EFFECT OF TILLAGE SYSTEM, RESIDUE MANAGEMENT AND NITROGEN FERTILIZATION ON MAIZE PRODUCTION IN WESTERN ETHIOPIA

by

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DECLARATION

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LIST OF ABBREVIATIONS

C	Carbon
^{O}C	Degree Celsius
CIMMYT	International Maize and Wheat Improvement Center
CML	CIMMYT line
CT	Conventional tillage
D	Dominated treatment
DM	Dry matter
EB	Ethiopian Birr
G	Genotype
GFB	Gross field benefit
GNU	Grain nitrogen uptake
GY	Grain yield
ha	hectare
K	Potassium
LSD	Least significant difference
MRR	Marginal rate of return
MARR	Minimum acceptable rate of return
MPa	Mega Pascal
MTRR	Minimum tillage with residue retention
MTRV	Minimum tillage with residue removal
N	Nitrogen
NB	Net benefit

Ndff	Nitrogen derived from fertilizer
Ndfs	Nitrogen derived from soil
Nfrs	Nitrogen fertilizer remained in the soil
NH_4^+	Ammonium
NO_3^-	Nitrate
NAE	Nitrogen agronomic efficiency
NRE	Nitrogen recovery efficiency
NPE	Nitrogen physiological efficiency
NUE	Nitrogen utilization efficiency
P	Phosphorus
PR	Penetration resistance
SNU	Stover nitrogen uptake
t	ton
TBNU	Total biomass nitrogen uptake
TSW	Thousand seed weight
TVC	Total variable cost

ABSTRACT

The decline in soil fertility, particularly N is one of the major constrains to maize production in western Ethiopia. This situation is worsened by the financial inability of most farmers to purchase N fertilizer for supplementation. In these conditions two basic approaches can be followed to improve maize productivity in a sustainable way. Firstly, integrated cropping practices can be developed for maize to make better use of N from organic and inorganic sources. Secondly, maize genotypes that are efficient in N uptake and utilization can be selected. In this context, experiments were conducted to determine the integrated effects of tillage system, crop residue management and N fertilization on the productivity of maize, and to evaluate different maize genotypes for N uptake and use efficiency.

The experiments on integrated cropping practices were conducted from 2000 to 2004 at five sites in western Ethiopia. Three tillage systems (MTRR = minimum tillage with residue retention, MTRV = minimum tillage with residue removal and CT = conventional tillage) and three N levels (the recommended rate and 25% less and 25% more than this rate) were combined in factorial arrangement. Every year yield response, usage of applied N and changes in some soil properties were measured. In 2004 the same experiments were used to monitor the fate of applied N in the soil-crop system. Labeled urea was applied at the recommended rate to micro plots within the MTRR and CT plots for this purpose.

Among the tillage treatments, MTRR significantly increased the grain yield by 6.6 and 12.2% compared to MTRV and CT, respectively. Similarly, application of N increased grain yield and the agronomically optimum level which is also economically profitable for both MTRR and CT was 92 kg N ha^{-1}. The larger grain yields that realized with MTRR were attributed to the higher contents of organic matter, extractable P and exchangeable K with this tillage system after five years, especially in the 0 to 7.5 cm soil layer. However, this system lowered soil pH values compared to the CT and MTRV systems.

All three indices for efficient use of applied N by maize, viz. N agronomic efficiency (NAE), N recovery efficiency (NRE) and N physiological efficiency (NPE) were consistently higher at the lower N level range of 69-92 kg ha^{-1} than at the higher N level range of 92-115 kg ha^{-1}. Both NAE and NRE were higher with CT at the lower N level range and higher with MTRR at the higher N level range. The NPE had a propensity to be higher with MTRR at both N level ranges.

At harvesting maize recovered on average 47 and 54% of the labeled urea N from the MTRR and CT soils, respectively. Conversely, 12 and 17% of the labeled urea N was still in the CT and MTRR soils at harvesting, respectively. Hence, the unaccounted labeled urea N in the two systems was 36% for MTRR and 34% for CT.

The experiments on genotype comparison for N uptake and use efficiency were done also at the sites mentioned earlier. In 2004 the response of five open-pollinated and five hybrid genotypes were evaluated at the N level range from 0 to 230 kg ha^{-1} with 46 kg ha^{-1} intervals.

Only two genotypes qualify as N use efficient, viz. the open-pollinated Ecaval 1 and the hybrid CML373/CML202/ CML384. These two CIMMYT genotypes on average out yielded their respective local genotypes with 5.9% at a low N application and with 17.5% at high N application.

The sustainability of maize production on Nitisols in western Ethiopia can be enhanced by the practicing of MTRR instead of CT with adoption of the recommended N application rate in use. Greater value can be added to this change in tillage system by planting of N use efficient maize genotypes.

Key words: conventional tillage, minimum tillage, labeled urea, maize genotype, nitrogen use efficiency

UITTREKSEL

Die afname in grondvrugbaarheid, in besonder N is een van die grootste beperkinge vir mielieproduksie in Wes-Ethiopië. Hierdie situasie word vererger deur die finansiële onvermoë van meeste boere om stikstofkunsmis te koop vir aanvulling. In hierdie toestande kan twee basiese benaderings gevolg word om mielieproduktiwiteit op ‘n volhoubare wyse te verbeter. Eerstens kan geïntegreerde gewasverbouingspraktyke vir mielies ontwikkel word sodat N vanaf organiese en anorganiese bronne beter benut word. Tweedens kan mieliegenotipes geselekteer word wat doeltreffend in die opname en gebruik van N is. In hierdie konteks is proewe uitgevoer om die effek van geïntegreerde bewerkingstelsel, gewasrestebestuur en stikstofbemesting op mielieproduktiwiteit te bepaal en ook verskillende mieliegenotipes vir doeltreffende stikstofopname en –gebruik te evalueer.

Die proewe oor geïntegreerde gewasverbouingspraktyke is vanaf 2000 tot 2004 by vyf lokaliteite in Wes-Ethiopië uitgevoer. Drie bewerkingstelsels (MTRR = minimum bewerking met behoud van gewasreste, MTRV = minimum bewerking met verwydering van gewasreste en CT = konvensionele bewerking) en drie stikstofpeile (die aanbevole hoeveelheid en 25% minder en 25% meer as die hoeveelheid) is gekombineer in ‘n faktoriale rangskikking. Elke jaar is die opbrengsreaksie, gebruik van toegediende N en verandering in sommige grondeienskappe bepaal. In 2004 is dieselfde proewe gebruik om die lot van toegediende N in die grond-gewas sisteem te monitor. Gemerkte ureum is teen die aanbevole hoeveelheid op mikro persele binne die MTRR en CT persele vir die doel toegedien.

In vergelyking met MTRR en CT het MTRR die graanopbrengs betekenisvol met onderskeidelik 6.6 en 12.2% verhoog. Net so het die toediening van N graanopbrengs verhoog en die agronomiese optimum, wat ook ekonomies winsgewend is, was 92 kg N ha^{-1}. Die groter graanopbrengste wat met MTRR gerealiseer het, is toegeskryf aan die hoër inhoude van organiese materiaal, ekstraheerbare P en uitruilbare K wat met hierdie bewerkingstelsel na vyf jaar aangeteken is, veral in die 0 – 7.5 cm grond laag.

Al drie indekse vir doeltreffende gebruik van toegediende N deur mielies, te wete die agronomiese (NAE), herwinnings (NRE) en fisiologiese (NPE) was deurgaans hoër by die laer stikstofpeilreeks van 69-92 kg ha^{-1} as by die hoër stikstofpeilreeks van 92-115 kg ha^{-1}. Beide NAE en NRE was die grootste met CT by die laer stikstofpeilreeks en met MTRR by die hoër stikstofpeilreeks. Die NPE het ‘n geneigdheid getoon om by beide stikstofpeilreekse hoër met MTRR as met MTRV en CT te wees.

Tydens oes het mielies gemiddeld 47 en 54% van die gemerkte ureumstikstof herwin vanaf onderskeidelik die MTRR en CT gronde. Hierteenoor was daar met oes nog 12 en 18% van die gemerkte ureumstikstof in die CT en MTRR gronde. Die gemerkte ureumstikstof waarvoor daar nie in die twee sisteme voor rekenskap gegee kon word nie was 36% vir MTRR en 34% vir CT.

Die proewe oor die vergelyking van genotipes vir stikstofopname en –gebruikstreffendheid is op dieselfde lokaliteite gedoen wat voorheen na verwys is. In 2004 is die reaksie van vyf oopbestuifde genotipes en van vyf baster genotipes geëvalueer by ‘n stikstofpeilreeks vanaf 0 tot 230 kg ha^{-1} met 46 kg ha^{-1} intervalle.

Slegs twee van die genotipes kwalifiseer as stikstofgebruiksdoeltreffend, naamlik die oopbestuifde Ecaval 1 en die hibried CML373/CML202/CML384. Hierdie twee CIMMYT genotipes se opbrengs was gemiddeld 5.9% by ‘n lae stikstoftoediening en 17.5% by ‘n hoë stikstoftoediening beter as die van hulle lokale genotipes.

Die volhoubaarheid van mielieproduksie op Nitisols in Wes-Ethiopië kan bevorder word deur MTRR in stede van CT toe te pas met die huidige stikstofaanbeveling. Groot waarde kan tot die verandering in bewerkingstelsels toegevoeg word deur die plant van stikstofgebruiksdoeltreffende genotipes.

Sleutelwoorde: gemerkte ureum, konvensionele bewerking, mieliegenotipes, minimum bewerking, stikstofgebruiksdoeltreffendheid.

CHAPTER 1

MOTIVATION, HYPOTHESES AND OBJECTIVES

1.1 Motivation

Maize (*Zea mays* L.) has become an important cereal in the world because of its high adaptability and productivity. Nowadays maize is regarded as the world's third most important cereal after wheat and rice. The annual production of maize in the world amounts to 592.9 million ton from 138.7 million ha, viz. a mean yield of 4.3 ton ha^{-1}. In Ethiopia the annual production of maize is 3.3 million ton from 1.9 million ha, viz. a mean yield of only 1.7 ton ha^{-1} (Anon., 2001). Despite of this low mean yield, the productivity of maize exceeds that of all other cereal crops in the country by accounting for 32.6 % of the total cereal production, from 20.8% of the total area planted with cereals (Mosisa *et al.*, 2002).

Millions of people depend on maize for their daily food in Ethiopia (Byerlee and Heisey, 1996). Maize is the staple food especially in the western and southern regions of the country (Kebede *et al.*, 1993). Despite the importance of the crop, maize yields remain low on small-scale farmers' fields, as manifested in the national mean yield of 1.7 ton ha^{-1} mentioned above (Ibrahim and Tamene, 2002). In fact, maize productivity has declined over years contributing to food insecurity and ultimately famine.

Ethiopia has been hit by two famines during the last three decades, namely in 1973/74 and 1983/85. The first famine claimed the lives of 100 000 people and expedited some political changes. In the second famine which was even more devastating close to one million people died and a considerable number were displaced (El Wakell and Astatke, 1996). Although prolonged droughts contributed to those famines, the prevailing land-use systems of conventional tillage cannot support the present population even in normal rainfall years. Accordingly, Ethiopia's drought-triggered famine is merely a symptom of decline in soil fertility caused by poverty.

Poverty is very likely to contribute to a decline in soil fertility for many reasons. When people lack access to alternative sources of livelihood, there is a tendency to exert more pressure on the few resources that are available to them. Moreover, poor people generally have no choice but to opt for immediate benefit, very often at the expense of long-term sustainability. The United Nations Centre on Transnational Corporations (1985) mentioned that poverty induces a decline in soil fertility which, in turn, reinforces poverty leading to further decline and so on, while Maher (1950) stated that poverty-ridden people pass their suffering to the soil.

Ethiopian soils, formed from old weathered rocks, are naturally low in fertility. Traditional systems of shifting cultivation such as slash and burn have broken down due to increasing population pressures that have shortened or eliminated fallow periods and accelerated nutrient mining by farmers. Sedentary agriculture without the addition of nutrients depletes the soil nutrient reserve, decreases soil organic matter below critical levels and increases the risk of soil erosion.

Soil erosion, widespread in sub-Saharan Africa, is the most serious in Ethiopia, and one of the major limiting factors in agricultural production today in the country (Mrema, 1996). It is estimated that Ethiopia loses about 1.5 billion ton of soil per year from agricultural lands (Hurni, 1989). This has a devastating effect not only on the nutrient content of the soil but also on the soil itself, and manifest itself in declining agricultural productivity. Kappel (1996) stated that declining soil fertility induced by erosion is among the greatest constraints to higher agricultural productivity in Ethiopia.

