dark brown (7.5YR 4/4) sandy loam to dark yellowish brown (10YR 4/4) loam surface over dark brown (7.5YR 4/4) and strong brown (7.5YR 5/6) loam and clay to clay-loam subsurface soils. The soil structure was moderately well developed and was predominantly sub angular blocky type. The particle-size distribution data showed that the soils had relatively high sand content which decreased with depth as the clay content increased. The clay accumulation in the subsurface horizons may be due to either illuviation from the surface horizons or *in situ* development or both. Argillic horizons are common features of the profiles. The silt:clay ratio was relatively low in the subsurface horizons. This normally indicates that the soils are strongly weathered. Soil pH ranged between 4.9 and 5.3 in the Ap horizons and between 4.8 and 5.8 in the subsurface horizons indicating a moderately to strongly acid soil reaction. The soils were low in organic carbon, total N, available P. Exchangeable bases except Ca appeared low. The exchangeable Ca content was between 1.80 and 5.24 $Cmol^{+}\ kg^{-1}$, and covered about 60-71 % of the adsorption

Table 4.02: Soil characteristics of on-farm sites

A. Physical properties

Site	Depth (cm)	Horizon	Particle size distribution (%) Sand (50-2000µm)	Silt (2-50µm)	Clay (<2µm)	Soil textuire
Profile TBR1: Typic Haplustalfs, fine loamy, isohyperthemic (Chromic Luvisols - FAO)						
Site 1						
(Low fertility)						
	0-12	Ap	44	42	14	L
	12-27	BA	34	38	28	CL
	27-36	Bt_1	30	30	40	C
	36-74	Bt_2	30	34	36	CL
	74-119	Bt_3	38	26	36	CL
	>119	Bt_c	32	32	36	CL
Profile TBR2: Typic Haplustalfs, fine loamy, isohyperthemic (Chromic Luvisols - FAO)						
Site 2						
(Low/Moderate fertility)						
	0-22	Ap	60	30	10	SL
	22-41	Bt_1	48	38	14	L
	41-95	Bt_2	36	26	38	CL
	95-150	Bt_3	34	30	36	CL
Profile TBR3: Typic Haplustalfs, fine loamy, isohyperthemic (Chromic Luvisols - FAO)						
Site 3						
(High fertility)						
	0-18	Ap	54	36	10	L
	18-33	Bt_1	46	24	30	CL
	33-89	Bt_2	32	40	28	L
	89-150	Bt_3	34	30	36	CL
Profile TBR4: Typic Haplustalfs, fine clay, isohyperthemic (Chromic Luvisols - FAO)						
Site 4						
(High fertility)						
	0-17	Ap	46	40	14	L
	17-30	BA	34	34	32	CL
	30-65	Bt_1	26	34	40	C
	65-119	Bt_2	26	34	40	C
	119-150	Bt_3	28	34	38	Cl

B. **Chemical properties**

Site	Depth (cm)	Horizon	Org. C	Total N	P	pH	pH	ECEC	Exch. acidity	Base saturation
			g kg^{-1}		Bray 1	H_2O	1N KCl		(H^+, Al^{3+})	(%)
								$Cmol^+ kg^{-1}$		
Profile: TBR1										
Site 1										
(Low fertility)										
	0-22	Ap	5.34	0.60	6.39	4.9	4.8	2.81	0.10	96.4
	22-41	Bt_1	3.50	0.47	3.15	5.1	5.1	6.41	0.10	98.4
	27-36	Bt_1	3.48	0.35	1.50	5.2	5.0	8.05	0.30	96.3
	36-74	Bt_2	3.42	0.28	1.23	5.6	5.4	7.11	0.10	98.6
	74-119	Bt_3	2.03	0.21	1.33	5.8	5.5	6.12	0.10	98.4
	>119	Bt_c	2.03	0.21	1.32	5.6	5.5	5.90	0.30	94.9
Profile: TBR2										
Site 2										
(Low fertility)										
	0-12	Ap	4.41	0.52	6.39	5.3	5.3	2.63	0.10	96.2
	22-41	Bt_1	3.19	0.39	1.78	5.1	5.1	4.32	0.20	95.4
	41-95	Bt_2	2.38	0.26	1.21	5.1	5.1	6.42	0.20	96.9
	95-150	Bt_3	1.80	0.27	1.05	4.8	4.2	6.43	0.90	86.0
Profile: TBR3										
Site 3										
(High fertility)										
	0-18	Ap	5.34	0.29	16.78	5.1	5.0	3.38	0.30	91.1
	18-33	Bt_1	4.64	0.26	-	5.3	5.2	4.94	0.20	96.0
	33-89	Bt_2	4.23	0.24	1.05	4.8	4.5	6.04	70.7	88.4
	89-150	Bt_3	2.20	0.23	0.76	4.5	3.8	4.41	70.9	78.6
Profile: TBR4										
Site 4										
(High fertility)										
	0-17	Ap	5.03	0.47	21.3	5.0	4.8	2.99	0.10	96.3
	17-30	BA	5.00	0.40	-	5.0	5.0	5.78	0.10	98.3
	30-65	Bt_1	4.41	0.42	1.76	5.1	4.9	6.46	0.20	96.9
	65-119	Bt_2	4.41	0.27	1.59	5.0	4.6	6.60	0.70	89.4
	119-150	Bt_3	2.78	0.17	1.69	4.8	4.4	6.01	0.70	88.4

C Exchangeable cations (NH_4OAC pH = 7.0) and micronutrients (0.1NHCl)

Site	Depth (cm)	Horizon	Ca^{2+}	Mg^{2+}	K^+	Na^+	Mn^{2+}	Fe^{2+}	Zn^{2+}	Cu^{2+}
			Cmol+ kg^{-1}				Mg kg^{-1}			
Profile: TBR1										
Site 1										
(Low fertility)										
	0-12	Ap	1.87	0.49	0.17	0.18	28.0	14.4	7.0	1.20
	12-27	BA	4.44	1.46	0.13	0.28	36.8	10.0	8.6	2.00
	27.36	Bt_1	5.24	1.87	0.26	0.38	22.0	6.4	8.4	1.68
	36-74	Bt_2	4.79	1.62	0.34	0.26	10.0	8.0	8.6	1.84
	74-119	Bt_3	3.87	1.48	0.41	0.26	11.2	5.6	8.4	1.12
	>119	Bt_c	3.54	1.44	0.40	0.22	16.0	5.2	8.0	1.52
Profile: TBR2										
Site 2										
(Low fertility)										
	0-22	Ap	1.80	0.37	0.12	0.24	24.0	11.6	7.6	1.20
	22-41	Bt_1	2.87	0.58	0.11	0.26	18.0	6.4	7.4	1.12
	41-95	Bt_2	3.99	1.71	0.26	0.26	6.0	8.0	9.0	1.04
	95-150	Bt_3	3.24	1.89	0.16	0.24	4.4	6.4	7.8	1.04
Profile: TBR3										
Site 3										
(High fertility)										
	0.18	Ap	2.12	0.60	0.12	0.24	25.6	13.6	7.0	1.28
	18-33	Bt_1	2.99	1.40	0.13	0.22	9.6	7.6	8.0	1.20
	33-89	Bt_2	2.99	1.87	0.24	0.24	4.8	10.0	6.8	1.36
	89-150	Bt_3	1.80	1.21	0.25	0.25	4.8	11.2	6.0	1.04
Profile: TBR4										
Site 4										
(High fertility)										
	0-17	Ap	2.00	0.53	0.11	0.25	24.0	9.2	6.2	1.20
	17-30	BA	4.11	1.19	0.10	0.28	36.0	6.4	9.0	1.44
	30-65	Bt_1	4.24	1.56	0.13	0.33	14.0	4.8	9.4	1.44
	65-119	Bt_2	3.87	1.69	0.12	0.22	8.0	5.6	7.6	1.28
	119-150	Bt_3	3.24	1.60	0.19	0.28	10.0	6.4	7.6	1.12

complex. The soils were also low in effective cation exchange capacity, ranging from 2.63 to 8.05 $Cmol^{+}$ kg^{-1} of soil at pH 7.0. This indicates that the soils possess low ability to with-hold cations against leaching. The base saturation was high.

Furthermore, the contents of cationic Cu, Zn, Mn, and Fe micro-nutrients were high. It should be noted that one of the fields grouped under low NO_3- class (site 2) was later reclassified as moderately high (Onyenuforo 1995, unpublished MSc. Thesis).

High nitrate fields (profiles TBR3 and TBR4):

The soil morphological features, physical and chemical properties were similar to those found in the low nitrate fields. However, the organic carbon content, and available P, especially in the Ap horizons, were higher than values found in the low nitrate fields. Also, the soil reaction tended to be strongly acid with increase in depth in the high nitrate fields, which may suggests that the soil parent material in these fields may be more acidic than the soils formed from it.

4.2. EXPERIMENT I - ON-STATION

4.2.1. Crop Establishment Growth and Phenological Development in Maize

4.2.1.1. Crop establishment

Data on plant population recorded at 25 DAP indicated that the cultivars were established at over 94 percent of their expected population (53, 333 ha^{-1}) in spite of the uneven distribution rainfall experienced at the beginning of both seasons (Appendix 2). This may imply that the moisture conservation strategy (bunding) adopted was effective in enhancing crop establishment. However, the population of SPL was comparatively lower than other genotype populations in 1994. Nitrogen application did not affect plant density.

4.2.1.2. Some growth parameters

Leaf elongation rate measured at the period of maximum primodia development, at 25-28 DAP (Fig. 4.01), plant height at 25 DAP (Fig. 4.02) and at silking (Fig. 4.03) were consistently higher where N was applied than without nitrogen application. Among the improved maize cultivars, SPL gave significantly higher leaf elongation rate and taller plants at 25 DAP than cultivar TZB-SR, the popular Open Pollinated (OP) maize in both years. However, TZB-SR and Mokwa 87TZPB-SR produced on average, relatively taller plants at mid-silking. Significant cultivar by nitrogen interactions were not detected for these growth attributes.

4.2.1.3. Days to phenological stages

Nitrogen application hastened anthesis and shortened the interval between anthesis and silking (ASI) by 1-3 days, but increased the duration of grain filling (LGF) by 3-4 days relative to the zero-N control (Fig. 4.04). Anthesis was attained 2-5 days earlier in 8644-27 than in other cultivars, while SPL and EV8728-SR showed greater ($P<0.001$) synchronization of anthesis and silking compared to other cultivars across years. Cultivars 8644-27 and EV8728-SR also, had longer duration of grain filling compared to other cultivars. When expressed in proportion to the total duration from sowing to maturity, the LGF varied from 38-41 days for TZB-SR and SPL, while for the other cultivars it varied from 40-45 days in both years. Days to anthesis and silking were significantly ($P<0.001$) longer by 4-5 days in the second year than in the first year, probably because of differences in the weather conditions such as rainfall and temperature of both years.

There were no significant cultivar by nitrogen interactions on all the recorded phenological stages, except LGF in the second year. In 1994, application of 120 kg N ha^{-1} to Mokwa 87TZPB-SR led to 2-13 days longer duration of grain filling compared to application of the same or different N rates to other cultivars.

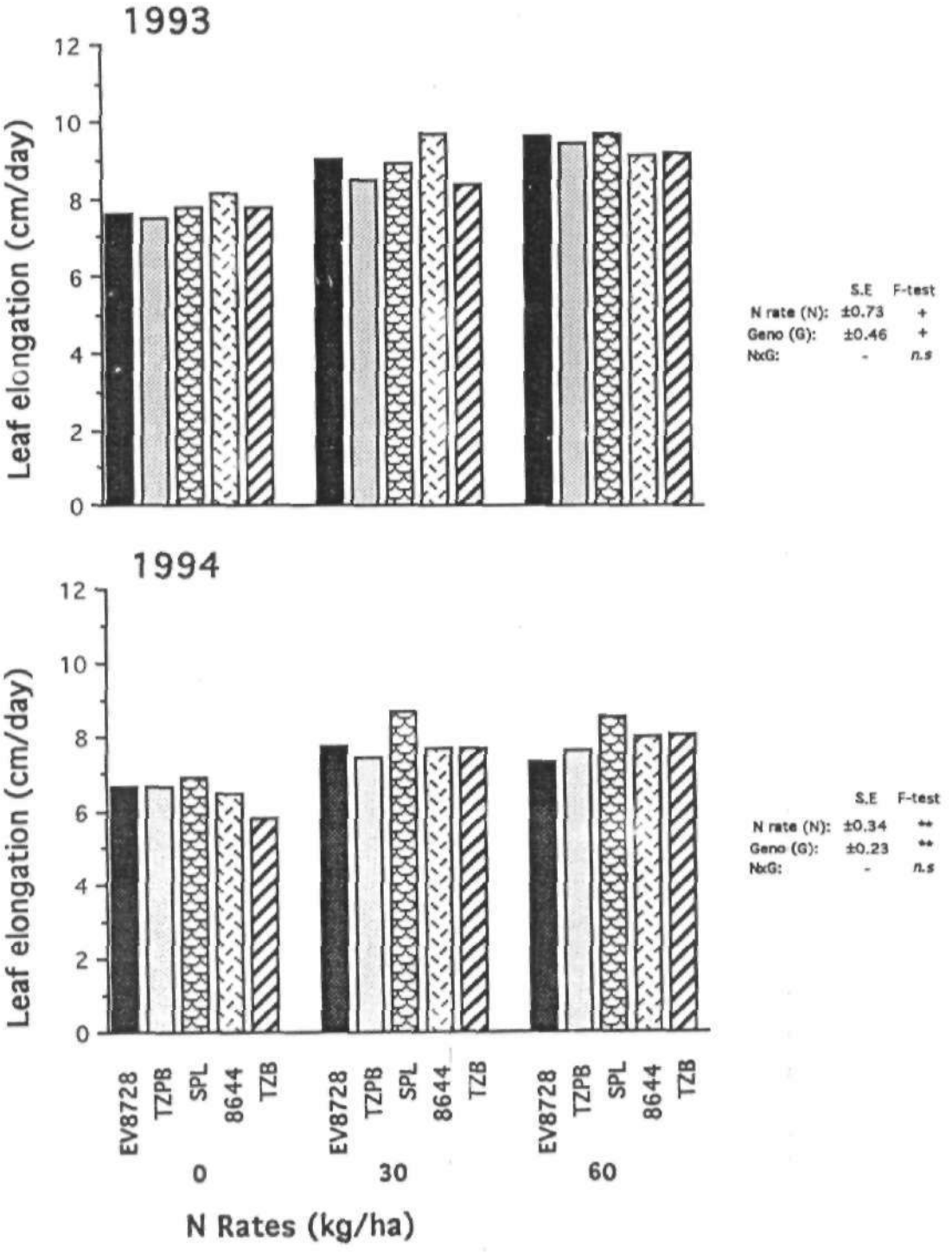


Fig. 4.01: Effect of N rates (kg/ha) on leaf elongation (cm/day) of five maize cultivars in 1993 and 1994.

+, * and ** means significant at P <0.1, 0.05 and 0.01.

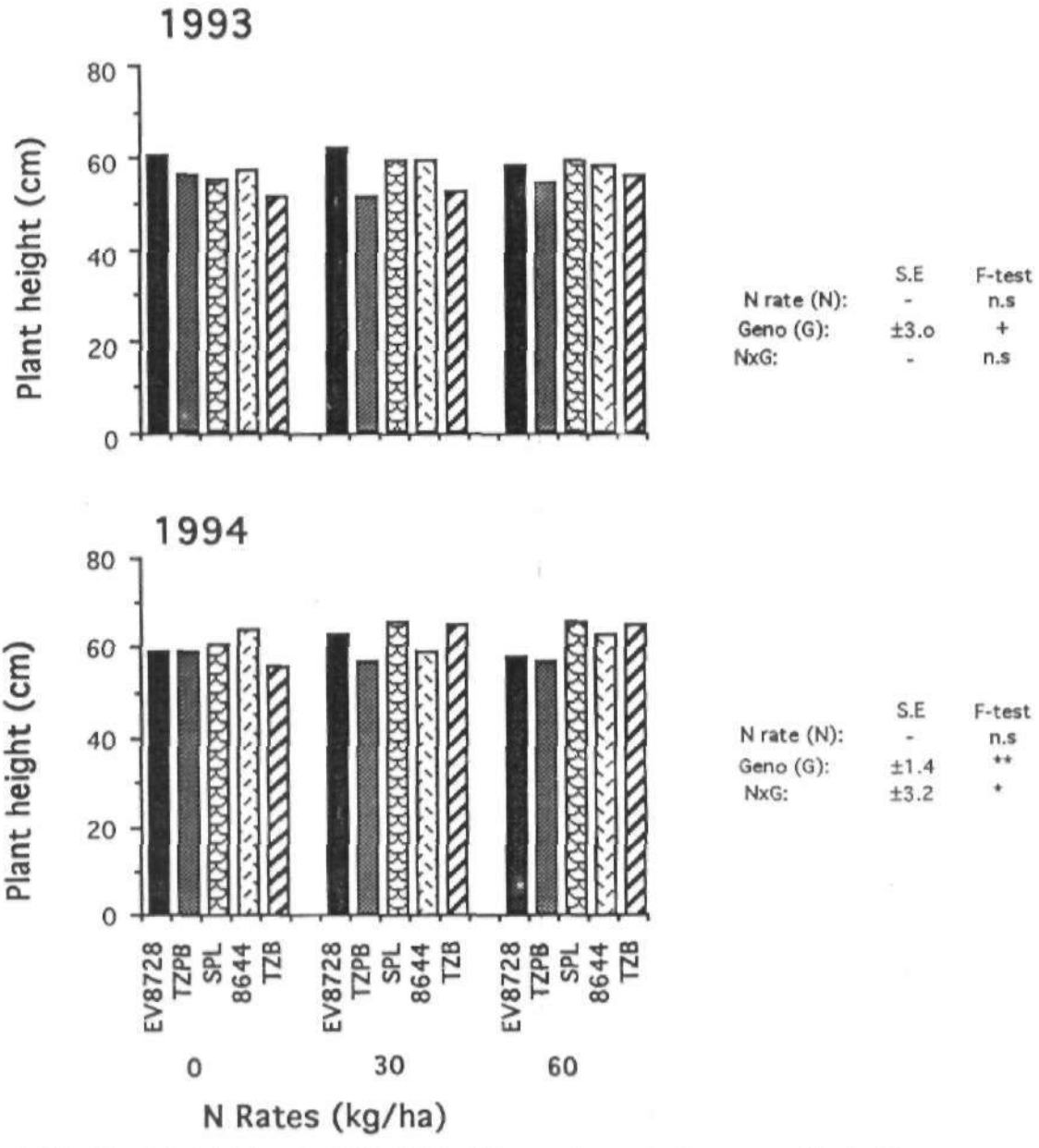


Fig. 4.02: Plant height (cm) at 25 DAP of five maize cultivarsas affected by N rates in 1993 and 1994.

+, * and ** means significant at P <0.1, 0.05 and 0.01.

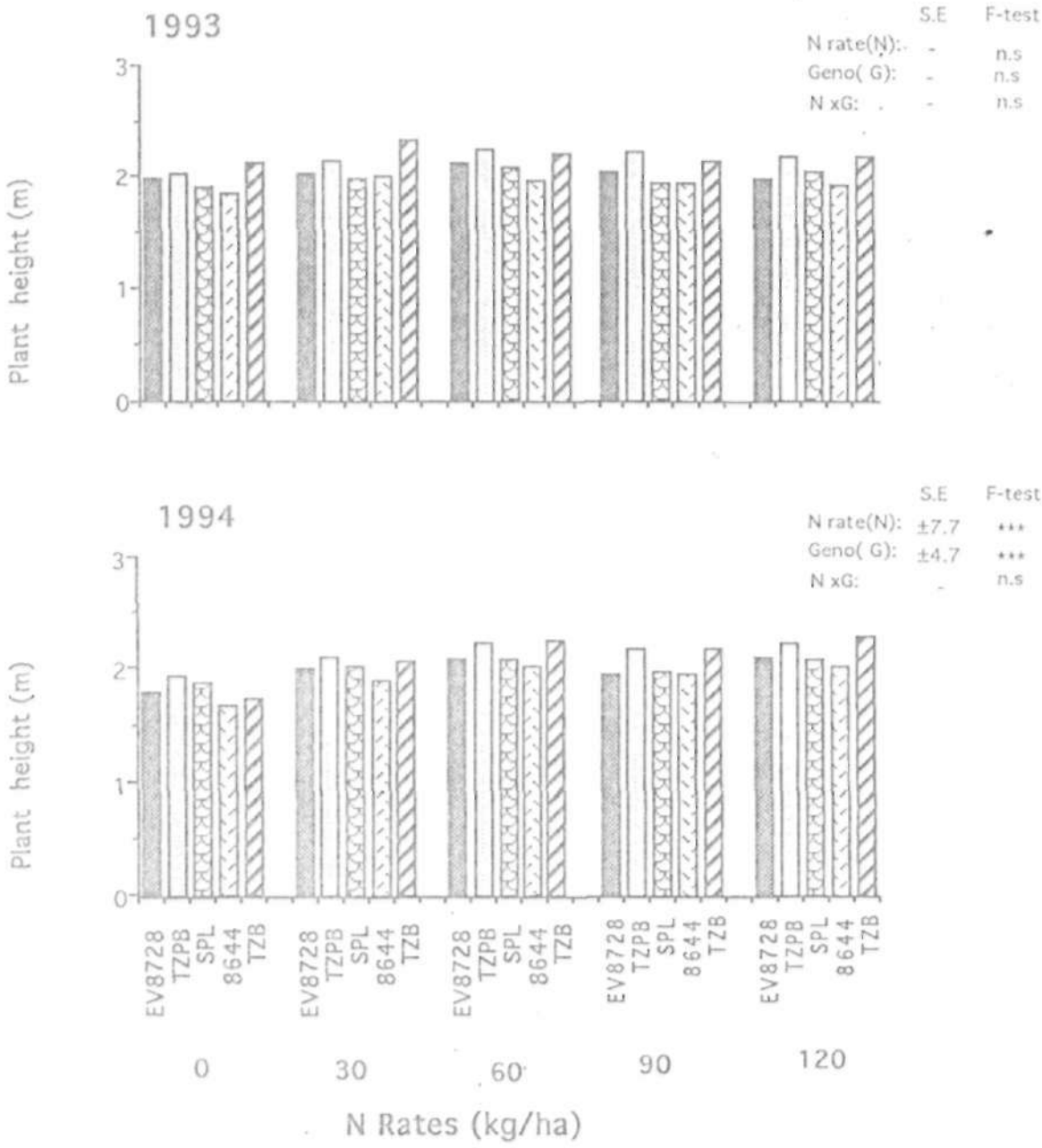


Fig. 4.03: Plant height (m) at silking of five maize cultivars as affected by N rates (kg/ha) in 1993 and 1994.

n.s and *** means not significant and significant at P <0.001.

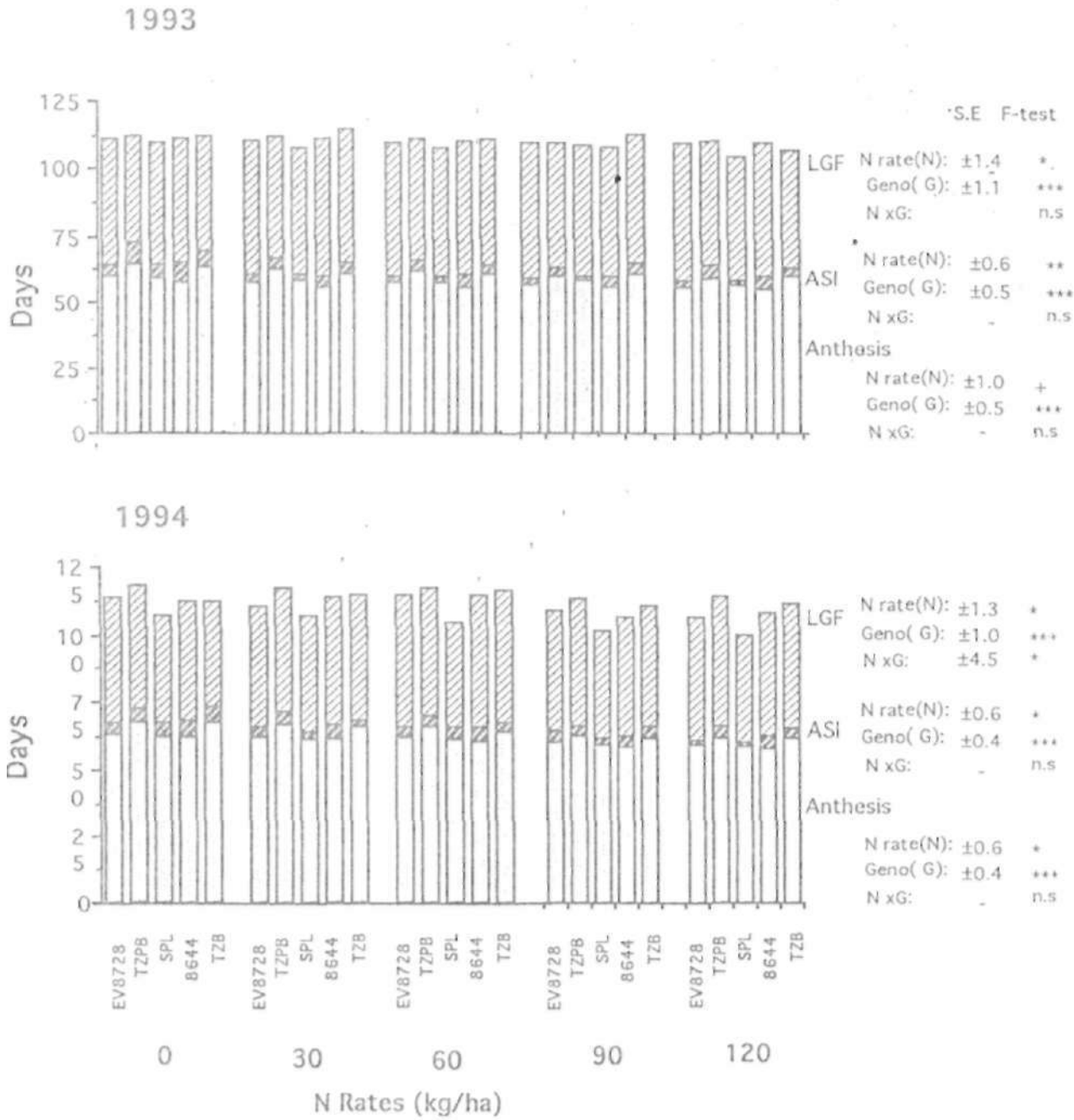


Fig. 4.04: Effect of N rates (kg/ha) on days to anthesis, anthsis-silking interval (ASI), and duration of grain filling (LGF) of five maize cultivars in 1993 and 1994.

n.s , +, *, ** and *** means not significant and significant at P <0.1, 0.05, 0.01, and 0.001.

4.2.2.Yields

4.2.2.1. Dry matter yield at 35 DAP and mid-silking/-heading

Nitrogen supply did not significantly increase total dry matter production at 35 DAP and at mid-silking in both years (Fig. 4.05 and 4.06). Dry matter at 35 DAP and at mid-silking in 1993, was slightly depressed by 120 kg N ha^{-1} (applied at 2 WAP) and at 35 DAP in 1994 by 60 kg N ha^{-1}. The recovery of the second dose of N (60 kg of the 90 kg N

ha^{-1}) applied at 5 WAP resulted in 7 percent less dry matter yield than at 60 kg N ha^{-1} at mid-silking in 1994 (Fig. 4.06). The growth of cultivar TZB-SR was relatively slow at 35 DAP and at silking as indicated by its lower dry matter yield compared with the improved cultivars. But in 1993, it had a higher dry matter at mid-silking and a similar amount at the same period in 1994, compared to all the improved cultivars. Slight delay in the application of N in 1993 due to lack of rains, may have resulted in the lower dry matter yield at 35 DAP in 1993 compared to 1994. There were no significant cultivar by nitrogen interaction on dry matter yield at 35 DAP and at mid-silking.

4.2.2.2. Accumulation and partitioning of dry matter within the plant at physiological maturity of maize and sorghum.

There were no significant cultivar x nitrogen interactions on yield and partitioning of dry matter within the plant of maize or sorghum at harvest. This suggests that a cultivar selected at low N will perform equally well under high N.

Significantly higher grain, stover and cob dry matter of maize were observed with application of N in both years (Fig. 4.05 and 4.06). In all cases, there were no statistical differences between 60 and 90 kg N ha^{-1}. This implies that N deficiency can be corrected, but the effect of N deficiency early in the season cannot be corrected by giving large amounts of N later. The plants may not have recovered from the initial N stress, and hence could not express any advantage of the added N.

Increasing N rate from 60 to 120kg ha^{-1} produced only 0.7-0.8t additional grains per hectare in both years.

Among the improved cultivars, the hybrid (cv.8644-27) gave 0.7t ha^{-1} more grain yield in 1994 ($P<0.01$) and 13-18 percent more cob dry matter in 1993 and 1994, compared to TZB-SR, the widely grown open pollinated cultivar (Fig. 4.05 and Fig. 4.06). Stover yields were highest ($P<0.01$) in TZB-SR and TZPB-SR, while cv.8644-27 produced the least stover yield in both years. Under severe N stress as observed at 0 kg N ha^{-1} in 1994, all the improved cultivars gave above average yield of 2.7t ha^{-1}, but the yield of TZB-SR (1.9t ha^{-1}) was below average. Total dry matter (TDM) accumulation followed a similar trend as stover yield. A greater proportion (53-62 percent) of TDM was accumulated between silking (64-69 DAP) and physiological maturity (107-120 DAP). A combined analysis indicated that the mean grain yield was about 40 percent higher ($P<0.001$) in 1993 than in 1994.

Harvest index (HI) calculated as kg grain per kg TDM showed that TZB-SR translocated significantly the least ($P<0.001$) dry matter to the grain, while HI was highest in hybrid cv. 8644-27. Similar trends were observed in 1993 and 1994, although 1993 values were relatively lower.

In 1993 sorghum dry matter at 35 DAP was similar at 90 and 120 kg N ha^{-1} (Fig. 4.07). Applied nitrogen significantly ($P<0.1$) increased the dry matter at 35 DAP in 1994 from 0.47 t ha^{-1} at 0 kg N ha^{-1} to 0.84 t ha^{-1} at 30 kg N ha^{-1} (Fig. 4.08). Further increment in applied N depressed dry matter by 8 percent compared to the 30 kg N ha^{-1} rate.

At maximum primodia development in both years, maize produced 20-42 percent more dry matter than sorghum. At their respective flowering and physiological maturity stages however, sorghum had 28-56 percent more total dry matter than maize in both years. This could be attributed to the longer duration of sorghum than maize, and hence, had more time to accumulate higher dry matter than maize. However, the

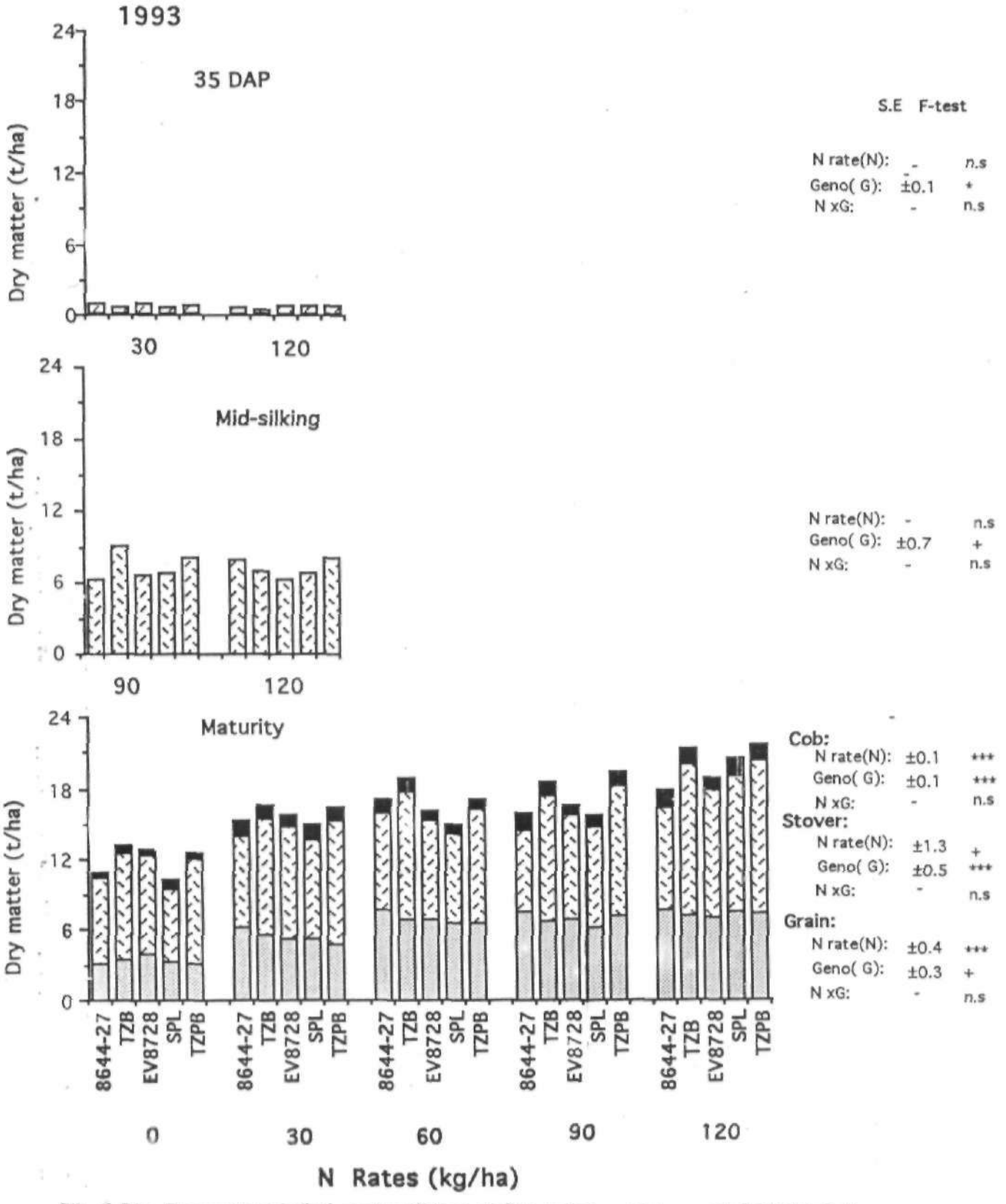


Fig. 4.05: Dry matter (t/ha) accumulation of five maize cultivars at 35 DAP and mid-silking, and partitioning at harvest as affected by N rates (kg/ha) in 1993.

n.s , +, * and *** means not significant and significant at P <0.1, 0.05 and 0.001.