It is therefore apparent and generally agreed that the direct causes of declining soil fertility include either no fallow or fallow periods that are too short for recovery, limited recycling of organic residues to the soil and insufficient application of external sources of plant nutrients. Factors underlying these direct causes include population pressure, poverty, high costs of and limited access to agricultural inputs and credit, fragmented land holdings and insecure land tenure, and farmers' lack of information about appropriate alternative technologies.

The reversing of soil fertility decline should be central to modernizing agriculture in Ethiopia. A holistic approach is needed to improve soil fertility and increase food production. Such an approach would include integrated soil nutrient replenishment strategies that coincide with better soil and water conservation.

Tillage plays an important role in the dynamic processes governing soil fertility. It is possible that with properly designed tillage practices to alleviate soil related constraints in achieving potential productivity and utility. However, improperly designed tillage practices can set in motion a wide range of degradative processes like accelerated erosion, depletion of soil organic matter and fertility, deterioration in soil structure, and disruption in cycles of water, carbon, nitrogen and other major nutrients (Lal, 1993).

The conventional tillage system for maize production in Ethiopia involves at least three times plowing with oxen over a four month period prior to planting. This usually results in a fine seed bed that is bare with pulverized soil. In a state like this the soil is very vulnerable to erosion because the rainfall is often intense. As experienced this conventional tillage system is not sustainable and should therefore be replaced by one that improves soil and water conservation.

World-wide the focus is shifted to conservation agriculture and sound tillage systems are an integral part of it. Various tillage systems were therefore investigated to establish their ability of enhancing soil and water conservation. Many studies (Harold and Edwards, 1972; Triplett and Van Doren, 1977; Phillips *et al.*, 1980) showed that minimum tillage is very beneficial for the conservation of soil and water. In essence it involves minimum disturbance of soil and good soil cover with residues. The crop residues remaining on the soil surface with minimum tillage provide not only essential physical protection to the soil particularly against erosion, but also make available decomposable biomass to the organic matter pool of soil which will improve fertility (Bruce *et al.*, 1991).

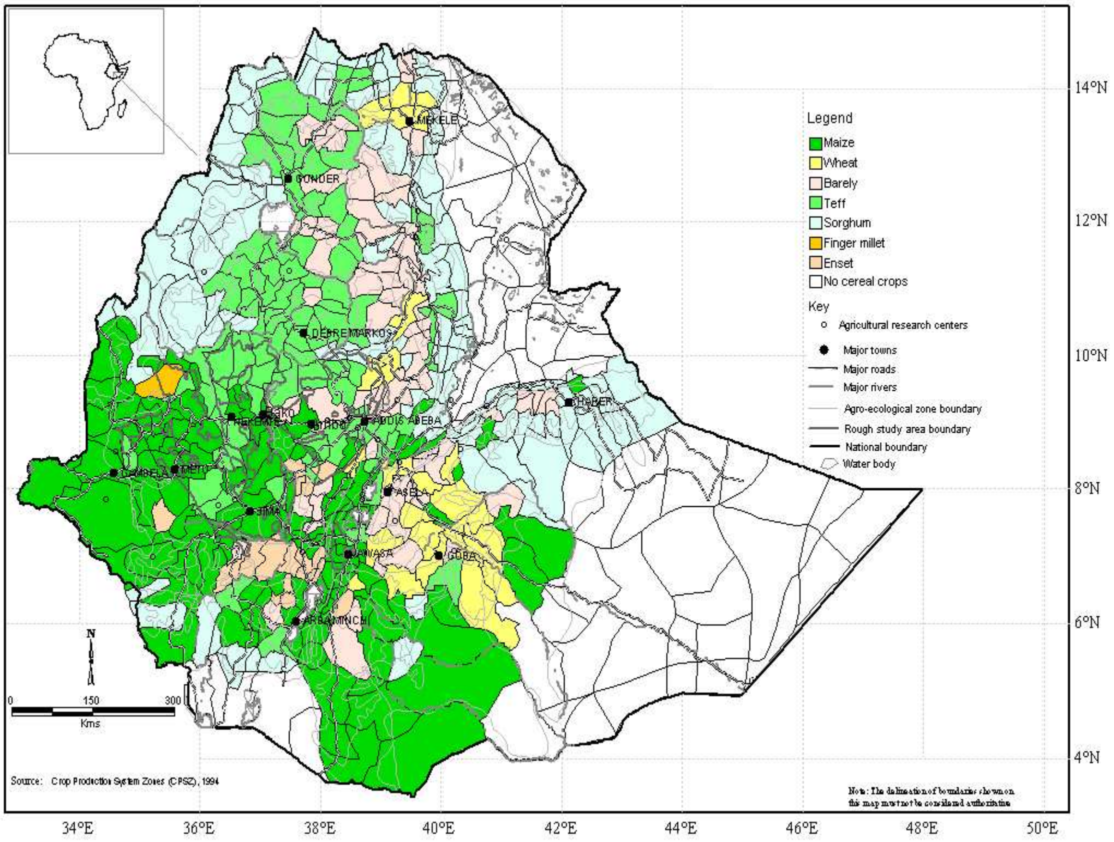
Minimum tillage has therefore great potential for the maintenance and restoration of soil productivity, while conventional tillage exhibited relative depletion of the soil nutrient reserve (Lal, 1976a; Blevins *et al.*, 1977). The introduction of minimum tillage often necessitates higher nitrogen fertilization to maintain crop yields, especially during the first few years (Phillips *et al.,* 1980; Meisinger *et al.*, 1985). However, several researchers reported higher yields from minimum than conventional tilled maize when the same amount of nitrogen fertilizer applied for both systems (Triplett and Van Doren, 1969; Moschler *et al.,* 1972) and a gradual increase of the organic nitrogen pool with minimum tillage could compensate for sustainable production (Rice *et al.,* 1986). Therefore, when minimum tillage is propagated, nitrogen fertilizer application must be considered carefully in a developing country like Ethiopia, where soils are inherently low in fertility and most farmers are applying far less than the recommended nitrogen fertilizer rate even for conventional tillage.

Any propagation of minimum tillage as an alternative to conventional tillage for maize production should coincide with sound advice on nitrogen management. This implies that optimum nitrogen fertilization rates must be established at least for those farmers who can afford it. As most of the farmers are unable to fertilize at the optimum nitrogen rate, another option may be the planting of maize genotypes that are efficient in nitrogen use. Several researchers (Lafitte and Edmeades, 1994a; Bänziger *et al.*, 1997; Prestrel *et al.*, 2002) showed sufficient genetic variability exist in maize for N use efficiency. Genotypes which are superior in the utilization of available nitrogen, either due to enhanced uptake capacity or because of more efficient use of the absorbed nitrogen in grain yield could reduce the impact of nitrogen deficiency on maize production.

The maize crop is not able to recover the entire amount of nitrogen applied as fertilizer due to losses from the soil-plant system. In this regard processes like volatilization, leaching and denitrification are of importance (Tyler and Thomas, 1977; Aulakh *et al.,* 1984; Kitur *et al*, 1984; Keller and Mengel, 1986). The portion of nitrogen fertilizer that escapes from the soil-plant system may exert harmful effects on the environment through the emission of toxic gases to the atmosphere and the contamination of ground water by leaching of nitrate. Hence, in order to develop sustainable crop production practices it is essential to understand the fate and behavior of applied fertilizer nitrogen in the soil-plant system.

Quantifying the fate of fertilizer nitrogen is especially important for coarse textured soils of western Ethiopia. Their low organic matter and nitrogen concentrations make nitrogen fertilizer applications essential for crop production, while high annual rainfall may result in substantial nitrogen loss through leaching, denitrification, or both.

The effects of tillage system, residue management and nitrogen fertilization on maize were investigated in western Ethiopia which is the most suitable agro-ecology for maize production (Figure 1.1). Maize is mainly cultivated by small-scale farmers who depend on oxen power for tillage under rainfed condition. The degraded soils are intensively cultivated, and maize yields are low even in good seasons, particularly due to nitrogen deficiencies. The current recommended N fertilizer rate for maize production is 92 kg ha^{-1} (Tolessa, 1999). However, farmers apply only 20-30 kg N ha^{-1} as a result of poverty.



Source: Crop Production System Zones (CPSZ), 1994

Note: The delineation of boundaries shown on this map must not be considered authoritative

Figure 1.1 Distribution of major crops in Ethiopia.

1.2 Hypotheses

Two hypotheses were formulated for this study:

1. Productivity of soil and hence maize can be enhanced by integrated effects of minimum tillage, residue management and nitrogen fertilization.
2. Maize genotypes differ in nitrogen use efficiency on account of sufficient genetic variation.

1.3 Objectives

The first major aim of this study was to investigate the integrated effects of tillage system, residue management and nitrogen fertilization on the sustainability of maize production in western Ethiopia. Specific objectives were to:

1. Determine the effects of above-mentioned crop management practices on yield and yield components of maize.
2. Establish the nitrogen recovery efficiency of maize with and without ^{15}N and assess the fate of fertilizer nitrogen in the soil as affected by the above-mentioned crop management practices.
3. Evaluate the effects of above mentioned crop management practices on some soil fertility parameters like pH, organic carbon and nitrogen as well as extractable phosphorus and potassium.
4. Verify whether the recommended nitrogen fertilizer rate for conventional tilled maize production is also applicable for minimum tilled maize production.
5. Determine the economic advantages of appropriate crop management practices to maize production in western Ethiopia.

The second major aim of this study was to investigate the response of different maize genotypes to nitrogen fertilization in western Ethiopia. Specific objectives were to:

1. Identify maize genotypes that would yield well on soils with low and high nitrogen fertility.

2. Compare nitrogen uptake and use efficiency of different maize genotypes.

3. Determine the economic advantages of planting maize genotypes efficient in nitrogen use.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review commence with a general discussion on the basic concepts of soil tillage, the value of crop residues and the importance of soil organic matter. Then, the response of the soil-maize system to conventional and minimum tillage is addressed in detail. The emphasis is on soil property changes, nitrogen transformation processes, maize grain yield, and nitrogen uptake by maize and weed control. Lastly, the nitrogen use efficiency of maize in general and of efficient genotypes is discussed.

2.2 Basic concepts of soil tillage

Soil tillage is probably as old as settle agriculture. It has been therefore an integral part of traditional and/or conventional agriculture. Tillage of agricultural soils is defined as the manipulation, generally mechanical, of soil properties to modify soil conditions for crop production (Soil Science Society of America, 1987). Specific reasons for tilling a soil include weed control, incorporation of soil amendments, crop residues and pesticides, and modification of soil physical properties, thereby improving soil conditions for crop establishment, growth and yield (Cassel, 1983).

The impacts of tillage on soil degradation and hence agricultural sustainability are more important now than ever before. There are various tillage systems that can be used but each of them has advantages and disadvantages to be considered. The two extremes are, however, conventional and minimum tillage.

Conventional tillage can be defined as moldboard plowing followed by disking one or more times to obtain a loose, friable seedbed (Phillips *et al.*, 1980). This intensive operations not only kills weeds competing with crop plants for water and nutrients, but also modifies the circulation of water and air within the soil which enhances organic matter decomposition and hence the release of nutrients like nitrogen for crop growth (Arnon, 1975; Reijntjes *et* *al.*, 1992). The release of nutrients from organic matter coincides with the emission of greenhouse gases like CO_2 into the atmosphere (Reicosky and Lindstrom, 1993). In many instances such intensive operations also adversely affect soil structure and cause excessive break down of aggregates leading to either wind or water erosion (Lal, 1976a; Triplett and Van Doren, 1977; Mahboubi *et al.*, 1993).

According to Phillips *et al.* (1980) minimum tillage can be defined as a system in which the crop is planted with just sufficient tillage to allow placement and coverage of the seed for germination and emergence. Usually no further cultivation is done before harvesting. Weeds and other competing vegetation are controlled by chemical herbicides. Soil amendments, such as fertilizers are applied to the soil surface.

Several other terms, such as zero tillage, reduced tillage, mulch tillage, direct seeding, sod planting and stubble planting are sometimes used to describe systems similar to what is defined as minimum tillage (Phillips *et al.*, 1980). Minimum tillage is also synonymous with conservation tillage (Willis and Amemiya, 1973) and implies retention of more than 30% of the crop residues on the soil surface. It is not surprising therefore that Lal (1989) stated minimum tillage was developed to alleviate soil related constraints for crop production and meet the need for the conservation of soil, water and energy resources.

The concept of minimum tillage, a combination of ancient and modern agricultural practices, was first introduced in the early 1950's when tillage was substituted by herbicides in pasture renovation. In the same decade, a similar concept was proposed for maize following sod with the emphasis on mulching to ensure soil and water conservation. Then, maize was planted with minimum tillage by removing plugs of soil with a sampling tube, dropping in a seed, and replacing the soil removed by the sampler, and much to surprise the maize grew well (Moody *et al.,* 1961).

Consequently, minimum tillage systems for crop production were rapidly adopted by farmers in the world. Over 50% of the farmers in the United States of America practice minimum tillage (Uri, 1999), and many commercial farmers in Africa have also abandoned conventional tillage (Findlay *et al.*, 2001). However, the adoption of minimum tillage among small-scale farmers in sub-Saharan Africa has been very limited. Nonetheless, Lal (1974a, 1989) showed that minimum tillage could be used successfully for tropical agriculture, also.

Minimum tillage has been shown to have several advantages over conventional tillage. Some of these were discussed by Triplett and Van Doren (1977) and others by Phillips *et al.* (1980). They included reduced erosion by wind and water, ability to grow crops on sloping land, increased productivity of farm workers, improved timing of planting and harvesting, more efficient use of soil water, lower machinery requirement, reduced soil compaction, standing residues provided shelter for wildlife and food for livestock where applicable. Advantages cited for minimum tillage in the tropics include a progressive increase in soil organic matter, resulting not only in a higher CEC but also higher N and P levels. In addition soil structure is promoted and soil water holding capacity is improved which contributed to less soil erosion, and lowering of the daily maximum temperature at the soil surface to a level more favorable for plant growth (Lal, 1974a, 1989). Crop yields under minimum tillage have generally been found equal to or greater than those under conventional tillage (Jones *et al.*, 1968; Triplett and Van Doren, 1969; Moschler *et al.*, 1972; Lal, 1974b; Phillips *et al.,* 1980).

Despite the listed advantages for minimum tillage there are some disadvantages frequently associated with this system. These include better management skills due to a greater incidence of insects and diseases which require more pesticides, lower soil temperature in spring delaying planting in some areas, and more leaching of NO_3^- from the root zone (Triplett and Van Doren, 1977; Phillips *et al.*, 1980). However, the lower soil temperature can be advantageous in the tropics, because the soil temperature is frequently above the optimum required for maximum plant growth. Phillips *et al.* (1980) is of opinion that the advantages of minimum tillage far outweigh the disadvantages.

2.3 Value of crop residues

Minimum tillage usually coincides with the retention of crop resides on the soil surface. The residues of especially grain crops are often regarded as a lower quality resource. However, in the tropics where it is one of the most abundant resources it can play a major role to improve the sustainability of cropping.

Crop residues have a number of functions. When left in the field after grain harvesting, crop residues play a significant role in nutrient cycling, soil and water conservation, maintenance of favorable soil properties, and enhance subsequent crop yields (Power *et al.*, 1986; Bationo and Mokwunye, 1991; Unger *et al.*, 1991). Other benefits of retaining crop residues on the soil surface include an increase of organic matter and nutrient levels, moderation of soil temperature and increased soil biological activity, all of which are important for sustaining crop production (Powell and Unger, 1997). Crop residues are also used for other purposes, such as to provide vital livestock feeds during long dry seasons, fuel and construction material (Latham, 1997).

Use of crop residues as a soil amendment is often limited due to its impediment to mechanical and hand tillage, negative effects on crop productivity arising from incidence and carryover of pests (Ferdu *et al.*, 2002), diseases (Osunlaja, 1990; Tewabech *et al.*, 2002), allelopathy (Guenzi *et al.,* 1967; Cochran *et al.*, 1977), and short term nutrient deficiency (Ocio *et al.*, 1991). For these reasons, much of crop residues are either fed to cattle or burnt.

When all crop residues are used as animal feed or removed for other purposes, the above mentioned soil related benefits are lost. As a result, sustaining soil productivity becomes more difficult. The magnitude of the beneficial effects associated with the retaining of crop residues on fields depends on the quantity and quality of the residue, the subsequent crop to be grown, edaphic factors, topography, climate and soil management (Powell and Unger, 1997). The benefits generally increase with increasing amounts of residues available (Lal *et al.*, 1979), however, even small amounts provide some benefits (Mannering and Meyer, 1963; Meyer, *et al.*, 1970; Unger *et al.*, 1991).

Crop residues act as a sink and source for plant nutrients (Hubbard and Jordan, 1996; Ambus and Jensen, 2001). The capacity of crop residues to serve as sink and source of nutrients for crop production depends to a large extent on climatic conditions, soil properties, crop characteristics and tillage practices (Doran and smith, 1991). A proper understanding of the decomposition of crop residues and the fate of the released nutrients is therefore essential.

Crop residues contains large quantities of plant nutrients and, if properly managed and returned to the soil from which it was grown, could serve as an effective means of maintaining the organic matter and nutrient levels in soil. Poulain (1980) indicated that recycling of crop residues is especially important in developing countries because: (i) the amount of the nutrients in crop residues are seven to eight times higher than the quantity of nutrients applied as fertilizers, (ii) crop residues is a source of trace elements which are absent in the commercial NPK fertilizers and (iii) organic and inorganic materials have a complementary role and their simultaneous use will ensure better crop yields. Proper usage of crop residues could therefore result in less importation of chemical fertilizers with great savings in scarce foreign exchange.

In most countries of Africa the nutrient balances of cropping systems are negative, with offtake being greater than input, indicating that farmers are mining the soils. For instance, Stoorvogel and Smaling (1990) reported that soils of sub-Saharan Africa are being depleted annually of 22 kg N, 2.5 kg P, and 15 kg K per hectare. Therefore, increased and sustained crop production requires appropriate soil management and conservation practices, involving the integrated use of organic and inorganic resources. Improved crop residue management should be an essential part of the strategy to reduce the nutrient mining. Larson *et al.* (1972) estimated that crop residues from the nine leading crops contain on average 40, 10, and 80% of the N, P, and K currently applied as fertilizer to those crops, respectively. For example a ton of maize residue contains 4-8 kg N, 1.5-1.8 kg P, 13-16 kg K, 3.8-6.6 kg Ca, and 1.5-3.4 kg Mg (Nandwa *et al.*, 1995).

Residues of cereal crops comprise 60 to 75 % of the total biomass production and have lower nutrient concentrations than the grain (Van Duivenbooden, 1992). However, these residues contain about half of the nutrients exported from the soil through crop production (Unger, 1990). Therefore, returning of them to the soil in systems particularly, where no or low inputs are used, is essential in slowing down nutrient losses. However, crop residues by themselves are not enough to offset nutrient mining in sub-Saharan Africa (Woomer and Swift, 1994)

Crop residue management influences the availability of nutrients especially N. When crop residues with a wide ratio of C:N are incorporated into soil the residual inorganic N remaining in the soil after harvesting is immobilized. After maximum immobilization, mineralization of the previously immobilized N occurs, resulting in a net release of N (Allison and Klein, 1962). In such conditions even a portion of fertilizer N added to soil is immobilized, but the mineralization rate of the recently immobilized fertilizer N is greater than that of indigenous organic N for the same period (Freney and Simpson, 1969).

The frequently-observed initial yield suppression which follows residue application to soil is attributed to N immobilization as mentioned above (Ocio *et al.*, 1991). It is generally reported that crop residues with a C:N ratio of greater than 35 or N content of less than 1.6%, usually decompose slowly, and cause immobilization (Nandwa, 1995). Apart from the quality of residues, decomposition and the subsequent release of nutrients are a function of the physical environment, and the activity of soil organisms (Powell and Unger, 1997). Factors that affect the rate of decomposition include the water content, temperature and pH of the soil, the C, N and lignin content of the residue, and particle size and degree of residue burial in the soil (Parr and Papendick, 1978).

Some management practices that can be implemented to synchronize the release of nutrients with crop demand or to avoid the release of phytotoxins at sensitive growth stages when residues are retained on fields include application of fertilizer N (Aulakh *et al.*, 1984), timing and placement of the residues (Guenzi, *et al.*, 1967). As far as placement is concerned, retention of crop residues on the soil surface with minimum tillage decreases the rate of decomposition (Parker, 1962) while with conventional tillage where crop residues are incorporated in the soil there is greater mechanical disruption and subsequently more intimate contact with decomposer organisms increases the rate of decomposition (Holland and Coleman, 1987; Staricka *et al.*, 1991; Ambus and Jensen, 2001). In addition, the secondary tillage operations commonly of conventional tillage systems are likely to further accelerate the rate of residue decomposition.

2.4 Importance of soil organic matter

Organic matter is an important constituent of soil. In the broadest context, organic matter may be referred to as the total complement of organic substances in the soil, including living organisms of various sizes, organic residues in various stages of decomposition and dark-colored humus consisting of non-humic and humic substances. Humus is relatively stable and has a major effect on soil characteristics and processes that play a role in soil quality (McLaren and Cameron, 1986).

It is not surprising therefore that soil organic matter has been a concern for centuries because it fulfills several major roles in the maintenance of soil quality. Very often organic matter is referred to as "black gold" because of its vital role in the physical, chemical and biological properties and processes within the soil system. Organic matter influences properties of especially mineral soils disproportionately to the quantities present: it is a major source of nutrients and microbial energy, holds water and nutrients in available form, usually promotes soil aggregation and root development and improves water infiltration and water-use efficiency (Allison, 1973). Reicosky (2001) mentioned that organic matter is a key indicator for soil quality. The quality of a soil can be defined as its capacity to sustain biological productivity, maintain environmental quality, and promote plant, animal and human health (Doran and Parkin, 1994).

Organic matter serves as a reservoir of nutrients essential for plant growth, provides exchange sites for the retention of cations and anions, acts as a source for storage and cycling of nutrients in the soil-plant system (Tisdale *et al.*, 1985; Doran and Smith, 1987). A decrease in soil organic matter will result in a decrease of the CEC and hence the nutrient-holding capacity of the soil (Bationo *et al.*, 1995). Usually, there is a strong linear relationship between the organic C content and CEC of soils (Robert, 2001). For example

De Ridder and Van Kuelen (1990) found that a difference of 1 g kg^{-1} in organic C results in a CEC difference of 4.3 mmol kg^{-1}.

Organic matter contains various amounts of C, H, O, N, P, K, S and traces of other elements. (Smith and Elliot, 1990). The actual amounts of especially N, P and S available for plants are determined in part by the total level of organic matter and its rate of decomposition as organic matter is the center of biotic activity in the soil that governs this process (Lal, 1990).

In tropical soils, the organic matter fraction constitutes the major portion of total N, P and S reserves of the soil. Typically 95% of the total N and S are in the organic form, while, the proportion of P is lower. According to Sanchez (1976) 60-80% and to Duxbury *et al.* (1989) 20-75% of the total P is in the organic form. Smith and Elliot (1990) indicated that the N, P and S content of surface soils averaged 0.12, 0.05 and 0.03%, respectively, with 95% of the N, 40% of the P, and 90% of the S being associated with the organic component. A decline in organic matter by two-thirds, such as happens when soils are continuously cultivated or there are major losses due to soil erosion, represents a serious decrease in both the total reserve and availability of essential plant nutrients.

Organic matter also has a tremendous effect on soil water management particularly in semi-arid regions, because it increases infiltration and water holding capacity (Rasmussen and Collins, 1991). Enhanced soil water-holding capacity resulted from organic matter more readily absorbs water and releases it slowly over the season to minimize the impacts of short-term drought. Hudson (1994) showed that for 1% increase in organic matter, the available water holding capacity in the soil increased by 3.7% on a volume basis. Similarly, Brady (1990) concluded that organic matter can absorb up to 90% of its weight as water which substantially increases the water holding capacity of mineral soils. All these factors contribute to improved soil-plant-water relationships which will enhance crop productivity on sustainable basis.

A secondary benefit of increased soil organic matter that usually coincides with minimum tillage is the potential to sequester carbon from the atmosphere and hence reduced air pollution. Conventional tillage releases large amounts of CO_2 on account of enhanced biological oxidation and decomposition of soil organic matter (Reicosky *et al.*, 1995). This CO_2 ends up in the atmosphere where it combines with other gases contributing to the greenhouse effect. Carbon sequestration by agriculture may be one of the most effective ways to slow processes of global warming (Reicosky, 2001) since soil is a large sink for C (Kern and Johnson, 1993). Small changes in the C content of the soil are significant to the environmental and agricultural potential of the soils.

Soil organic matter is therefore a vital on-site resource and of fundamental concern for sustainable agriculture. Practices for soil and crop management are often focused towards accumulating as much organic matter as possible. The effect of these practices on soil organic matter content is influenced mainly by climatic, vegetation and edaphic factors. In general, soil organic matter increases with increasing precipitation and decreases with increasing temperature (Jenny, 1941; Kononova, 1966; Burke *et al.*, 1989). Thus, the impact of soil and crop management practices on the dynamics of organic matter varies between and within regions, and is therefore location specific.