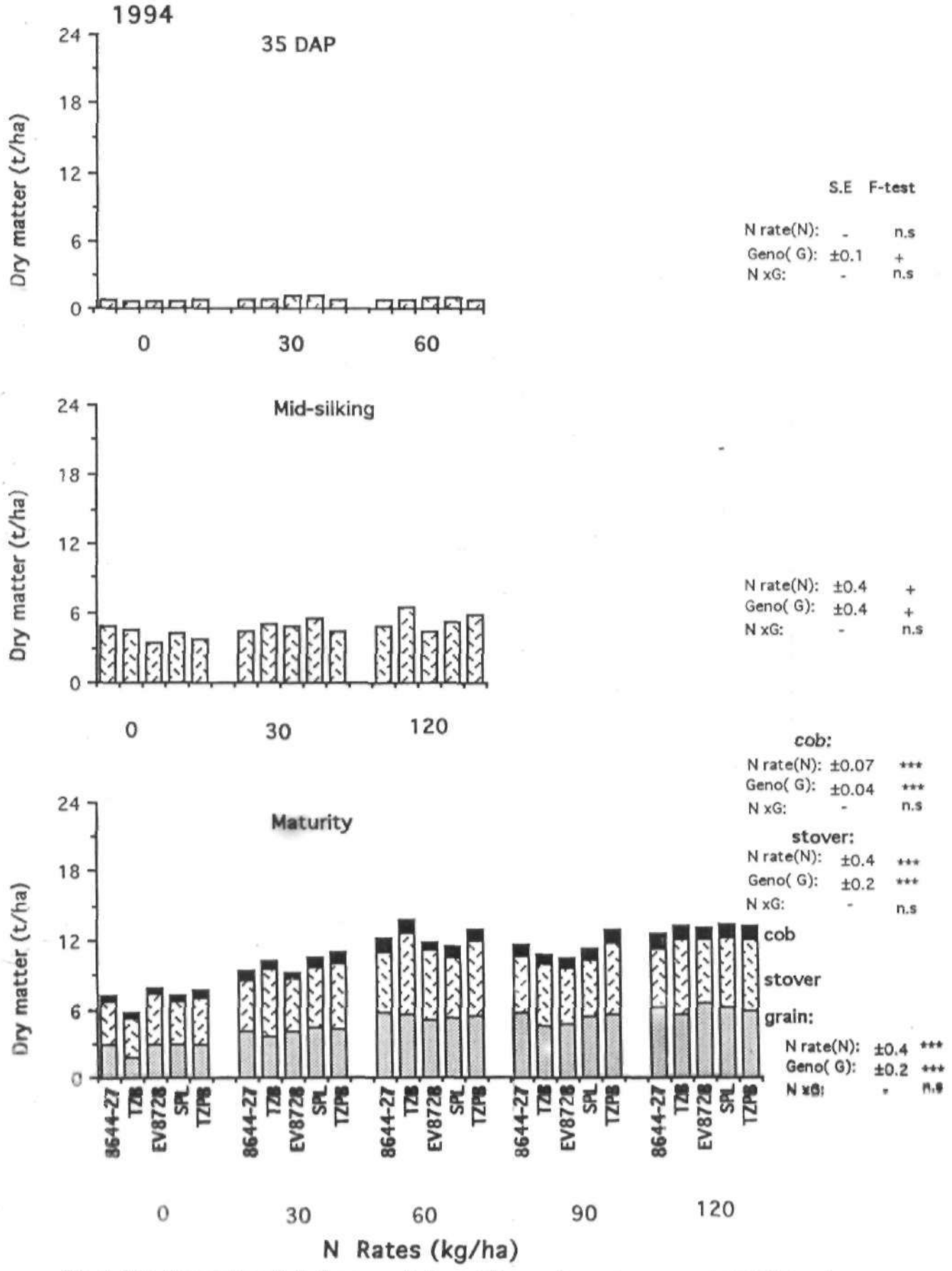


Fig. 4.06: Dry matter (t/ha) accumulation of five maize cultivars at 35 DAP and mid-silking, and partitioning at harvest as affected by N rates (kg/ha) in 1994.

n.s , +, and *** means not significant and significant at P <0.1 and 0.001.

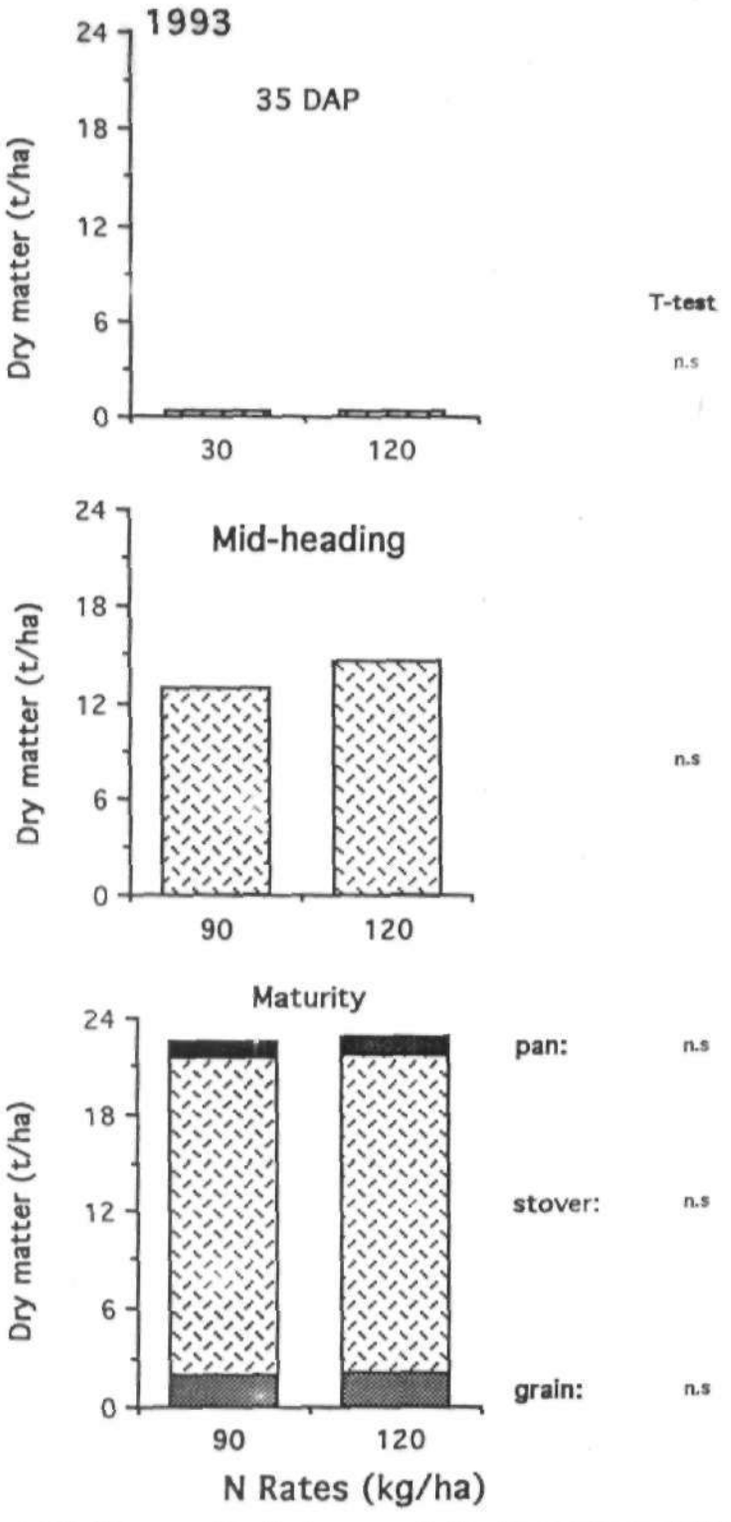


Fig. 4.07 Nitrogen (kg/ha) accumulation in sorghum at 35 DAP and mid-heading, and partitioning at harvest as affected by N rates (kg/ha) in 1993.

n.s means not significant *t*-test.

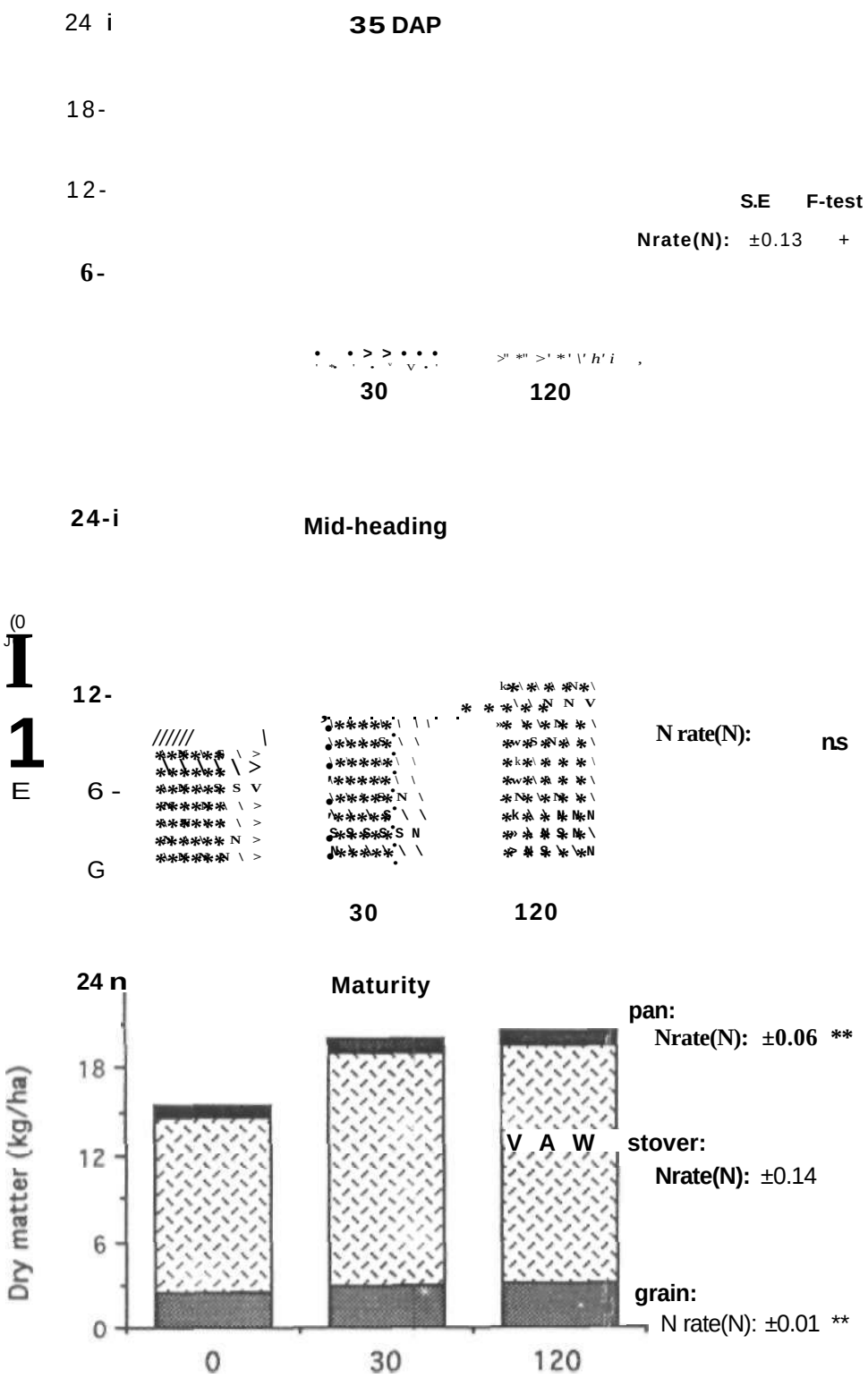


Fig. 4.08: Dry matter (t/ha) accumulation in sorghum at 35 DAP and mid-heading, and partitioning at harvest as affected by N rates (kg/ha) in 1994.

n.s, and ,*,**, *** means not significant and significant at *P* <0.05, 0.01, 0.001.

efficiency of conversion of assimilates for grain formation was relatively lower in sorghum than in maize.

Nitrogen had no effect on the total dry matter at mid-heading of sorghum in both years. However, at physiological maturity in 1994, dry matter content of the grain, stover and panicle were all significantly increased when 30 or 120 kg N ha^{-1} was applied compared to the control.

4.2.2.3. Components of yield and kernel growth rate in maize

The effect of applied N on all the components of yield including, thousand-kernel weight, kernel number per ear, number of ears per plant, and on kernel growth rate followed similar trends as dry matter partitioning in the plant (Fig. 4.09, 4.10, 4.11, 4.12). The hybrid, 8644-27 and Mokwa 87TZPB-SR had on average, over 18 percent larger ($P<0.001$) kernels compared to the widely grown OP, TZB-SR (Fig. 4.09). However, TZB-SR had at least 10 percent significantly more kernels per ear compared to the improved cultivars (Fig. 4.10). Only the semiprolific maize (SPL) could attain an average of one ear per plant at low N of 30 kg ha^{-1} (Fig. 4.11). It also had the highest ($P<0.001$) mean kernel growth rate of 2.34g day^{-1} in 1994 (Fig. 4.12).

4.2.2.4. Relationship between maize grain yield and N application

A second-order polynomial regression analysis gave the best curve fit for the data relating grain yield to N fertilizer rates across years. The equations for yield prediction curves, the predicted maximum yields, and their corresponding maximum N rates calculated from differentiation across season, are summarized in Table 4.03. Both SPL and EV8728-SR seemed to have higher potentials to adapt to nitrogen stress compared to other cultivars as indicated by higher yields in the absence of applied nitrogen in both years. Calculated maximum grain yields could be obtained at 102-162 kg N ha^{-1} with lowest rate for the hybrid 8644-27, and the highest rate for EV8728-SR.

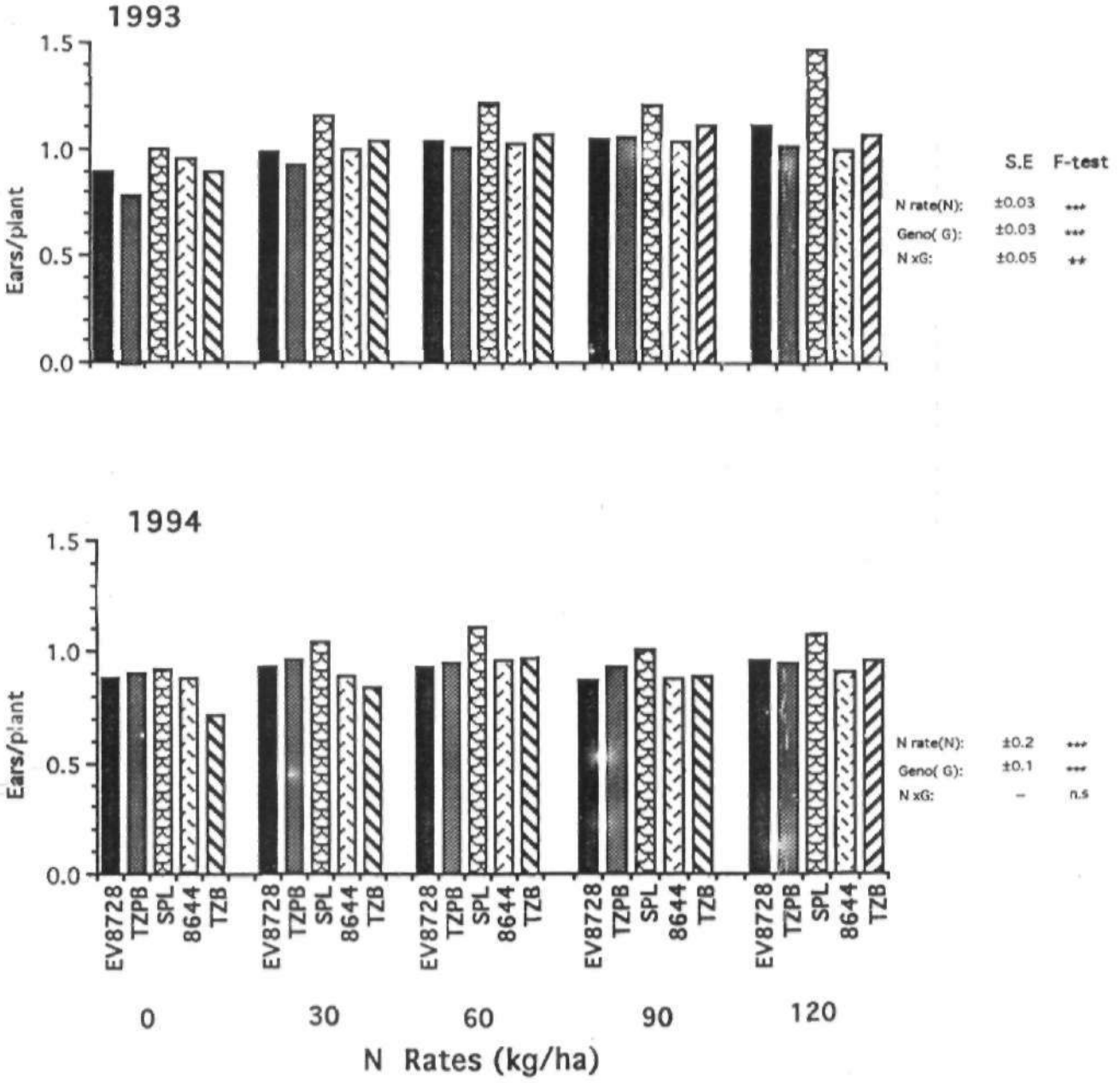


Fig. 4.09: Effect of N rates (kg/ha) on ear number/plant of five maize cultivars in 1993 and 1994.

n.s and **, *** means not significant and significant at $P < 0.01, 0.001$.

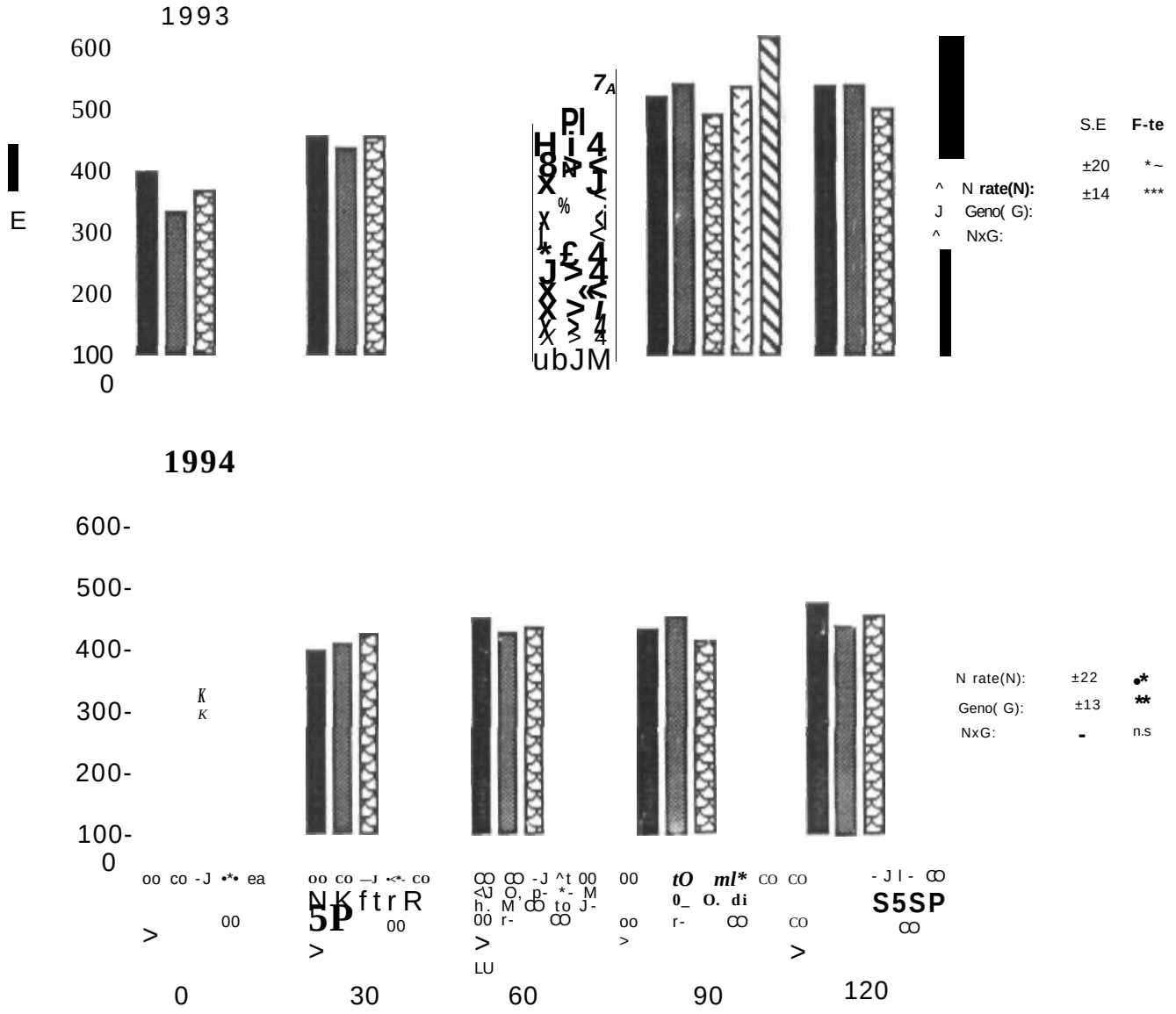


Fig. 4.10: Effect of N rates (kg/ha) on kernel number/plant of five maize cultivars in 1993 and 1994.

n.s ,** **and** *** **means** not significant and significant at *P* <0.01 **and** 0.001.

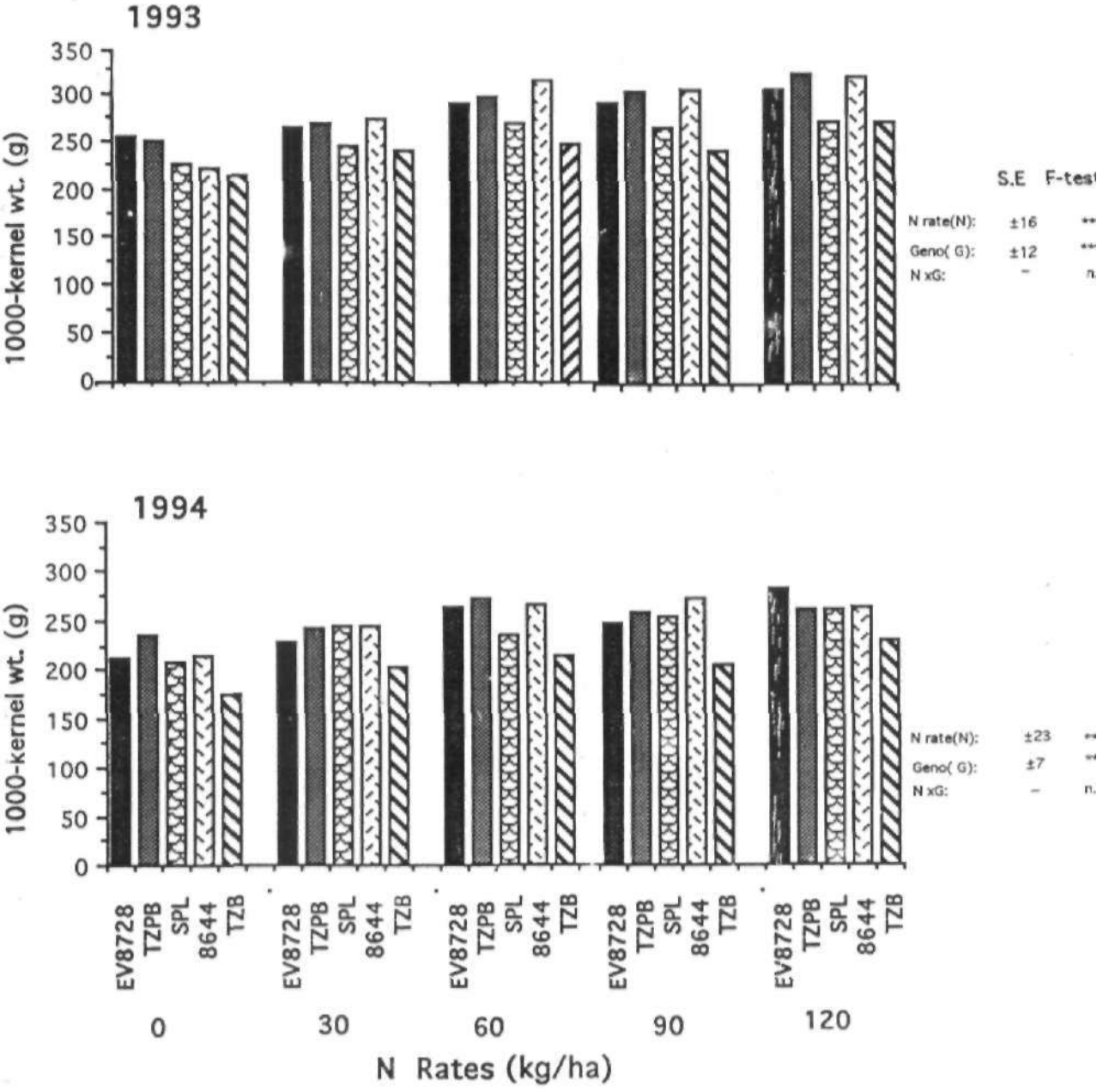


Fig. 4.11: Effect of N rates (kg/ha) on 1000-kernel weight (g) of five maize cultivars in 1993 and 1994.

n.s and *** means not significant and significant at $P < 0.001$.

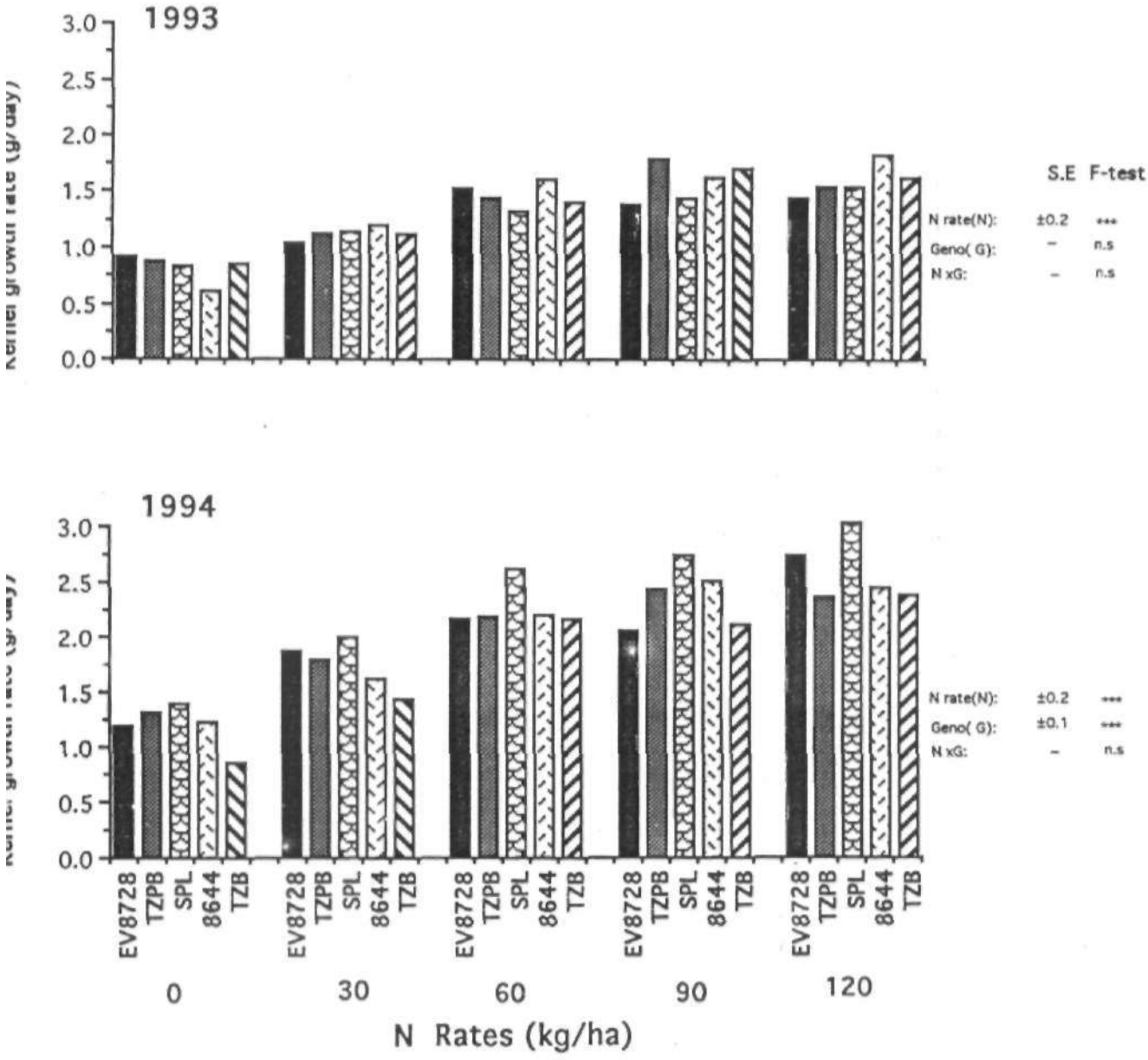


Fig. 4.12: Effect of N rates (kg/ha) on kernel growth rate (g/day) of five maize cultivars in 1993 and 1994.

n.s and *** means not significant and significant at $P < 0.001$.

Table 4.03: Regression models relating grain yield of the five varieties with N rates in 1993 and 1994

Variety	Regression equation[a] $Y = a + bX + cX^2$	R^2	N rate for max. yield (kg/ha)[a]	Maximum yield (t/ha)
EV8728-SR	$Y = 3267+41.908X -0.129X^2$	0.460***	162.43	6.67
Mokwa 87TZB-SR	$Y = 2772+62.992X -0.276X^2$	0.501***	114.12	6.37
SPL (Semi prolific)	$Y = 3117+47.073X -0.162X^2$	0.550***	145.29	6.54
8644-27 (Oba Super 2)	$Y = 2399+75.737X -0.373X^2$	0.531***	101.52	6.24
TZB-SR	$Y = 2537+68.436X -0.331X^2$	0.473***	103.38	6.07

[a]N rate for maximum yield was calculated with -b/2c (from differentiation); then substituted in the equation to get maximum yield. Number of observations= 45 ***$P<0.001$.

4.2.2.5. Relationship between maize grain yield and N deficiency symptom rating

Nitrogen application significantly reduced nitrogen deficiency symptom rating on the plants at mid-silking in both years, but no significant differences were observed among the cultivars in the rating (Appendix 3). This suggests that the rating scale can be used to assess the degree of N deficiency problem in any of the cultivars. A simple linear regression model could best express the relationship between grain yield and N deficiency symptom rating in both years (Fig. 4.13). The potential yield when there was no N deficiency ranged from 7.1 to 7.6t ha^{-1}. Under very severe N deficiency, or a scale of 9, yield reduction was as high as 64-80 percent in both years.

4.2.3. Nitrogen Accumulation in Maize and Sorghum

4.2.3.1. Nitrogen uptake at the vegetative growth phase

In 1993, evaluations were done only on 30 and 120 kg N ha^{-1} at 35 DAP, and 90 and 120 kg ha^{-1} at silking. At both sampling dates, differences in N uptake at these rates were not significant (Fig. 4.14). Nitrogen application in 1994 significantly increased N uptake by more than 50 percent at stem elongation growth phase (35 DAP). But at silking, significant differences were observed only with 120kgN ha^{-1} (Fig. 4.15).

Nitrogen uptake at 35 DAP in 1993 was relatively lower than in 1994 and ranged between 17-20kg N ha^{-1} among the improved cultivars. In 1993 and 1994 the least N accumulation of 12-18kg ha^{-1} were observed in cultivar TZB-SR at 35 DAP (Fig. 4.14 and 4.15). Among the improved cultivars, except the hybrid cv.8644-27 which accumulated 19.4kg Nha^{-1}, all others had taken up 20-24kg Nha^{-1} at 35 DAP in 1994.

Total nitrogen uptake at silking in 1994 was about 15 percent higher (P=0.05) in Mokwa 87TZPB-SR and 8644-27 than in TZB-SR. Differences among cultivars were not significant in 1993, although Mokwa 87TZPB-SR accumulated more N (211 kg ha^{-1}) than all other cultivars. Rate of N uptake between 35 DAP and silking,

calculated as difference in N uptake between the two sampling dates, showed that the hybrid cv. 8644-27 and EV8728-SR had significantly higher ($P<0.05$) N-uptake rate of 111-116 g N ha^{-1} day^{-1} compared to TZB-SR in 1994 (calculated from Fig. 4.15). There were no clear differences between cultivars in rate of N-uptake in 1993 (Fig. 4.14). The proportion of total N taken up by the different cultivars at 35 DAP and at silking in 1994 were:

EV 8728-SR	18 and 70 percent
Mokwa 87TZPB-SR	22 and 79 percent
SPL	27 and 62 percent
hybrid cv.8644-27	25 and 80 percent
TZB-SR	21 and 63 percent

4.2.3.2. Nitrogen taken up at the generative growth phase

In 1994 nitrogen taken up during the generative growth phase, between silking and harvest, was comparatively low (15 kg ha^{-1}) in the hybrid cultivar 8644-27 as against 22-35 kg ha^{-1} recorded in other cultivars (Fig. 4.14). Cultivars TZB-SR and SPL had a higher extended N uptake as indicated by a relatively higher N uptake of 33-35 kg ha^{-1} compared to the other cultivars. Due to differences in N rates at which sampling was done at silking and at harvest in 1993, a similar comparison could not be made on 1993 results.

4.2.3.3. Accumulation and partitioning of nitrogen within the plant at physiological maturity

The total above-ground N uptake (net N uptake) at harvest followed the same trend as dry matter at harvest (Fig. 4.14). Net N uptake was significantly lower by 51 kg ha^{-1} in 1994 than in 1993.

The effect of N application on nitrogen allocation to the grain, stover and cob in both years, followed a similar trend as dry matter partitioned to these organs

(Fig. 4.14 and 4.15). There were no statistically significant differences between cultivars in N allocation to the grain (21-89 kg ha^{-1}) in both years.

Nitrogen partitioned to the stover was always higher ($P<0.001$) and varied from 64 to 75 kg ha^{-1} in TZB-SR and Mokwa 87TZPB-SR and from 44 to 65 kg ha^{-1} in the other cultivars in both years (Fig. 4.14 and 4.15). There were no differences among cultivars in N concentration in the stover. The hybrid cultivar 8644-27 had the highest cob-N uptake of 5.8kg ha^{-1} in both years (Fig. 4.14 and 4.15), and could be a good filler in animal feed formulation.

The partitioning of N to the grain, nitrogen harvest index, calculated as kg grain nitrogen/kg total N uptake (from Fig. 4.14 and 4.15), increased significantly from 0.47 to 0.62 with increasing N rates until 60 to 90 kg N ha^{-1}. Increasing N to 120 kg ha^{-1} decreased nitrogen harvest index in 1993. A similar trend was observed in 1994, but the values significantly increased from 0.18 at 0 kg N ha^{-1} to 0.27 at 120 kg N ha^{-1}.

In both years, nitrogen harvest index of the hybrid cv. 8644-27 was higher than the values obtained for the other cultivars, and was lowest in TZB-SR and Mokwa 87TZPB-SR.

The effect of N application on N uptake and N allocation in sorghum followed a trend observed on their effects on dry matter partitioning in the whole plant (Fig. 4.16 and 4.17). Also, N uptake in maize relative to sorghum followed the same response pattern as the dry matter.