Crop residues are important to the accumulation or loss of soil organic matter (Larson *et al.*, 1972; Barber, 1979). Unfortunately, addition of crop residues on conventionally tilled soils does not increase soil organic matter content (Beale *et al.,* 1955), while minimum tillage coupled with crop residue addition has been reported to increase soil organic matter content of the surface horizon (Bruce *et al.,* 1991; Unger, 1991).

Crop residue decomposition is a fundamental factor in organic matter stabilization, since degradation products are incorporated into various pools (Parr and Papendick, 1978). Levels of soil organic matter will continue to change as long as any of the controlling factors continue to change. Its level mainly depends on the rate of residue addition in relation to the rate of residue decomposition. New equilibrium levels will be highly dependent on farming practices, especially those involving crop residue utilization, crop rotation and tillage. Crop residues play a significant role in setting a new organic matter equilibrium level in soil. The effect of crop residue on soil organic matter content is highly related to the amount and only weakly related to the type of residue applied. Larson *et al.* (1972) found that different types of crop residues such as maize stover, oat straw, alfalfa, saw dust and bromegrass had similar effects on soil organic matter content.

The native fertility of most agricultural soil has declined significantly as organic matter was mined by cropping without subsequent addition of plant and animal residues. As soil organic matter levels declined to 40-60% of their original levels, soil productivity declined, erosion losses of surface soil increased, and net mineralization of organic N fell below that needed for sustained crop production. Hence, the production of large quantities of residues, and their subsequent decay, is necessary to good crop and soil management. The greatest source of soil organic matter is the residue contributed by current crops. Consequently, the selection of cropping systems and methods of handling the residues are equally important.

Generally, in soils that contain little organic matter, the amounts can be increased by suitable crop residue management practices, and in soils that are naturally high in organic matter, conventional tillage and cropping tend to accelerate the decomposition of organic matter and releases of N. A goal of sound management is to maintain organic matter at desirable levels in various soils.

2.5 Response of the soil-maize system to conventional and minimum tillage

2.5.1 Soil properties

2.5.1.1 Physical properties

The two most prominent features of minimum tillage compared with conventional tillage are the retention of crop residues on the soil surface and the reduced mechanical manipulation and mixing of the soil. These features may greatly change the physical soil environment when switching from conventional to minimum tillage. However, the actual effects of such a switch depend on several factors including differences in antecedent soil properties, climatic conditions, history of cultural management and extent and type of tillage (Mahboubi *et al.*, 1993). The degree and extent of changes brought about by minimum tillage are determined largely by the amount of crop residue produced and retained annually, the degree of reduction in tillage, and the length of time that the system is practiced (Blevins *et al.*, 1983a).

Minimum tillage systems, which maintain high surface soil coverage, have resulted in significant changes of soil physical properties, especially in the upper few centimeters (Lal 1976a; Brady, 1990). Soil properties that were altered include water holding capacity, bulk density, mechanical strength, structure, porosity and temperature (Lal 1976a; Blevins *et al.*, 1983a,b; Mahboubi *et al*., 1993; Griffith *et al.*, 1986).

Conservation and more efficient use of soil water is one of the major advantages of minimum tillage crop production systems (Phillips *et al.*, 1980; Unger and McCalla, 1980). In such systems the mulch that develops over time is beneficial for water infiltration and higher soil water content (Triplett *et al.*, 1968). The additional water conserved could carry crops through short drought periods without severe water stresses developing in the plants (Jones *et al.*, 1969; Blevins *et al.*, 1971). However, the extra water conserved can occasionally be detrimental under conditions in which excessive amounts contribute to denitrification losses.

Lal (1976a) and Mahboubi *et al.* (1993) found higher rates of water infiltration in minimum tilled soils than in conventional tilled soils. Subsequently, Blevins *et al.* (1983a) observed higher soil water contents under minimum tilled maize than under conventional tilled maize throughout the growing season. However, Lal (1976a) noted that minimum tilled plots in comparison with conventional tilled plots had higher soil water contents to 10 cm depth especially during drought stress periods. During these periods the plants on the conventional tilled plots showed more severe leaf curling than those on the minimum tilled plots. On the other hand, Reijntjes *et al.* (1992) stated that conventional tillage reduces heat conduction and breaks capillary connections in the soil. As a result the tilled layer dries quickly, but the subsoil water can be conserved better as with minimum tillage.

The crop residue retained at the soil surface with minimum tillage reduces water evaporation and the greater ability of the soil to store water increases the water available for plant use. Phillips *et al.* (1980) noted lower evaporation and transpiration losses from minimum tilled plots than from conventional tilled plots. Blevins *et al.* (1971) reported that minimum tillage in comparison with conventional tillage resulted in higher volumetric soil water contents to 60 cm depth during most of the maize growing season. The greatest differences occurred in the upper 8 cm. Beyond a depth of 60 cm, tillage systems had little influence on soil water contents during the growing season.

High soil temperatures are often encountered in the tropics during the seedling stage of crop growth when the soil surface is unprotected (Lal, 1974a,b). Use of crop residues as mulch on the soil surface minimize these problems (Larson 1962; Lal, 1973; Willis and Amemiya 1973; Triplett and Van Doren, 1977). Crop residues retained on the soil surface as a result of minimum tillage reflect the light and insulate the soil, reduces heat movement into and from the soil and thereby reduces soil temperatures and evaporation losses of water (Bond and Willis, 1969; Gupta *et al.*, 1983; Clay *et al.*, 1990). Johnson and Lowery (1985) showed that the surface mulch associated with minimum tillage not only lowers soil temperature, but results also in less fluctuation of soil temperature during the growing season when conventional tillage serves as a reference.

In a tropical environment, extreme temperatures often reduce biological activity in the soil. Crop residues on the soil surface can counteract this phenomenon. For example Lal (1974a) reported that as little as 2 t ha^{-1} of residues on the surface reduced soil temperature at 5 cm depth by as much as 8 ^{O}C. However, in temperate environment when soils are warming, the soil temperature at 10 cm depth decreased with 0.15 to 0.30 ^{O}C for each 1 t ha^{-1} application of crop residues to the soil surface (Allmaras *et al.,* 1973). Therefore, in a tropical climate, surface mulching may reduce soil temperature to a level more optimal for growth and activity of plants and micro-organisms, while when soils are warming in temperate climates, the lower temperatures associated with mulching often reduce biological activity.

Bulk density has a major impact not only on the dynamics of water and air in soil but also on the root development of crops and all of these may affect crop growth and yield (Unger and Cassel, 1991). Conventional tillage operations are performed inter alia to decrease soil bulk density within the disturbed zone. Soil bulk densities under minimum tillage are often reported to be higher than under conventional tillage (Gantzer and Blake, 1978; Bauder *et al.,* 1981; Heard *et al.,* 1988; Roth *et al.,* 1988; Unger and Cassel, 1991). However, some reports showed that soil bulk densities with minimum tillage are usually lower than with conventional tillage (Russel *et al.,* 1975; Lal, 1976a; Griffith *et al.,* 1977). A number of researchers reported also no difference in soil bulk densities due to the two tillage systems (Shear and Moschler, 1969; Cannell and Finney, 1973; Blevins *et al.,* 1977, 1983b).

Lal (1976a) mentioned that because of greater earthworm activity and less crusting, the bulk density and hence penetrometer resistance of minimum tilled plots was not as high as those of conventional tilled plots. The penetrometer readings at 20 cm depth were for example 2.6 kg/cm^2 in the conventional tilled plots and 2.2 kg/ cm^2 in the minimum tilled plots. On the contrary other researchers (Bauder *et al*., 1981; Mahli and O'Sullivan, 1990) reported a higher soil resistance to penetration of a cone penetrometer with minimum tillage than with conventional tillage. In their study Mahli *et al*. (1992) determined 7 years after the tillage treatments started, that the penetration resistance in the 0-10 cm soil layer was higher under minimum tillage than conventional tillage, but did not differ in the 10-20 cm and 20-30 cm soil layers.

2.5.1.2 Chemical properties

Tillage systems have also profound effects on the chemical properties of soils which may ultimately influence crop growth and yield. It is especially the pH and nutrient content of soils that are substantially affected by different tillage systems (White, 1990).

The pH in the upper few centimeters of a soil usually decreases rapidly under minimum tillage, especially when high rates of N fertilizer are used (Moschler *et al.,* 1973; Blevins *et al.,* 1977; Blevins *et al*. 1983a,b; White, 1990; Ismail *et al.,* 1994). This drop in pH is attributed mainly to the H^+ released through the nitrification of NH_4. The NH_4^+ originated from the surface-applied nitrogenous fertilizers and the N mineralized from the crop residues (Ismail *et al.,* 1994). Some of the pH reduction could be also apparently due to organic acids that form when crop residues are broken down (Brady, 1990). Thomas (1975), however, pointed out that the organic matter which usually accumulates near the surface of minimum tilled soils tends to ameliorate the acidity. Any changes in pH resulting from tillage systems may have a bearing on fertilizer application strategies.

It is generally accepted that as a result of minimum tillage the soil organic matter increases in the upper five centimeters of a soil mainly due to the fact that the crop residues are not mechanically mixed into the soil as with conventional tillage (Baeumer and Bakermans, 1973; Lal 1976a; Blevins *et al.,* 1977; 1983b; White, 1990; Rasmussen and Collins, 1991; Mahboubi *et al.,* 1993; Ismail *et al.,* 1994). As described earlier in Section 2.4 the N, P and S in the organic matter can be mineralized to plant available forms which are beneficial for crop growth and yield (Blevins *et al.,* 1977; Rasmussen and Collins, 1991).

The burning of crop residues often coincides with conventional tillage to get rid of excessive amounts (Prasad and Power, 1991). In a sandy loam soil, two years of conventional tillage with residue burning led to a 33% loss in organic matter from the top 5 cm relative to minimum tillage with residue retention. This decrease could be accounted for by the increase of organic matter in the 10-20 cm layer which is attributed to redistribution by soil inversion (Chan and Mead, 1988).

Minimum tillage in comparison with conventional tillage has been shown to produce higher concentrations of extractable nutrients like P and K in the surface layers of soil, and lower concentrations in the deeper layers (Shear and Moschler 1969; Triplett and Van Doren 1969; Lal 1976a; Juo and Lal, 1979; Robbins and Voss, 1991; Ismail *et al.,* 1994). Due to a lack of mechanical incorporation of fertilizers, these two relatively immobile nutrients remains concentrated in the upper 5 cm soil layer of minimum tilled plots (Shear and Moschler, 1969; Triplett and Van Doren, 1969; Fink and Wesley, 1974; Ketcheson, 1980; Ismail *et al.,* 1994). On the other hand, El-Baruni and Olsen (1979) suggested that the solubility of P is known to be enhanced by the presence of organic matter, and Ismail *et al.* (1994) mentioned greater storage and cycling of P in organic matter under minimum tillage than conventional tillage. For example the concentration of plant available P in the 0-1.25 cm layer of minimum tilled soil was eight times higher than in a conventional tilled soil (Eckert and Johnson, 1985). The plant available P and K values for the 0-5 cm layer of minimum tillage were on average 3.5 times greater than those for the 5-15 cm layer (Robbins and Voss, 1991). Stratification of other nutrients such as Ca, Mg, Mn, Fe, Cu and Zn has also been associated with the adoption of minimum tillage (Lal, 1976a; Blevins *et al.,* 1983b; Shuman and Hargrove, 1985). It is also interesting to note that Blevins *et al.* (1977) reported no significant differences in extractable Ca under conventional and minimum tillage. Triplett and van Doren (1969) showed higher K levels in the upper 5 cm of soil subject to minimum tillage when conventional tillage serves as reference. In contrast, Hargrove *et al.* (1982) reported lower K levels under minimum tillage compared to conventional tillage.

In general, conventional tillage plays an important role in the redistribution of organic matter and plant nutrients within the disturbed soil zone. The accumulation of organic matter and nutrients within the surface soil layer of 0-5 cm is commonly observed with minimum tillage. However, below a depth of 5-10 cm the pattern is often reversed or no difference is recorded between the two tillage systems (Blevins *et al.,* 1977; Mahboubi *et al.,* 1993; Ismail *et al.,* 1994). This is because under minimum tillage the bulk of the crop residues are retained on the soil surface instead of being mixed throughout the tilled layer. Moreover, conventional tillage increases the rate of organic matter loss because it stimulates greater microbial contact with residue and thus greater microbial activity. However, the increased microbial activity under conventional tillage continues only until the readily available organic residue has been converted to CO_2 and stabilized humic compounds. The distribution of other organic constituents in minimum tilled soils, such as organic N and P, follows closely that of organic C (Dick, 1983).