4.2.4 Nitrogen Dynamics and Available N Depletion

Data on soil available N during both growing seasons are presented in Fig. 4.18 and 4.19. Soil available N in 0-90 cm horizon was significantly ($P<0.01$) higher by more than 20 percent under 120 kg ha^{-1} than under 0 or 30 kg N ha^{-1} at mid-silking in 1994 only. Analysis by depth showed that at 35 DAP in 1994, more ($P<0.01$) available N of 61 kg ha^{-1} was found at 30-60 cm layer with application of 120 kg ha^{-1}

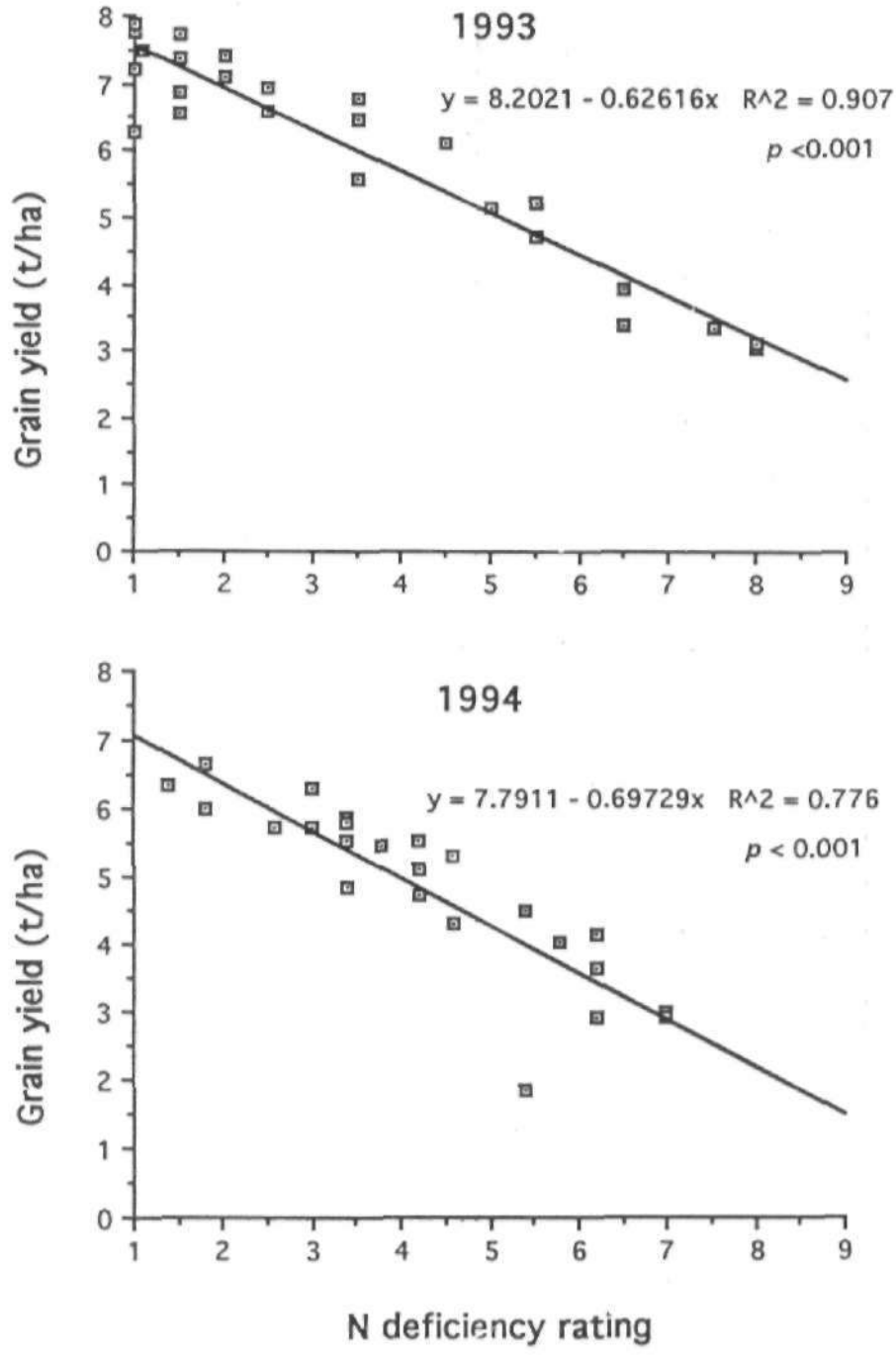


Fig. 4.13: Relationship between grain yield (t/ha) and N deficiency symptom rating in five maize cultivars in 1993 and 1994.

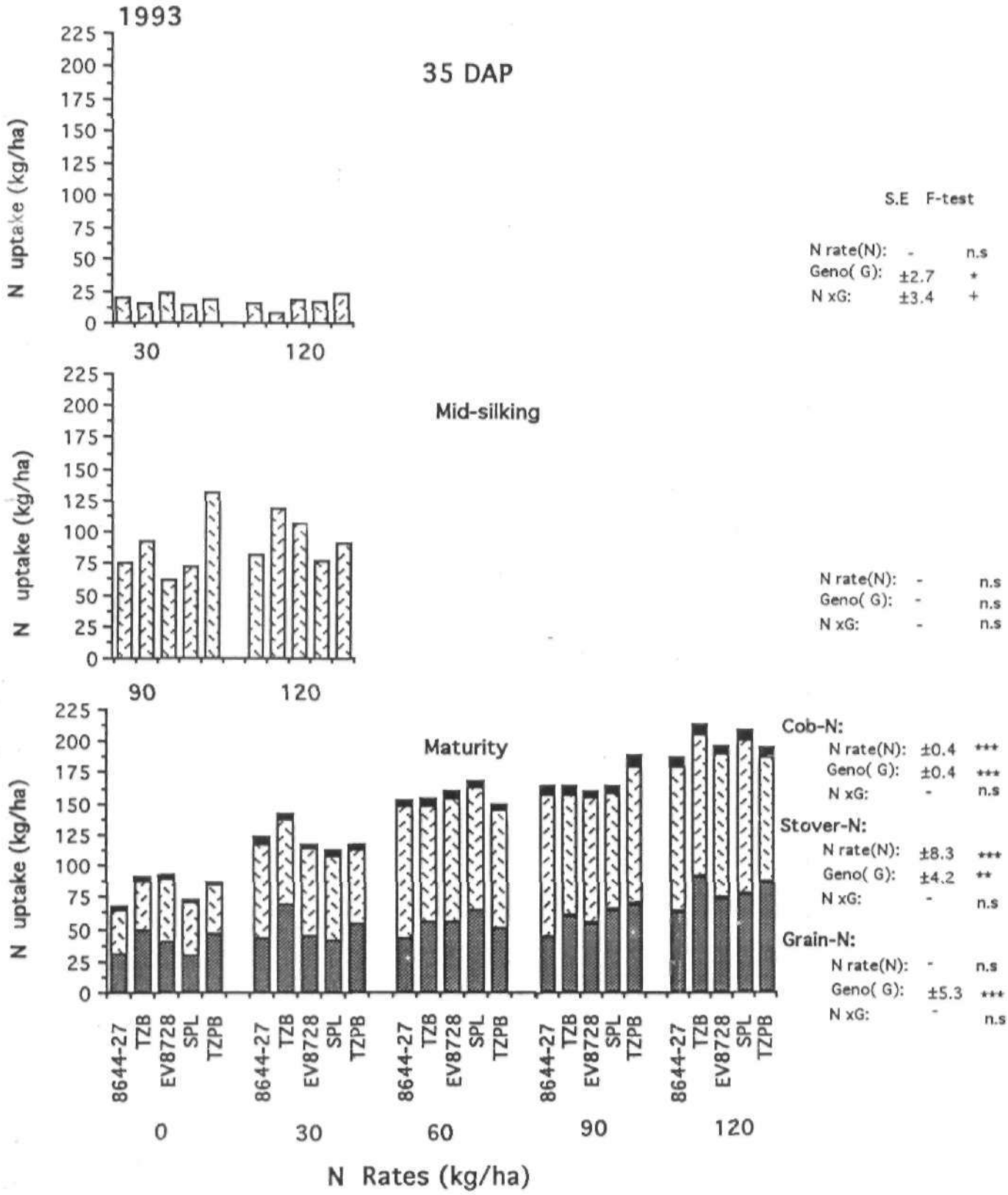


Fig. 4.14: Nitrogen (kg/ha) accumulation of five maize cultivars at 35 DAP and mid-silking, and partitioning at harvest as affected by N rates (kg/ha) in 1993.

n.s , +, * * and *** means not significant and significant at P <0.1, 0.01and 0.001.

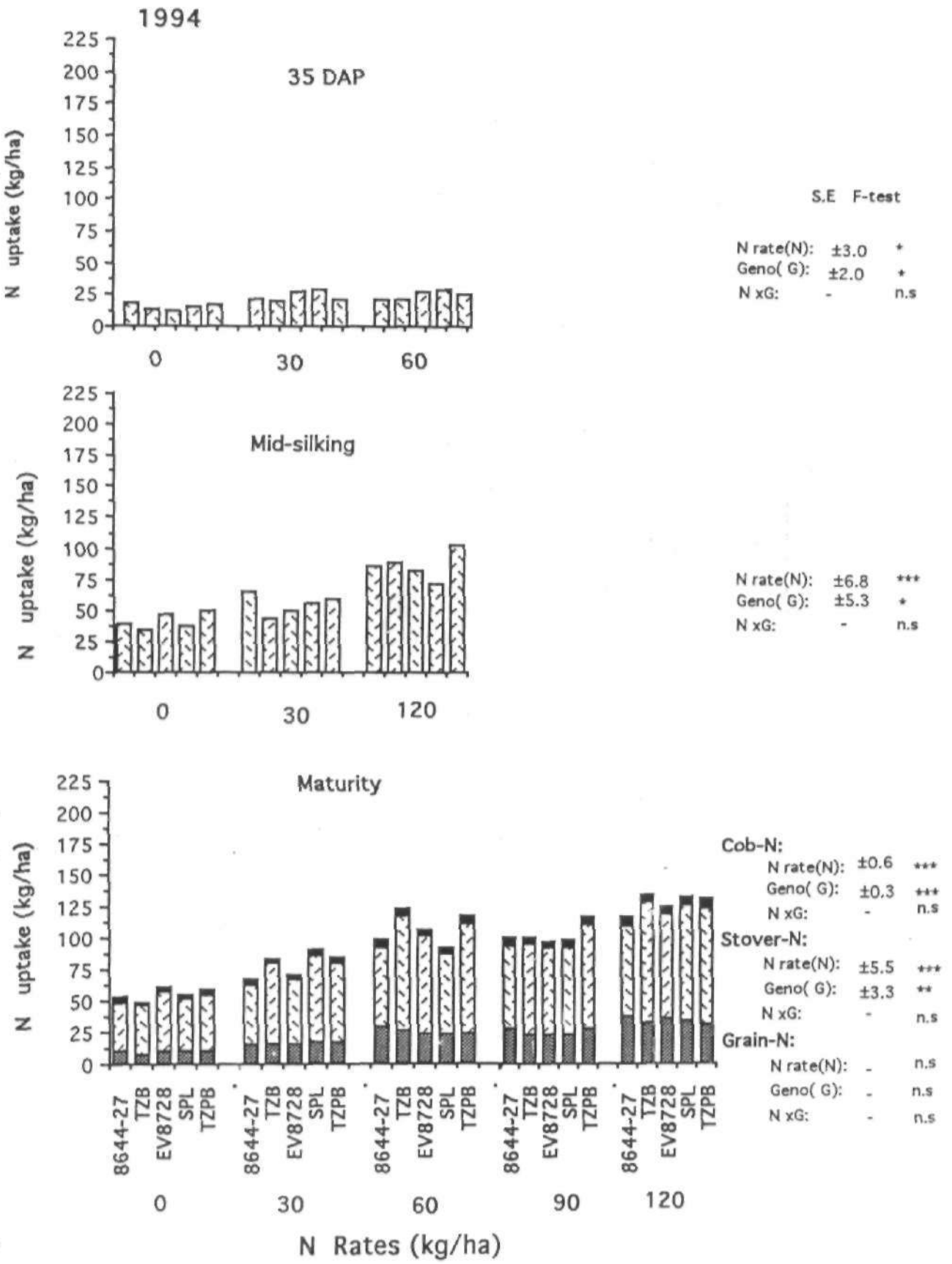


Fig. 4.15: Nitrogen (kg/ha) accumulation in five maize cultivars at 35 DAP and mid-silking, and partitioning at harvest as affected by N rates (kg/ha) in 1994.

n.s and *, **, *** means not significant and significant at $P < 0.05$, 0.01, and 0.001.

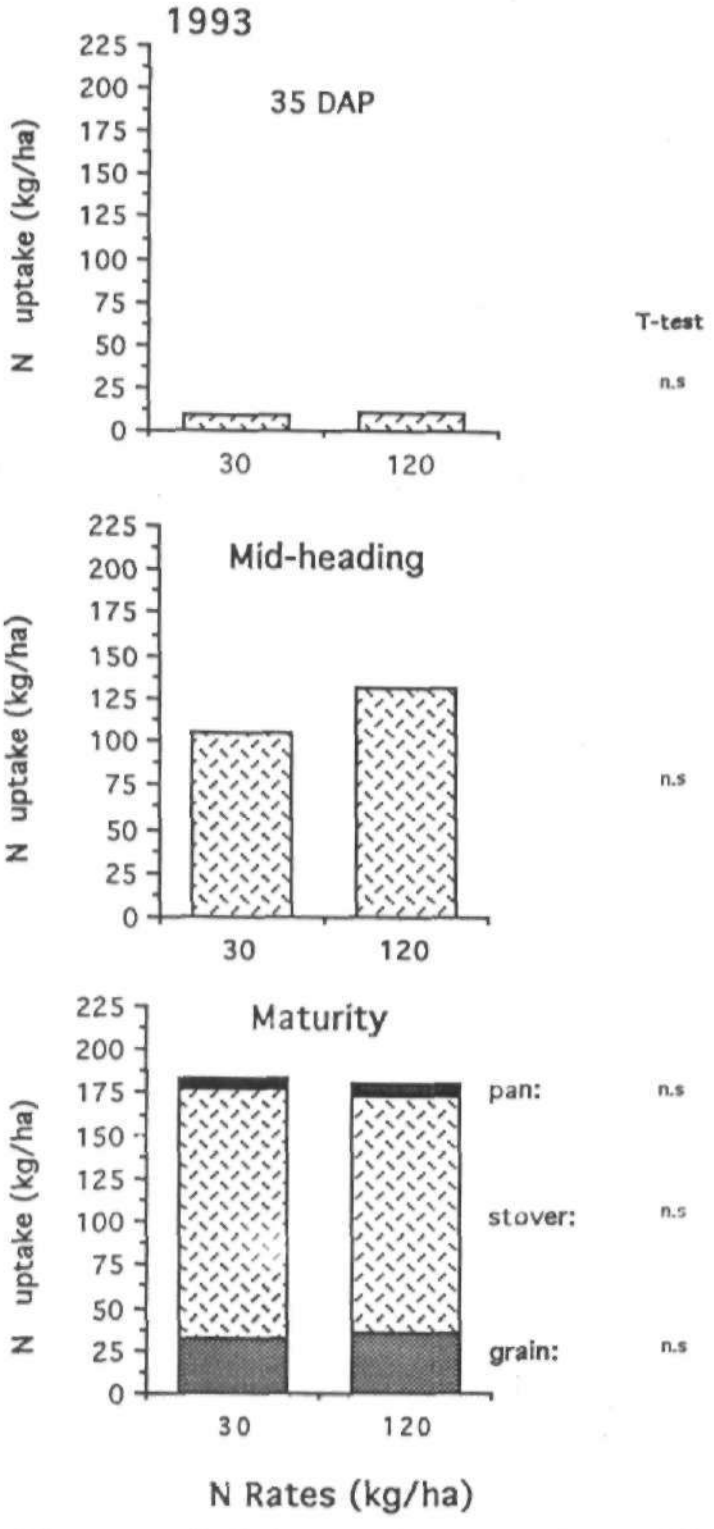


Fig. 4.16 Nitrogen (kg/ha) accumulation in sorghum at 35 DAP and mid-heading, and partitioning at harvest as affected by N rates (kg/ha) in 1993.

n.s means not significantt-test.

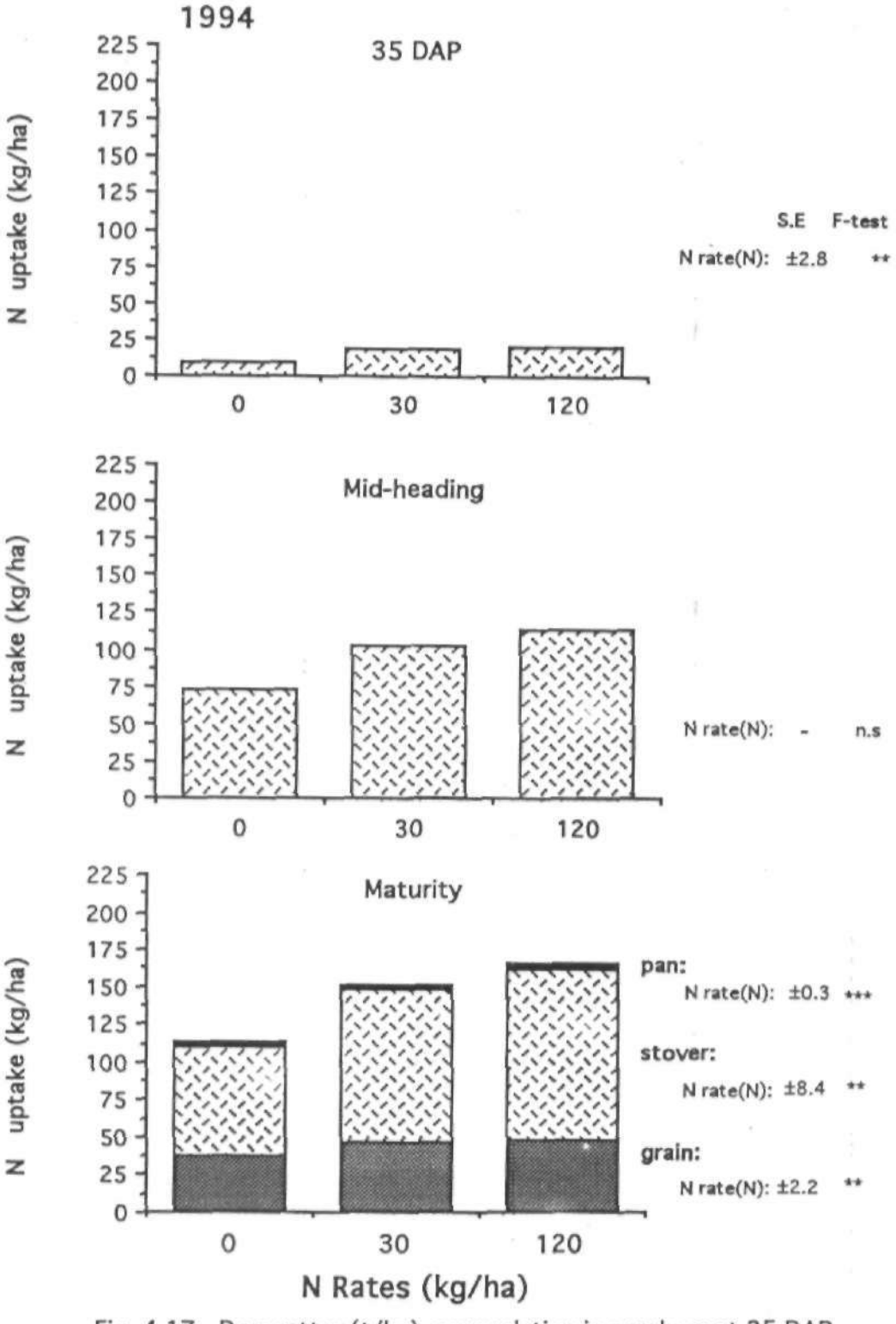


Fig. 4.17: Dry matter (t/ha) accumulation in sorghum at 35 DAP and mid-heading, and partitioning at harvest as affected by N rates (kg/ha) in 1994.

n.s and **, *** means not significant and significant at P <0.01, 0.001.

as against 46 and 38 kg ha^{-1} under 30 and 0 kg N ha^{-1}, respectively (Fig. 4.19). N rates did not affect soil N at other depths. However, there were no significant differences between N applied at 90 and 120 kg ha^{-1} at all sampling dates in 1993 trial (Fig. 4.18).

At mid-silking, 120 kg N ha^{-1} gave 13-21 percent more ($P<0.01$) available N at 15-30 cm soil layer than 0 or 30 kg ha^{-1}. Also, at 30-60 cm depth, 0 and 30 kg N ha^{-1} significantly gave lower soil N of 13-15 kg ha^{-1} compared to 24 kg ha^{-1} obtained under 120 kg ha^{-1}. Differences in soil N at other depths were not significant.

The residual N content in 60-90 cm layer at physiological maturity of maize in 1994 was 36-40 kg ha^{-1} ($P<0.01$) under 120 kg N ha^{-1} compared to 24 kg ha^{-1} under zero-N. Nitrogen application did not affect the residual N at other soil depths. On the whole, the residual available N in the 0-90cm soil layer ranged from 53-64 kg ha^{-1} in 1993 and from 70-97 kg ha^{-1} in 1994.

There were no obvious differences between cultivars in soil available N during the two growing seasons. Also cultivar by depth interactions were not significant. However, some trends were noted. At 35 DAP in 1994, soil N in the topsoil (0-15cm) was slightly lower (59 kg ha^{-1}) under Mokwa 87TZPB-SR and the hybrid cv. 8644-27 than under the other cultivars (63-69 kg ha^{-1}). A similar trend was observed in 1993.

In 1994 available N depletion between planting and stem elongation phase was non significantly lowest, 10 kg ha^{-1} under SPL (Fig. 4.19). Both SPL and 8644-27 had 8-11 kg ha^{-1} soil N depletion at the same period in 1993 (Fig. 4.18). There was little or no depletion of soil N under the other cultivars. The available N depletion at 35 DAP in 1994 in 0-30cm layer slightly reflected differences in N uptake among cultivars. At 30-90cm horizon, 0-27 kg available N ha^{-1} was depleted between 0 and 35 DAP in both years. This may have been lost from the system through leaching.

At mid-silking in 1994, soil N in 0-90cm horizon was 10-13 percent higher

(not significant) under cultivars 8644-27 and EV8728-SR and under SPL and EV8728-SR in 1994. Available N depletion in this depth at the vegetative growth phase, the phase of most active N uptake, was 39-44 kg ha^{-1} under EV8728-SR and SPL compared to 10-16 kg ha^{-1} under the other cultivars. At the same period in 1994, N removal was 118 kg ha^{-1} under Mokwa 87TZPB-SR and 8644-27 compared to 86-99 kg ha^{-1} removed under the other cultivars.

The residual N in 0-90 cm horizon at physiological maturity in both seasons was similar under all the cultivars. It ranged from 54-62 kg ha^{-1} in 1993 and from 81-86 kg ha^{-1} in 1994. However, when the available N at the beginning of the seasons was accounted for at the end of 1994 growing season, N removal in 0-90 cm horizon was significantly ($P<0.05$) higher (159-179 kg ha^{-1}) under Mokwa 87TZPB-SR and TZB-SR, than under EV8728-SR and SPL. In 1993, N removal was higher, but not significant under Mokwa 87TZPB-SR and SPL (81-99 kg ha^{-1}).

At the generative growth phase (i.e, between mid-silking and maturity) there was only a slight removal of N (less than 10 kg ha^{-1}) in surface 0-15cm layer in 1993, and in 0-60 cm layer in 1994. In both years, more N was depleted from 60-90cm layer.

Furthermore, in both growing seasons independent of cultivars and N rates, significantly higher N was found in the 30-90cm subsoil layer than in the topsoil at all sampling dates.

There were no clear differences between 90 and 120 kg N ha^{-1} on available soil N under sorghum at all sampling dates in 1993 (Fig. 4.18). Also, increasing N rates from 0 to 30 or 120 kg ha^{-1} had no significant effect on soil N under sorghum in 1994 (Fig. 4.19). The range of values of available soil N in the 0-30cm topsoil horizon from planting to physiological maturity were: 73-85, 47-84, 26-38, and 13-30 kg ha^{-1} for 0 and 35 DAP, mid-heading (117-121 DAP) and maturity (153-160 DAP), respectively. The corresponding values in the subsoil (60-90cm) were

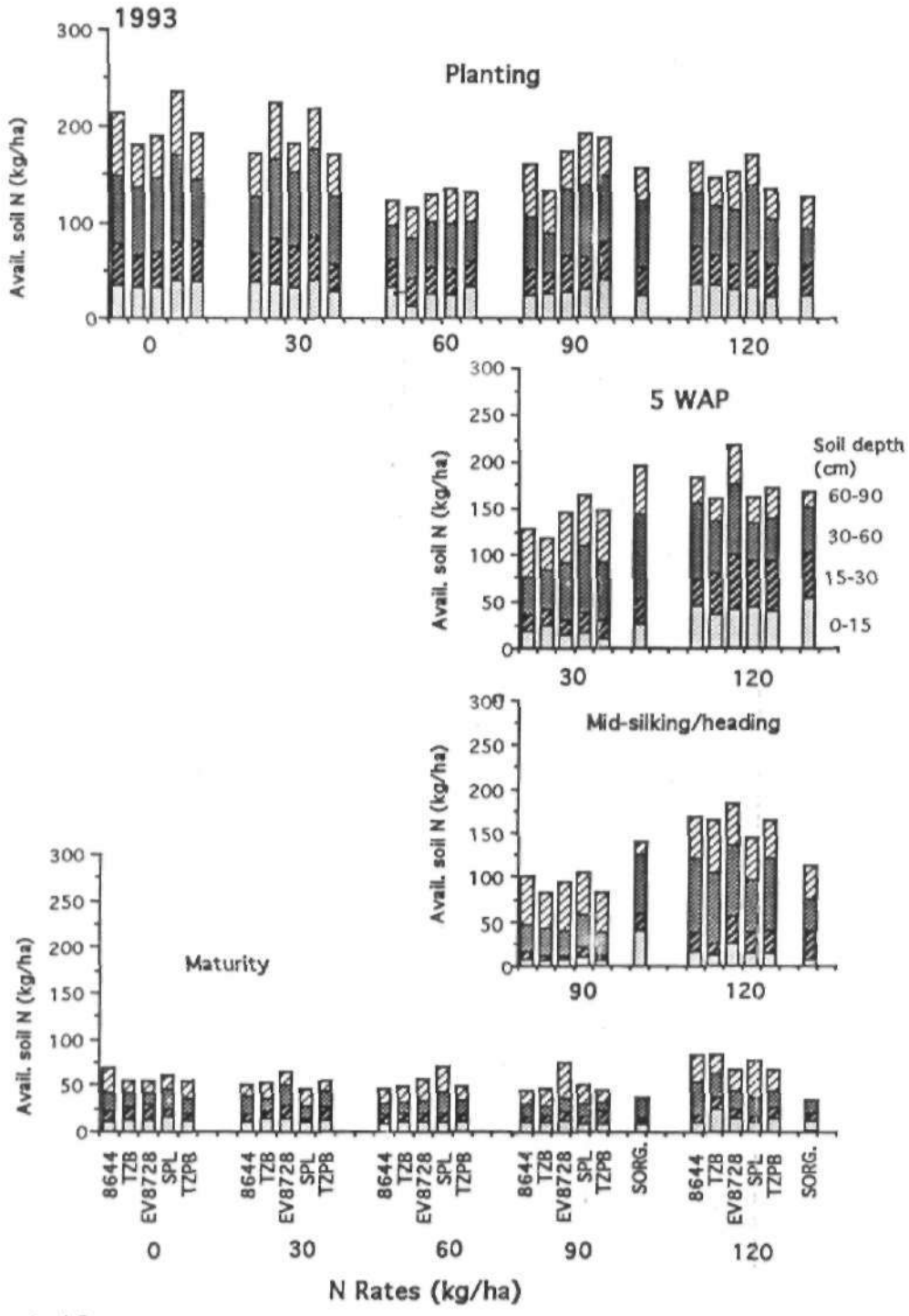


Fig. 4.18: Available N contents (kg/ha) at 4 profile depths under five maize cultivars and sorghum from 28/5-6/11/1993 as affected by N rates.

Statistics has been explained in section 4.2.4

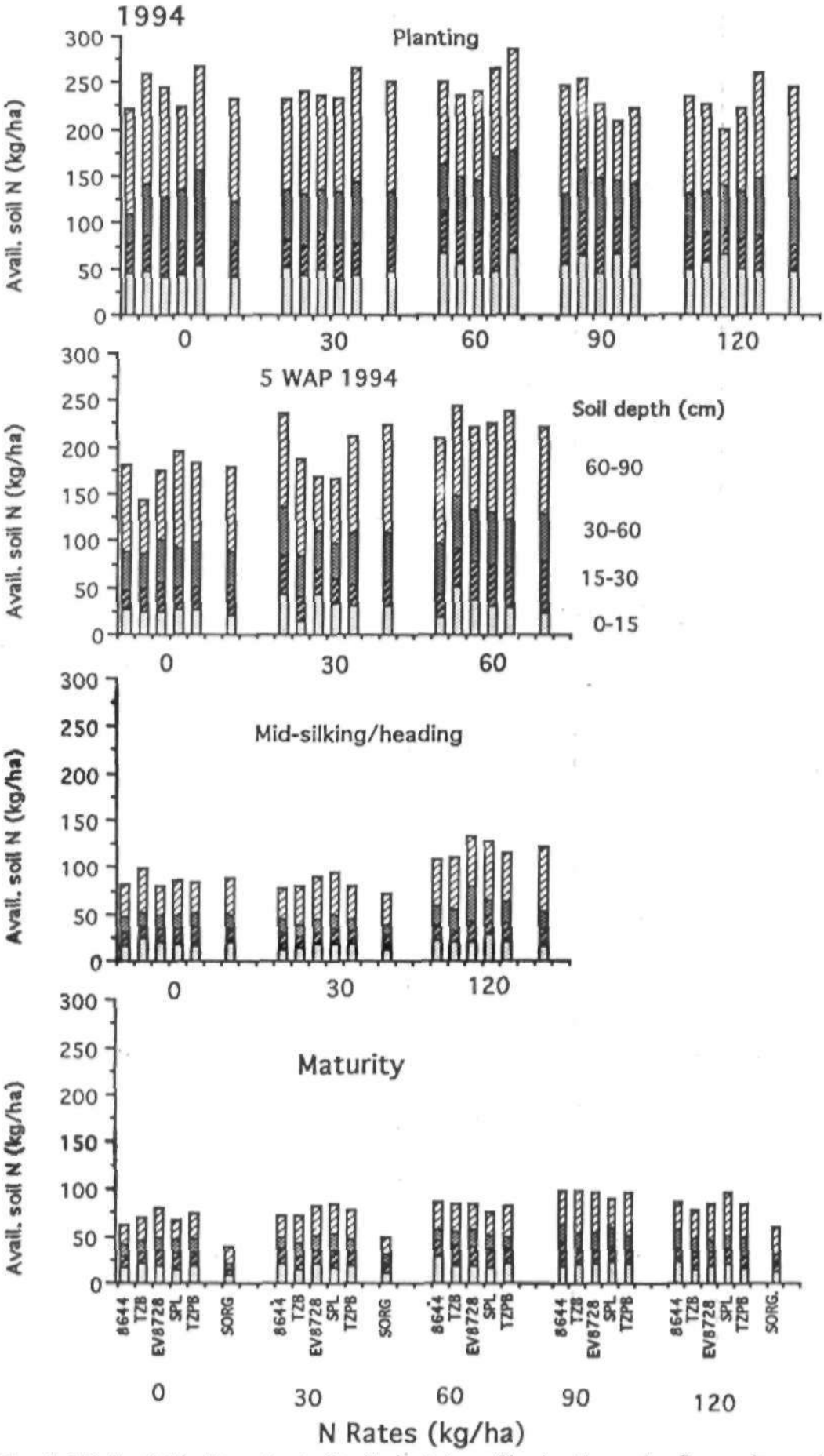


Fig. 4.19 :Available N contents (kg/ha) at 4 profile depths under five maize cultivars and sorghum from 16/6-18/11/1994 as affected by N rates.

Statistics has been explained in section 4.2.4

94-118, 91-116, 34-69 and 16-27 kg ha^{-1}.

4.2.5 Root Morphological Characterization

4.2.5.1 Root length density

At 35 DAP: Root length density in cm cm^{-3} responded significantly to N application in 1994, with the highest ($P<0.01$) root length density of 0.13 cm cm^{-3} found at 60 kg N ha^{-1} (Fig. 4.20). Although not significant, root length density average over N rate was higher (0.09-0.13 cm cm^{-3}) in all the improved cultivars than in TZB-SR. There were significant ($P<0.01$) differences in root length density between depths. About 64 percent of the total root length in 0-60cm horizon was located in the surface 0-15cm layer. Significantly ($P<0.01$) more root length density (0.37 cm cm^{-3}) was found in the surface layer were 60 kg N ha^{-1} was applied than in other depths with or without N application. Analysis by depth showed that in 0-15cm layer the improved cultivars had 38-53 percent significantly more root length density than cultivar TZB-SR. Root length density was highest (0.34 cm cm^{-3}) in Mokwa 87TZPB-SR at 0-15cm, and at 15-30cm depths but these were not significant. Root length density was not measured in 1993.

In 1994, root length density in sorghum at 35 DAP increased non significantly from 0.3-0.5 cm cm^{-3} when N rate was increased from 0 to 60 kg ha^{-1} (Fig. 4.20). The roots were concentrated in 0-45cm horizon with 53 percent of this located in 15-30 cm layer.

There were 30 percent more roots in sorghum than in maize at stem elongation phase (35 WAP). Whereas more maize roots were found in 0-15cm layer, there were more sorghum roots located in 15-30cm layer showing deeper penetration of sorghum roots than maize roots at stem elongation phase.

At Mid-silking/-heading: Root length density averaged over cultivars and depths although not significant increased by 16 and 11 percent when 30 and 120 kg N ha^{-1} was applied than 0 kg N ha^{-1} in 1994 (Fig. 4.20). Root length density was depressed

in SPL and TZB-SR by 120 kg N ha^{-1}, while this rate stimulated root length density in the other cultivars more than the control (0 kg N ha^{-1}). There were no clear differences in root length density between 90 and 120 kg N ha^{-1} in 1993 (Fig. 4.20).

The root length densities of Mokwa 87TZPB-SR and SPL were 27 percent higher ($P<0.05$) than the root length density of TZB-SR or 8644-27 in 1994. All the cultivars had roots distributed down to 90cm, and differences in root length density were significant ($P<0.01$) between depths with 23 and 27 percent of the total root length density in 0-90cm layer found in 15-30 and 30-45cm layer. Except where 120 kg N ha^{-1} was applied which gave a high root length density of 3.1cm cm^{-3} in the surface 0-15cm layer, root length density was lower ($P<0.01$) in this depth than in the other depths when 0 or 30 kg N ha^{-1} was applied in 1994. This may be attributed to localized stimulation of root length in 0-15cm from the addition at 5 WAP, of the second split (60 kg ha^{-1}) of the highest rate. In the subsoil 60-90cm, root length density was lower ($P<0.01$) by 47 and 63 percent at zero-N and 120 kg N ha^{-1} rates than at 30 kg N ha^{-1}.

There were no significant cultivar by depth interactions. Analysis by depth however, showed that root length density at 0-45cm layer in 1993 were higher in Mokwa 87TZPB-SR than in the other cultivars, but differences were significant ($P<0.01$) only in the 0-15cm layer. Root length density in 1994 were higher ($P<0.05$) in Mokwa 87TZPB-SR and SPL than in the other cultivars at 45-60cm and 60-75cm depths. There were no clear differences in root length density among cultivars at other depths.

Nitrogen application had no significant effect on sorghum root length density at mid-heading stage (Fig. 4.20). The highest rate of 120 kg N ha^{-1} slightly decreased the root length density. There were also, no significant differences between 90 and 120 kg N ha^{-1} in 1993. The highest ($P<0.001$) root length (47 percent of the total root length in the 0-60cm soil layer sampled) was found in the surface 0-15cm,

while only 8 percent was found in 45-60cm horizon.

A sole crop sorghum system had more roots but more superficially located than a sole crop maize system. In 0-90cm horizon the total root length density of maize was 10.5cm cm^{-3} while in only 0-60cm horizon, the total root length density of sorghum was 11.8cm cm^{-3} and 47 percent of this was in 0-15cm layer.

4.2.5.2 Root dry matter production

35 DAP: Application of 60 kg N ha^{-1} gave 25 percent more (P<0.01) root dry matter than zero-N (Fig. 4.21). Root dry matter averaged over N rates, was significantly higher in Mokwa 87TZPB-SR and the hybrid cv. 8644-27 than in cv. TZB-SR. There were highly significant differences in root dry matter between soil depths. About 50 percent of the total root dry matter in 0-60 cm horizon was found in the surface 0-15cm layer. Also, root dry matter contained in 0-15cm and 15-30 cm layers was significantly (P<0.01) higher by 14-39 percent when 60 kg N ha^{-1} was applied than under zero-N. Furthermore, significantly (P<0.01) greater proportion of the root dry matter of all the improved maize cultivars was found in 0-15cm layer compared to the root dry matter of cultivar TZB-SR contained in this layer. There was no significant cultivar x N rate interaction on root dry matter.

At 35 DAP sorghum root dry matter followed a similar trend as the root length density at the same period in 1994 (Fig. 4.21).