2.5.1.3 Biological properties

Agricultural intensification and associated practices like tillage cause environmental modifications that often influence the population and diversity of fauna and flora in soils. There is usually a marked decrease in soil-borne organisms during cropping. Conventional tillage and its effect of leaving the soil bare for long periods are especially detrimental to soil macrofauna (Boyer and Chabanne, 2001). The role of macrofauna in pedological processes has been fully described (Lal, 1988; Lavelle, 1997), and their involvement in regulating soil microbial activity is now recognized. Studies have also highlighted a direct correlation between the activity of some soil macrofauna populations and plant growth (Stephens *et al.,* 1994).

Greater biological activity has been shown to exist at the surface of minimum tilled soils as compared to conventional tilled soils due to the higher water content and the presence of carbon substrate (Doran, 1980). The maintenance of organic matter in topsoil is of great importance therefore to promote biological activity (Epperlein, 2001). Biological activity has an influence on a number of soil properties and processes like structure, water infiltration, nutrient supply and cycling, and organic matter content (Reuter and Kubiak, 2001). The higher microbial activity in the surface of minimum tilled soils resulted in more immobilization of applied N fertilizer (Rice and Smith, 1984) and greater denitrification losses of N (Doran, 1980; Rice and Smith, 1982).

Many researchers showed that earthworm activity increased under minimum tillage systems that maintain crop residues on the soil surface. Minimum tillage improves the development of earthworm population in soil, especially that of *L. terrestris* by 200% as compared to conventional tillage (Epperlein, 2001). This higher level of *L. terrestris* activity leads to better pore continuity and hence infiltration, even in the subsoil on account of deep burrowing. The deep digging earth worm species take profit from the extensive nutrient supply at the soil surface in minimum tillage systems.

Haines and Uren (1990) found in long-term field experiments in Australia that the biomass of earthworms in the top 10 cm of minimum tilled soil is more than twice that of conventional tilled soil. Lal (1976a) reported that minimum tillage resulted in four to five times more earthworm activity than conventional tillage. The more casting that coincided with higher activity of earthworms resulted in low bulk density, penetrometer resistance and soil strength.

Earthworms have been termed by Lal (1983) as the best plowing implements for tropical soils since they turned the soil over without causing the erosion problems associated with moldboard plowing.

2.5.2 Nitrogen processes

The availability of indigenous and supplemental N to crop plants can be greatly affected by management practices such as soil tillage. For example soil tillage modifies the soil environment that influences microbial activity and hence N transformation (Fox and Bandel, 1986). Some of the N can undergo many transformations before taken up by crops. The main forms in which N is taken up are NO_3^- and NH_4^+ (Tisdale *et al.,* 1985; Mengel and Kirkby, 1987). The two ions are dissimilar in the charge they carry and their reactions in soil and plants differ therefore. Maize prefers NH_4^+-N during early growth stages and NO_3^--N in later growth stages (Dibb and Welch, 1976).

The quantity of these two ions presented to the roots of crops depends largely on the amounts supplied as commercial fertilizers and released from soil organic compounds. Regardless of the source, a number of transformation processes affect the fate of N in soil and its availability to crops. They are for example mineralization, immobilization, nitrification, denitrification, leaching, volatilization and erosion. The rates of these processes usually vary with soil and climatic conditions. Numerous observations suggest therefore significant differences between minimum and conventional tilled soils with regard to the N transformations processes (McMahon and Thomas, 1976; Kitur *et al.,* 1984; Meisinger *et al.,* 1985; Keller and Mengel, 1986). In most cases conversion from conventional to minimum tillage results in a cooler, wetter, less aerobic soil environment that affects many of these processes (Fox and Bandel, 1986). The most common observation has been that the availability of soil N was less in minimum than conventionally tilled soils for the first few years after conversion.

2.5.2.1 Mineralization

Mineralization is the microbial transformation of organically bound N to inorganic forms like $NH_4^+$and NO_3^-. As a result, both substrate and environmental factors control the mineralization rate in soils. Substrate properties influencing mineralization rate are the total amount of soil organic N and the nature of the organic matter such as its C:N ratio (Alexander, 1977; Van Veen *et al.,* 1981). Usually only 1 to 3% of the organic N in soils is mineralized during a growing season (Bremner, 1965). Important environmental parameters affecting mineralization are soil pH, water and temperature (Fox and Bandel, 1986).

Modification of the soil environment by tillage systems can significantly influence N mineralization (Smith and Sharpley, 1990). Moreover, mineralization rate is affected by the wetting and drying of soils. Birch (1960) reported that when soils are rewetted after a period of drying there was an increase in the rate of mineralization in comparison with soils which had been maintained in a moist condition. As a result, organic matter is mineralized more slowly in minimum than in conventional tilled soils.

Conventional tillage causes soil disturbance and places crop residues in intimate contact with soil, leading to more rapid decomposition and mineralization than surface placement of crop residues with minimum tillage (Dowdell and Cannell, 1975; Powlson, 1980; House *et al.,* 1984). In experiments done by Burford *et al.* (1976) the conventionally tilled soil contained 11-34 kg ha^{-1} more nitrate-N than minimum tilled soil. Similar findings were reported by Dowdell and Cannell (1975), namely that the concentration of nitrate-N to 30 cm depth in a clay soil was two times greater after conventional tillage than after minimum tillage. The observed differences between the two tillage systems were ascribed to decreased mineralization of soil N in the minimum tilled soil.

Consequently, depletion in the reserves of soil N is often observed in long-term conventional tillage systems (Lal, 1976a; Blevins *et al.,* 1977; Blevins *et al.,* 1983b; Dick, 1983). Despite that the rate of organic N mineralization may continue to be higher in conventional tilled soils, gradual accumulation of more organic N in minimum tilled soils could compensate for this to maintain production. Several researchers found that the organic

N concentration in the upper 5 cm of minimum tilled soils was significantly greater than in conventionally tilled soils (Lal, 1976a; Blevins *et al.* 1977; Dick, 1983; White, 1990). After 5 to 10 years of minimum tillage, soils may begin to supply as much N to the crop as with conventional tillage (Rice *et al.,* 1986).

On the other hand, Triplett *et al.* (1979) concluded from conventional and minimum tillage systems where several rates of N were applied, that mineralization of N in minimum tilled soils was inadequate to support maximum maize yields at equivalent N rates for both tillage systems. There was also no difference in the N content of leaves from the two tillage systems. In the control plots where no N was applied and a deficiency in N was experienced the yield was not improved by plowing. Based on this it was concluded that there was no difference in mineralization due to tillage system.

Legg (1975) suggested that organic N and its mineralizable contents are higher in soil from minimum than conventional tillage systems. Bennett *et al.* (1975) planted maize in minimum and conventional tilled plots and found that the total and hence mineralizable N were much higher in the former plots. In contrast, Bandel *et al.* (1975) found that total N in soil to a depth of 30 cm was not affected by tillage systems, but agreed with Bennett *et al.* (1975) that N mineralization potential in the upper 15 cm layer was higher for the minimum than for conventionally tilled maize plots

2.5.2.2 Immobilization

Immobilization is essentially the opposite process of mineralization in that it involves the microbial conversion of inorganic N into organic N. Although this process may not actually results in a loss of N, it competes with the crop plants for available N. Addition of organic materials to the soil has been shown to decrease N losses through immobilization (Tisdale *et al.,* 1985). For example Terman and Brown (1968) reported that the addition of maize residues caused that a much higher percentage of fertilizer N remains in the soil. In contrary, Parker (1962) reported that maize residues applied to soil had little influence on the supply of N for plant use. A negligible amount of N was immobilized as the residues decomposed rapidly, and attained by the end of the season a C:N ratio sufficiently low that mineralization of N could be expected.

Greater immobilization occurs most commonly when plant residues, especially low in N are retained on the soil surface with minimum tillage than with conventional tillage when it is incorporated into the soil (Rice and Smith, 1984). Intimacy of contact between soil and residues as well as differential soil temperature, water contents and microbial populations were responsible for the differences observed (Parker 1962; Doran, 1980; Rice and Smith, 1984). Doran (1980) stated that there was a greater potential for immobilization of surface applied N in minimum tilled soils because larger microbial populations are needed to breakdown the residues at the soil surface.

Immobilization of surface applied N fertilizer may account for the differences recorded in N fertilizer use efficiency between minimum and conventional tillage. Kitur *et al.* (1984) observed greater immobilization and less crop uptake of N at low fertilizer rates with minimum tillage. Rice and Smith (1984) concluded that the increased potential for immobilization of N at the surface of minimum tilled soils where organic matter accumulates may significantly reduce crop recovery of fertilizer N. Several results from tracer studies show that about 25 to 60% of applied fertilizer N remains immobilized in the soil (Allison, 1965, 1966; Bartholomew, 1965), and this immobilization has been found to increase with increasing amounts of fertilizer N applied (Legg and Allison, 1959; Allison, 1966; Stewart *et al.,* 1963). Brady (1990) mentioned that experiments with labeled N showed that only 2-3% of the immobilized N are mineralized annually.

2.5.2.3 Nitrification

Nitrification is the biochemical oxidation of NH_4^+ to NO_3^- by nitrifying organisms in an aerobic environment. As in the case of mineralization, nitrification is affected by factors that include soil pH, water, temperature and aeration for example. Nitrification is usually more rapid than mineralization and is therefore substrate limited. This process can take place only if there is a source of ammonium to be oxidized. Therefore, nitrification can be inhibited by crop residues with high C:N ratios as the release of ammonium is slow. On the other hand, good soil drainage and hence aeration are also required to provide oxygen for the nitrification process. Therefore, plowing may promote nitrification and as a result the rates are generally higher under conventional than minimum tillage (Fox and Bandel, 1986).

Differences in soil water content between minimum and conventional tillage systems could either enhance or inhibit the nitrification process. Birch (1958) has shown that the process is better in a soil subjected to repeated cycles of wetting and drying, rather than being wetted up from a dry state and maintained at constant high water content. Furthermore, he has also shown that the amount of nitrate release through nitrification upon wetting a dry soil is dependent on the length and intensity of the preceding dry period (Birch, 1959, 1960). Consequently, nitrate production will be greater under conventional than minimum tillage.

Several researchers reported lower NO_3 contents in soil profiles under minimum than conventional tillage (Thomas *et al.,* 1973; Dowdell and Cannel, 1975). This phenomenon has generally been attributed to slower mineralization of organic N and greater losses of N through leaching and denitrification in the minimum tilled soils. On the other hand, McMahon and Thomas (1976) found that due to rapid nitrification that the NO_3 levels were always higher under conventional than minimum tillage.

In their study on the dynamics of N in the cultivated soils, Hoyt and Todd (1981) found higher NO_3^- concentrations under conventional than minimum tillage during the crop growing season, while the NH_4^+ concentrations for the two tillage systems remained essentially the same. The NO_3-N to NH_4-N ratios were twice as high as in the minimum than conventional tilled soils. They concluded from this study that nitrification was inhibited under minimum tillage.

On the other hand, some researchers (Caskey, 1983; Rice and Smith, 1983) found that the factor most often limiting nitrification in well-drained soils was water availability. As a result of the higher water content in minimum tilled soils, the nitrification rate was often higher in these soils than in the conventional tilled soils. However, in poorly aerated or drained soils, the higher water content associated with minimum tilled soils may limit the supply of oxygen needed by nitrifying bacteria and thus reduced nitrification. Doran (1980) reported higher nitrifying bacteria populations in minimum than conventional tilled soils.

2.5.2.4 Denitrification

Denitrification as it most commonly occurs in soils is the microbial reduction of either NO_2^- or NO_3^- to NO, N_2O or N_2. Interest in this process exists because (i) it is a major mechanism of loss of soil N resulting in decreased fertilizer efficiency, (ii) it contributes significantly to N in the atmosphere, and (iii) it is a major step in the global nitrogen cycle. Soil conditions conducive to denitrification are low oxygen concentrations, presence of bacterial populations capable of denitrification, a source of energy such as organic carbon, presence of either NO_2^- or NO_3^-, and environmental conditions suitable for biological activity (Fox and Bandel, 1986). These conditions most often occur in agricultural soils when the water content increases.

Soil tillage practices could influence denitrification rates. For example the crop residues normally accumulated on minimum tilled soil reduces evaporation and often results in higher water contents (Jones *et al.,* 1969; Blevins *et al.,* 1971), causing a higher population of denitrifying bacteria (Doran, 1980) that enhances N losses due to denitrification as compared to conventional tilled (Rice and Smith 1982; Caskey, 1983). Thus, Rice and Smith (1982) argued that due to enhanced denitrification under minimum tillage, higher N fertilizer rates may be required as compared to conventional tillage.

2.5.2.5 Leaching

Leaching is the downward movement of soluble compounds present in water percolating through the soil profile. Loss of N through leaching is mainly in the form of NO_3^-. Although NH_4^+ is relatively immobile in the soil, it is rapidly converted to NO_3^- by the microbiologically controlled process of nitrification. Nitrate is very soluble in water, and the negatively charged ions are not adsorbed by the negatively charged colloids that dominate in most soils. Consequently, NO_3^- is subjected to ready leaching from the soil, and moved downward freely with water.