Mid-silking/heading: Application of nitrogen did not affect the root dry matter of maize at mid-silking in both growing seasons. The values followed a similar trend as the root length density (Fig. 4.21). Also, differences in root dry matter between cultivars and between depths followed a similar trend as the root length density at silking in both years.

N application did not affect sorghum root dry matter at mid-heading in both growing seasons. Root dry matter distribution in the soil profile followed a similar trend as the root length density distribution (Fig. 4.21).

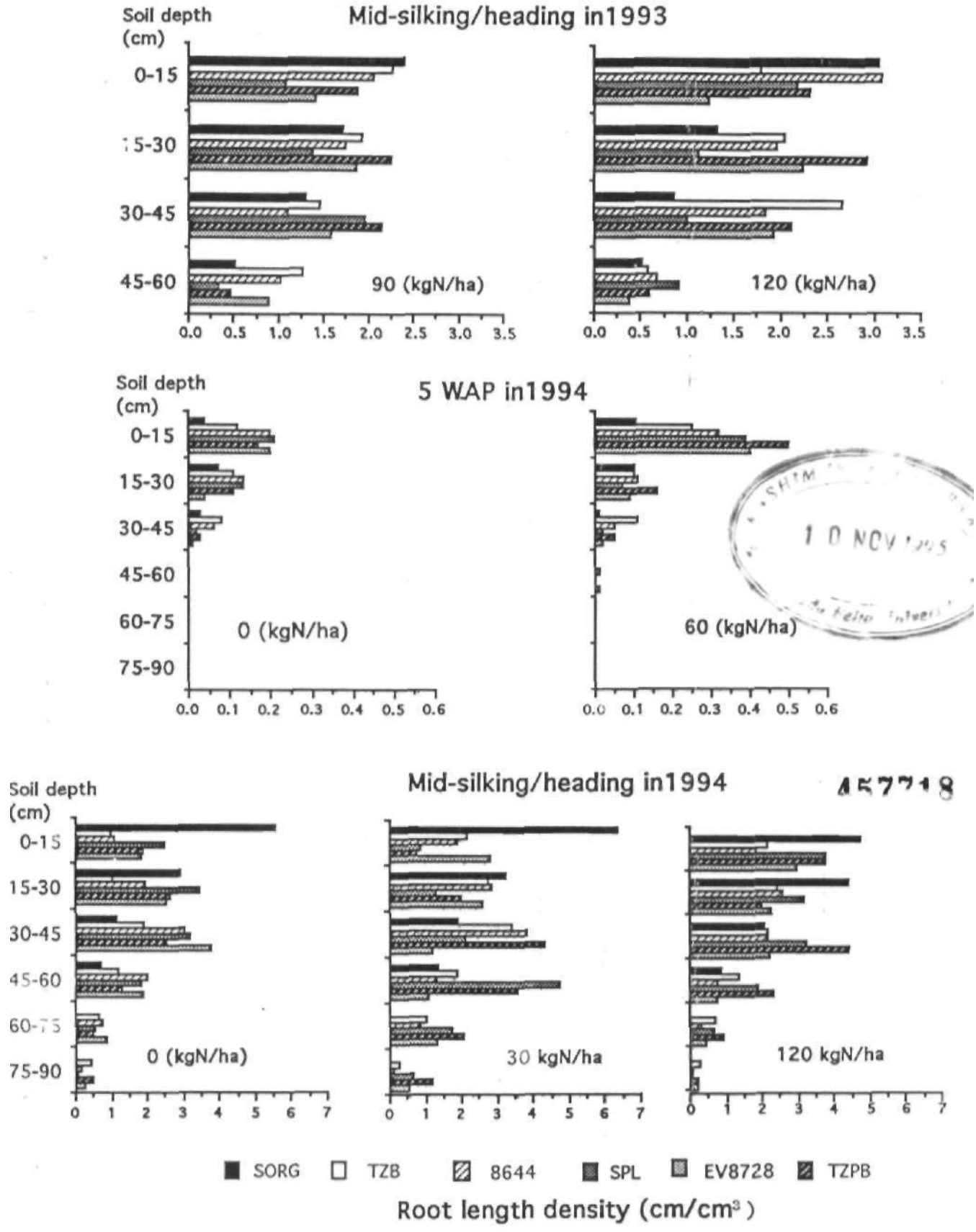


Fig. 4.20 Root length density (cm/cm³) at various profile depths at 35DAP and silking/heading of five maize cultivars and sorghum as affected by N rates in 1993 and 1994.

n.s, +, * and ** means not significant and significant at P <0.1, 0.05, 0.01, for maize at each depth.

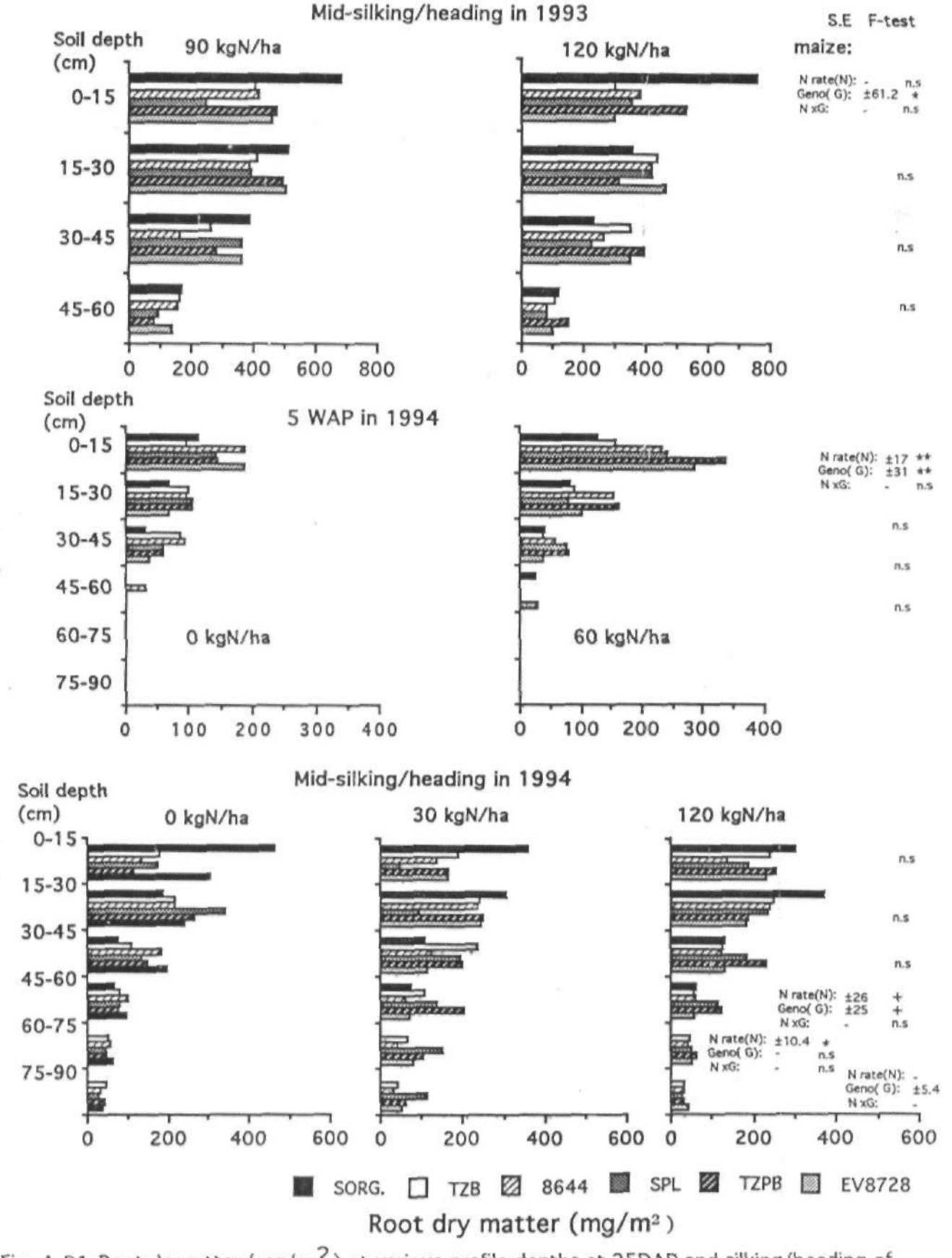


Fig. 4. 21: Root dry mtter (mg/m^2) at various profile depths at 35DAP and silking/heading of five maize cultivars and sorghum as affected by N rates in 1993 and 1994.

n.s , +, * and ** means not significant and significant at P <0.1, 0.05, 0.01, for maize at each depth.

4.5.2.3 Shoot/ Root ratio and N uptake rate per root length in maize

Shoot/root ratio is a measure of partitioning of dry matter to the above- and below-ground parts. At 35 DAP and mid-silking in 1994, it was not affected by N application (Table 4.04). At 35 DAP, the ratio was lower ($P<0.1$) in Mokwa 87TZPB-SR and 8644-27 (222-224) than in TZB-SR with a ratio of 357. This suggests that there was more partitioning of dry matter to the shoot of TZB-SR. While at mid-silking, SPL gave non-significantly lower ratio of 430 compared to the ratio of 460-483 obtained in the other cultivars. Cultivar by nitrogen interactions were not significant.

Rate of nitrogen uptake per metre root length in 0-90cm horizon in 1994 was estimated at 0 and 120kg N ha^{-1}, and 120 kg N ha^{-1} gave 46 percent more ($P<0.01$) N uptake per m root length than the zero-N control. N uptake was higher (1.05 mmol m^{-1} day^{-1}) in TZB-SR than in the improved cultivars, but not statistically significant.

4.2.6. Nitrogen Efficiency Parameters in Maize and Sorghum

4.2.6.1. Nitrogen uptake efficiency

Nitrogen uptake efficiency (NupE) is defined as kg N taken up by the crop per unit kg of available soil N (mineral N at planting + fertilizer N, where applicable). At 35 DAP and mid-silking, N supply had no effect on NupE in both years (Tables 4.05 and 4.06). At maize harvest in 1993 (Table 4.05b) NupE significantly increased with N application from 0.4 kg at 0 kg N ha^{-1} to 0.87 kg at 60 kg N ha^{-1} for every kg of available soil N. Subsequent increments in N depressed uptake efficiency. A similar trend was observed in 1994, but values were not significant (Table 4.06b).

Differences among cultivars in NupE at 35 DAP in both years presented in Tables 4.05 and 4.06 were not obvious. However, at silking in 1993 SPL and EV8728 were the least efficient ($P<0.05$) in absorbing mineral N from the soil. Cultivar SPL also had the lowest efficiency at silking in 1994 and at harvest in both years. Nitrogen uptake efficiency was relatively lower in 1994 than in 1993, probably because of the

Table 4.04: Shoot/root ratio of five maize cultivars at 35 DAP and mid-silking and N uptake rate per m root length (mmol m^{-1} day^{-1}) as affected by N rates in 1994

A.	N Rates (kg ha^{-1})						
Cultivar	0	120[1]	Mean	0	30	120	Mean
Shoot/root ratio	5 WAP			Silking			
Improved:							
EV8728-SR	306	275	290	426	420	565	470
Mokwa 87TZPB-SR	333	167	222	469	389	521	460
SPL	276	296	286	459	433	398	430
8644-27 (Oba Super 2)	278	212	242	389	407	583	460
Popular OP							
TZB-SR	281	350	358	492	332	626	483
Mean	309	243	272	447	396	539	461
S.E. for N Rate	ns			ns			
S.E. for cultivar	±377*			±126*			
S.E. for N Rate x Cultivar	ns			ns			
CV (%)	38.4			36.7			

B.	N Rates (kg ha^{-1})		
Cultivar	0	120	Mean
N uptake rate (mmol m^{-1} day^{-1})			
Improved:			
EV8728-SR	0.75	1.14	0.94
Mokwa 87TZPB-SR	0.62	1.04	0.83
SPL	0.54	0.64	0.61
8644-27 (Oba Super 2)	0.41	1.34	0.89
Popular OP			
TZB-SR	0.64	1.46	1.05
Mean	0.60	1.13	
S.E. for N Rate	±0.7***		
S.E. for Cultivar	ns		
S.E. for N Rate x Cultivar	ns		
CV (%)	49.6		

[1]Only the first split o 60 kg ha^{-1} had been applied.

large soil mineral N content at planting in 1994 (See Fig. 4.18 and 4.19).

Application of nitrogen did not significantly affect NupE in sorghum in both years, although NupE was slightly higher in 120 kg N ha^{-1} plots than in zero-N plots at 35 DAP and at harvest in 1994 (Tables 4.05 and 4.06).

In relative terms, NupE in sorghum was 27-44 percent lower than NupE in maize at their respective period of maximum stem elongation in both years, but was 69 percent higher at heading in 1994. At their respective physiological maturity stage, NupE in sorghum was 18-27 percent higher than in maize in both years.

4.2.6.2. Nitrogen utilization efficiency

The efficiency of utilizing the absorbed N in the plant for dry matter or grain yield (NutE) is presented in Tables 4.07 and 4.08. There were no clear differences between 90 and 120 kg N ha^{-1} in NutE at 35 DAP and mid-silking in 1993 (Table 4.07). However, every kg of N absorbed by the maize plant was utilized to produce 36-40 kg dry matter at both sampling dates. Application of N in 1994 significantly decreased NutE by 7-19 percent at 35 DAP and 11-40 percent at mid-silking (Table 4.08). Since dry matter at these stages was not affected by N, the high NutE under zero-N was as a result of the significantly lower N uptake at 0 kg N ha^{-1} compared to when N was applied. At harvest there were no obvious differences in NutE with N application in 1994. In 1993 however, the highest dose (120 kg N ha^{-1}) decreased ($P<0.05$) NutE at harvest by 4.2-5.4 kg for every kg of N absorbed, over the lower rates (30 to 90 kg N ha^{-1}).

All the maize cultivars had equal efficiency to utilize absorbed N for dry matter production at stem elongation and mid-silk growth stages in both years. The efficiency ranged from 35-94 kg dry matter per unit kg of N absorbed. Differences among the cultivars in NutE became obvious at physiological maturity in both years with the hybrid, 8644-27 having a significantly ($P<0.001$) higher utilization efficiency of 47-59 kg grain per kg N uptake compared to an efficiency of 39-55 in the other

Table 4.05: Effects of applied nitrogen on nitrogen uptake efficiency (kg N uptake/kg avail. soil N) of five maize cultivars and sorghum at 35 DAP, mid-silking/heading and harvest in 1993.

A.	N Rate (kg ha^{-1})					
Cultivar	90[1]	120[2]	Mean	90	120[2]	Mean
(Kg dry biomass-N/kg avail. soil N)	35DAP:			Mid-Silking/Heading:		
Improved:						
EV8728-SR	0.12	0.09	0.10	0.63	0.75	0.62
Mokwa 87TZPB-SR	0.09	0.12	0.10	0.88	0.74	0.81
SPL	0.08	0.07	0.07	0.63	0.60	0.62
8644-27 (Oba Super 2)	0.12	0.06	0.10	0.77	0.63	0.70
Popular OP:						
TZB-SR	0.10	0.04	0.07	0.87	0.82	0.85
Mean	0.10	0.08	0.09	0.76	0.71	0.73
Local sorghum	0.05	0.04	0.05	0.44	0.62	0.53
	Maize	Sorghum		Maize	Sorghum	
S.E. for N Rates	n.s	n.s (T-test)		n.s	n.s (T-test)	
S.E. for Cultivars	n.s			±0.14*		
S.E. for N rate x cultivar	±0.04*			n.s		
CV (%)	35.2			19.7		

B.	N Rate (kg ha^{-1})					
Cultivar	0	30	60	90	120	Mean
(Kg dry biomass-N/kg avail. soil N)	Harvest:					
Improved:						
EV8728-SR	0.48	0.61	0.86	0.63	0.74	0.66
Mokwa 87TZPB-SR	0.42	0.60	0.88	0.71	0.70	0.66
SPL	0.31	0.49	0.85	0.59	0.67	0.58
8644-27 (Oba Super 2)	0.31	0.64	0.84	0.73	0.62	0.63
Popular OP:						
TZB-SR	0.49	0.54	0.92	0.73	0.70	0.68
Mean	0.40	0.58	0.87	0.68	0.69	0.64
Local sorghum	-	-	-	0.79	0.75	0.77
	Maize			Sorghum		
Sorghum						
S.E. for N Rates	±0.06***			n.s (T-test)		
S.E. for Cultivars	n.s					
S.E. for N rate x cultivar	n.s					
CV (%)	22.6			20.2		

[1]Only the first split of 30 kgNha^{-1} had been applied.
2Applied once at 2 WAP
3Applied in 2 splits of 60:60 at 2 and 5 WAP

Table 4.06: Effects of applied nitrogen on nitrogen uptake efficiency (kg N uptake/kg avail. soil N) of five maize cultivars, and sorghum at 35 DAP, mid-silking/heading, and harvest in 1994.

A.	N Rate (kg ha^{-1})							
Cultivar	0	30	120[1]	Mean	0	30	120	Mean
(Kg dry biomass-N/kg avail. soil N)	35 DAP:				Mid-silking/heading:			
Improved:								
EV8728-SR	0.06	0.11	0.11	0.09	0.24	0.19	0.27	0.23
Mokwa 87TZPB-SR	0.08	0.07	0.09	0.08	0.22	0.21	0.30	0.24
SPL	0.08	0.12	0.12	0.10	0.19	0.23	0.21	0.21
8644-27 (Oba Super 2)	0.08	0.08	0.08	0.08	0.18	0.26	0.25	0.23
Popular OP:								
TZB-SR	0.07	0.08	0.08	0.08	0.17	0.17	0.28	0.21
Mean	0.08	0.09	0.09	0.09	0.20	0.21	0.26	0.22
Local sorghum	0.04	0.07	0.07	0.06	0.75	0.61	0.78	0.71
	Maize		Sorghum		Maize		Sorghum	
S.E. for N Rates	n.s		±1.9		n.s		n.s	
S.E. for Cultivars	±0.01*				n.s			
S.E. for N rate x cultivar	n.s				n.s			
CV (%)	28.6		38.1		25.4		40.1	

B.	N Rate (kg ha^{-1})					
Cultivar	0	30	60	90	120	Mean
(Kg dry biomass-N/kg avail. soil N)	Harvest:					
Improved:						
EV8728-SR	0.30	0.27	0.39	0.32	0.40	0.34
Mokwa 87TZPB-SR	0.28	0.32	0.37	0.39	0.37	0.35
SPL	0.27	0.34	0.32	0.34	0.38	0.33
8644-27 (Oba Super 2)	0.24	0.26	0.35	0.33	0.34	0.31
Popular OP:						
TZB-SR	0.26	0.32	0.44	0.30	0.42	0.35
Mean	0.27	0.31	0.37	0.34	0.38	0.33
Local sorghum	0.44	0.43	-	-	0.49	0.45
	Maize			Sorghum		
Sorghum						
S.E. for N Rates	n.s			n.s		
S.E. for Cultivars	n.s					
S.E. for N rate x cultivar	n.s					
CV (%)	21.5			15.2		

[4]Only the first split of 60 kgNha^{-1} had been applied.

cultivars (Tables 4.07b and 4.08b). Mokwa 87TZPB-SR and TZB-SR were the leastefficient in utilizing N for grain production. Differences between the popular OP and the improved cultivars in NutE were larger at 0 and 30 kg N ha^{-1} than at higher N rates in 1994. Except Mokwa 87TZPB-SR in 1993 and EV8728-SR in 1994, application of 120 kg N ha^{-1} tended to reduce NutE by 6-19 percent compared to the lower N rates.

There were no clear differences among N rates in NutE of sorghum, except at 85 DAP (mid-heading) in 1994 when the efficiency was significantly decreased from 46.8 to 38.1 kg dry matter per kg N uptake with increments in N from 0 to 60 kg ha^{-1} (Tables 4.07 and 4.08).

At stem elongation phase in both years, NutE was similar (36-43kg dry matter/kg N uptake) in both local sorghum and the maize cultivars. The conversion of N to dry matter was 68% higher in sorghum than in maize at their respective flowering stages in 1993. In 1994 however, the NutE in maize was 46 percent higher than in sorghum. At physiological maturity in both years, each unit of N taken up by the six cultivars, the conversion to grain production was higher by 43 to 73 percent and 66 to 76 percent in TZB-SR, and in the improved cultivars than in the local sorghum cultivar.

4.2.6.3. N-use efficiency

The combined efficiency of absorbing and utilizing the absorbed nitrogen for grain production (NUE) in both years has been summarised in Tables 4.09 and 4.10. The highest ($P<0.05$) NUE of 38 kg grain/kg soil N supply was obtained at 60kg N ha^{-1} in 1993. Higher doses of applied N significantly decreased N use efficiency by 23-31 percent. A similar trend was observed in 1994 but values were not significant.

Among the improved cultivars, the hybrid cv.8644-27 was the most N-use efficient (18-30kg grain/kg soil N supply) in both years. The efficiency was lowest (24-26kg grain/kg soil N supply) in Mokwa 87 TZPB-SR and in SPL in 1993, and

Table 4.07: Effects of applied nitrogen on nitrogen utilization efficiency (kg dry biomass or grain/kg N uptake) of five maize cultivars and sorghum at 35 DAP, mid-silking/heading and harvest in 1993.

A.	N Rate (kg ha^{-1})					
Cultivar	90[1]	120[2]	Mean	90	120[2]	Mean
(Kg dry biomass-N/kg N uptake)	35 DAP:			Mid-Silking/Heading:		
Improved:						
EV8728-SR	35.8	33.8	34.8	39.0	39.3	39.2
Mokwa 87TZPB-SR	36.5	32.6	34.6	39.6	36.9	38.3
SPL	35.1	36.7	35.9	38.8	45.8	37.3
8644-27 (Oba Super 2)	39.2	38.1	38.6	39.4	37.2	38.3
Popular OP:						
TZB-SR	34.3	40.4	37.4	42.3	37.6	40.1
Mean	36.2	36.3	36.3	39.8	37.3	38.6
Local sorghum	39.2	32.7	36.0	27.9	11.7	19.8
	Maize	Sorghum		Maize	Sorghum	
S.E. for N Rates	n.s	n.s (T-test)		n.s	n.s (T-test)	
S.E. for Cultivars	n.s			n.s		
S.E. for N rate x cultivar	n.s			n.s		
CV (%)	43.9			6.9		

B.	N Rate (kg ha^{-1})					
Cultivar	0	30	60	90	120	Mean
(Kg dry biomass-N/kg N uptake)	Harvest:					
Improved:						
EV8728-SR	44.4	44.4	44.5	44.4	37.1	43.0
Mokwa 87TZPB-SR	31.4	40.4	40.1	40.2	40.3	38.5
SPL	46.5	45.8	41.7	40.5	38.2	42.5
8644-27 (Oba Super 2)	46.4	50.4	49.6	47.5	43.0	47.4
Popular OP:						
TZB-SR	38.2	40.4	44.2	43.0	35.8	40.3
Mean	41.4	44.3	44.0	43.1	38.9	42.3
Local sorghum	-	-	-	11.1	11.8	11.5
	Maize			Sorghum		
Sorghum						
S.E. for N Rates	±1.79*			n.s (T-test)		
S.E. for Cultivars	±1.46***					
S.E. for N rate x cultivar	±3.43+					
CV (%)	10.9					

[1]Only the first split of 30 kgNha^{-1} had been applied.

[2]Applied once at 2 WAP

[3]Applied in 2 splits of 60:60 at 2 and 5 WAP

Table 4.08: Effects of applied nitrogen on nitrogen utilization efficiency (kg dry biomass /grain per kg N uptake) of five maize cultivars, and sorghum at 35 DAP, mid-silking/heading, and harvest in 1994.

A.	N Rate (kg ha^{-1})							
Cultivar	0	30	120[1]	Mean	0	30	120	Mean
(Kg dry biomass/kg N uptake)	35 DAP:				Mid-silking/heading:			
Improved:								
EV8728-SR	52.9	43.1	37.1	44.4	104.0	98.5	60.0	87.5
Mokwa 87TZPB-SR	49.3	39.4	35.7	41.5	95.0	89.5	64.4	83.0
SPL	51.7	39.0	35.5	42.1	100.8	90.7	63.9	85.1
8644-27 (Oba Super 2)	52.7	38.5	37.8	43.0	110.5	85.7	60.9	85.7
Popular OP:								
TZB-SR	54.9	42.3	35.1	44.1	114.1	100.6	65.7	93.5
Mean	52.3	40.4	36.3	43.0	104.9	93.0	63.0	87.0
Local sorghum	46.8	43.3	38.1	42.7	52.6	49.0	49.2	50.3
	Maize		Sorghum		Maize		Sorghum	
S.E. for N Rates	±1.47***		±1.9**		±5.5***		n.s	
S.E. for Cultivars	n.s		-		n.s		-	
S.E. for N rate x cultivar	n.s		-		n.s		-	
CV (%)	11.5		7.1		15.7		7.5	

B.	N Rate (kg ha^{-1})					
Cultivar	0	30	60	90	120	Mean
(Kg grain/kg total N uptake)	Harvest:					
Improved:						
EV8728-SR	48.5	60.2	49.0	50.6	55.0	52.7
Mokwa 87TZPB-SR	49.1	47.8	47.4	50.4	47.4	48.4
SPL	54.2	53.6	57.4	59.8	49.2	54.8
8644-27 (Oba Super 2)	56.6	62.0	59.2	61.5	55.9	59.0
Popular OP:						
TZB-SR	33.0	43.2	45.2	50.7	43.2	43.0
Mean	48.3	53.4	51.6	54.6	50.1	51.6
Local sorghum	21.6	19.5	-	-	18.7	19.9
	Maize		Sorghum			
S.E. for N Rates	n.s		±1.1^{+}			
S.E. for Cultivars	±1.8***		-			
S.E. for N rate x cultivar	±5.2*		-			
CV (%)	12.6		8.9			

[1]Only the first split of 30 kgNha^{-1} had been applied.

[2]Applied once at 2 WAP

[3]Applied in 2 splits of 60:60 at 2 and 5 WAP

(15-16kg grain/kg soil N supply) in TZB-SR and Mokwa 87 TZPB-SR in 1994. Nitrogen use efficiency was relatively lower by 38 percent in 1994 than in 1993, probably because of the large amount of available N in the subsoil of the 1994 site compared to 1993 site.

Nitrogen application had no effect on N-use efficiency in sorghum in both years. For each unit of available soil N in each plot in both years, the absorption and utilization for grain production was higher by 41-67 percent and 45-71 percent in TZB-SR and the improved cultivars than in sorghum.

4.2.6.4. Comparison of efficiency parameters

The different cultivars can be classified based on the three efficiency parameters at physiological maturity thus:

NupE:	1993:	Sorghum>TZB-SR>TZPB-SR=EV8728-SR>8644-27>SPL
	1994:	Sorghum>TZB-SR>TZPB-SR>EV8728-SR>SPL>8644-27
NutE:	1993:	8644-27>EV8728-SR>SPL>TZB-SR>TZPB-SR>Sorghum
	1994:	8644-27>SPL>EV8728-SR>TZPB-SR>TZB-SR>Sorghum
NUE:	1993:	8644-27>EV8728-SR>TZB-SR>TZPB-SR>SPL>Sorghum
	1994:	8644-27>EV8728-SR=SPL>TZPB-SR>TZB-SR>Sorghum

The most efficient cultivars in absorbing nitrogen from the soil were the least efficient in utilizing the absorbed N for grain production. Cultivar EV8728-SR had moderate efficiency in absorbing available soil N and in utilizing the absorbed N for grain formation. Nitrogen utilization efficiency was the most important component of NUE in the cultivars studied.

4.2.7. Economic Analysis of Maize Yield

Partial budget analysis showed that there was benefit from the use of N fertilizer by at least \$139.00 ha^{-1} (Table 4.11). The gain was only \$9.00 ha^{-1} by increasing N fertilization rate from 60 kg ha^{-1} applied at 2 WAP to 120 kg ha^{-1} applied in two equal splits. There was however, a loss of \$31.00 ha^{-1} for using 90 kg N ha^{-1} in two splits of 30:60 kg ha^{-1}. Marginal analysis (Table 4.12) showed that the marginal return for extra unit invested in N will continue to yield higher return than the cost of the extra unit of N up to 60 kg N ha^{-1}. If the farmers are to apply 120 kg N ha^{-1}, they will get a marginal rate of return of only 43 percent of their investment of the last \$28.00. It is most likely that they would be willing to invest their money in nitrogen up to 60

Table 4.09: Effects of applied nitrogen on nitrogen use efficiency (kg grain/avail. soil N) of five maize cultivars and sorghum at harvest in 1993.

A.	N Rate (kg ha^{-1})					
Cultivar	0	30	60	90[1]	120[2]	Mean
Improved:						
EV8728-SR	20.4	26.8	38.1	28.1	27.5	28.2
Mokwa 87TZPB-SR	14.5	24.0	35.3	28.6	27.1	25.9
SPL (semi-prolific)	14.0	22.3	34.5	23.6	25.1	23.9
8644-27 (Oba Super 2)	14.4	32.4	41.8	34.7	26.5	30.0
Popular OP:						
TZB-SR	18.7	22.3	40.7	31.6	24.7	27.6
Mean	16.4	25.5	38.1	29.3	26.2	27.1
Local sorghum	-	-	-	8.3	8.8	8.6

	Maize	Sorghum
S.E. for N Rates	±2.90***	n.s (T-test)
S.E. for Cultivar	±1.79*	
S.E. for N rate x cultivar	n.s	
CV (%)	20.9	

[1]Applied in 2 splits of 30:60 at 2 and 5 WAP.
[2]Applied in 2 splits of 60:60 at 2 and 5 WAP.

Table 4.10: Effects of applied nitrogen on nitrogen use efficiency (kg grain/avail. soil N) of five maize cultivars and sorghum at harvest in 1994.

A.	N Rate (kg ha^{-1})					
Cultivar	0	30	60	90[1]	120[2]	Mean
Improved:						
EV8728-SR	14.1	15.6	19.4	16.2	21.5	17.4
Mokwa 87TZPB-SR	12.9	15.0	17.2	19.2	17.3	16.3
SPL (semi-prolific)	14.6	16.2	18.0	19.3	18.9	17.4
8644-27 (Oba Super 2)	13.4	18.1	20.3	19.9	19.6	18.3
Popular OP:						
TZB-SR	9.1	13.8	19.5	14.4	17.9	15.0
Mean	12.8	15.7	18.9	17.8	18.9	16.8
Local sorghum	9.5	8.3	-	-	8.9	8.9
	Maize			Sorghum		
S.E. for N Rates	n.s			n.s		
S.E. for Cultivars	±1.0*					
S.E. for N rate x cultivar	n.s					
CV (%)	21.2			15.8		

[1]Applied in 2 splits of 30:60 at 2 and 5 WAP.
[2]Applied in 2 splits of 60:60 at 2 and 5 WAP.

kg ha^{-1}, and then ask if there is not some other way of investing that final $28.00 that would
give them a better return than 43 percent.

Farmers will benefit $33.00 ha^{-1} by changing from their widely grown OP cv.TZB-SR to N-use efficient hybrid cv.8644-27, but will gain only $23.00 by growing the N-use efficient OPs(Table 4.13). From Table 4.14, by changing from TZB-SR to the hybrid cv.8644-27, the farmers will get a marginal rate of return of 10 percent However, investing the last $30.00 on the hybrid rather than on the N-use efficient OPs, the farmers will suffer a loss of 67 percent on their investment.

4.3. EXPERIMENT II - ON-FARM

4.3.1. Dry Matter and N Yield in Legumes and Maize in 1993.

Total dry matter yield by the legumes were in moderate to high fertility sites about twice the values under low fertility, site 1 (Fig. 4.22). Soybean grain yield was more than 70 percent lower under low fertility compared to high fertility sites. The harvest index for N (NHI) calculated as N in harvested grain/total above-ground N, in soybean was 62 percent under high fertility and 71 percent in low fertility site. Total nitrogen accumulation in the above-ground parts of the legumes ranged from 83 kg ha^{-1} in site 1 to 227 kg ha^{-1} under moderately high fertility (site 2) for stylo, and the corresponding values for soybean were 102 to 281 kg ha^{-1} (Fig. 4.23). Maize N uptake showed little variation between sites at about 75-125 kg ha^{-1}.

4.3.2. Growth Development and Protection of Subsequent Crops in 1994

4.3.2.1. Effects of rotation on crop growth and development

A similar plant height was observed at 25 DAP in subsequent maize (cvs. 8644-27 and TZB-SR) across all sites and independent of the previous crops (Fig. 4.24). Sorghum plant height at 42 DAP was significantly increased by the previous legumes only in the high fertility site 4 (Fig. 4.24, Append. 4 and 5).

The N concentration in maize ear leaves at silking can give an indication of whether the differences between maize yields in rotation with legumes and in continuous sole crop

Table 4.11 Partial budget, Nitrogen application in 1993 and 1994

	Nitrogen Rate (kg ha^{-1})				
	1	2	3	4	5
	0	30	60	90	120[1]
Average yield (kg ha^{-1})	3050	4745	6155	6225	6875
Adjusted yield (kg ha^{-1})	1830	2847	3693	3735	4125
Gross field benefits($ ha^{-1})	320	498	646	654	722
Cost of nitrogen ($ ha^{-1})	0	28	56	84	112
Cost of labour ($ ha^{-1})	0	11	11	22	22
Total costs that vary ($ ha^{-1})	0	39	67	106	134
Net Benefits ($ ha^{-1})	320	459	579	548	588

[1]Applied in 2 splits of 60:60 at 2 and 5 WAP.

Table 4.12: Marginal analysis, nitrogen application in 1993 and 1994.

N rate ((kg ha^{-1})	Total costs that vary ($ ha^{-1})	Net benefits ($ ha^{-1})	Marginal rate of return (%)
0	0	320	
			356
30	39	459	
			429
60	67	579	
			(-79)[2]
90	106	548[2]	
			143
120	134	588	

[2] Treatment 4 is dominated

Table 4.13 Partial budget, Improved maize Vs popular OP maize in 1993 and 1994

	Genotype		
	1 Popular OP	2 Improved OP	3 Hybrid (8644-27)
Average yield (kg ha^{-1})	5165	5377	5760
Adjusted yield (kg ha^{-1})	3099	3226	3456
Gross field benefits($ ha^{-1})	542	565	605
Cost that vary ($ ha^{-1})	15	15	45
Net Benefits ($ ha^{-1})	527	550	560

[1] Cost of seeds is the only cost that varies.

Table 4.14: Marginal analysis, Improved maize Vs popular OP maize in 1993 and 1994.

Genotype	costs that vary ($ ha^{-1})	Net benefits ($ ha^{-1})	Marginal rate of return (%)
Popular OP	15	527	
			110
Improved OP	15	550	
			33
Hybrid (8644-27)	45	560	

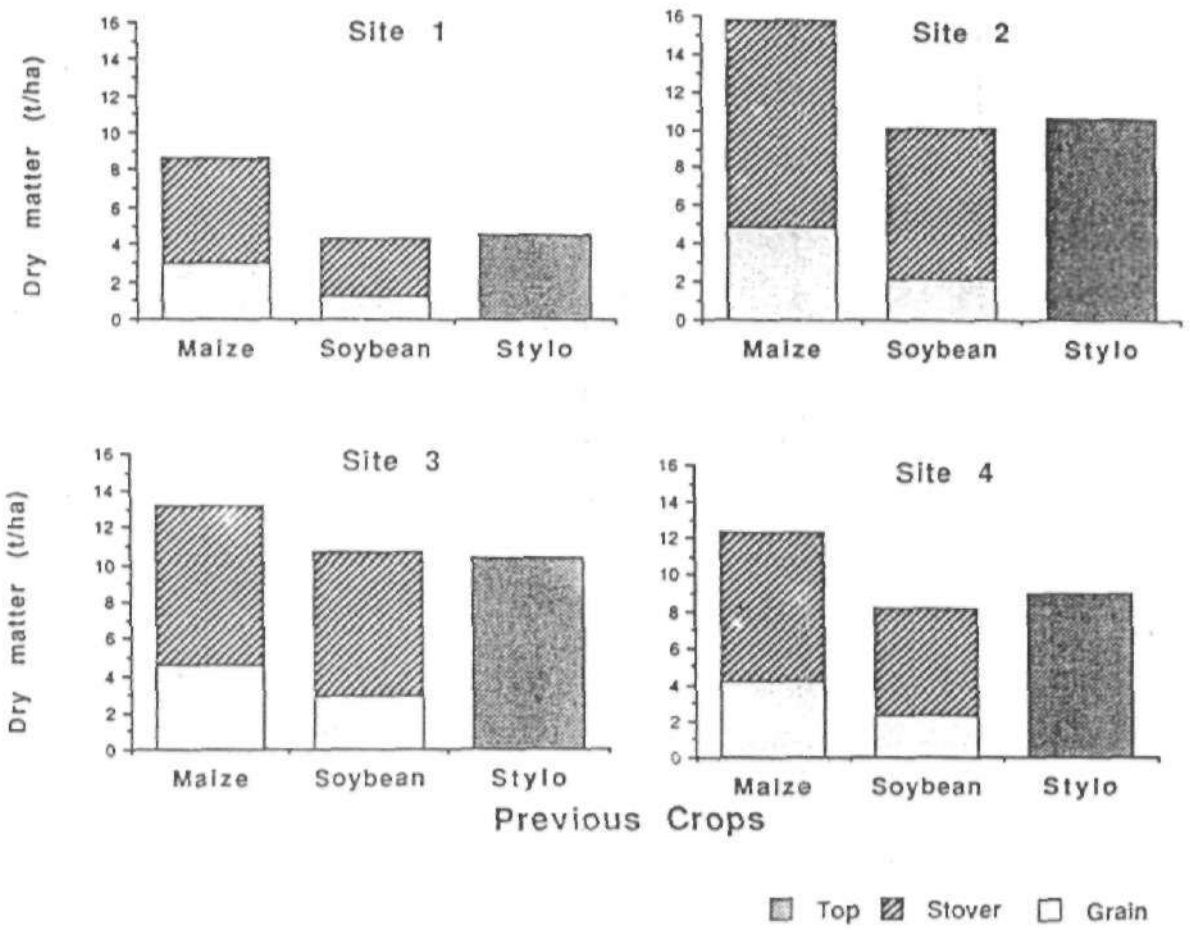


Fig. 4.22. Grain and stover yields (t/ha) of maize, soybean and stylo in 1993 at 4 sites differing in fertility.

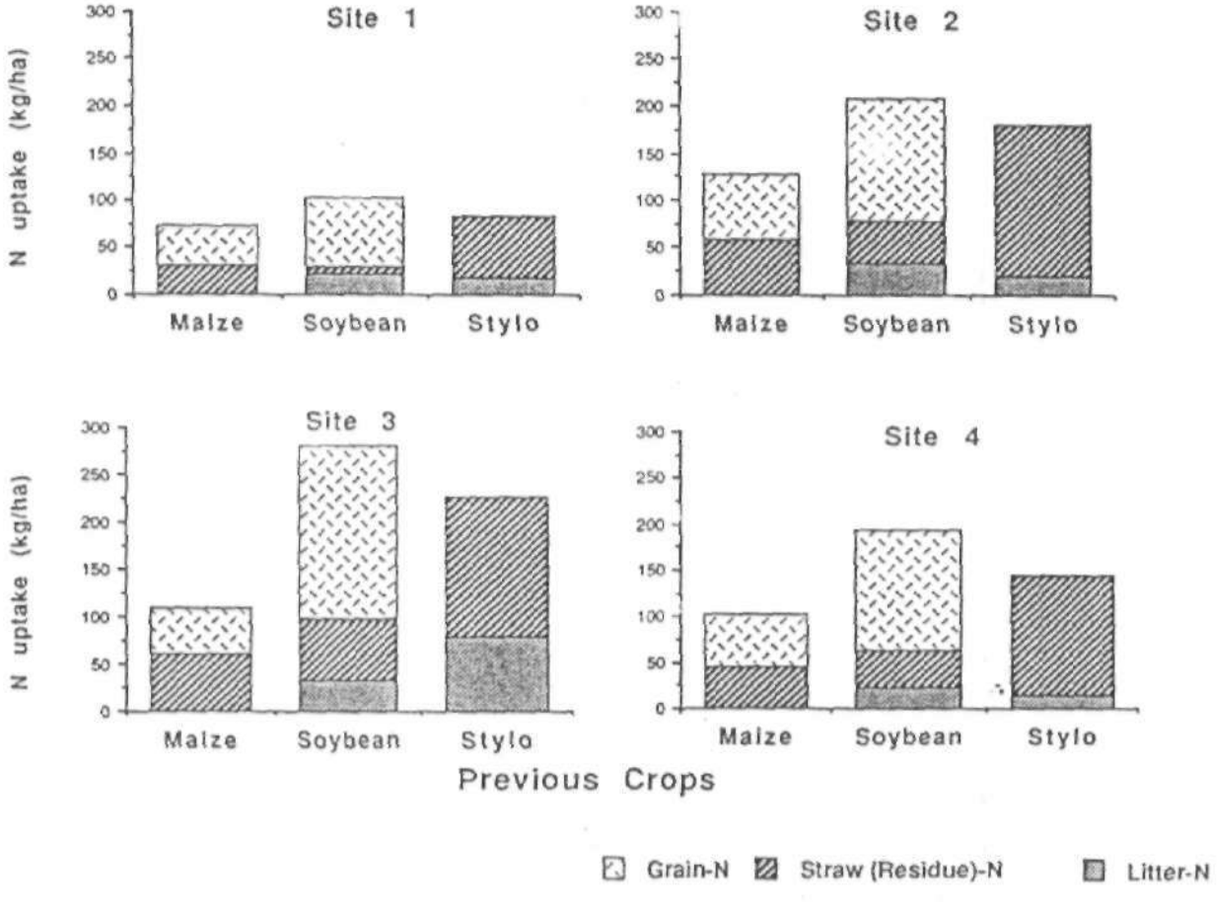


Fig. 4.23. Nitrogen contents of grain, straw (residue) and litter (kg/ha) of maize, soybean and stylo in 1993 at 4 sites differing in fertility.

were caused by differences in the use of soil available N. Leaf N was significantly higher (23.4-26.1 mg g-1) when maize was grown in rotation with legumes than in two-year sole crop maize (22.0-22.8 mg g^{-1}) in all the sites, except site 1 (Fig. 4.25). Leaf N was higher in cultivar 8644-27 than in cultivar TZB-SR. When leaf N concentration on weight basis was converted to an area basis i.e, specific leaf N, SLN (Fig. 4.26), there was a slight improvement in the level of significance of treatments (Appendix 4). Leaf N concentration and SLN in sorghum flag leaf were not affected by the previous crops (Fig. 4.25 and 4.26), except in site 1 where SLN was significantly higher in the previous plots of maize compared to the previous soybean plots. Leaf N values obtained for sorghum (16-22 mg g^{-1}) were relatively lower than those obtained for the maize cultivars (18-27 mg g^{-1}).

3.3.2.2. Rotation effects on *Striga hermonthica* control

Number of emerged *Striga* per maize plant and percent severity of *Striga* on maize were evaluated at 12 WAP. Under moderate to high infestation as observed in sites 1 and 3, rotation with soybean significantly reduced the number of emerged *Striga* per plant, and also the severity on the subsequent maize crop compared to rotation with stylo or maize (Fig. 4.27, Fig. 4.28 and Appendix 4).

Site means showed both the number of *Striga* per maize plant and severity of *Striga* were significantly higher in site 3 compared to the other sites, in spite of its high fertility. This implies that fertility level had no effect on *Striga*, at least in this experiment. Combined sites analysis also showed that the incidence of *Striga* was over 90% higher ($P<0.05$) in the previous stylo plots compared to the previous soybean or maize plots. This indicates lack of rotation effect on *Striga* by the previous stylo crop.

Log transformation of number of *Striga* per plant showed that cultivar 8644-27 had significantly ($P=0.05$) lower *Striga* density than cultivar TZB-SR in Site 3 which had the highest infestation.

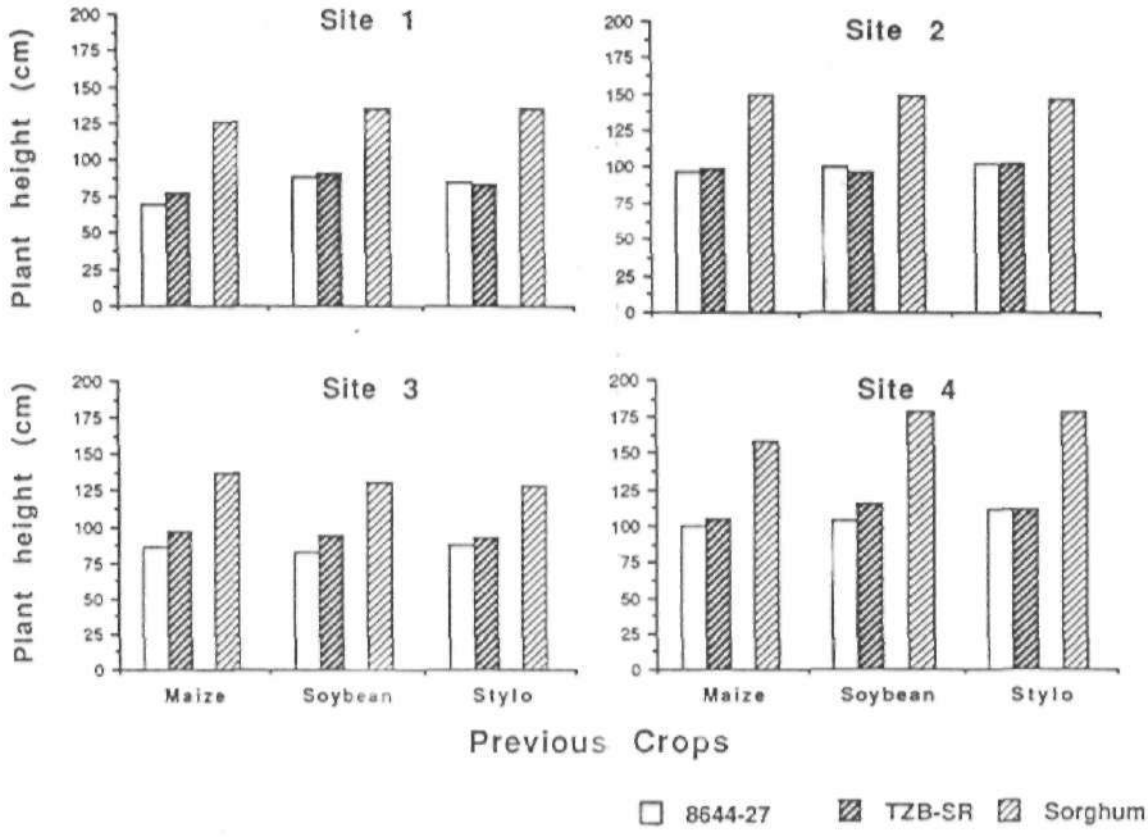


Fig.4.24. Plant height (cm) of 8644-27, TZB-SR and sorghum in 1994 as affected by previous crop of maize, soybean and stylo at 25 /42 DAP at 4 sites differing in fertility.

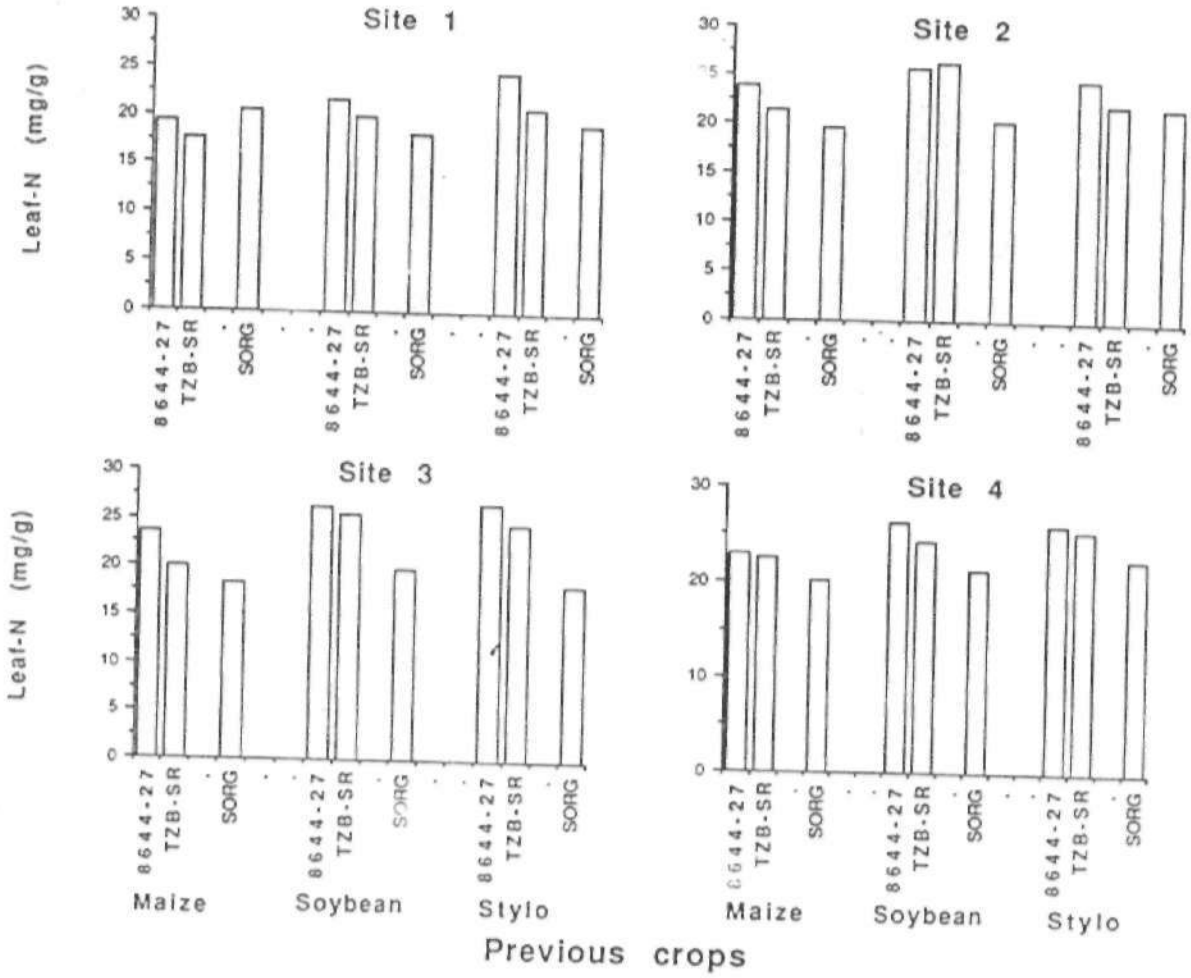


Fig. 4.25. Leaf N concentration (mg/g) of 8644-27, TZB-SR and sorghum in 1994 as affected by previous crop of maize, soybean and stylo at 4 sites differing in fertility.

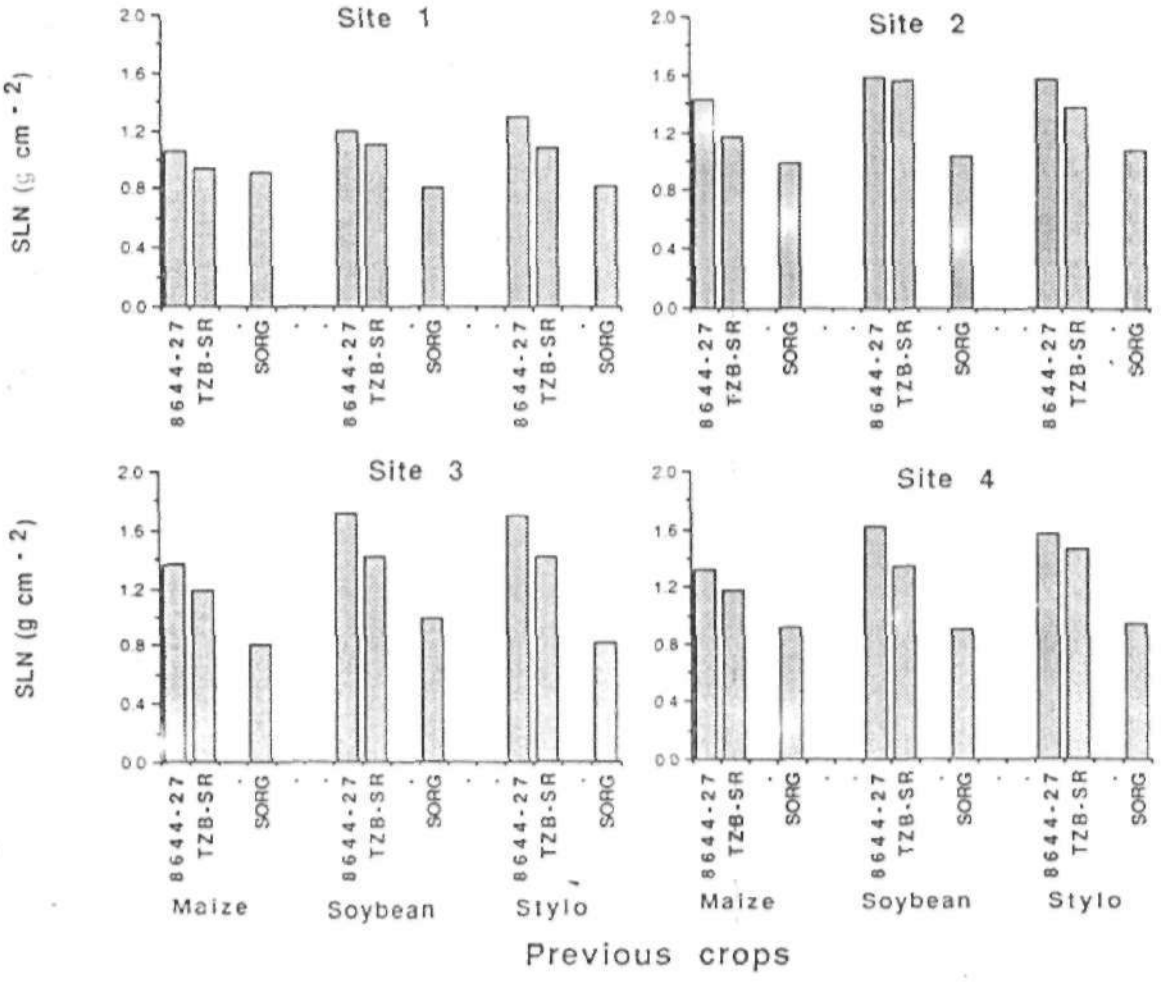


Fig. 4.26. Specific leaf N concentration-SLN (g cm^{-2}) of 8644-27, TZB-SR and sorghum in 1994 as affected by previous crop of maize, soybean and stylo at 4 sites differing in fertility.

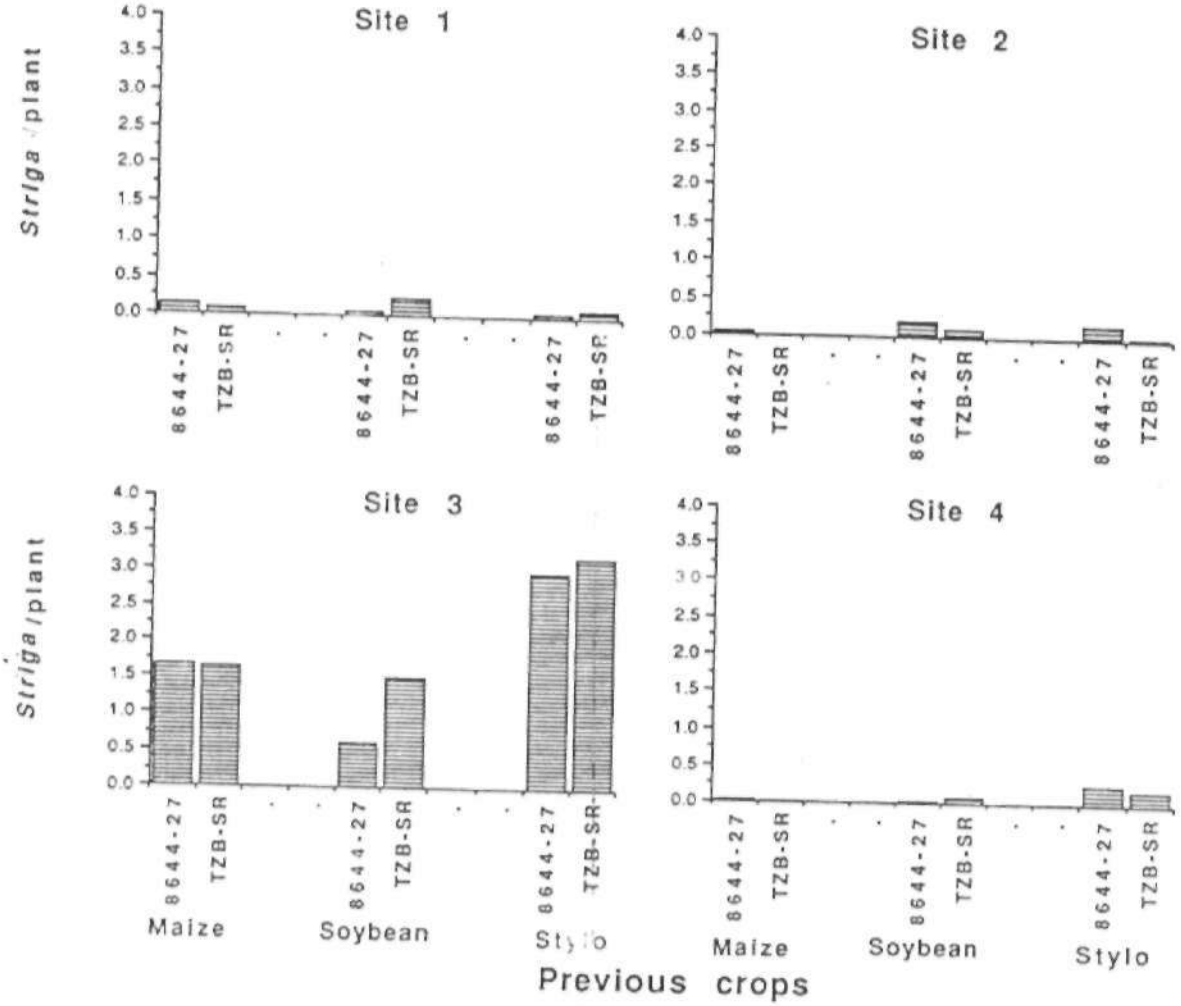


Fig.4.27. Number of *Striga*/plant of 8644-27 and TZB-SR in 1994 as affected by previous crop of maize, soybean and stylo at 4 sites differing in fertility.

4.3.3. Yield and Yield Components of Subsequent Crops

4.3.3.1. Rotation effects on dry matter accumulation

There were no clear interaction effects of previous crops by cultivars on the yield of grain, stover, and cob (Appendix 6). Effects of the previous crops on grain yield were not consistent at all sites. At sites 1 and 4 the previous stylo crop gave grain yield of 3.2-5.7t ha^{-1} compared to the previous maize which gave grain yield of 2.3-4.4 t ha^{-1} (Fig. 4.29 and Appendix 6). While, in sites 2 and 3 grain yield from the previous soybean were 4.8-5.8 t ha^{-1} as against 3.7-4.7 t ha^{-1} from the previous maize. On average, legume rotation with an N-use efficient maize, cv. 8644-27 gave a yield advantage of 1.3 t ha^{-1} over a two-year sole crop of cv. TZB-SR.

Maize grain yield across sites, was significantly higher by 20 and 24 percent when grown after stylo and soybean than after maize, in spite of the removal of the standing legume biomass from the fields. Culltivar 8644-27 produced 8 percent higher (P<0.05) grain yield compared to TZB-SR, mean across sites. Similar effects of previous crops were obtained for stover and cob dry matter yields.

The translocation of assimilates to the ear was lower in cultivar TZB-SR as indicated by the significantly higher stover dry matter compared to cultivar 8644-27. Harvest index (Fig. 4.30) was significantly higher by 16 percent in 8644-27 than in TZB-SR, across all sites.

Effects of the previous crops on dry matter accumulation in sorghum were not significant (see Fig. 4.29 and Appendix 5).

4.3.3.2. Rotation effects on components of maize yield

On the average, 1000-kernel weight (g) was significantly higher (P<0.001) by over 24 percent in 8644-27 than in TZB-SR (Fig. 4.31 and Appendix 6). But there were 7 percent more (P<0.0001) kernels per ear (Fig. 4.32), and more (P<0.05) ears per plant (Fig. 4.33) of TZB-SR compared to 8644-27. Kernel size compared to ear or kernel number was a major yield component differentiating these cultivars in terms of

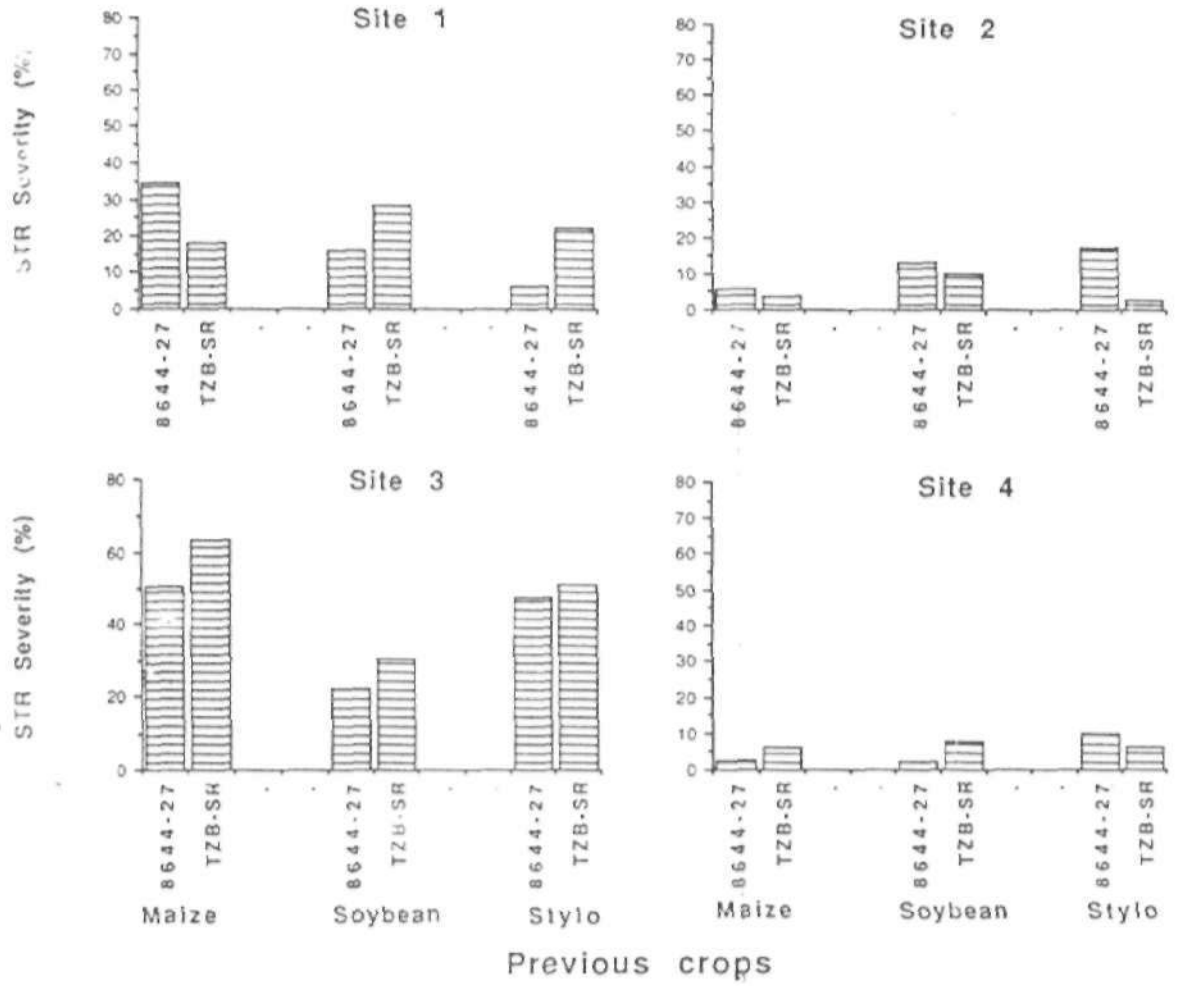


Fig. 4.28 Severity (%) of *Striga* on 8644-27 and TZB-SR in 1994 as affected by previous crop of maize, soybean and stylo at 4 sites differing in fertility.

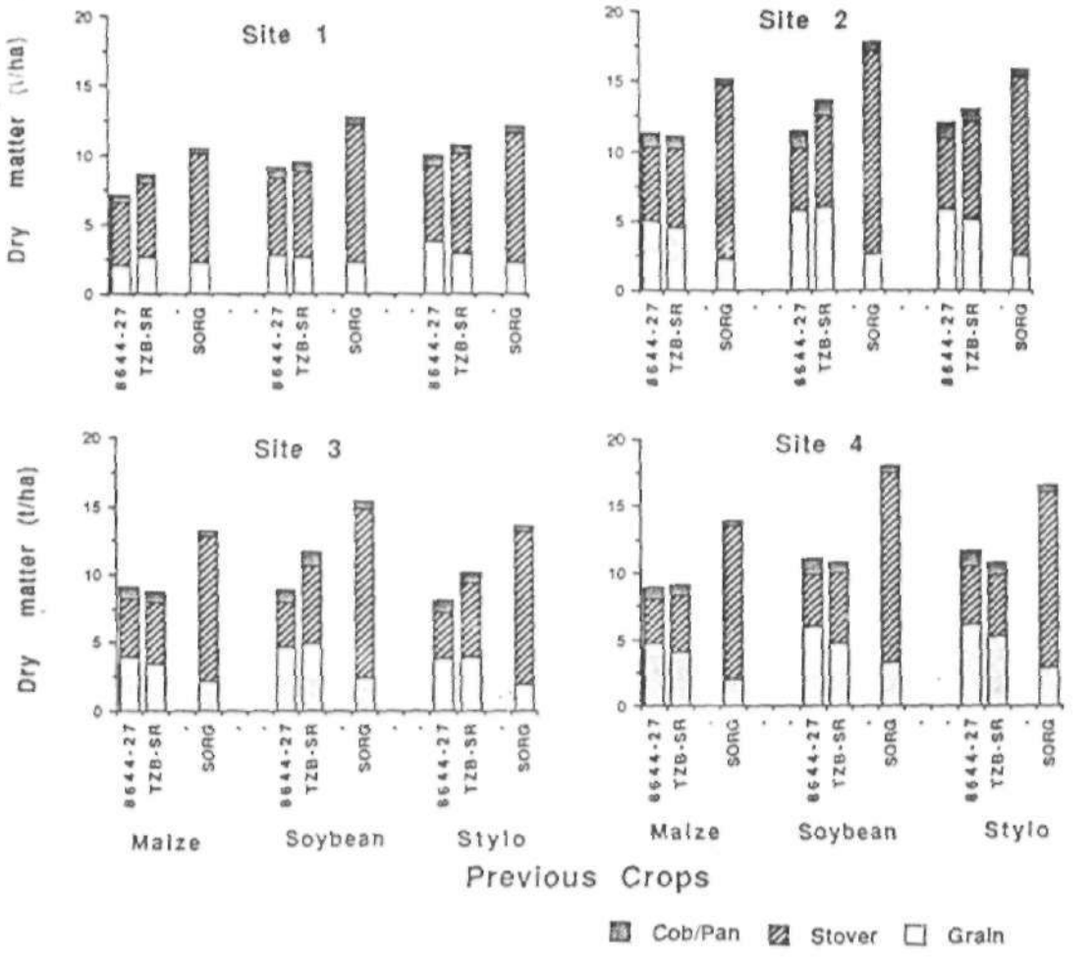


Fig. 4.29. Grain, stover and cob yields (t/ha) of 8644-27, TZB-SR and sorghum in 1994 as affected by previous crop of maize, soybean and stylo at 4 sites differing in fertility.

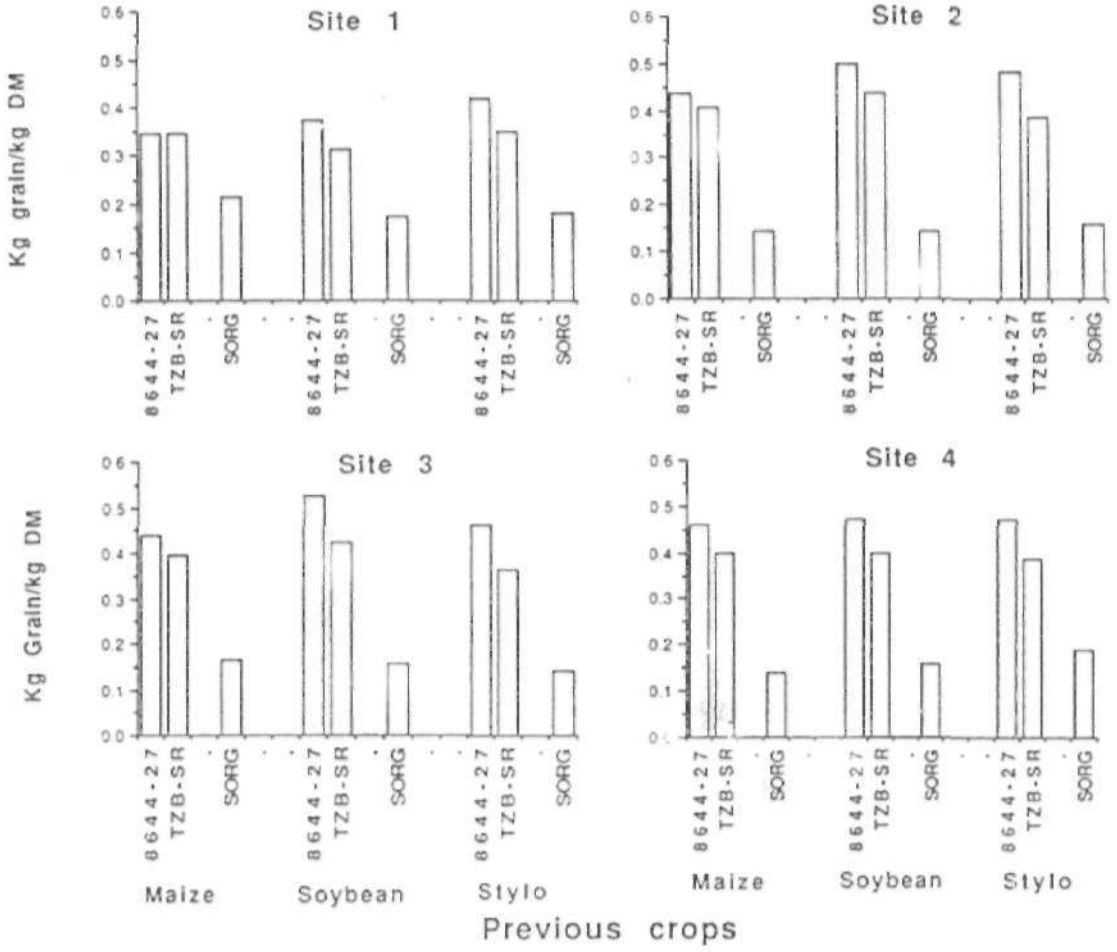


Fig. 4.30. *Grain in kg per kg total dry matter (HI) of 8644-27, TZB-SR and* sorghum in 1994 as affected by previous crop of maize, soybean and stylo at 4 sites differing in fertility.