The amount of fertilizer N accumulating in soils as NO_3^- or lost through leaching is determined primarily by the amounts of N applied in relation to the amount needed and removed by the crop (Jolley and Pierre, 1977). Minimum tilled maize requires more fertilizer N as compared to conventional tilled maize (Meisinger *et al.,* 1985), and leaching losses of N increase with increasing rates of fertilizer N applications (Kohl *et al.,* 1971). Losses of N through leaching can be further accentuated by the crop residues that coincide with minimum tillage as they usually resulted in higher water contents (Thomas *et al.,* 1973; McMahon and Thomas, 1976; Tyler and Thomas 1977; Meisinger *et al.,* 1985; Brady, 1990).

The enhanced preferential leaching of NO_3^- in minimum tilled soils is due to increased water movement through a larger number of continuous macropores that lead to rapid channelized downward water and nitrate movement through the soil profile (Thomas *et al.,* 1973; Tyler and Thomas, 1977). Consequently, leaching losses of N from the crop root zone can be considerable and contribute to the accumulation of NO_3^- in ground and surface water (Kohl *et al.,* 1971; Tyler and Thomas, 1977). Kohl *et al.* (1971) estimated that a minimum of 55 to 60% of the N found as NO_3^- in the surface waters of a maize belt watershed originated from fertilizer N.

2.5.2.6 Volatilization

This process usually refers to the loss of N in the form of NH_3 into the atmosphere. Volatilization happens when fertilizers which either containing or forming ammonia are improperly applied or in amounts beyond the capacity of a soil to absorb it. Soil and environmental factors that affect volatilization of ammonia include the pH, organic matter content, cation exchange capacity, water content and temperature of a soil, the amount and type of crop residues present and the N sources used (Ernst and Massey, 1960; Terman, 1979; Keller and Mengel, 1986).

A considerable amount of N losses have been attributed to volatilization of NH_3 when ammonium containing or forming fertilizers, particularly urea are applied on soil surfaces with crop residues (Ernst and Massey, 1960; Terman, 1979; Bandel *et al.,* 1980; Keller and

Mengel, 1986). Besides, volatilization losses of NH_3 increases with increasing rates of N applied. The low N use efficiency frequently observed with minimum tilled maize when fertilizer is applied on the soil surface with residues was partly attributed to volatilization of NH_3 (Keller and Mengel, 1986).

Excessive supply of NH_3 to plants on account of over fertilization may results in that the ability of plants to convert it to amines is exceeded. The resulting effect is the accumulation of NH_3 in plants and hence the volatilization of it (Stutte *et al.,* 1979; Hooker *et al.,* 1980). Plants are able to absorb N in excess of their needs and, through translocation to aerial parts, effectively remove N from the soil and expose it to volatilization. This permits a higher percentage uptake of fertilizer N as rates are increased (Legg and Allison, 1967).

2.5.2.7 Surface run-off

The colloidal fraction of the soil consisting of clay minerals and organic matter is the main source of plant nutrients and has a major impact on nutrient availability (Brady, 1990).These soil constituents also determine the ability of the soil system to sustain the supply of a given level of nutrient over an extended period of time. However, loss of organic matter and clay components by surface runoff represents a major loss in nutrient availability and overall fertility.

One of the greatest merits of minimum tillage is its potential to reduce surface runoff and hence erosion. With reduced erosion there will also be a decline in the loss of soil organic matter and therefore N. Soil erosion generally increases with increasing amounts of tillage and decreases with increasing amounts of crop residues. Several studies have shown higher erosion losses of soil from conventional than minimum tilled soils (Harold and Edwards, 1972; Lal, 1976a; Chichester and Smith, 1978). For example experiments by Chichester and Smith (1978) showed an annual sediment loss of 35 kg ha^{-1} with minimum tillage and 3267 kg ha^{-1} with conventional tillage. These losses correspond respectively to 8.4 and 14.2% of the total N transported in runoff. An estimated 40% of all nutrient losses in sub-Saharan Africa are due to soil erosion (Stangel, 1995). Loss of N through erosion, however, would be minimal under minimum tillage.

2.5.3 Maize grain yield

The effect of different tillage systems on the grain yield of maize were investigated by many researchers. Divergent results were obtained which can be attributed to various climatic conditions, soil types, fertilization practices and periods of implementation to mention a few.

Several researchers reported lower maize grain yields under minimum than conventional tillage with low rates of N application and the reverse with high rates of N application (Triplet and Van Doren, 1969; Bandel *et al.,* 1975; Moschler and Martens 1975; Kitur *et al.*, 1984; Meisinger *et al.,* 1985). This phenomenon has been attributed inter alia to more immobilization of fertilizer N and less mineralization of soil N (Kitur *et al.,* 1984; Rice and Smith, 1984), enhanced nitrate leaching (McMahon and Thomas, 1976) and increased ammonia volatilization (Terman, 1979; Keller and Mengel, 1986) in minimum than in conventional tilled soils. With time, however, yield differences between the two tillage systems disappear.

There are also other findings by Moschler *et al.* (1972) and Fox and Bandel (1986) who reported higher yields from minimum than conventional tillage at all N levels used in their experiments. Blevins *et al*. (1971) reported that in their experiments on average a maize grain yield difference of 600 kg ha^{-1} was obtained in favor of minimum tillage as compared to conventional tillage. An increased content of soil water during the growing season was the most important factor causing the higher yields of maize under minimum tillage. Similar results were also reported by other researchers (Jones *et al.,* 1968, 1969; Triplett *et al.,* 1968).

Altering of the crop environment by eliminating tillage has been shown to influence the availability of N. Blevins *et al.* (1977) found that the poor response of maize commonly observed with maize under minimum tillage with N application rates lower than optimum was the result of N being immobilized. In minimum tilled soils, organic residues at or near the surface usually enhance microbial activity since it is an energy source (Doran, 1980). Surface residues of organic nature may also increase the potential for N loss through denitrification. Rickman and Klepper (1980) reported for example that crop residues in a minimum tillage environment on a poorly-drained soil contribute to prolonged anaerobic conditions, resulting in a loss of fertilizer N and a 20% reduction in yield.

Lal (1986) investigated the effects of eight tillage systems on maize yield for eight consecutive crops grown over four years on an Alfisol. He concluded that water conservation was better in minimum than conventional tilled plots as maize grain yield declined with increasing intensity of tillage, especially during frequent dry spells.

It has been widely accepted that, in the absence of other limitations such as diseases and nutrients water is the major factor limiting maize grain yield under dryland conditions (Rhoades and Bennett, 1990). In locations where soil water availability limits plant growth, minimum tillage has been reported to produce crop yields similar to or higher than conventional tillage (Blevins *et al.,* 1971). However, in relatively humid environments, crop yields from minimum tillage were comparable to or lower than those obtained under conventional tillage (Fox and Bandel, 1986). The poor performance of minimum tillage under such conditions was associated with more crop residues and cooler temperatures at the soil surface (Griffith *et al.,* 1986) and slower release of nitrate from soil organic matter (Meisinger *et al.,* 1985).

On poorly drained soils, eventually high grain yields of maize from minimum tillage can not be expected as from conventional tillage. Dickey *et al.* (1983) and Iragavarapu and Randall (1995) showed that reduced grain yields coincide with continuous practice of minimum tillage, especially on finer textured soils that are poorly drained. They mentioned soil compaction and poor aeration as possible factors contributing to the lower yields. However, periodic moldboard plowing solves this problem to a large extent.

Thomas *et al.* (1973) studied the effects of N application on the grain yield of maize under minimum and conventional tillage systems. They found that when N was applied yields tended to be higher under minimum than conventional tillage in dry years and about the same in wet years. However, when no N was applied yields were much lower on the minimum than conventional tilled plots in wet years. These results suggested that higher N rates may be required when maize is grown under minimum tillage when conventional tillage serves as reference.

Results from several research reports indicated that maize under minimum tillage may require more N fertilizer to reach production levels similar to conventional tillage because of a low extraction efficiency of the available N (Thomas *et al.,* 1973; Kitur *et al.,* 1984; Meisinger *et al.,* 1985). Meisinger *et al.* (1985) concluded that the N requirement of maize is about 17 kg N ha^{-1} greater for minimum than conventional tilled maize due to the 10% greater total dry matter yield that coincide with minimum tillage. However, Maskina *et al.,* (1993) claimed that the response of continuous maize under minimum tillage to N fertilization declined over time because of the increased availability of N resulting from adequate fertilization. Similarly, Rice *et al.* (1986) argued that as both conventional and minimum tillage are practiced over many years, each system approaches a new steady state condition in which the total N reservoir in the minimum tilled soil exceed those in the conventional tilled soil.

Bandel *et al.* (1975) showed that with low to moderate application rates of N, minimum tilled maize showed more pronounced deficiency symptoms of N than did conventional tilled maize. No deficiency symptoms were noted by them on either tillage system at high rates of N application. However, the optimum level of N for grain and dry matter yields did not differ between the two tillage systems.

The effects of either crop residue addition or removal on maize under minimum tillage were studied by Doran *et al.* (1984) and Wilhelm *et al.* (1986). It was found by Doran *et al.* (1984) that complete removal of crop residues after harvest reduced maize grain yield by 22%. Results of the study by Wilhelm *et al.* (1986) showed a linear response between grain yield and amount of residue on the soil surface for maize. Each t ha^{-1} of residue removed resulted in about 0.1 t ha^{-1} reduction in grain yield and vice versa. The major advantages of maintaining crop residues on the soil surface were increased water storage and decreased temperature during stressful periods, in the growing season of maize.

2.5.4 Nitrogen uptake by maize

With the advent of minimum tillage as an alternative and/or substitute to conventional tillage different environmental conditions are being created that influences the dynamics of N in the soil-plant-atmosphere system. The fertilizer N uptake by maize differed between the two tillage systems due to position of applied N (Timmons and Cruse, 1990), N immobilization (Rice and Smith 1984) and N losses from soil (Aulakh *et al.,* 1984).

Kitur *et al.* (1984) and Meisinger *et al.* (1985) found that at suboptimal application rates of N, its uptake by maize was generally larger with conventional tillage than with minimum tillage. At high rates of N application they recorded either no difference or the reverse between the two tillage systems. Legg *et al.* (1979) also found that when soil water is limiting, the uptake of N by maize was larger in minimum than conventional tillage.

There is evidence that at similar N application rates minimum tilled maize had lower N concentrations than conventional tilled maize, indicating lower N availability with minimum tillage. Levels of N sufficiency, previously estimated at about 11 to 12 mg N g^{-1} in the total dry matter at the dough stage (Stanford, 1973), were often reached with lesser amount of N fertilizer on conventional tilled plots, but additional N fertilizer was needed on minimum tilled plots to reach the same N concentrations (Meisinger *et al.,* 1985).

Application of N fertilizer has been shown to increase the uptake of soil N by plants and this priming effect has ascribed to a number of factors. Some of them are improved ion exchange and increased root development (Broadbent, 1965). This priming effect on account of N fertilization has also been attributed to an increase in mineralization of organic N resulting from a stimulation of the microflora in soil (Broadbent and Norman, 1947), and a decrease in immobilization of inorganic N by rhizosphere microorganisms utilizing organic material derived from roots (Legg and Allison, 1960). Other researchers have argued that neither the mineralization rate nor the immobilization rate changed and that fertilizer N simply replacing soil mineral N in the immobilization pool, thus allowing more soil N to be available for plant uptake (Stewart *et al.,* 1963). Broadbent and Carlton (1978) stated that plants will take up fertilizer N in the same proportions as they occur in the soil solutions.

In a greenhouse experiment using nine different soils from nine different countries and four application rates of labeled N fertilizer, Aleksic *et al.* (1968) found that uptake of soil N by plants increased with increasing application rates of N fertilizer. The increased uptake of soil N was ascribed to an increased rate of total N uptake induced by the fertilizer N application and related to rapid development of shoots and roots.

Westerman and Kurtz (1973) found with the application of labeled urea to sorghum-sudan (*Sorghum sudanense*) that the N fertilizer increased the uptake of soil N by 17 to 45%. The increase in uptake of soil N by the crop was attributed to enhanced microbial activity and hence increased mineralization of soil N, thus making more soil N available for use by plants. Westerman and Kurtz (1974) also found that plants growing in N fertilized plots contained more native soil N than did plants growing in control plots. These observations were contrary to the results of Legg and Allison (1959, 1960) who found with labeled N in greenhouse experiments that mineralization remained essentially constant with increasing rates of N fertilizer application.