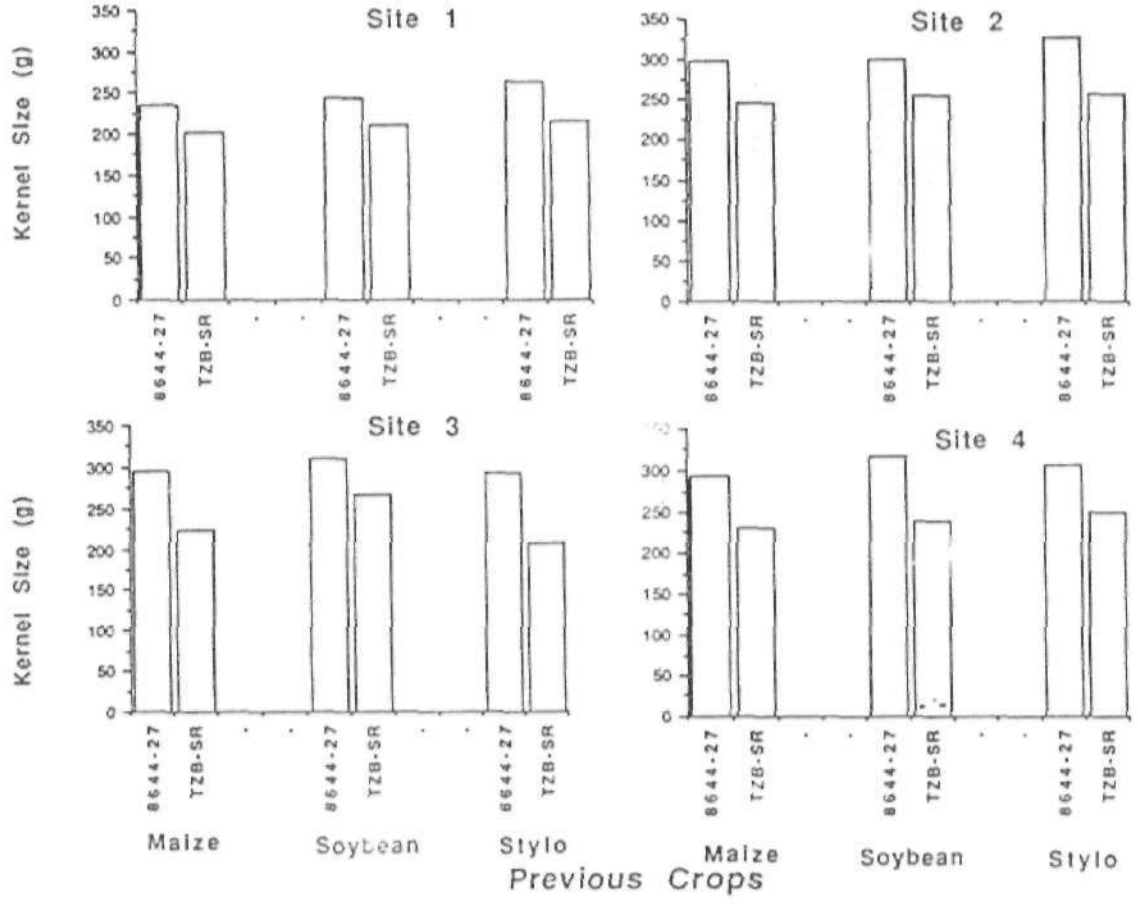


Fig. 4.31. Kernel size (thousand grain weight-g) of 8644-27 and TZB-SR in 1994 as affected by previous crops of maize, soybean and stylo at 4 sites differing in fertility.

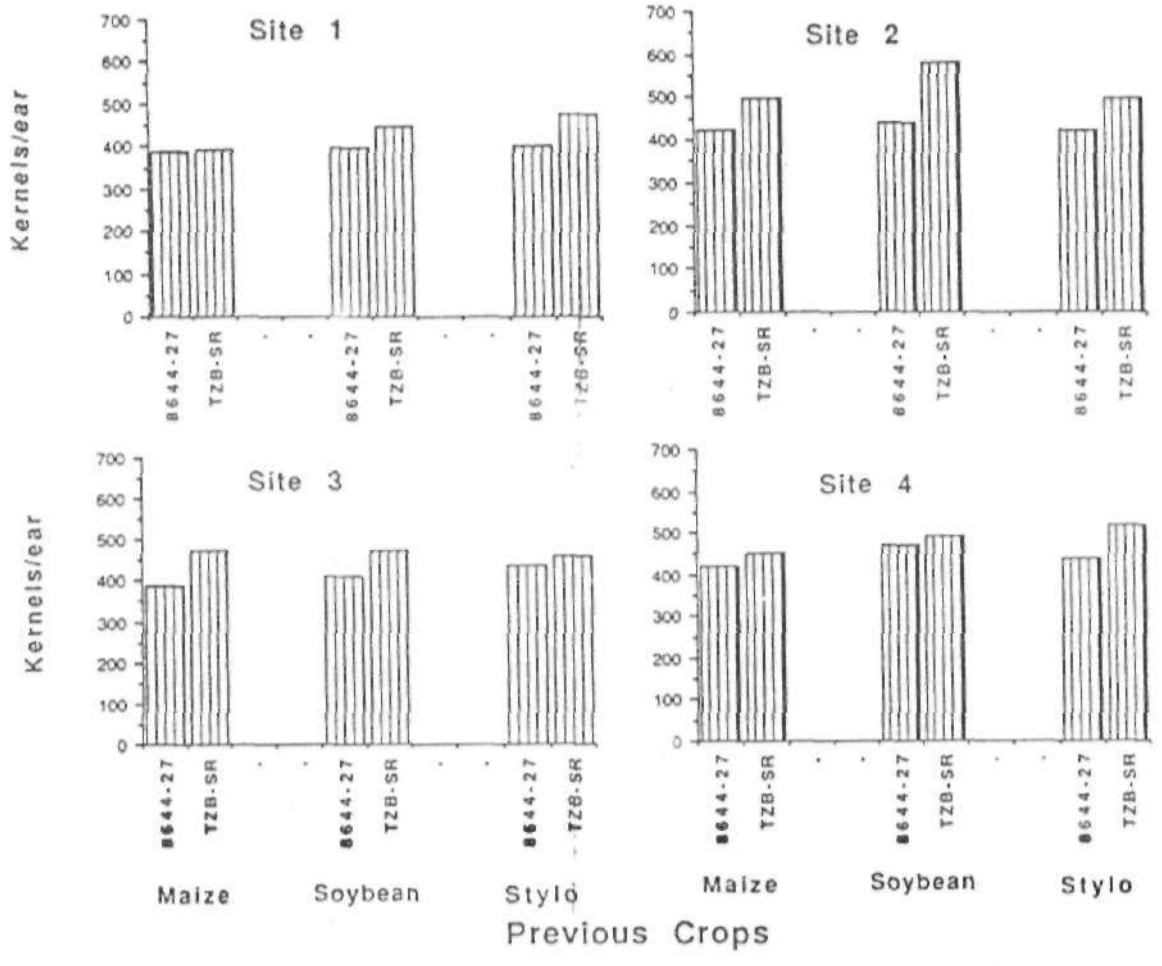


Fig. 4.32. Number of kernels per ear of 8644-27 and TZB-SR in 1994 as affected by previous crops of maize, soybean and stylo at 4 sites differing in fertility.

grain yield at the selected sites.

4.3.4. Nitrogen Uptake at Harvest

The effects of the previous crops and differences between cultivars on net N uptake and N partitioning to plant fractions are presented Fig. 4.34 and Appendix 7. Independent of the differences in fertility of the sites, the net N uptake, and N partitioned to grain, stover, and cob were at least 20 percent lower ($P<0.01$) after a two-year sole crop maize than after a legume/maize rotation. There were no differences between the two legume rotation systems, although N accumulation in the subsequent maize was slightly larger under stylo rotation. There were no clear differences between cultivars in N accumulation (Appendix 7), implying that both cultivars had similar capacity to take up available soil N independent of the differences in soil fertility level. In site 1 (low fertility), the grain-N of 8644-27 was significantly higher under previous stylo compared to TZB-SR or 8644-27 under previous maize. There was no clear interaction of previous crops by cultivars on net N uptake (Appendix 7). Harvest index for N (NHI), was only significant in sites 3 and 4, high fertility, with 8644-27 having an index of 0.62-0.65 as against 0.60 index by TZB-SR (Fig. 4.35).

Except N content of panicle residues and nitrogen harvest index (NHI) in sites 1 and 4, previous crops had no major effects on N uptake by sorghum (Fig.4.35 and Appendix 8).

At moderate to high fertility sites (Fig. 4.35), for every unit of N taken up by sorghum grown after maize, 46 percent of it was converted to grain while, only 38 percent was converted to grain by sorghum grown after stylo. This higher index could have resulted from lower net N uptake by sorghum after maize compared with uptake after stylo or soybean.

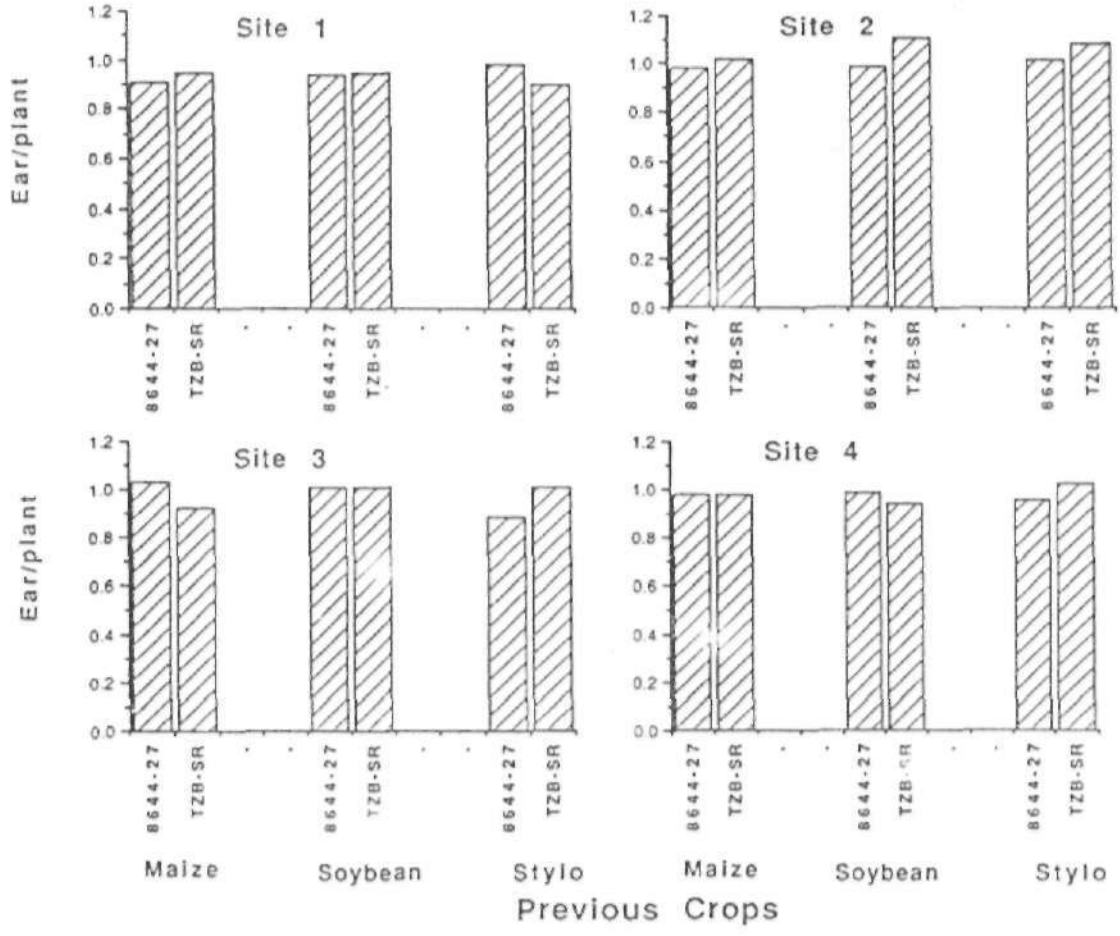


Fig. 4.33. Number of ears per plant of 8644-27 and TZB-SR in 1994 as affected by previous crops of maize, soybean and stylo at 4 sites differing in fertility.

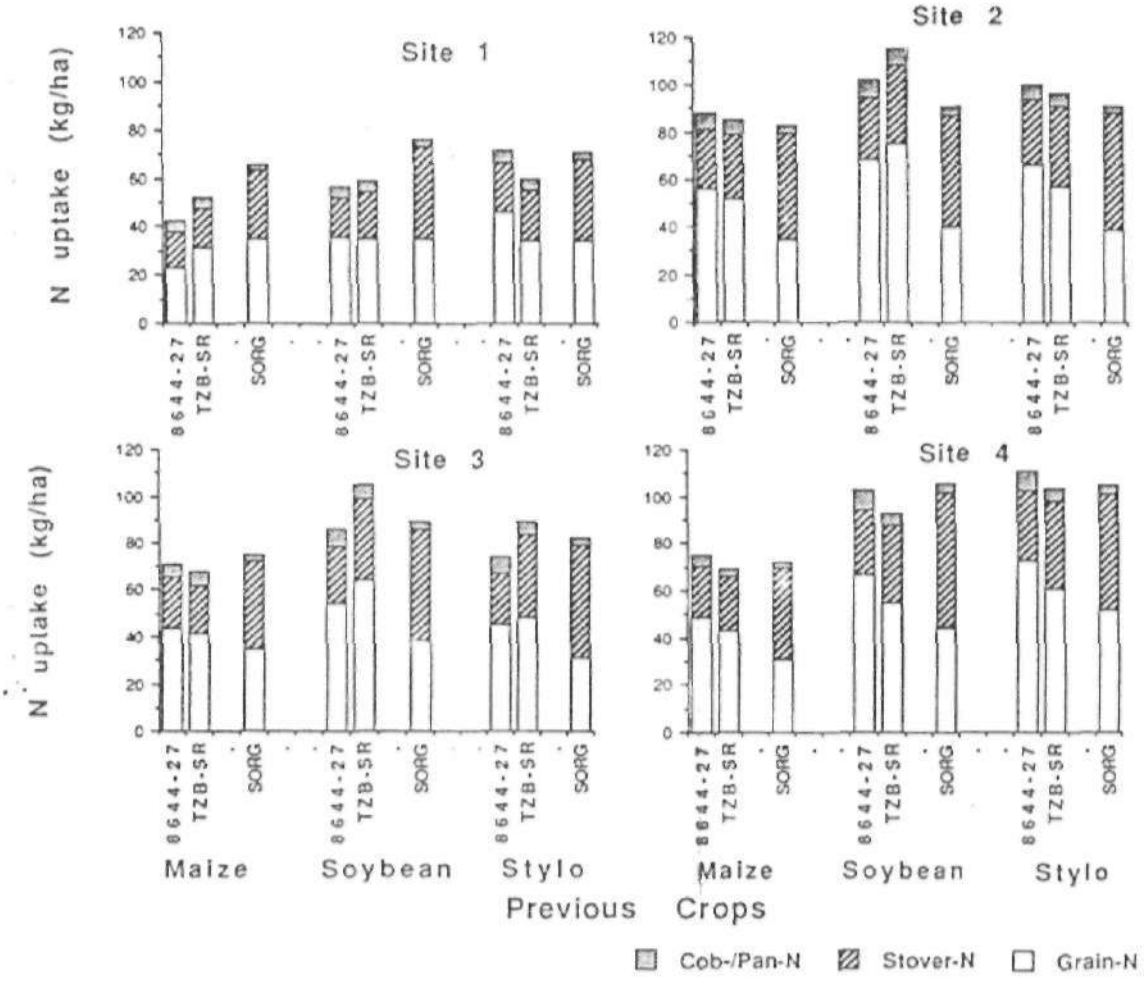


Fig. 4.34. Nitrogen contents of grain, stover and cob/panicle (kg/ha) of 8644-27, TZB-SR and sorghum in 1994 as affected by previous crops of maize, soybean and stylo at 4 sites differing in fertility.

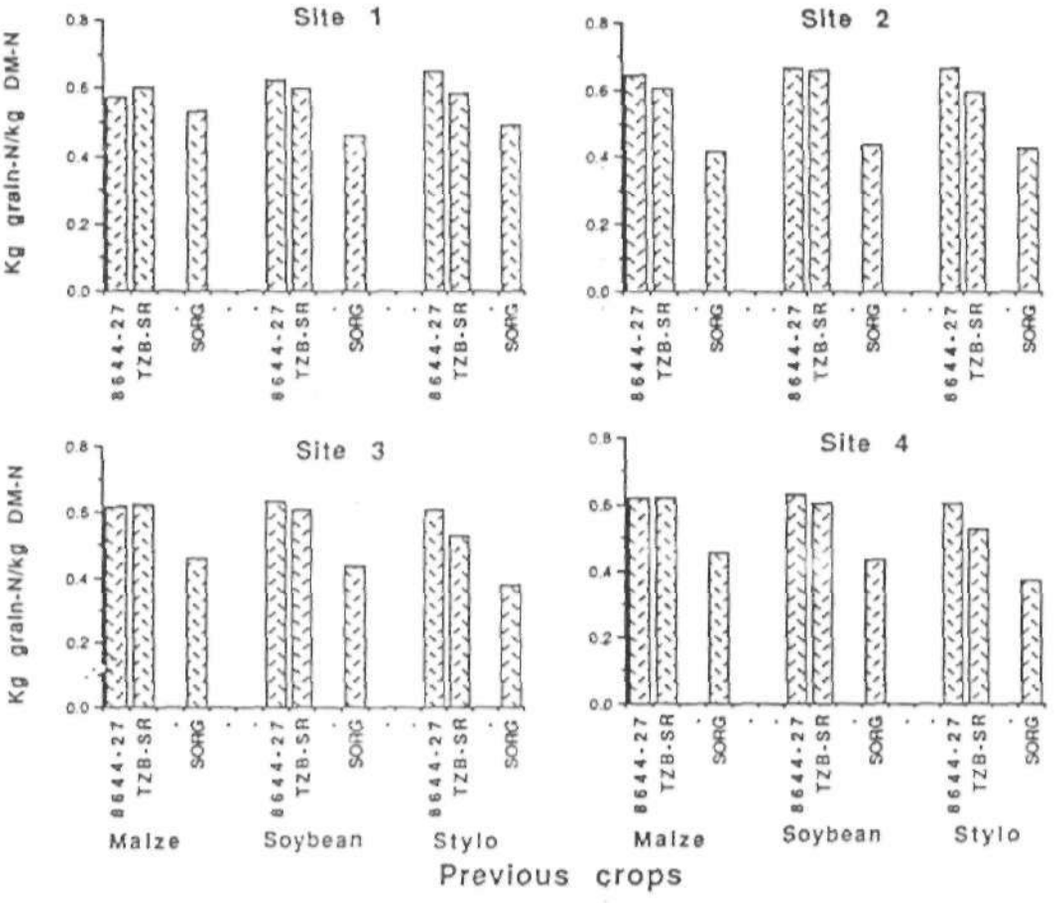


Fig.4.35. Grain-nitrogen in kg per kg total dry matter-nitrogen (NHI) of 8644-27, TZB-SR and sorghum in 1994 as affected by previous crop of maize, soybean and stylo at 4 sites differing in fertility.

4.3.5. Nitrogen-dynamics and Balance

4.3.5.1. Dynamics of available soil N after one year rotation

Available N contents in the soil during the growing season of 1994 under the subsequent maize crop reflected differences in N-dynamics between the cropping systems (Fig. 4.36, Appendices 9 and 10). The total available soil N includes available NO_3- and NH_4+ although, there was little contribution from NH_4+ especially at planting on 27/5/94. In each site at planting of the subsequent crops in 1994, the previous soybean consistently gave higher available soil N in the topsoil, particularly at 0-15cm compared to the previous stylo or maize. Under high fertility, the previous legumes gave about 70-120 kg ha^{-1} total available soil N in the topsoil (0-30cm) as against 56 kg ha^{-1} from previous fertilized maize. Independent of the soil fertility level, previous soybean supplied significantly higher (75kg ha^{-1}) total available N compared 52 and 44 kg ha^{-1} from the previous stylo and maize in the topsoil (0-30cm), across sites.

Also, at planting, the low fertility site 1 had clearly lower available N compared to the high fertility site 4. Other sites had moderate values. The previous soybean at site 4 had over 200 kg N ha^{-1} at 0-90cm profile. This is a lot higher than amount required for the production of a subsequent maize crop. But the values from previous stylo plots under high fertility were moderate (100-160 kg ha^{-1}).

Furthermore, there were sharp increases in available N independent of the previous crops and sites, from at least 50 kg ha^{-1} in the surface 15-30cm to over 80 kg ha^{-1} in 30-60cm depth. The values dropped slightly at 60-90cm.

At 5 WAP (1/7/94) differences between previous crops in available N at the topsoil (0-30cm) were not significant, except in site 4 (high fertility) where there was a sharp drop in available N content, from 188 kg ha^{-1} at 0 WAP to 47 kg ha^{-1} at 5 WAP in the previous soybean plots (Fig 4.36). At the other sites, there were increases of 70-200 percent available N in the surface soil layer after previous legumes,

particularly stylo. Although there were no significant site by previous crop interactions at 5 WAP, the N-availability patterns after fast and slowly N releasing legumes such as soybean and stylo at low/high fertility seemed to be different.

At mid-silking (28/7/94), the available N contents of the topsoil under two-year sole crop maize plots were significantly lower than under legume rotation plots at low fertility (site 1). After legume rotation, at low fertility, especially after stylo, available N contents in 0-30cm layer decreased rapidly between 5 WAP and mid-silking which coincides with the main uptake period of the subsequent crops. Whereas, under high fertility, there was an increase of over 70 percent in the surface 0-15cm layer under stylo, and of about 45 percent in 15-30cm under soybean rotation. There were only slight changes in soil N between planting and mid-silking in the two-year sole crop maize plots independent of soil fertility.

At harvest there were no clear differences in residual N after legume rotation and two-year sole crop maize (Appendix 10). Also, differences between the maize cultivars were not obvious.

For sorghum, distribution of N in the profile under low fertility followed a similar trend as obtained for maize. The values were however, lower than those obtained at the respective physiological stages of maize. Residual N at sorghum harvest was much lower than the residual N at maize harvest, especially in the surface soil (Fig. 4.36). The differences are at least partly due to the fact that rains had ceased at these sampling times and the soil was dry.

4.3.5.2. Depletion of soil available N and N balance after one year rotation

When the available N in 0-90cm soil profile at harvest of maize was discounted from values obtained at the beginning of the cropping season, N depletion under soybean rotation was 32-172 kg ha^{-1} as against 32-98 kg ha^{-1} under stylo rotation and 17-74 kg ha^{-1} under two-year sole crop maize (Fig. 4.36). Higher N depletion under soybean rotation could be explained from higher N uptake data of the subsequent maize under the previous soybean compared to the previous stylo or maize (Fig. 4.34). It could also have arisen from high leaching losses of available N as indicated by the lower negative N of -51.0 kg ha^{-1} from N balance estimates, compared with

-21 kg ha^{-1} under stylo rotation and -35 kg ha^{-1} under two-year sole crop maize, across sites (Fig 4.37 and Appendix 10). Losses of available N were lowest ($P<0.05$) under stylo rotation. This may have resulted from higher synchronization of N released from the previous stylo plots with N uptake by the subsequent maize crop from these plots.

Available N depletion and N balance in sorghum were only significant in site 4, and values were higher under soybean rotation than under previous stylo or maize (Fig. 4.37).

4.3.6 Nitrogen Efficiency of the Succeeding Crops

4.3.6.1 Rotation effects on N efficiency parameters

The efficiency of absorbing nitrogen from the soil (NupE) was higher in all sites under legume rotation than in two-year sole crop maize (Fig. 4.38). However, values were significant across all sites, only at $P<0.1$. N uptake efficiency was similar in both cultivars ranging from 0.35 in the low fertility site 1 to 0.60 kg dry matter-N/avail. N in the moderately fertile site 2.

Although cropping systems effect was not significant, previous stylo plots consistently gave higher N uptake efficiency in sorghum, while soybean rotation gave either the same or slightly lower value compared to the previous maize plots (Fig. 4.38). The relatively low efficiency under soybean rotation in spite of its high initial available N, may have resulted from slow uptake rate of sorghum, leading to high N losses and a consequent low efficiency. The release of available N from the previous stylo during the growing season could have synchronized better with the uptake by sorghum. Hence, its higher efficiency under stylo rotation compared to the other cropping systems.

When the supply of nitrogen is limited, plants have to make most efficient use of N that they have absorbed to produced yield, referred to as N utilization efficiency (NutE). Means across sites showed NutE of 8644-27 was significantly ($P<0.0001$)

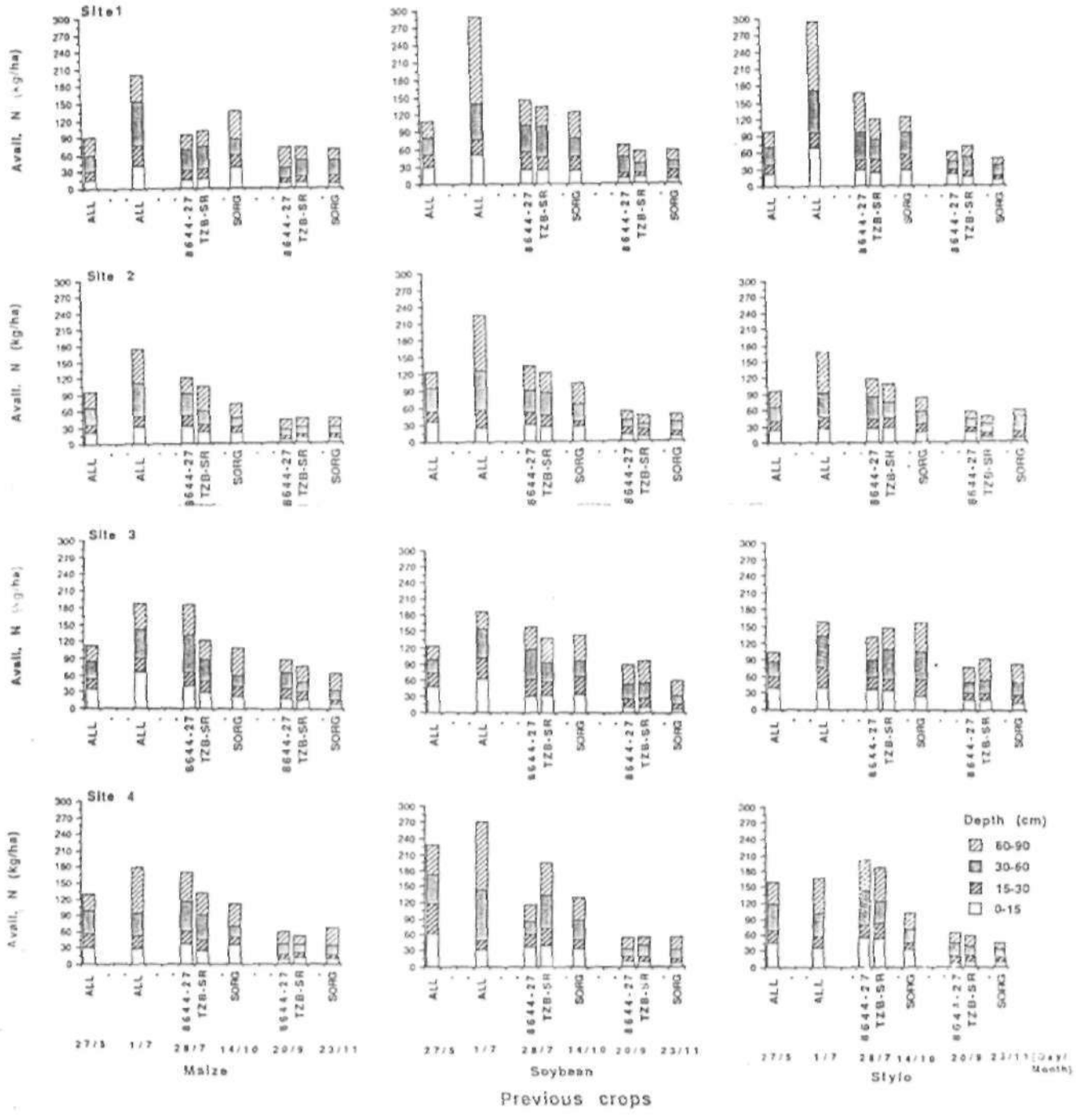


Fig. 4.36 Available N contents (kg/ha) at 4 profile depths under 8644-27, TZB-SR and sorghum from 27/5- 23/11/1994 as affected by previous crop of maize, soybean and stylo at 4 sites differing in fertility. The first 2 samplings labeled ALL were done across genotypes.

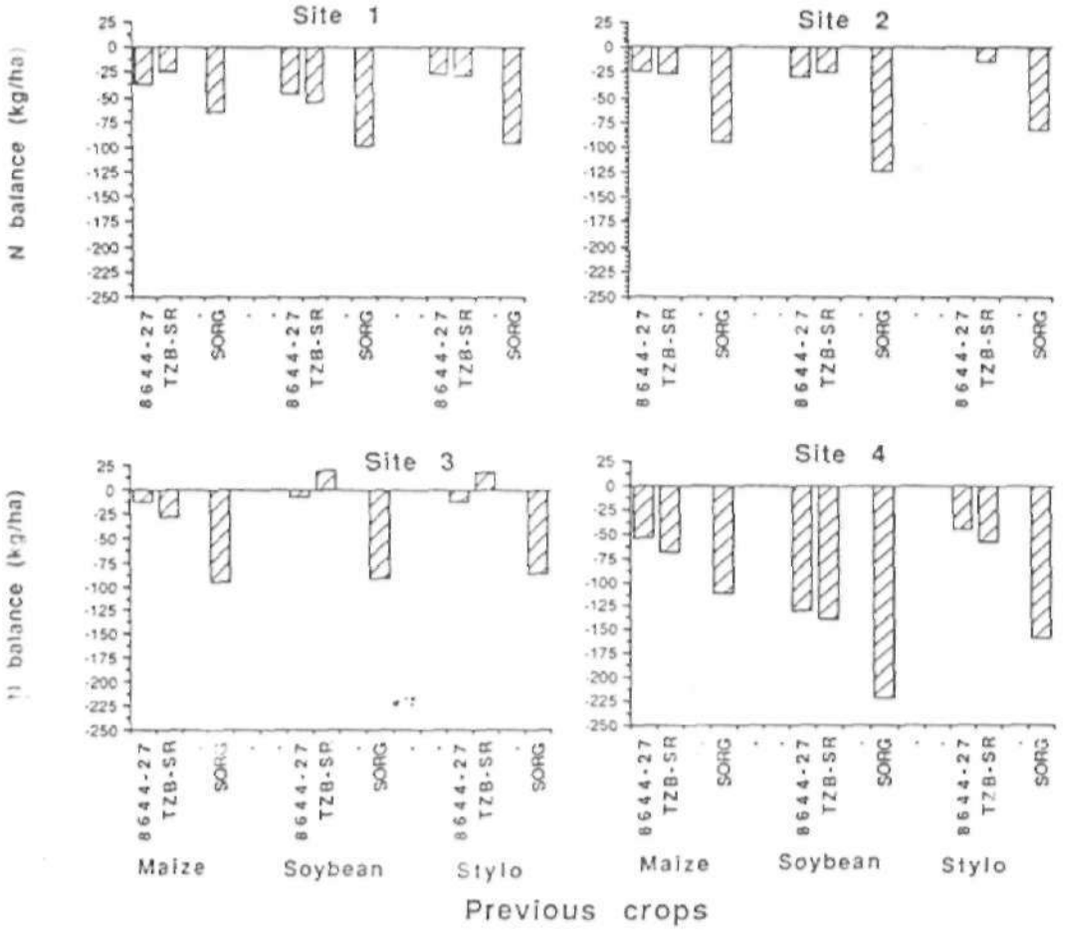


Fig.4.37. Nitrogenbalance(kg/ha) under 8644-27, TZB-SR and sorghum in 1994 as affected by previous crop of maize, soybean and stylo at 4 sites differing in fertility.

higher than of TZB-SR by 10 percent (Fig. 4.39 and Appendix 10).

Sorghum utilization efficiency followed the same pattern as NUpE obtained for sorghum (Fig. 4.39).

Nitrogen use efficiency (NUE) presented in Fig. 4.40, showed that in the high fertility site 4, differences between cropping systems were significant. 27 kg grain was produced for every kg of available N from the previous stylo plots as against 19 and 23 kg grain from the previous soybean and maize plots. On the average, 25.4 kg ($P<0.05$) grains of 8644-27 was produced for each kg of available N supplied to the crop, while 23.4 kg grains of TZB-SR was produced from a kg of available N. The NUE of 8644-27 compared to TZB-SR may be associated with its stay-green characteristics as indicated by its extended grain filling duration observed in on-station trial.

Utilization of available N for sorghum grain production was slightly higher under the sylo rotation than under the previous soybean or maize (Fig. 4.40).

4.3.6.2. Comparison of N efficiency parameters of the subsequent crops

Uptake efficiency of cultivars 8644-27, TZB-SR and the local sorghum cultivar were comparable under moderate to high fertility levels. But under low fertility site 1, sorghum was over 25 percent more efficient in absorbing N from the soil than the two maize cultivars (Fig. 4.38). Sorghum has longer growing period and hence, it absorbs N and other nutrients more slowly than maize. As such, it could tolerate low fertility. This confirms the farmers' reason for growing sorghum in preference to maize when fertilizers are not available.

However, under low to moderate fertility level, for every unit of N taken up by the three cultivars, the conversion to grain production was higher by 60-160 percent and 50-130 percent in 8644-27 and in TZB-SR than in sorghum (Fig. 4.39). This would therefore, imply that if high grain production is the major goal of the farmer, growing an N-use efficient cultivar (8644-27) will be a better option even under low

fertility.

The utilization of soil available N for grain production (NUE) followed a similar trend as NutE (Fig. 4.40).

4.3.7 Farmers' Perception of N-use Efficiency of Crops on their Fields

A farm visit was organised with a group of farmers from the village to get their perception of the research work. They were quite impressed by the performance of the crops in plots planted with legumes in the previous year. They said the amount of N applied to the succeeding crops per row of 11 stands (60 KgN/ha) by their standard, was low. They would have used that amount for three stands (i.e. about 180 kg ha^{-1}) at planting/2 WAP and an additional amount should have been given at 5 WAP in order to have a good crop that looks like the legume plots. They however, said they would not commit their fields to forage legumes as this would not give them any food, although they could see the positive effect of stylo, especially in the low fertility field. This is quite understandable as the farmers intensively use their land for food or cash crop production. Moreover, the return from forage legumes is much lower compared to the return from food crops.