Other investigators, who also used labeled N have found no increase in soil N uptake by plants as a result of fertilizer N application. For example Legg *et al.* (1979) using three rates of labeled ammonium sulfate on minimum and conventional tilled maize reported that soil N uptake tended to decrease with increasing rate of N applied, and was generally unaffected by method of tillage. Olson (1980) showed in a two year field experiment with sprinkler-irrigated maize that the application of labeled ammonium sulfate did not significantly alter the amount of soil N uptake by the crop as there was no priming effect on the mineralization of indigenous soil N.

In well drained soils, minimum tillage that coincide with crop residue retention resulted in higher plant available N than conventional tillage (Caskey, 1983; Rice and Smith, 1983). In conditions like this usually a strong correlation between inorganic N in soil and N uptake by maize was found (Staley and Perry, 1995; Kumar and Goh, 2000). According to Bacon (1987) the retention of crop residues at or near the soil surface increased N uptake while the incorporation of crop residues into the soil decreased N uptake. Some of the reduced growth associated with incorporation of large quantities of residues at sowing could be due to the release of phytotoxic substances during decomposition that accumulating near the seed (Guenzi *et al.,* 1967; Yakle and Cruse, 1984).

On the other hand, several researchers reported that retention of the crop residues at or near the soil surface reduced the level of inorganic N at least temporally (Dowdell and Cannel, 1975; House *et al.,* 1984; Rice and Smith, 1984). However, some of the N immobilized by the residues can be remobilized later in the same growing season and become available for uptake by the crop (Parker, 1962).

2.5.5 Weed control

Weeds are a menace in cropping systems the world over and their management has squandered enormous human and financial capital since the beginning of plant domestication. Although extensive research has been done to tackle this problem, weeds have continued to proliferate and to perfect their survival tactics. Weeds are even challenging the efficacy of many renowned herbicides. They are endowed with an exceptional ability to survive more competently under a low resource base. Subsequently, crop yields can be reduced to the point of total crop failure as a consequence of aggressive weed competition.

Tillage and control of weeds continue to present severe limitation to the improvement of crop production by smallholder farmers in Ethiopia. In general about 50% of their seasonal farm inputs are allocated to these two production operations (Kassa *et. al.,* 2002). The commonly used method for opening up land and control of weeds is either oxen plowing or hand hoeing. This method is slow, tedious and exerts a lot of drudgery to the user. The frequency of weedings is a function of the method of land preparation.

Changes in tillage systems can cause shifts in weed species and density (Froud-Williams *et al.,* 1983; Johnson *et al.,* 1989; Blackshaw *et al.,* 1994). Weed species, seed production, soil seed density, and surface residue can influence weed population dynamics under different tillage systems. In situations with a uniform soil seed density, cultivation generally stimulates weed emergence as was found by Roberts and Dawkins (1967). The result of this phenomenon is a faster decline of the soil seed reserves in cultivated than undisturbed plots. It was also demonstrated by Roberts and Potter (1980) that weed emergence was dependent on the time of cultivation relative to rainfall.

A reduction in tillage has generally promoted some annual grassy weeds (Froud-Williams *et al.,* 1983; Wrucke and Arnold, 1985; Koskinen and McWhorter, 1986) and inhibited annual broadleaf weeds (Froud-Williams *et al.,* 1983; Teasdale *et al.,* 1991). On the other hand, minimum tillage may increase the population of biennial and perennial broadleaf and grassy weeds (Kapsuta and Strieker 1976; Robertson *et al.,* 1976; Froud-Williams *et al.,* 1983). This is possibly due to the fact that less soil disturbance would favor plants that rely on underground reproductive structures for propagation.

Tillage may influence the fate of weed seed in a number of ways. With conventional tillage much of the seed is buried and either decomposed or remains in a dormant state which is not the case with minimum tillage (Roberts and Feast, 1972). More weed seed is also incorporated into soil aggregates with conventional than minimum tillage, where it is less likely to germinate (Pareja *et al.,* 1985). In the case of minimum tillage, weed seed stay near the soil surface where germination and emergence is possible if the soil conditions are favorable (Phillips *et al.,* 1980).

Minimum tillage generally increases the amount of crop residues left on the soil surface. This is beneficial for soil and water conservation but has raised concerns with regard to weed control. A major concern is the potential for decreased efficacy of pre-emergence herbicides due to interception and binding of it on crop residue, and the proximity of the residue to the site of weed seed germination on the soil surface.

Research findings involving weed control in minimum tilled soil have provided mixed results. There have been many reports of poor herbicidal weed control in minimum tillage systems with the presence of surface crop residue (Wicks *et al.,* 1972; Kapsuta and Strieker 1976; Robertson *et al.,* 1976). In contrast, there are also several reports of comparable weed control with pre-emergence herbicides in both minimum and conventional tillage systems

(Robison and Wittmus, 1973; Erbach and Lovely, 1975), and a few of them credit crop residue with controlling weeds (Teasdale *et al.,* 1991).

Adoption of conservation tillage systems is to some extent inhibited by real and perceived weed control problems. Greater reliance on herbicides is sometimes ineffective, uneconomical and perhaps environmentally undesirable. Most studies showed that crop rotation, tillage and herbicides can have a large impact on weed population (Froud-Williams *et al.,* 1983). The adoption of conservation tillage systems may be more successful if carefully planned to incorporate a good varied crop rotation with properly used herbicides that are effective against the predominant weeds (Blackshaw *et al.,* 1994).

2.6 Nitrogen use efficiency of maize

2.6.1 General

Among the major plant nutrients, N is the most essential for successful cereal production in all environments. Application of inorganic N as fertilizer to the soil-crop system is therefore of great importance for enhancing the productivity of cereals. Unfortunately, cereal crops do not recover and use the entire amount of N applied as fertilizer. Nitrogen fertilizer applied to the soil-crop system, in contrast to most other nutrients, is highly soluble and may be lost or made unavailable through the processes of leaching, denitrification, volatilization and immobilization (Bock, 1984; Stanford and Legg, 1984). As discussed earlier the portion of N fertilizer that escapes from the soil-crop system may exert harmful effects on the environment through the emission of toxic gases to the atmosphere and the contamination of ground water by leaching of nitrate. Kohl *et al.* (1971) confirm for example that cropping is a major source of nitrate in ground and surface waters.

Thus N fertilizer, besides being important in cereal production, is also an expensive commodity which can cause harm to the environment. Any use of N fertilizer requires therefore specific management practices to optimize its efficiency. A central issue with fertilizer N should be to minimize losses during establishment of crops when demand for N is low and to maximize availability during vegetative and reproductive growth of crops when demand for N is high. Several factors related to the management of fertilizer N can influence its efficient use by maize (Jokela and Randall, 1997). They are inter alia type of fertilizer (Balasubramanian and Singh, 1982; Mughogbo *et al.,* 1990; Mahli *et al.,* 1996), rate of application (Jokela and Randall, 1997), time of application (Jokela and Randall, 1997; Gerwing *et al.,* 1979; Russelle *et al.,* 1981; Legg and Meisinger, 1982; Mughogbo *et al.,* 1990; Karlen *et al.,* 1996), method of placement (Christianson and Vlek, 1991), soil water content (Olson, 1984; Pilbeam *et al.,* 1995), and early planting to capture the flush of mineralized N often experienced in soils (Birch, 1960).

Under field conditions the uptake, recovery and utilization of fertilizer N can vary widely, depending on its interaction with environmental conditions such as climate, soil and crop since these factors control the rate of dry matter production (Olsen and Kurtz, 1982). Therefore, to develop sustainable production practices it is essential to understand the fate and behavior of applied fertilizer N in the soil-crop system under different environments. Tillage systems and the fertilizer management coincide with it can influences fertilizer N uptake, recovery and utilization by maize (Timmons and Cruse, 1990). In this regard several processes might account for the differences observed between tillage systems. Tillage systems have been reported to affect crop N recovery (Kitur *et al.,* 1984; Meisinger *et al.,* 1985; Timmons and Cruse 1990; Karlen *et al.,* 1996), immobilization (Kitur *et al.,* 1984), leaching (Thomas *et al.,* 1973; McMahon and Thomas 1976; Tyler and Thomas 1977), and denitrification (Rice and Smith 1982) of applied N. Hence, the quantification of the efficient uptake, recovery and utilization of applied N by maize under different tillage systems is important.

The N use efficiency (NUE) of a crop is a function of its genetic constitution and the environment. Gardner *et al.* (1985) defined the environment to be made up of climate, soil and management. Hence, the NUE of a crop must be considered in the light of the many factors that interactively affect the uptake, recovery and utilization of the nutrient. Therefore, the three common ways in which the NUE is expressed are the N agronomic efficiency (NAE), N recovery efficiency (NRE) and N physiological efficiency (NPE) as shown with Equations 2.1 to 2.3:

$$NAE = \frac{(Yf - Yo)}{Nr} \qquad 2.1$$

$$NRE = \frac{(NRf - NRo)}{Nr} \quad * \quad 100 \qquad 2.2$$

$$NPE = \frac{(Yf - Yo)}{(NRf - NRo)} \qquad 2.3$$

where, Yf and Yo are respectively the yields of the fertilized and unfertilized crop, NRf and NRo are respectively the N uptake by the fertilized and unfertilized crop, and Nr the rate of fertilizer N application.

Estimation of NRE with Equation 2.2 is the so-called difference method (Rao *et al.,* 1992). Some problems may be experienced with this method as it is based on the assumptions that (i) rates of N transformation processes like mineralization and immobilization are similar in fertilized and unfertilized soils (Hauck and Bremner, 1976) and (ii) equal amounts of mineralizable soil N were taken up by the crop from the fertilized and unfertilized soils (Powlson and Barraclough, 1993). Quite often there may be better root development in fertilized plots (Olson and Swallow, 1984), or stimulation of microbial activity induced by fertilizer N application (Westermann and Kurtz, 1973), or lower mineralizable N in plots that had not received fertilizer (Powlson *et al.,* 1986). This may lead to an overestimation of the NRE of a crop.

An alternative is to establish the NRE of a crop with the isotopic method using Equation 2.4 (Rao *et al.,* 1992). The isotopic method which is also referred to as the direct method is based on the use of ^{15}N enriched fertilizer (in excess of natural abundance for ^{15}N) and the recovery of ^{15}N by crops growing with the fertilizer. The fertilizer N recovery in this method is expressed by the following relationships:

$$NRE = \frac{Atom\ \%\ excess\ ^{15}N\ in\ crop\ plants}{Atom\ \%\ excess\ ^{15}N\ in\ fertilizer} \quad * \quad \frac{TNU}{NF} \quad * \quad 100 \qquad 2.4$$

where, TNU is the total N uptake by the plants and NF is the rate of labeled N fertilizer applied.

The major assumptions for this direct method is that (i) isotopes compositions in the fertilizers are constant, (ii) living organisms can not distinguish one isotope from another of the same element and (iii) chemical identities of isotopes are maintained in biological systems (Hauck and Bremner, 1976).

Several researchers (Harmsen and Moraghan, 1988; Roberts and Janzen, 1990; Rao *et al.,* 1992) made a comparison between the difference and isotopic methods to estimate the NRE of crops. They concluded that the former method is easy and less expensive to implement than the latter method. However, the isotopic method is scientific superior to the difference method. Therefore, it is not surprising that several studies have been conducted using the isotopic method to estimate the amounts of fertilizer N recovered in crop components, retained in soils and lost from the soil-crop systems (Malhi and Nyborg, 1991; Reddy and Reddy 1993; Pilbeam and Warren, 1995; Karlen *et al.,* 1996; Malhi *et al.,* 1996). Compared to the difference method, the isotopic method the fate and behavior of fertilizer N can be detected with more accuracy and greater sensitivity (Russelle *et al.,* 1981; Rao *et al.,* 1992), without using of control plots (Hauck and Bremner, 1976).

In instances where a linear relationship ($y = a + bx$) exists between N uptake by the crop (y) and the levels of N applied (x), neither the difference method nor the isotopic method is needed to estimate NRE (Terman and Brown, 1968). The NRE could then be estimated by multiplying the slope of the relationship, viz. b with 100. Unfortunately, it is not known in advance whether such a relationship will be linear or not.

Many experiments with and without labeled N as reviewed by Allison (1966) indicated that the average recoveries of fertilizer N under field conditions for a single harvest ranges between 50-70%. Kundler (1970) reported a 30-70% recovery of applied N by crops, with 10-40% of the applied N retained in soil, 5-10% lost by leaching and 10-30% unaccounted for and presumably lost in gaseous form. Van der Kruijs *et al.* (1988) studied the fate of ^{15}N labeled urea in soil, crop and drainage water using 12 lysimeters and observed that of the added ^{15}N 19-31% was recovery by the crop, 10-30% was immobilized in the soil, 22-29% was lost through leaching, and 7-30% was lost through denitrification. Recent findings by

Karlen *et al.* (1996) with labeled fertilizer showed that of the added ^{15}N 20-34% was taken up by the crop, 20% was retained in the soil to a depth of 90 cm and approximately 50% was apparently lost through volatilization, denitrification, or leaching below the root zone. These studies illustrate the large potential for losses and hence the low recoveries of fertilizer N by cereal crops like maize (Bartholomew, 1972; Balasubramanain and Singh, 1982; Legg and Meisinger, 1982; Simonis, 1988; Rao, *et al.,* 1993).