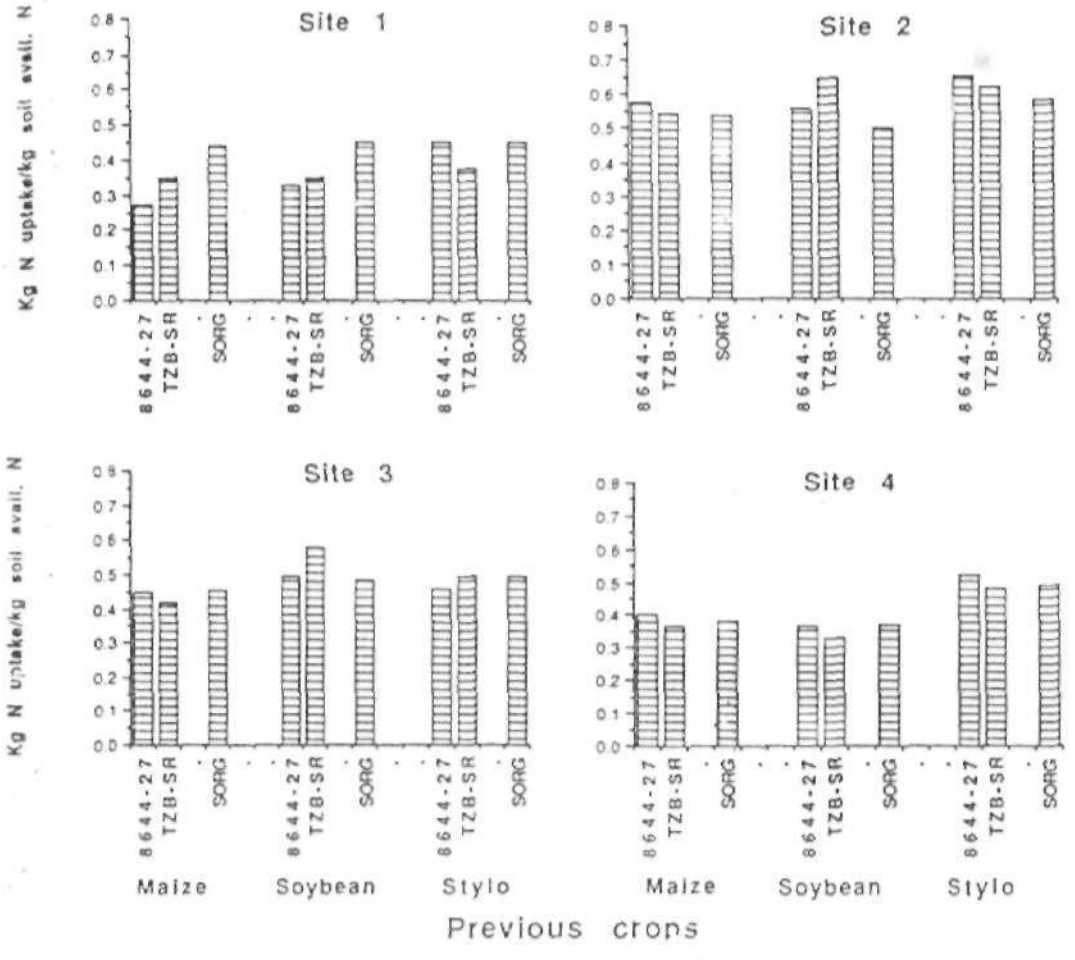


Fig. 4.38. Nitrogen uptake efficiency (kg N uptake/Kg soil avail. N) of TZB-SR and sorghum in 1994 as affected by previous crop of soybean and stylo at 4 sites differing in fertility

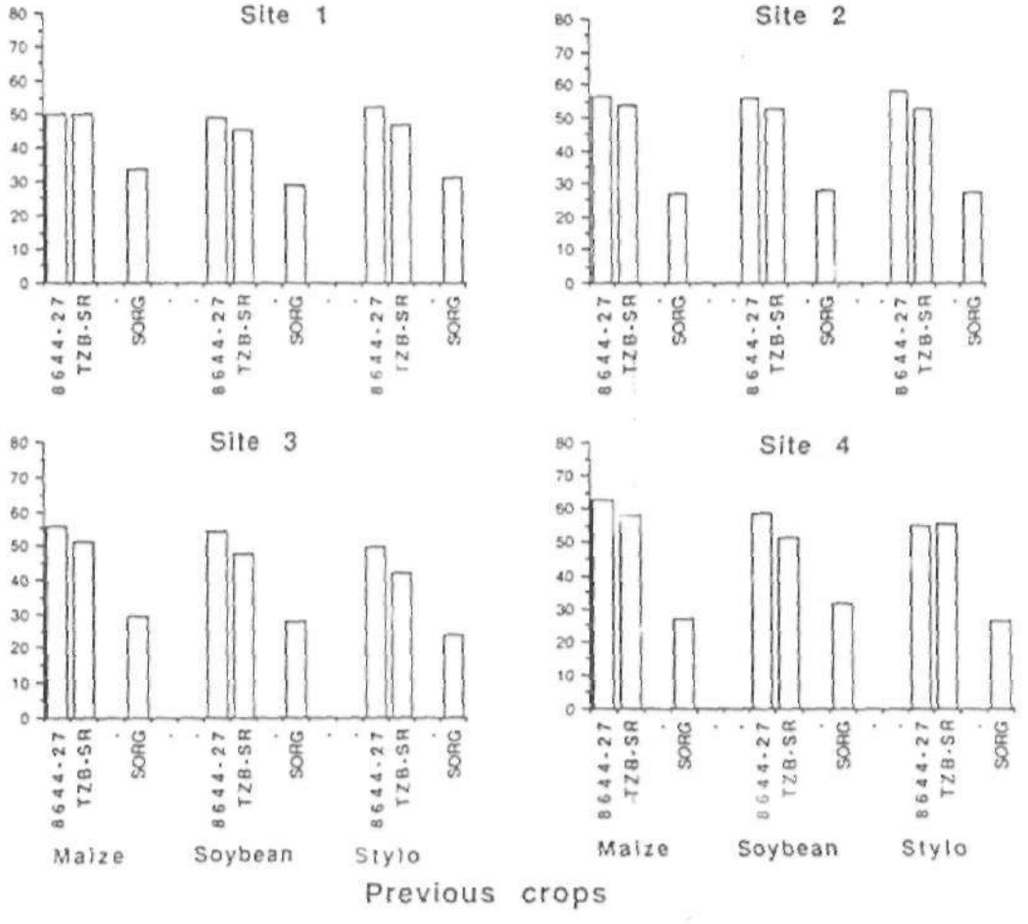


Fig. 4.39. Nitrogen utilization efficiency (kg grain/Kg N uptake) of 8644-27, TZB-SR and sorghum in 1994 as affected by previous crop of maize, soybean and stylo at 4 sites differing in fertility.

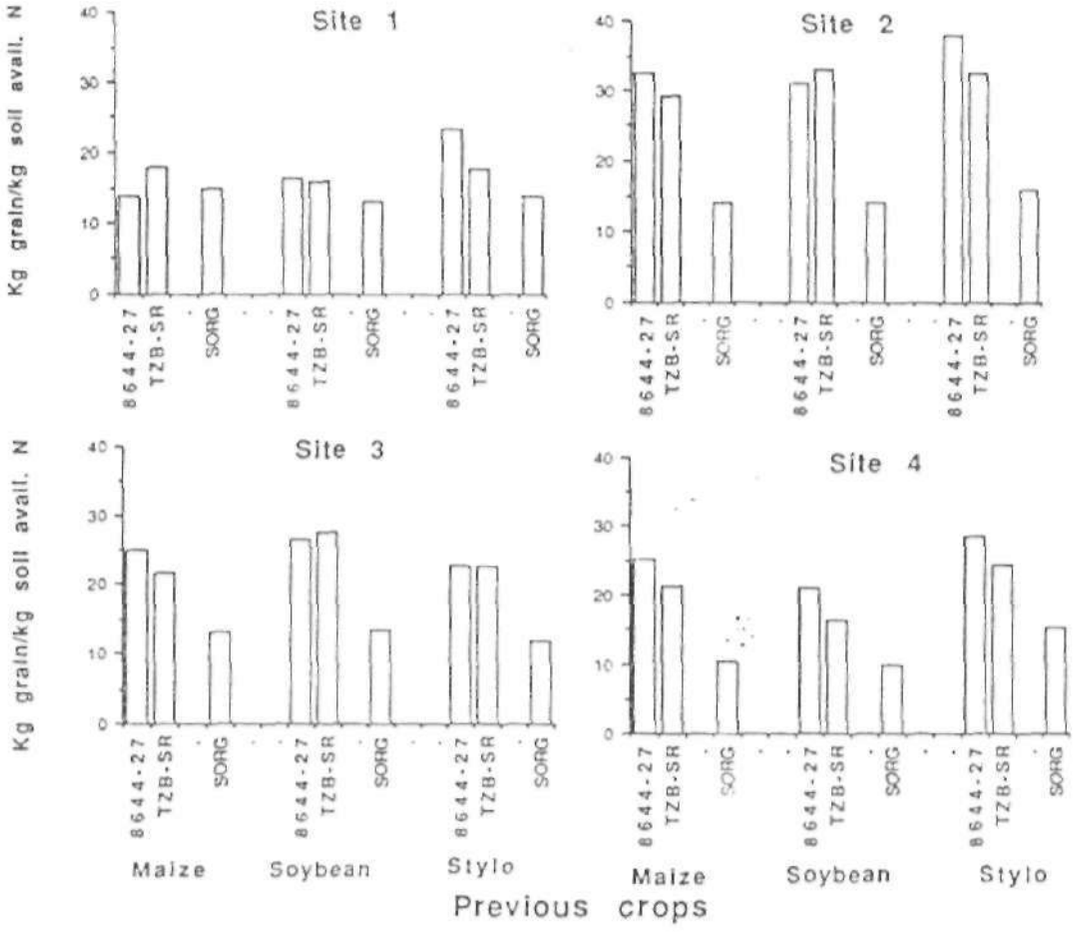


Fig. 4.40. Nitrogen use efficiency (kg grain/kg soil avail. N) of 8644-27, TZB-SR and sorghum in 1994 as affected by previous crop of maize, soybean and stylo at 4 sites differing in fertility.

CHAPTER FIVE

DISCUSSION

5.1 EXPERIMENT I - ON-STATION

5.1.1 Growth and Development

Nitrogen application had a marked influence on growth and development including leaf elongation, plant height, days to anthesis and silking, anthesis-silking interval, and grain filling duration of the maize cultivars studied. Nitrogen fertilization beyond 30 kg ha^{-1} had no significant effects on plant height at silking, although some earlier studies by Ogunlela *et al.* (1988) showed remarkable increases in maize height with N supply up to 100 kg ha^{-1}. The hastening of anthesis and shortening of the interval between anthesis and silking due to N application supported the studies of Ogunlela *et al.* (1988). They reported a reduction in number of days to anthesis with increase in N rates from 0 to 100 kg ha^{-1}. In the present study however, increasing N beyond 30 kg ha^{-1} had no further effects on days to anthesis and silking, anthesis-silking interval, and grain filling duration. Cultivar EV8728-SR and cv. Semiprolific (SPL) appeared to have a greater potential to adapt to nitrogen stress compared to the other cultivars. They showed better synchronization of anthesis and silking under N stress (0 kg ha^{-1}). Bolànos and Edmeades (1988) reported that the gains in performance of a maize genotype under stress were related mostly to improved synchronization of male and female flowering (shorter ASI), leading to more ears with grains. Anthesis-silking interval has therefore, been proposed as an important easily observed indicator of ear biomass at anthesis in field evaluation of maize cultivars under low N (Laffitte and Edmeades, 1994a).

Furthermore, the hybrid cv. 8644-27 and cv. EV8728-SR had on the average, longer duration of grain filling (LGF) under N stress (0 kg ha^{-1}) compared to the other cultivars further suggesting the adaptation of cv. EV8728-SR to N stress.

Duvick (1992) reported that genetic gains in maize yield were found mainly from an extended grain-filling period and delayed foliar senescence (photosynthetic longevity) under low N. Therefore, LGF should be considered for further investigation for inclusion in a breeding programme aimed at increasing maize yield under low N in the savanna. The shorter ASI and longer grain filling period observed in cv. EV8728-SR compared to the other cultivars, confirmed the results of Bolànos (1995), that there is a strong and negative relationship between LGF and ASI in tropical maize.

5.1.2. Yields and Yield Components

The large increases in grain and stover yields with increase in N rates is consistent with the work of Muchow (1988b), Jones (1972) and Ogunlela *et al.* (1988). Agbede *et al.* (1991), found increases in grain yields with increasing N applied up to 90 kg ha^{-1} beyond which further addition resulted in yield decline. Other studies showed little or no increase and even depression in dry matter yield with increase in N supply (Douglas *et al.*, 1972). However, the present practice of split-application of N doses, supplying a smaller dose first, relying on mineral N released early in the growing season, and larger amounts later at five weeks after planting is uneconomical. It should be discouraged when planting is done early in the season. The second dose should be applied earlier than five weeks after planting. The crop suffers N deficiency which cannot be overcome by applying a high dose of N later in the season, thus resulting in reduced yield where the N content of the field is low.

Differences between cultivars in response to N application occurred as early as 35 DAP. This suggests that the cultivars have different capacities to accumulate dry matter and in yield formation. Wiesler and Horst (1993) reported differences among temperate maize cultivars in yield formation at silking and at silage maturity in Germany. They also found a general trend towards higher stover yields in the late maturing cultivars. In the present study, cultivars Mokwa 87TZPB-SR and TZB-SR showed longer days to maturity and had higher stover yield than the other cultivars.

The hybrid cv. 8644-27 produced on average, significantly higher grain yield compared to cultivar TZB-SR. This may be associated with higher sink capacities of cv. 8644-27 as indicated by higher harvest index, bigger 1000-kernel weight, and longer grain filling period.

At the International Maize and Wheat Improvement Center (CIMMYT), Mexico, Bolànos (1995) observed that the superior yield of hybrids compared to open pollinated cultivars (OP) was due to both increased source and sink capacities. Cultivar TZB-SR had the lowest grain yield and kernel growth rate of 1.56 g day^{-1}. This confirms other studies that lower yield of maize cultivars especially among OP was due to a poor kernel growth rate (Perenzin *et al.* 1980; Bolànos 1995).

Differences in grain yield between the hybrid and the other cultivars were higher under sub optimal N dose of 60 kg ha^{-1}. This agrees with the work of Smith *et al.* (in press) that maximum yield advantage in hybrid maize is attained at a moderate N rate of 50-60 kg ha^{-1} as opposed to the recommended rate of 120 kg ha^{-1}. This may be due to more efficient remobilization of N for high yield or the consequence of higher sink activity of the grains (Sattelmacher, 1994).

The higher response of maize to N fertilization compared to the local sorghum could probably be due to its shorter growth period and hence greater intensity of nutrient demand (Stockinger, 1971). The local sorghum seemed to be well adapted to low soil fertility and does not respond remarkably to high N levels in the soil. This may be the reason for farmers preference for sorghum when fertilizer is not available for maize production.

There were no significant cultivar by nitrogen interactions in yields and components of yield, as well as most of the other variables measured. The implication is that cultivars selected under low N may perform equally well under high N supply.

5.1.3. Nitrogen Partitioning and Utilization Efficiency

Nitrogen allocation to the grain, stover and cob at physiological maturity was significantly increased with increase in applied N as also observed by Simonis (1987). Genetic differences in grain-N has been reported in tropical maize (Ta and Weiland 1992; Lafitte and Edmeades *et al.*, 1994). In the present work, no cultivar differences in grain-N were evident, despite differences observed in grain yield. There were differences however, in nitrogen harvest index and nitrogen utilization efficiency among the cultivars. Such differences have been reported by Kamprath *et al.*(1982). The hybrid cv. 8644-27 which had the highest NHI also had the highest NutE, as also observed by Sattlemacher *et al.* (1994) under temperate conditions.

According to Moll *et al.* (1982) variation in components of nitrogen use efficiency including N uptake and N utilization, were related to the level of N supply and the particular maize genotype. This was confirmed in the present study. There were large differences in N utilization efficiency among cultivars at 0 and 30 kg N ha^{-1} than at higher N rates. The result therefore, suggests that selection under low N supply may favour genotypes which are efficient in N utilization.

The variation in NUE at low N supply may be due mainly to better utilization of N. The relatively low NUE of cv. TZB-SR was due to its low ability to assimilate N and its low N utilization efficiency during grain filling. Probably it was selected under high N which favours high N uptake rather than utilization efficiency (Moll *et al.*, 1982; van Sanford and MacKnown 1986). To increase NUE in tropical maize therefore, it is important to develop cultivars with both high N uptake and utilization efficiencies under low to moderate N supply.

The unfertilized sorghum plants had relatively higher translocation of N from the vegetative parts to the grain than plants supplied with N. This confirms the observation

of Roy and Wright (1974) that unfertilized improved sorghum plants translocated

relatively higher N and P from the vegetative parts to the developing grains. In general, the local sorghum had very low capacity to translocate N to the grain compared to the improved cultivars. In the present study, only 32-36 percent of the total N in the whole plant was contained in the head. In improved sorghum, Roy and Wright (1974) found that the head contains 65-70 percent of the total N yield of the whole plant.

High N utilization efficiency is good for grain yield. It is not good for fodder value of the stover. For some farmers who use maize stovers as an important fodder source, improving N utilization efficiency will reduce the quality of the stover which is highly dependent on the residual N content in the stover. As N utilization efficiency is improved in maize therefore, a complementary use of N-rich fodder (legume fodder) will be highly desirable for the small-holder farmers.

5.1.4. Root Development in Relation to Soil Nitrogen Utilization.

Little or no investigations have been made on the root system of tropical maize under the moist savanna soil conditions. The size, distribution, and rate of development of roots are important because of their influence in supplying nutrients and water to crops. In this study, root length density and root dry matter increased with increase in applied N particularly, at 0-15cm layer, the zone of application at stem elongation phase (35 DAP) and at mid-silking, in accordance with the reports of Feil *et al.* (1990) and Durieux *et al.* (1994).

More roots were found at silking, particularly at lower (>30cm) depths, under 30 than under 120 kg ha^{-1}. At low N supply a higher proportion of dry matter is allocated to the root system than to the shoot, while at high N supply there was a greater dry matter allocation to the shoot at the expense of root production (Fusseder 1984; Durieux *et al.*, 1994; Sattelmacher *et al.*, 1994). Root length density at silking in 1994 was higher at 0-15cm layer when 120 kg ha^{-1} was supplied in two equal splits at 2 and 5 WAP. The second dose might have stimulated lateral root development at this layer (Granato and Raper, 1989; Sattelmacher and Thoms, 1989 ; Durieux *et al.*,

1994). It shows that root growth is not completely regulated by the shoot.

There were remarkable differences between cultivars in root development. The cultivar TZB-SR had the lowest root production at 35 DAP. It also had the least shoot dry matter and nitrogen yields at this growth stage in both years. The limited root system may have restricted N uptake. However, N uptake at stem elongation phase led only to a marginal depletion of soil N within 0-30cm soil layer. A similar observation was made by Wiesler and Horst (1993) under temperate soil conditions. It therefore, means that if the objective is to obtain N released early in the growing season before it is leached to the subsurface, screening for rapid early root growth may not be very effective.

At mid-silking in 1994, relative differences in root length density and root dry matter between the cultivars were largest at depth ≥45cm. This contrasts with the results of Mackay and Barber (1986), that maize cultivars differ in root length density exclusively in the topsoil. It confirms however, the work of Wiesler and Horst (1994b) who found maize cultivars differences in root length density were largest in 0.6-1.2m depth under temperate conditions. In another study, Wiesler and Horst (1994a) showed that increase in root growth in this zone (0.6-1.2m) had a marked effect on nitrate utilization. While in an earlier study, Wiesler and Host (1993) reported a significant negative correlation between root length density in the subsoil and nitrate leaching in suction probes under maize production. This suggests that nitrate uptake efficiency and ability of a maize cultivar to minimize ground water pollution by nitrate would largely depend on its ability to develop a deep root system to extract nitrate from deeper soil layer late in the season (Greenwood, 1986).

In the present study, cultivar Mokwa 87TZPB-SR had the highest vegetative yield at mid-silking and it also had the highest root length density at 45-75 cm in 1994. Nitrogen removal at the phase of most active N uptake between stem elongation and mid-silk was highest (118 Kg ha^{-1}) under Mokwa 87TZPB-SR. Therefore, screening

maize genotypes at mid-silking for improved root development at the subsoil (>30 cm depth), could be a better indicator of N uptake efficiency than screening for rapid early root growth.

The semiprolific cv. SPL had the least N uptake at silking in 1994, although it had a high root production similar to Mokwa 87TZPB-SR. Pan *et al.* (1984) found that prolific hybrids showed reduced N uptake during reproductive growth phase. While, Durieux *et al.* (1994) suggested that prolific corn hybrids may display enhanced root growth before silking because they have a higher yield potential, but a less N uptake after silking than non-prolific plants. In the present study however, N uptake after silking was highest in SPL compared to the other cultivars. Although cv. TZB-SR had low root length density, it had similar dry matter and nitrogen yields to cv. Mokwa 87TZPB-SR. It is likely that its low root length density was sufficient to meet its N demand. From computer simulation models, Barraclough (1989) indicated that only at very low root length densities (<< 1 cm cm^{-3}) does the absorbing surface limit nitrate absorption in oilseed rape crop.

Sorghum root length density and root dry matter at mid-heading were higher, but more superficially located, mostly within 0-30 cm, than maize roots at mid-silking. In the Sahelian soils of Niger Republic, Zaongo *et al.* (1994) also found that the bulk of sorghum roots were concentrated in the top 0-30cm soil layer. Due to the dry nature of the soil during sorghum root extraction, it was not possible to go beyond 60cm. However, the result showed that there was a low root production at 45-60 cm layer. Considering the higher N uptake in sorghum than in maize, it may be concluded that sorghum has a more efficient root system than maize under the moist savanna conditions.

The differences between cultivars in N utilization for grain production (NUE) reflected differences in N utilization efficiency more than N uptake efficiency. Therefore, under savanna soil conditions N utilization efficiency appeared to be more

important than N uptake efficiency in determining NUE in maize.

5.2. EXPERIMENT II - ON-FARM

5.2.1 The Contribution of Legumes to Available Soil N and N Dynamics

The short term contribution of legumes to soil nitrogen and to a subsequent cereal crop would depend largely on its capacity to fix atmospheric nitrogen. The actual amount of N added to the soil, however, depends on the N accumulation in the crop (and recycled to the soil), its root mass and also the purpose for which the crop is grown either for grain, fodder or green manure. In the present study, N_2 fixation could not be estimated because the reference crop received an optimum N rate of 90 kg ha^{-1} (CAN) in 1993. This was necessary to simulate an identical situation to what farmers normally practice, so as to evaluate with them the possibility of integrating legumes for soil fertility improvement. Previous studies have shown that soybean (cv. TGx 1660-19F) derived an average of 126 kg N ha^{-1} (52 percent) from N_2-fixation in the moist savanna of Nigeria (Sanginga *et al.*, unpublished). Based on the amount of N accumulated in the previous crops, across fields in this study, soybean contributed higher N to the farming system than stylo.

The above-ground N harvest index (NHI) of soybean (62-71 percent) obtained for high to low fertility sites were generally lower than the range of 75-90 percent reported by Eaglesham *et al.* (1982) at Ibadan. Therefore, Eaglesham *et al.* (1982) reported very low contribution of 10 to 25 kg N ha^{-1} from soybean fertilized with N as against 75 kg N ha^{-1} found in the topsoil (0-30cm) in the present study without addition of N fertilizer to the crop. However, the general low productivity of site 1 may be due to other soil problems limiting yield rather than low N release, because N deficiency was not observed. Phosphorus deficiency was suspected. The site had the lowest soil P of

6.39 g kg^{-1} compared to the other sites.

The high available N found in the topsoil (0-30cm) of the previous legume plots compared to the previous maize plots at the beginning of 1994 could be due to N_2 fixation and the return of N through legume leaves, litter nodules, and roots. Nnadi *et al.* (1981) also found higher available N in the top 0-30cm soil horizon of previous cowpea and local bambara nuts than on previous sorghum plots. While, Jones (1974) showed increased in nitrogen availability in the topsoil after groundnut but not after cowpea. More recently, Horst and Hardter (1994) reported a comparable nitrate content of the soil after cowpea and after maize monoculture at the beginning of the cropping season in northern Ghana. In the present study, litter N content was lower than the critical range of 15-25g kg^{-1} above which net mineralization will occur (Stevenson, 1986). Lignin and polyphenol concentrations are other plant factors controlling N mineralization rate of plant materials added to the soil (Haynes, 1986; Tian *et al.*, 1992). Higher lignin and polyphenol contents of the stylo (Fox *et al.*, 1990) might have been involved in the delayed release of N from stylo species used in the present study.

Soybean and stylo are relatively new crops to tropical Africa and little has been done on their contribution to N dynamics and to a succeeding crop in a rotation system. Nitogen-fixing potentials of legume varieties, soil mineralization potential, litter N-concentration, and lignin and polyphenol concentrations generally influence N release from previous legume crops.

There were sharp increases in available N in 30-60cm horizon independent of the cropping system. According to the studies of Nnadi *et al.* (1981) and Weber *et al.* (1995c) available soil N decreases with depth. However, their sampling was restricted to 0-45cm soil depth and could not reveal the sharp increases in 30-60cm. But the present study confirms the work of Wong *et al.* (1987) and Jones (1976) who found that NO_3-accumulated more in the lower horizons of acid Nigerian soils. Different explanations have been given for this phenomenon including, a preferential flow of water through

macropores leaving behind NO3- in the micropores, (Wetselaar 1962 and Wild and Babiker 1976), nitrate retention related to anion sorption (Singh and Kanehiro, 1969; Black and Waring, 1976), and low soil moisture contents resulting in low NO3- diffusion in the soil (Burns, 1980). This NO3- in the subsoil with the associated cations are destined to leach to the lower depths beyond the root zone except deep rooting crops which could tolerate subsoil acidity and could attract NO3- retained in the subsoil are planted. Therefore, appropriate technology involving deep rooting legumes that could survive the dry season and utilize this sub-surface NO3- and which could then serve as green manure in the following season need to be identified.

5.2.2 Crop Rotation and *Striga hermonthica* Control

Striga hermonthica (Del.) Benth., is a parastic weed of economic importance in the savannas of Africa. It attacks cultivated cereal crops such as maize and sorghum among others. The experimental sites were originally selected based on a three-year history of no soil-borne problems including *Striga*. It was therefore, surprising to notice *Striga* emergence in all the sites in 1994 particularly in the high fertility, site 3. Wilson 1953 reported that *Striga* seeds can stay dormant in the soil for years and each year a given proportion lose dormancy, and when the right host is available it emerges. Crop rotation using non-*Striga* host such as legumes is a recommended cultural method to suppress it (Doggett, 1984; Parkinson *et al.*, 1987). In this study, rotation with soybean reduced the incidence and severity of *Striga* compared to rotation with stylo or a two-year sole crop maize. Similar reduction in the emergence and reproduction of *Striga* under rotation with soybean and *Aeschynomene* (a forage legume) was found in the Northern Guinea Savanna of Nigeria by Weber *et al.* (1995a). It has been reported that soybean promotes the suicidal germination of *Striga* seeds, but stylo does not (A. Awad unpublished; Alabi *et al.*, 1994).

Inherent soil fertility and fertilization have been identified as major factors influencing *Striga* incidence and severity (Parker, 1976). In the present study however,

site 3 field with high fertility had more *Striga* infestation than the less fertile site 1. Weber *et al.* (1995a) also could not associate N fertilization with *Striga* emergence and concluded that soil fertility and N fertilization had only a modifying effect on *Striga* epiphytotics rather than being a primary determinant of *Striga* infestation in the Northern Guinea Savanna of Nigeria.

5.2.3. Crop Rotation, Yield and N Uptake of Subsequent Crops.

Higher available soil N contributed in this study to higher maize yields following legumes in spite of the removal of the legume crop residues from the plots. This result is consistent with those of Hesterman *et al.* (1986); Dakora *et al.* (1987); Horst and Hardter (1994); Carsky and Berner (1995), who reported increase in maize yields from a legume-maize rotation system compared to a continuous maize system. However, only Carsky and Barner (1995) removed the above-ground legume residues from the field. In the present study, the previous legume plots gave 40 percent higher available N across sites compared to the previous maize plots. The N-release patterns appeared to be different between soybean and stylo rotation and between low and high fertility sites, although further research on this is needed. There were indications of enhanced mineralization of N from the previous stylo plots during the season. But, after previous soybean only a fraction of the N released at the beginning of the season was utilized by the maize crop as indicated by the high losses of N from the N balance study.

Differences between cropping systems in maize yield site 3 reflected differences in N concentrations at silking. However, values were generally lower than the N sufficiency range of 26-40 mg g^{-1} reported by Binford *et al.*, (1990). Net above-ground N uptake of the succeeding maize under the different cropping systems followed the same pattern as yield. Thus, differences in N nutrition rather than N-uptake was the major factor contributing to the yield differences between a legume rotation system and a two-year sole crop maize. A similar observation was reported by Horst and Hardter (1994).

Finally, legume rotation system may have a greater benefit in soil fertility maintenance if targeted into the production systems based on inherent soil fertility and legume quality. However, the role of legume quality in improving soil fertility will need further studies under different fertility regimes. Special emphasis should be given to soybean cultivars adapted to soils of low fertility, forage legumes with adequate agronomic potential and deep rooting, drought tolerant species for nutrient recycling.

5.3. FUTURE RESEARCH NEEDS

The present study has shown that cultivar differences exist in root morphology, particularly at the subsoil, of tropical maize cultivars grown in the moist savanna. Further research on root should emphasis more on identifying cultivars with improved root system at the subsoil(>30cm depth) late in the season. This will increase the recovery of nitrate from the subsoil and reduce N losses due to leaching.

More effort is still required to develop N-use efficient cultivars as the present N-use efficient cultivars could give only 10 percent yield difference over the widely grown cultivar TZB-SR. Selection for higher sink capacities including extended grain filling period could be effective criteria that would need further investigation.

Further work is required to integrate appropriate legume-based technologies into the farming system based on an identification of soil N- and legume N-release patterns as N-use efficient maize cultivars are being developed and integrated into the savanna farming system.

CHAPTER SIX

SUMMARY AND CONCLUSIONS

The soils of Trial 1 site were classified as Plinthustalfs (1993 site) and Typic Haplustalfs (1994 site), while soils of Trial 2 sites were classified as Typic Haplustalfs, fine loamy, isohyperthermic according to the US Soil Taxonomy System. The soils of all the sites were well drained sandy-loam to loam. The pH of the topsoil was strongly to moderately acid.

Root morphology characteristics including root length density and root dry matter at 35 DAP in 1994 were significantly increased at all depths sampled with increase in N supply. Application of 120 kg ha^{-1} in splits of 60:60 at 2 and 5 WAP stimulated lateral root development in the surface 0-15 cm soil layer. At depths >45cm significantly more roots were produced under 30 than under 0 or 120 kg N ha^{-1} at mid-silking in 1994. There were significant differences among cultivars in root length density and root dry matter in the surface 0-15cm at 35 DAP and in 45-90cm layer at silking in 1994, and in 0-15cm layer at silking in 1993. Root production and N uptake were highest in Mokwa 87TZPB-SR in both years. When sampled at their respective phenological stages, sorghum root production was higher but more superficially located within the topsoil (0-30cm) than maize roots. Screening maize cultivars for improved root development at the subsoil (>30cm depth) late in the season was a.better indicator of N-uptake efficiency than screening for rapid early root growth.

The hybrid cv.8644-27 gave the highest grain yield of 5.8 t ha^{-1} and was the most N-use efficient cultivar. The most widely grown OP, cv. TZB-SR was the least efficient in utilizing available soil N for grain production, although it had the highest kernel number per ear and total above ground dry matter. The semiprolific (SPL) and EV8728-SR cultivars appeared to have a higher potential to adapt to N stress than the

other cultivars. They had higher grain yields under zero-N in both years. They also showed greater synchronization of anthesis and silking which indicates better ability to adapt to N stress.

The efficiency of the local sorghum to convert available soil N to grain production was relatively low, 9 kg grain per kg avail. soil N as against 17 kg grain per kg avail.soil N in maize under 30 kg ha^{-1}. The present practice of shifting to sorghum when N is in limiting supply is not productive, when grain yield is of major interest to the small-holder farmers.

Marginal analysis showed that 60 kg N ha^{-1} was the most profitable rate for maize production under the conditions of the experiment. Farmers will have better return for their investment when they grow hybrid cv.8644-27 than growing their present OP cv.TZB-SR. However, they will benefit more in growing N-use efficient OPs when available, than growing the hybrid cv.8644-27.

The hypothesis that the contributions of maize cultivars efficient in N use and legumes to N-use efficiency can be improved by matching legume residue decomposition rates with soil nitrate-release was evaluated in four farmers' fields of different native fertility in the 1993 and 1994 growing seasons. Total available soil N in the 0-30 cm layer at the beginning of the 1994 season was 75, 52 and 44 kg ha^{-1} following previous soybean, stylo and maize, respectively. At 5WAP, there was a sharp drop in available N from 188 kg N ha^{-1} at 0 WAP to 47 kg N ha^{-1} in previous soybean plots under high fertility. While increases of 70-100 percent was obtained at moderate fertility after previous stylo. Available N content of the top soil after previous legumes under low fertility was significantly higher than under two-year sole crop maize. Independent of the previous crops, there was higher accumulation of available soil N at 30-60 cm than in other depths at 0 and 5 WAP.

Total N uptake of maize was over 25 percent higher following legumes than following maize. A combination of legume rotation, 60 kg N ha^{-1} at 2WAP and early

planting of an N-use efficient cultivar 8644-27 gave a yield advantage of 1.3 t ha^{-1} over a two-year sole crop maize, cv.TZB-SR supplied with 60 kg N ha^{-1} at 2 WAP. There was no effect of previous crops on sorghum yield. Furthermore, losses of N probably due to leaching were lowest in plots previously planted with stylo.

Soybean rotation system reduced *Striga hermonthica* emergence and severity compared to a two-year sole crop maize or a stylo rotation system. The emergence of *Striga* was highest in the previous stylo plots. There was less *Striga* emergence in the N-use efficient cv.8644-27 plots than in plots planted with cv.TZB-SR.

Results indicate opportunities to integrate appropriate legume-based technologies into savanna farming system based on an identification of soil N- and legume N-release patterns. Special emphasis should be given to soybean cultivars adapted to soils of low fertility, forage legumes with adequate agronomic potential and deep rooting, drought tolerant species for nutrient recycling.

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APPENDICES

Appendix 1

Profile Description

Profile Number	:	**IAR 1 (On-Station Site 1993)**
General site information		
Location	:	Institute for Agricultural Research (IAR) Farm -Samaru.
Taxonomic classification	:	**Plinthustalfs, fine-loamy, isohyperthermic (Plinthic Luvisols - FAO).**
Soil parent material	:	Igneous/metamorphic rocks (granite/ gneiss)
Geology	:	Basement complex rocks
Geomorphology	:	Undulating plain with occasional laterite micas and granitic inselbergs
Topography	:	Upper slope; gently sloping or undulating, 2-4% slope
Vegetation	:	Northern Guinea Savanna; *Isoberlinia sp.*, *Hyperrhenia sp.*
Land use	:	Research field (IAR) crops
Soil erosion hazard	:	Slight sheet erosion
Drainage	:	Well drained
Depth to water table	:	Not encountered at 82cm (profile depth)
Depth to impenetrable layer:		Lateritic materials at 82cm and below
Surface characteristics	:	Concretionary iron/manganese nodules >2mm on the surface
Described by	:	T. Kparmwang and Sylvester Oikeh
Date sampled	:	4th June, 1993

Horizons Description

Horizon	Depth (cm)	Description
Ap	0-17	Dark brown (7.5 YR 4/4 moist) loam texture, moderate, coarse subangular blocky structure; slightly sticky and slightly plastic (wet) friable (moist); many fine pores; common very fine roots; common hard concretionary Fe/Mn nodules, especially on the surface; common very fine mica flakes; few earthworms; few medium ant nests; abrupt smooth boundary.
B/A	17-31	Yellowish red (5 YR 5/6 moist) clay loam; moderate coarse subangular blocky structure. Sticky and plastic (wet) and friable (moist); many fine pores; common very fine dead roots; common very fine mica flakes; few medium ant nests; clear smooth boundary.
Bt	31-82cm	Yellowish red (5 YR 5/8 moist) reddish yellow (7.5 YR 6/8 dry) clay loam; strong coarse prismatic structure; sticky and plastic (wet) friable (moist) very hard (dry); common fine pores; few very fine roots; common very fine mica flakes; common coarse ant nests (moist); few fine tissue; clear wavy boundary.
Bt_{cv}	82++	Reddish yellow (7.5 yr 6/8 moist) yellowish red (5 YR 5/8 dry) very gravelly clay loam; (massive) structureless; sticky and plastic (wet) friable (moist) hard (dry); many fine pores; many hard Fe/Mn concretionary nodules; common plinthite.

Profile Number	:	**IAR 2 (On-Station Site 1994)**
General site information		
Location	:	Institute for Agricultural Research (IAR) Farm - Samaru, Zaria
Taxonomic classification	:	**Typic *haplustalfs*, fine loamy, isohyperthermic (Chromic Luvisols - FAO).**
Soil parent material	:	Loesial over basement complex material
Geology	:	Basement complex rocks
Geomorphology	:	Slightly undulating Northern Guinea Savanna terrain
Topography	:	Mid-slope; level to nearly level, 0-2% slope
Vegetation	:	Northern Guinea Savanna; *Isoberlinia sp., Hyperrhenia sp.*
Land use	:	Research field (IAR) crops
Soil erosion hazard	:	Slight sheet erosion
Drainage	:	Moderately well drained
Depth to water table	:	Not encountered at 185cm (profile depth)
Depth to impenetrable layer:		≥185cm
Surface characteristics	:	Slightly crusting
Described by	:	O. Odunze and Sylvester Oikeh
Date sampled	:	19th May, 1994

Horizons Description

Horizon	Depth (cm)	Description
Ap	0-20	Dark brown (7.5 YR 4/4 moist) loam; weak, fine subangular blocky structure; non-sticky (wet); very friable (moist) and soft (dry); common fine pores; common fine roots; clear wavy boundary.
Bt_1	20-57	Yellowish red (5 YR 5/6 moist) clay loam; moderate, medium subangular blocky structure, sticky (wet) and friable (moist); common medium fine pores; few medium dead roots; common manganese oxides; few ant nest (krotovenia) clear smoot boundary.
Bt_2	57-80	Yellowish red (5 YR 4/6 moist) clay loam; moderate, medium, subangular blocky structure; sticky (wet) firm (moist) and hard (dry); few medium pores, few concretions/nodules; iron/ manganese oxides, quartz stones and few mica flakes; few ant nests; gradual irregular boundary.
C	80-185	Light grey (2.54 YR 7/1 moist) clay loam, common, medium, distinct, yellowish red (5 YR 5/8) mottles; strong, medium subangular blocky structures; very sticky (wet) firm (moist) and hard (dry) consistence; few very fine pores; common Fe/Mn concretionary nodules; common Fe/Mn oxides; plinthic at 185cm and beyond.

Profile Number : **TBR 1 (Site 1)**

General site information

Location	:	Tsibiri village, about 2km off Shika (NAPRI)
Taxonomic classification	:	**Typic Haplustalfs, fine loamy, isohyperthermic (Chromic Luvisols - FAO)**
Soil parent material	:	Aeolian material over granitic and/or gneissous residium
Geology	:	Basement complex rocks
Geomorphology	:	Undulating plain
Topography	:	Mid-slope; gently sloping or undulating 2-4% slope
Vegetation	:	Northern Guinea Savanna
Land use	:	Maize
Soil erosion hazard	:	Moderate sheet erosion
Drainage	:	Moderately well drained
Depth to water table	:	Not encountered at 150cm depth
Depth to impenetrable layer	:	None encountered
Surface characteristics	:	Common hard Fe/Mn nodules
Described by	:	T. Kparmwang and Sylvester Oikeh
Date sampled	:	4th June, 1993

Horizons Description

Horizon	Depth (cm)	Description
Ap	0-12	Dark yellowish brown (10 YR 4/4 moist) loam; weak medium subangular blocky structure; non-sticky and non-plastic (wet) very friable (moist); many fine pores; few medium and common fine roots; many very fine mica; few ants and medium ant nests; clear smooth boundary.
BA	12-27	Dark brown (7.5 YR 4/4 moist) clay loam; weak medium subangular blocky structure; slightly sticky and slightly plastic (wet) friable (moist); common medium and many fine pores; many fine roots; many very fine mica flakes; few coarse ant nests; clear broken boundary.
Bt_1	27-36	Dark brown (7.5 YR 4/4 moist) clay; weak coarse subangular blocky structure; slightly sticky and plastic (wet), firm (moist); common medium and many fine pores; many very fine mica flakes; common ant nests; clear broken boundary.
Bt_2	36-74	Yellowish red (5 YR 4/8 moist) clay loam; strong coarse subangular blocky and prismatic structures; slightly sticky and plastic (wet); firm (moist); many medium and fine pores; common fine roots; many very fine mica flakes; common medium and few coarse ant nests; gradual smooth boundary.
Bt_3	74-119	Strong brown (7.5 YR 5/6 moist) clay loam; moderate coarse subangular blocky structure; sticky and plastic (wet) firm (moist) hard (dry); many fine and medium pores; many very fine roots; common firm Mn concretions; many very fine mica flakes; common very coarse ant nests; clear smooth boundary.
Bt_c	119-150	Reddish yellow (7.5 YR 6/6 moist) clay loam; structureless (massive); slightly sticky and plastic (wet) friable (moist); many fine and medium pores; few very fine roots; many hard Fe/Mn nodules.

Profile Number	:	**TBR 2 (Site 2)**
General site information		
Location	:	Tsibiri village, about 2km off Shika (NAPRI)
Taxonomic classification	:	**Typic Haplustalfs, fine loamy, isohyperthermic (Chromic Luvisols - FAO)**
Soil parent material	:	Aeolian material over granitic and/or gneissous residium
Geology	:	Basement complex rocks
Geomorphology	:	Undulating plain
Topography	:	Mid-slope; gently sloping or undulating, 2-4% slope
Vegetation	:	Northern Guinea Savanna
Land use	:	Maize
Soil erosion hazard	:	None
Drainage	:	Well drained
Depth to water table	:	Not encountered at 150cm depth
Depth to impenetrable layer	:	None encountered
Surface characteristics	:	No special features
Described by	:	T. Kparmwang and Sylvester Oikeh
Date sampled	:	4th June, 1993

Horizons Description

Horizon	Depth (cm)	Description
Ap	0-22	Dark brown (7.5 YR 4/4 moist) light brown (7.5 YR 6/4 dry) sandy loam; weak coarse subangular blocky structure; nonsticky and nonplastic (wet) firm (moist) slightly hard dry; many fine and medium pores; many very fine roots; many very fine mica flakes; few medium ant nests; clear wavy boundary.
Bt_1	22-41	Dark brown (7.5 YR 4/4 moist) strong brown (7.5 YR 5/6 dry) loam; weak coarse prismatic structure; slightly sticky and slightly plastic (wet) friable (moist) very hard (dry); many fine and medium pores; common very fine roots; many very fine mica flakes; few medium ant nests; few fine tissues; clear smooth boundary.
Bt_2	41-95	Strong brown (7.5 YR 5/6 moist) reddish yellow (7.5 YR 6/8 dry) clay loam; moderate coarse prismatic structure; sticky and plastic (wet) friable (moist) very hard (dry); common medium and many fine pores; few very fine roots; many very fine mica flakes; few fine tissues; gradual smooth boundary.
Bt_3	95-150	Strong brown (7.5 YR 5/6 moist) reddish yellow (7.5 YR 6/6 dry) clay loam with many fine faint light yellowish brown (10 YR 6/4) mottles; moderate coarse subangular blocky structure; sticky and plastic (wet) friable (moist); many fine pores; few very fine pores; few very fine roots; common hard Fe and Fe/Mn concretionary nodules; many very fine mica flakes; common medium ant nests; few fine tissues.

Profile Number	:	**TBR 3 (Site 3)**
General site information		
Location	:	Tsibiri village, about 2km off Shika (NAPRI)
Taxonomic classification	:	**Typic Haplustalfs, fine loamy, isohyperthermic (Chromic Luvisols - FAO)**
Soil parent material	:	Aeolian material over granitic and/or gneissous residium
Geology	:	Basement complex rocks
Geomorphology	:	Undulating plain
Topography	:	Mid-slope; gently sloping or undulating 2-4% slope
Vegetation	:	Northern Guinea Savanna; *Isoberlinia sp.*
Land use	:	Millet/Maize
Soil erosion hazard	:	Slight sheet erosion
Drainage	:	Moderately well drained
Depth to water table	:	Not encountered at 150cm depth
Depth to impenetrable layer	:	None encountered
Surface characteristics	:	No special features
Described by	:	T. Kparmwang and Sylvester Oikeh
Date sampled	:	10th June, 1993

Horizons Description

Horizon	Depth (cm)	Description
Ap	0-18	Dark brown (7.5 YR 4/4 moist) pink (7.5 YR 7/4 dry) sandy loam; moderate medium and coarse subangular blocky structure; nonsticky and nonplastic (wet) firm (moist) slightly hard (dry); common medium and many very fine and fine pores; many very fine and fine roots; many very fine mica flakes; few medium ant nests; clear wavy boundary.
Bt_1	22-41	Yellowish red (5 YR 5/8 moist) reddish yellow (5 YR 6.6 dry) loam; moderate coarse subangular blocky structure; sticky and plastic (wet) firm (moist) very hard (dry); many medium pores; common medium and many fine dead roots; many very fine mica flakes; common medium and coarse ant nests; gradual smooth boundary.
Bt_2	41-95	Yellowish red (5 YR 5/8 moist) reddish yellow (5 YR 6/6 dry) clay loam; moderate coarse primastic structure; sticky and plastic (wet) firm (moist) hard (dry); common medium and many fine pores; common very fine and fine roots; many very fine mica flakes; common coarse ant nests; gradual smooth boundary.
Bt_3	95-150	Strong brown (7.5 YR 5/8 moist) clay loam; moderate coarse subangular blocky structure; slightly sticky and slightly plastic (wet); friable (moist) hard (dry); common medium and many very fine and fine pores; common fine roots; common soft Fe nodules; many very fine mica flakes; common coarse krotovinas.

Profile Number	:	**TBR 4 (Site 4)**
General site information		
Location	:	Tsibiri village, about 2km off Shika (NAPRI)
Taxonomic classification	:	**Typic Haplustalfs, fine loamy, isohyperthermic (Chromic Luvisols - FAO)**
Soil parent material	:	Aeolian material over granitic and/or gneissous residium
Geology	:	Basement complex rocks
Geomorphology	:	Undulating plain
Topography	:	Upper-slope; gently sloping or undulating 2-4% slope
Vegetation	:	Northern Guinea Savanna; Isoberlinia sp.
Land use	:	Maize
Soil erosion hazard	:	Moderate sheet erosion
Drainage	:	Well drained
Depth to water table	:	Not encountered at 150cm depth
Depth to impenetrable layer:		None encountered
Surface characteristics	:	No special features
Described by	:	T. Kparmwang and Sylvester Oikeh
Date sampled	:	10th June, 1993

Horizons Description

Horizon	Depth (cm)	Description
Ap	0-17	Dark yellowish brown (10 YR 4/4 moist) loam; weak medium subangular blocky structure; non-sticky and non-plastic (wet) friable (moist); common medium and many very fine and fine pores; many very fine and fine roots; many very fine mica flakes; few ants and their nests; clear wavy boundary.
BA	17-30	Yellowish red (5 YR 4/6 moist) clay loam; moderate coarse subangular blocky structure; sticky and plastic (wet) firm (moist); many medium, fine and very fine medium; many very fine mica flakes; many very fine mica flakes; common ants and few medium ant nests; clear smooth boundary.
Bt_1	30-65	Yellowish red (5 YR 4/8 moist) strong brown (7.5 YR 5/6 dry) clay; strong very coarse prismatic and coarse subangular blocky structures; sticky and plastic (wet) friable (moist) very hard (dry); few thin clay cutans in continuous pores; few medium and coarse and many fine pores; few fine and common very fine roots; many very fine mica flakes; common ant nests; common fine tiffues; clear wavy boundary.
Bt_2	65-119	Strong brown (7.5 YRYR 5/6 moist) clay loam; moderate coarse subangular blocky (wet) firm (moist); many very fine and fine pores; common very fine roots; common firm Fe and/or Mn nodules; few tissues.

Appendix 2: Plant population at 25 DAP of five maize cultivars as affected by N application in 1993 and 1994.

	N Rates (kg ha^{-1})					
Cultivar	0	30	60	90[1]	120[1]	Mean
1993						
Improved:						
EV8728-SR	53333	50000	50000	51333	51333	51200
Mokwa 87TZPB-SR	52667	52000	52667	52667	50000	52000
SPL (semi-prolific)	52667	50667	52000	50667	52667	51734
8644-27	52000	52000	50000	53333	50000	51467
Popular OP:						
TZB-SR	50000	52000	50667	50667	48000	50267
Mean	52133	51333	51067	51733	50400	51334
LSD(0.05) N Rate	n.s[2]					
LSD(0.05) Cultivar	n.s					
LSD(0.05) N Rate x Cultivar	n.s					
CV (%)	5.6					
1994						
Improved:						
EV8728-SR	51636	49212	50182	52121	51636	50958
Mokwa 87TZPB-SR	50424	51879	52848	51152	53090	51879
SPL (semi-prolific)	49212	49455	51152	49212	49939	49794
8644-27	51152	50909	52121	51393	52606	51636
Popular OP:						
TZB-SR	49454	53090	52364	50182	51636	51346
Mean	50376	50909	51733	50812	51782	51122
LSD(0.05) N Rate	n.s					
LSD(0.05) Cultivar	1541					
LSD(0.05) N Rate x Cultivar	n.s					
CV (%)	4.4					

[1]Only the first split of 30, and 60 kg Nha^{-1} had been applied at sampling.
[2]Not significant.

Appendix 3: Nitrogen deficiency symptom score at mid-silking of five maize cultivars as affected by N rates in 1993 and 1994

	N Rates (kg ha^{-1})					
Cultivar	0	30	60	90[1]	120[2]	Mean
1993						
Improved :						
EV8728-SR	**6.5**	5.5	1.5	2.0	1.0	3.3
Mokwa 87TZPB-SR	**8.0**	5.5	1.5	2.0	1.0	3.6
SPL	7.5	5.0	3.5	1.0	1.5	3.7
8644-27 (Oba Super 2)	8.0	4.5	2.5	1.0	1.0	3.4
Popular OP						
TZB-SR	**6.5**	3.5	3.5	2.5	1.5	3.5
Mean	**7.3**	4.8	2.5	1.7	1.2	3.5
S.E. for N Rate	± 0.5***					
S.E. for Genotype	n.s					
S.E. for N Rate x Cultivar	n.s					
CV (%)	34.3					
1994						
Cultivar	0	30	60	90[1]	120[2]	Mean
Improved :						
EV8728-SR	**6.2**	5.8	4.2	3.4	1.8	4.3
Mokwa 87TZPB-SR	6.2	4.6	3.8	3.0	1.8	3.9
SPL	7.0	5.4	4.6	3.4	3.0	4.7
8644-27 (Oba Super 2)	7.0	6.2	3.4	3.4	1.4	4.3
Popular OP						
TZB-SR	**5.4**	6.2	4.2	4.2	2.6	4.5
Mean	6.4	5.6	4.0	3.5	2.1	4.3
S.E. for N Rate	± 0.7***					
S.E. for Cultivar	n.s					
S.E. for N Rate x Cultivar	n.s					
CV (%)	28.7					

[1] Applied in 2 splits of 30:60 at 2 and 5 WAP.
[2] Applied in 2 splits of 60:60 at 2 and 5 WAP.

Appendix 4: ANOVA Mean Squares for some growth and development traits of 8644-27 and TZB-SR in 1994 at 4 sites differing in fertility.

Fertility level	Source	d.f	Mean Squares: Plant ht. 25 DAP (cm)	Ear leaf area (cm^{-2})	Leaf-N ($mg\ g^{-1}$)	Specific leaf-N ($g\ m^{-2}$)	Leaf[a] sene. (%)	STR ($plant^{-1}$)	STR incidence (%)
Low/moderate:									
Site 1	Rep	2	3.18	11828.75	3.88	0.032	0.05	0.002	257.54
	Perop	2	448.15	5681.01*	27.83	0.066	1.68	0.008+	221.49
	Rep x Perop	4	170.14	696.47	9.03	0.026	0.54	0.002	125.02
	Geno	1	46.72	3000.36	24.97*	0.091*	0.03	0.020+	75.65*
	Perop x Geno	2	30.91	1043.24	1.56	0.006	0.05	0.022*	484.27***
	Error	6	50.06	1989.83	2.72	0.018	0.18	0.005	12.04
	CV(%)		8.5	7.7	8.0	12.0	19.4	59.4	16.8
Site 2	Rep	2	186.74	110.22	4.94	0.013	0.18	0.011	269.00
	Perop	2	45.30	14757.64*	19.34*	0.114*	1.69*	0.028+	86.00+
	Rep x Perop	4	25.61	1645.17	2.14	0.014	0.10	0.005	18.24
	Geno	1	2.21	5290.93	9.25	0.108*	0.01*	0.039	202.68+
	Perop x Geno	2	14.81	3567.37	4.51	0.026	0.34	0.006	79.35
	Error	6	43.10	2772.63	5.36	0.010	0.12	0.013	56.77
	CV(%)		6.6	7.8	9.6	6.9	33.4	120.8	105.76
High:									
Site 3	Rep	2	57.39	3628.93	3.29	0.029	0.43	3.916	105.76
	Perop	2	10.87	5619.09+	27.48*	0.157+	0.55	6.361	1527.97
	Rep x Perop	4	53.93	1722.29	4.19	0.037	1.03	7.327	2932.01
	Geno	1	348.48+	4487.00	17.41*	0.246**	0.63+	0.258	32.81
	Perop x Geno	2	23.72	3650.81	1.90	0.003	0.09	0.512	183.94
	Error	6	66.59	2283.25	3.15	0.010	0.13	1.039	88.08
	CV(%)		9.1	7.5	7.3	6.8	45.5	57.4	12.2
Site 4	Rep	2	107.86	10720.76	2.42	0.018	0.36	0.012	131.09
	Perop	2	191.85	3266.06	15.94+	0.127+	0.49	0.075+	27.77
	Rep x Perop	4	81.95	2211.59	3.85	0.028	0.32	0.015	11.59
	Geno	1	120.64	951.19	4.30	0.131+	0.18	0.001	16.63
	Perop x Geno	2	3.29	1043.14	1.20	0.012	0.10	0.005	35.70
	Error	6	52.72	2823.42	2.93	0.025	0.69	0.033	58.33
	CV(%)		6.7	7.8	6.0	11.1	62.9	1.84	136.2

[a]Leaf sene (%) = proportion of senescenced leaf at 60 DAP; STR $plant^{-1}$ = No. of *Striga* per plant.
***, **, * and + indicate significance at the $p<0.001$, 0.01, 0.05, 0.1 level.

Appendix 5: ANOVA Mean Squares for some growth parameters, grain yield, stover, and panicle residues of local sorghum (cv. 'mori') in 1994 at 4 sites differing in fertility.

Fertility level	Source	d.f	Mean Squares							
			Plant ht. 42 DAP	Ear leaf area (cm^2)	Leaf-N ($mg\ g^{-1}$)	Specific leaf-N (gm^{-2})	Grain yield	Stover ($t\ ha^{-1}$)	Panicle residues	HI[a] (kg grain $kg\ DM^{-1}$)
Low/moderate:										
Site 1	Rep	2	6.44	800.94	4.03	0.003	91.30	3279.09	1.26	0.0007
	Prop	2	88.48	1200.48	3.97	0.011*	0.15	6.06	4.90	0.0015
	Error	4	103.28	429.57	2.48	0.002	83.02	3777.19	10.43	0.0008
	CV(%)		7.7	14.3	8.1	4.69	13.0	19.9	22.3	15.0
Site 2	Rep	2	119.75	1102.96	10.67	0.049	26.55	8158.50	0.39	
	Prop	2	5.92	2.42	3.70	0.007	95.61	3782.86	3.68	0.0005
	Error	4	157.58	281.26	4.89	0.013	159.10	2733.39	3.37	0.0001
	CV(%)		8.4	11.2	10.7	11.0	16.6	12.4	11.7	6.4
High:										
Site 3	Rep	2	9.29	4240.07	6.88	0.036	835.29	13869.03	43.97	0.0013
	Prop	2	61.53	1071.64	2.89	0.031	183.34	2556.60	8.69	0.0012*
	Error	4	58.91	466.40	9.02	0.041	240.50	6472.59	17.89	0.0001
	CV(%)		5.8	15.3	16.0	23.4	22.3	22.4	27.9	4.5
Site 4	Rep	2	114.71	958.92	7.09	0.025	63.91	627.89	25.09	0.0001
	Prop	2	465.88*	88.56	4.57	0.002	1377.14	89.38	23.62	0.0021
	Error	4	48.61	422.64	1.50	0.014	606.45	5269.55	10.85	0.0008
	CV(%)		4.0	12.9	5.7	12.9	29.0	9.8	20.5	17.5

[a]HI = Harvest index; * indicate significance at the $p<0.05$ level.

Appendix 6: ANOVA Mean Squares for dry matter partitioning and yield components of 8644-27 and TZB-SR in 1994 at 4 sites differing in fertility.

Fertility level	Source	d.f	Mean Squares: Grain yield (t ha^{-1})	Stover (t ha^{-1})	Cob (t ha^{-1})	HI (kg grain kg DM^{-1})	Ear (plant^{-1})	Kernels ear^{-1})	Kernel size (g)
Low/moderate:									
Site 1	Rep	2	48.95	42.63	8.88	0.0018	0.00003	5070.51	872.12
	Perop	2	1296.36	1116.62^{+}	25.90	0.0032	0.00055	3541.66	626.48
	Rep x Perop	4	529.97	230.43	26.11	0.0058	0.00258	2087.54	337.46
	Geno	1	82.11	3235.64^{+}	25.92	0.0082*	0.00071	9022.72^{+}	6517.78**
	Perop x Geno	2	858.88^{+}	522.87	30.62	0.0021	0.00653+	1728.44	150.00
	Error	6	223.61	704.52	9.49	0.0013	0.0016	2117.94	239.06
	CV(%)		17.0	19.4	16.10	10.0	4.3	11.1	6.8
Site 2	Rep	2	238.38	836.93	8.22	0.0008	0.00339	383.44	106.38
	Perop	2	1954.55**	680.91	66.78^{+}	0.0033	0.00536**	4557.84	627.53
	Rep x Perop	4	80.09	987.44	14.35	0.0010	0.00022	927.83	252.04
	Geno	1	376.02	9047.30*	49.95	0.0172*	0.03003**	31183.37**	13652.13***
	Perop x Geno	2	413.06	1475.09	1.47	0.015	0.00237	4442.27^{+}	319.57
	Error	6	434.1	811.32	18.37	0.0023	0.00130	982.42	217.0
	CV(%)		12.4	15.7	13.3	10.9	3.5	6.4	5.2
High:									
Site 3	Rep	2	863.24	1186.57	31.89	0.0009	0.00616	2800.54	295.92
	Perop	2	2242.64	3.41	99.49	0.0074	0.02628	572.88	2448.92
	Rep x Perop	4	3483.75	1853.41^{+}	19.49	0.0014	0.02578	1511.55	654.54
	Geno	1	10.90	1092.29**	2.35	0.0295**	0.01010	14803.47**	20580.15**
	Perop x Geno	2	291.8	1852.41+	79.49	0.0043	0.01290	1395.83	2879.10
	Error	6	409.68	400.66	16.41	0.0005	0.00987	464.38	643.36
	CV(%)		15.5	14.2	15.6	5.1	10.0	4.9	9.5
Site 4	Rep	2	37.11	1149.88	6.02	0.0013	0.00837	1317.16	225.78
	Perop	2	2691.56*	3275.81*	93.92**	0.0001	0.00112	3793.53	15.38
	Rep x Perop	4	207.47	518.98	6.22	0.0009	0.00672	1800.35	545.94
	Geno	1	39644.69^{+}	4768.89*	355.88**	0.0245**	0.00056	9522.00*	137.57***
	Perop x Geno	2	141.47	608.66	15.25	0.0002	0.00541^{+}	1275.55	19657.48
	Error	6	792.41	1181.14	17.63	0.0008	0.00149	1595.28	222.51
	CV(%)		17.4	18.7	13.6	6.6	4.0	8.6	5.5

***, **, * and + indicate significant at $p<0.001$, 0.01, 0.05 and 0.1 level.

Appendix 7: ANOVA Mean Squares for nitrogen contents of grain, stover and cob, net N uptake and NHI of 8644-27 and TZB-SR in 1994 at 4 sites differing in fertility.

			Mean Squares				
Fertility level	Source	d.f	Grain-N	Stover-N	Cob-N	Net N Uptake	NHI
			(kg ha^{-1})				(kg grain-N kg net N^{-1})
Low/moderate:							
Site 1	Rep	2	12.84	29.25	0.55	92.15	0.0029
	Pcrop	2	250.54	38.39*	3.00	556.48*	0.0015
	Rep x Pcrop	4	84.31	4.04	0.91	78.93	0.0074
	Geno	1	9.70	15.52	0.68	2.72	0.0020
	Pcrop x Geno	2	151.79*	1.87	1.61	201.82	0.0039
	Error	6	28.84	15.23	0.60	66.14	0.0016
	CV(%)		15.6	21.8	18.4	14.4	6.7
Site 2	Rep	2	165.94	44.18	5.22	434.80	0.0002
	Pcrop	2	472.21*	38.46	3.46+	766.45	0.0025
	Rep x Pcrop	4	49.07	123.18	0.76	300.26	0.0032
	Geno	1	22.29	120.95	2.44	22.22	0.0065
	Pcrop x Geno	2	110.06	4.95	0.38	141.10	0.0018
	Error	6	58.53	56.44	1.02	173.91	0.0021
	CV(%)		12.2	26.0	15.5	13.5	7.2
High:							
Site 3	Rep	2	63.75	27.27	3.94	156.12	0.0009
	Pcrop	2	442.53	125.25	3.29	1051.48	0.0055
	Rep x Pcrop	4	451.14	61.66	3.14	852.68	0.0059
	Geno	1	46.61	282.00*	6.64+	442.85	0.0049*
	Pcrop x Geno	2	54.59	83.93	0.15	234.97	0.0023*
	Error	6	85.62	32.38	1.59	245.81	0.0005
	CV(%)		18.6	21.7	20.20	19.1	3.5
Site 4	Rep	2	88.23	37.56	0.59	65.03	0.0056
	Pcrop	2	717.63**	198.40**	11.65*	1949.19**	0.0001
	Rep x Pcrop	4	38.90	9.95	1.29	71.03	0.0010
	Geno	1	447.39	87.02	18.93*	261.59	0.0159*
	Pcrop x Geno	2	22.02	16.75	0.75	4.36	0.0016
	Error	6	163.92	73.84	2.87	397.15	0.0028
	CV(%)		22.1	29.9	29.0	21.6	8.4

**, * and + indicate significance at $p<0.01$, 0.05 and 0.1 level.

Appendix 8: ANOVA Mean Squares for nitrogen contents of grain, stover and panicle residues, net N uptake and NHI of local sorghum (cv. 'mori') in 1994 at 4 sites differing in fertility.

Fertility level	Source	d.f	Mean Squares				
			Grain-N	Stover-N	Pan. residue-N	Net N Uptake	NHI
			(kg ha^{-1})				(kg grain-N kg net N^{-1})
Low/moderate:							
Site 1	Rep	2	22.51	26.57	0.07	74.30	0.0009
	Prop	2	0.04	73.31	28.1	79.75	0.0038
	Error	4	20.46	53.03	0.43	125.7	0.0013
	CV(%)		13.0	21.9	22.4	15.8	7.2
Site 2	Rep	2	6.55	139.58	0.01	173.97	0.0028
	Prop	2	23.57	13.66	0.09	69.90	0.0003
	Error	4	39.21	19.50	0.15	76.00	0.0015
	CV(%)		16.6	9.3	12.7	9.9	9.1
High:							
Site 3	Rep	2	205.89	554.92	2.52	1506.10	0.0013
	Prop	2	45.19	110.79	0.20	150.69	0.0012*
	Error	4	59.28	117.16	1.23	381.22	0.0001
	CV(%)		22.3	24.2	37.6	23.8	2.3
Site 4	Rep	2	15.75	1.23	1.24	12.96	0.0008
	Prop	2	339.45	263.67+	1.40*	1098.02	0.0052
	Error	4	149.48	43.42	0.18	274.95	0.0043
	CV(%)		29.0	13.5	12.4	17.6	14.9

* and + indicate significance at $p<0.05$ and 0.1 level.

Appendix 9: ANOVA Mean Squares for the distribution of available N in 0-90cm soil profile at planting and 5 WAP (across genotypes), 50% silking/heading and harvest of 8644-27, TZB-SR and sorghum in 1994 at 4 sites differing in fertility.

Fertility level	Source	d.f	Mean Squares: Available N at: Planting	5 WAP	50% silking	Maize harvest	50% heading	Sorghum harvest
					(kg ha^{-1})			
Low/moderate:								
Site 1	Rep	2	144.4	1073.0	153.3	21.01	111.6	41.2
	Perop	2	92.7*	2100.8	944.5*	49.3	43.7	78.7
	Rep x Perop	4	21.4	2187.1	206.3	43.4	394.2	35.2
	Geno	1	-	-	299.9	0.1	-	-
	Perop x Geno	2	-	-	284.7	41.3	-	-
	Rep x Geno (Perop)	6	-	-	94.0	41.3	-	-
	Depth	3	186.5**	8833.8***	2206.4***	882.3***	415.7*	222.7***
	Perop x Depth	6	48.9	2410.8*	211.2	116.9*	217.0	46.2*
	Geno x Depth	3	-	-	207.8	51.2	-	-
	Perop x Geno x Depth	6	-	-	202.7	104.6*	-	-
	aError	36(18)	26.8	710.5	117.3	40.0	160.6	17.3
	CV(%)		21.8	40.9	34.1	37.6	39.4	28.3
Site 2	Rep	2	212.9	357.9	111.9	10.8	215.1	153.4
	Perop	2	208.4	738.7	115.3	24.1	197.6	33.2
	Rep x Perop	4	167.2	556.2	135.8	95.6	108.3	186.1
	Geno	1	-	-	169.9	31.6	-	-
	Perop x Geno	2	-	-	5.2	17.2	-	-
	Rep x Geno (Perop)	6	-	-	241.7	18.3	-	-
	Depth	3	434.1***	6216.6**	1337.4***	104.9*	549.9*	287.9
	Perop x Depth	6	42.3	301.7	15.6	40.1	62.7	53.1
	Geno x Depth	3	-	-	113.0	8.0	-	-
	Perop x Geno x Depth	6	-	-	103.8	23.7	-	-
	aError	36(18)	46.8	1287.4	99.4	36.4	178.0	157.9
	CV(%)		26.0	76.1	33.9	50.6	61.9	100.3
High:								
Site 3	Rep	2	1197.4	223.9	386.1	134.7	269.1	19.18
	Perop	2	68.6	232.5**	79.7	51.6	477.3	115.1
	Rep x Perop	4	55.5	9.4	160.6	466.8	363.4	249.6
	Geno	1	-	-	514.1+	14.2	-	-
	Perop x Geno	2	-	-	608.9*	75.5	-	-
	Rep x Geno (Perop)	6	-	-	125.3	225.3	-	-
	Depth	3	583.3**	1170.6*	1843.6***	1269.1***	873.2	894.5**
	Perop x Depth	6	83.7	318.5	66.0	122.5	191.8	6.1
	Geno x Depth	3	-	-	23.3	90.4	-	-
	Perop x Geno x Depth	6	-	-	286.7**	17.6	-	-
	aError	36(18)	98.0	496.9	88.9	110.9	364.1	129.8
	CV(%)		35.1	50.3	25.6	48.5	56.0	65.8
Site 4	Rep	2	649.3	801.7	167.0	44.6	77.7	8.8
	Perop	2	1716.2*	2447.5	648.4	13.6	155.8	101.1
	Rep x Perop	4	125.2	690.1	460.8	31.6	77.6	38.0
	Geno	1	-	-	50.6	17.0	-	-
	Perop x Geno	2	-	-	1000.5*	9.3	-	-
	Rep x Geno (Perop)	6	-	-	133.1	25.8	-	-
	Depth	3	254.8	9275.3***	2111.1***	457.1***	905.8*	437.5***
	Perop x Depth	6	140.6	1178.7**	174.2	8.4	72.1	72.1*
	Geno x Depth	3	-	-	83.5	34.3	-	-
	Perop x Geno x Depth	6	-	-	246.6	34.3	-	-
	aError	36(18)	225.1	284.2	172.7	22.7	126.2	30.1
	CV(%)		35.2	32.9	31.3	33.1	39.5	38.9

*Figures in parenthesis represent the corresponding d.f for samples at planting and 5 WAP and for sorghum data analysed on a separate ANOVA.
***, **, * and + indicate significance at $p<0.001$, 0.01, 0.05 and 0.01 level.

Appendix 10: ANOVA Mean Squares for available N at planting, 5 WAP, 50% silking, and harvest, available N depletion and N balance in 0-90cm soil profile and N efficiency of 8644-27 and TZB-SR in 1994 at 4 sites differing in fertility.

Fertility level	Source	d.f	Mean Squares								
			[a]Soil available N at: planting	5 WAP	50% silking	harvest	N depletion	N balance	Nitrogen efficiency uptake (kgDM-N/ kg avail.N)	utilization (kg grain/ kg DM-N)	use (kg grain/ kg avail.N)
			(kg ha^{-1})								
Low/moderate:											
Site 1	Rep	2	433.24	4291.9	613.3	84.1	1487.1	1629.4	0.0085	15.6	26.63
	Perop	2	299.38+	8403.6	3777.9+	197.2	1457.6*	949.5	0.0162	13.1	42.3
	Rep x Perop	4	64.23	8748.4	825.1	173.8	209.0	277.9	0.0045	46.2	25.8
	Geno	1	-	-	1199.7	0.5	0.5	0.9	0.0003	33.5	2.1
	Perop x Geno	2	-	-	1138.7	165.3	165.3	178.3	0.0085+	11.5	36.9+
	Error	6	-	-	375.8	313.9	314.0	372.4	0.0024	15.1	8.9
	CV(%)		8.0	35.9	15.3	26.4	54.4	-53.5	13.8	7.9	17.0
Site 2	Rep	2	857.8	1431.5	447.5	43.2	1623.7	1215.8	0.0261	56.6	18.6
	Perop	2	833.6	2954.6	461.3	96.4	1608.7	792.2	0.0094	3.5	43.8
	Rep x Perop	4	668.6	2224.7	543.1	382.2	1481.4	934.8	0.0231	42.7	31.6
	Geno	1	-	-	671.6	126.3*	126.3	42.5	0.0003	65.9*	51.6
	Perop x Geno	2	-	-	20.8	69.0	69.0	158.6	0.0068	3.3	21.8
	Error	6	-	-	966.8	73.4	73.4	211.8	0.0072	7.1	21.9
	CV(%)		24.5	25.0	26.5	18.0	14.8	-73.6	14.1	4.8	13.2
High:											
Site 3	Rep	2	4789.5	895.5	1544.6	538.8	8155.1	6324.9	0.0444	54.2	174.8
	Perop	2	274.2	930.1**	318.7	206.4	250.9	1373.6	0.0165	85.5	37.4
	Rep x Perop	4	221.90	37.8	642.6	1867.3	1699.7	3302.4	0.0270	69.2	112.8
	Geno	1	-	-	2056.4+	56.9	56.9	817.2	0.0086	189.9***	4.3
	Perop x Geno	2	-	-	2435.6*	302.1	302.1	1014.9	0.0062	3.9	7.5
	Error	6	-	-	505.3	901.3	901.3	471.4	0.0061	2.7	12.6
	CV(%)		13.2	3.5	15.2	34.6	116.0	-57.1	15.9	3.3	14.5
Site 4	Rep	2	2632.2	3206.8	606.7	178.4	5945.7	7227.6	0.0237	9.7	52.4
	Perop	2	7585.8**	9790.1	2398.3	54.5	15789.5*	12320.1	0.0401*	88.7**	89.9*
	Rep x Perop	4	518.4	6498.4	1843.4	126.5	1680.2	1581.7	0.0052	5.3	11.0
	Geno	1	-	-	244.2	68.0	68.0	596.3	0.0063	146.7+	80.3+
	Perop x Geno	2	-	-	4002.1*	37.4	37.4	17.3	0.001	4.4	0.3
	Error	6	-	-	532.5	115.2	115.2	629.4	0.0060	33.1	15.9
	CV(%)		13.2	25.6	13.7	10.7	9.4	-30.6	18.9	10.2	17.5

[a]Sampling at planting and 5 WAP was done across gentoypes including sorghum;
***, **, * and + indicate significance at p<0.001, 0.01, 0.05 and 0.1 level.