In general, the amount of fertilizer N recovered by crops increases with N application rate, while the NRE declines with increasing rates of application. The NRE, however, varies with climate, soil, crop and management practices (Allison 1965, 1966; Simonis 1988; Varvel and Peterson, 1990) as well as method and time of measurement (Rao *et al.,* 1992). For maize as demonstrated by several ^{15}N studies, NRE varies from as low as 7 to as high as 86% (Gerwing *et al.,* 1979; Jolley and Pierre, 1977; Broadbent and Carlton, 1978; Kitur *et al.,* 1984; Meisinger *et al.,* 1985; Pilbeam and Warren, 1995; Sanchez and Blackmer, 1988; Simonis, 1988; Timmons and Cruse 1990; Timmons and Baker, 1992; Reddy and Reddy, 1993). Especially climate seems to have a large influence on the NRE of maize as low values were found by Torbert *et al.* (1992) with either low or high water supply. Pilbeam (1996) reported that in a humid environment more fertilizer N was recovered in the crop than in the soil, while in a dry environment more fertilizer N was recovered in the soil than in the crop. He observed also regional differences in the recovery of fertilizer N in both crop and soils.

2.6.2 Genotypes

The improvement of the NUE of maize for better grain yields at low soil N levels has become feasible (Muruli and Paulsen, 1981) since maize genotypes differ with respect to this property (Lafitte and Edmeades, 1994a; Bänziger *et al.,* 1997). According to Moll *et al.* (1982) the two primary components affecting N efficiency among maize genotypes are the efficiency of N uptake and utilization. They indicated that at low soil N levels differences in N efficiency among maize genotypes were due largely to variation in N utilization efficiency and at high soil N levels the differences were due largely to variation in N uptake efficiency. In contrast Kamprath *et al.* (1982) showed that N uptake efficiency was the most important factor contributing to the N efficiency of maize at low soil N levels. A variation in the efficiency of N utilization among maize genotypes has been demonstrated not only with respect to N fertilizer (Tsai *et al.,* 1984; Tsai *et al.,* 1992), but also to absorbed N (Beauchamp *et al.,* 1976; Chevalier and Schrader, 1977; Moll and Kamprath, 1977; Pollmer *et al.,* 1979; Duncan and Baligar 1990). These genotypic differences suggest the possibility of using maize varieties with high NUE on soils with low N levels. For example Eghball and Mananville (1991) found a 19% difference between the least and the most efficient maize hybrids in terms of grain produced per kg total N uptake.

The two most important factors controlling the N content of maize grain are the uptake of N from the soil and the translocation of N from the vegetative parts to the grain. Several studies showed genotypic differences in maize with regard to the translocation and partitioning of N during grain development (Hay *et al.,* 1953; Hanway, 1962a,b; Beauchamp *et al.* 1976). Appreciable differences were found among maize genotypes in their apparent propensity to translocate N from the rest of the plant parts to the developing ear. About half of the N in the grain at maturity appeared to have been translocated from other above ground plant parts. These results have demonstrated that although maize can absorb substantial quantities of N following silking, mobilization of vegetative N accumulated before silking provides the major source of N in the grain.

Maize plants are in fact able to accumulate large amounts of N in stover and roots during the vegetative growth phase (Hay *et al.,* 1953, Chevalier and Schrader 1977). During grain filling this stored N is exported, in various degrees based on genotypes, to the developing seeds. There is evidence that this N utilization is influenced by absorption, transportation, partitioning and remobilization of N within the plant parts (Novoa and Loomis 1981; Moll *et al.,* 1982; Engles and Marschner 1995). Hirel *et al.* (2001) indicated that the increased productivity in maize genotypes was due to their ability to accumulate nitrate in their leaves during vegetative growth, and to efficiently remobilize this stored N during grain filling. Beauchamp *et al.* (1976) showed that the capacity of maize plants to accumulate reduced N in the vegetative parts is genetically controlled.

The differences amongst maize genotypes in relation to nutrient uptake and translocation have been attributed to genetically-controlled differences in root growth (Wiesler and Horst, 1994). Such differences affect not only uptake of water and nutrients, but also improve N utilization. At conditions of high N supply, uptake is mainly dependent on the growth-related demand for N, whereas at conditions of low N supply, uptake is dependent on morphological and physical root characteristics (Engles and Marschner 1995). Robinson (1986) concluded that the efficiency of nutrient uptake depends mainly on root length while Pan *et al.* (1985) found nutrient uptake is influenced by the relationship between the reduction of nitrate and lateral root proliferation. Genetic variation in root growth among maize hybrids has been reported (Wiesler and Horst, 1994).

Zhang and Forde (1998) stated that the development of plant root systems is sensitive to the availability and distribution of nutrients within the soil. In their study with maize Feil *et al*. (1990) found that the root surface area as well as the number and total length of the seminal roots were greater at low N than high N supply. These changes in root morphology might assist N use efficient maize genotypes in their acquisition and uptake of N from soil when it has low levels of the nutrient.

2.7 Conclusions

Improved crop production technologies should be directed to alleviate soil related constraints like erosion losses, fertility depletion, nutrient imbalances and water stress. Conventional tillage systems where crop residues are incorporated into the soil are therefore gradually replaced by minimum tillage systems where crop residues are retained on the soil surface. Compared to conventional tillage, minimum tillage enhances the quality of soil as it has positive effects on the most important physical, chemical and biological properties. This benefit of minimum tillage manifested not always in better grain yields of maize, especially during the first few years after implementation. The reason for this phenomenon seems to be in most developing countries insufficient N supply as the fertilization rates are not adapted due to financial constraints. An alternative in these countries may be to plant maize genotypes that are more efficient in N use during these transitional periods.

CHAPTER 3

EFFECT OF TILLAGE SYSTEM, RESIDUE MANAGEMENT AND NITROGEN FERTILIZATION ON MAIZE YIELD, YIELD COMPONENTS AND GROWTH PARAMETERS

3.1 Introduction

The major maize producing regions of Ethiopia, namely the western part of the country has a high yield potential as a result of favorable environmental conditions. However, self-sufficient maize production declined and the low national average maize yield remained stagnant (Ibrahim and Tamane, 2002). The inability to increase yield is attributed to non-sustainable cropping practices, particularly plow- or hoe-based cultivation (Bezuayehu *et al.*, 2002). To overcome this inability it is important to evaluate the effects of various cropping practices that influence yield.

Arable land in western Ethiopia is limited and therefore production has to be increased per unit area which will require the application of technology, particularly integrated cultivation practices for sustainable crop production. Therefore, the restoration and maintenance of soil productivity has to be sustained through integrated use of tillage systems and residue management practices (Lal *et al.*, 1979; Lal, 1993, Latham, 1997).

Generally, conventional tillage has been for centuries the basic tool of cropping. However, conventional tillage is being displaced by minimum tillage (Triplett and Van Doren, 1977; Phillips *et al.*, 1980). Minimum tillage is widely recognized for its role in conservation of both soil and water (Phillips *et al.*, 1980; Lal, 1989; Uri, 1999) and eventually enhances crop yields (Moody et al., 1961; Jones *et al.*, 1968; Moschler *et al.*, 1972; Phillips *et al.*, 1980). There is increasing concern to conserve the limited natural resources of soil and water, resulting from the need to produce more food and fiber for the ever rising population.

Minimum tillage systems retain at least 30% of crop residues evenly distributed on the soil surface and this protects the soil against potential rainfall energy by decreasing crust formation and water runoff (Uri, 1999). The comparison of conventional tillage with minimum tillage on highly erodible land showed that minimum tillage reduced soil erosion by 50% and more (Phillips *et al.*, 1980). Furthermore, the maintenance of crop residues on the soil surface is also considered to improve soil nutrient content and enhance yield, resulting in increased crop nutrient uptake (Prasad and Power, 1991; Powell and Unger, 1997; Kumar and Goh, 2000).

Maize has been recognised as a heavy feeder of nutrients, and uses more N than any other nutrient (Arnon, 1975). Since N is an expensive input and can be easily lost from the soil-crop system, its management in maize production requires close attention. Therefore, the recommended rate of N fertilization for a specific locality needs to be related to available soil inorganic and mineralizable N, the N mineralized from residues of previous crops, and the N response of the crop to be grown (Moschler *et al.,* 1972). In order to sustain crop production over time it is necessary to replenish nutrients removed through harvestable crop products.

Hence, successful crop production is a combination of many factors including proper management of inputs and a thorough understanding of the soil resources and how they respond to production practices (Uri, 1999). The decision by Ethiopian farmers to adopt an integrated nutrient management practice could lead to an increase in net benefits and eventually benefit the society as a whole.

In western Ethiopia, no previous study examined the integrated effects of tillage systems, residue management and N fertilization on maize performance. Therefore, this study was initiated to evaluate the effects of tillage systems, residue management and N fertilization on maize yield, yield components and growth parameters.

3.2 Materials and methods

3.2.1 Experimental sites

The experiments for this study were conducted at Bako Agricultural Research Center, and on farmers' fields at Shoboka, Tibe, Ijaji and Gudar. All five sites are in the major maize producing areas of western Ethiopia. Bako is located at 09^0 01'N and 37^0 02'E, Shoboka at $09^0$06' N and $37^0$21'E, Tibe at $09^0$29'N and $37^0$32'E, Ijaji at $09^0$43'N and $37^0$47'E, and Gudar at $08^0$09'N and $38^0$08'E latitude and longitude, respectively. The altitude for Bako, Shoboka, Tibe, Ijaji and Gudar are 1650, 1695, 1730, 1820 and 2000 meter above sea level, respectively. Only climatic data of the Bako and Gudar sites as obtained from nearby weather stations is given in Table 3.1 since there are no weather stations close to the other three sites. At all five sites the soil was classified as a Nitisol (FAO, 1998). Some of the physical and chemical characteristics of these Nitisols are summarized in Table 3.2.

3.2.2 Experimental layout

At every site an experiment was laid out in a randomized complete block design with three replications. Three tillage systems (MTRR = minimum tillage with residue retention, MTRV = minimum tillage with residue removal, and CT = conventional tillage), and three N fertilization levels (recommended rate and 25% less and more than this rate) were combined in complete factorial arrangement. An application of 92 kg N ha^{-1} is the recommended fertilization rate for conventional maize production at the study sites. Immediately after harvesting, maize residues were cut at ground level and spread uniformly in the MTRR plots and removed from the MTRV plots. These experiments were conducted from 2000 until 2004. The experimental plots were kept permanent to observe the carry-over effects of the treatments for the five cropping seasons.

3.2.3 Agronomic practices

For the MTRR and MTRV treatments soil disturbance was restricted to the absolute minimum, viz. the soil was disturbed only to place the seed in the soil at the time of sowing. In contrast, the soil was plowed three times with the local oxen-plow 'maresha' prior to sowing to obtain a suitable seedbed for the CT treatments.

Weed control in the MTRR and MTRV treatments was done by applying round-up at the rate of 3 L ha^{-1} prior to planting and lasso-atrazine at the rate of 5 L ha^{-1} as a pre-emergence

Table 3.1 Climatic data for the Bako and Gudar sites as obtained from nearby weather stations

	Bako												
Rainfall (mm)	J	F	M	A	M	J	J	A	S	O	N	D	Total
1990-1999	13.2	17.7	53	64.2	146.1	214.1	254.1	231.7	141.4	70.8	23.4	14.0	1243.7
2000	0.0	0.0	0.0	79.3	135.1	278.2	236.9	289.6	162	103.4	48.4	12.6	1345.5
2001	0.0	42.8	87.2	51.8	161.3	219.3	328.9	264.3	96.7	92.7	1.5	7.7	1354.2
2002	23.5	15.1	88.8	73.0	68.3	236.0	239.2	205.9	42.1	0.0	6.8	42.2	1040.9
2003	4.0	34.3	51.7	59.1	5.7	265.1	420.6	434.4	39.9	11.5	1.2	27.6	1355.1
2004	9.4	5.0	23.6	66.1	14.1	268.6	225.5	257.8	85.2	43.5	48.2	14.3	1061.3
2000-2004	7.4	19.4	50.3	65.9	76.9	253.4	290.2	290.4	85.2	50.2	21.2	20.9	1231.4
Temp. (^{O}C)													
Minimum	11.1	12.5	14.3	14.8	15	14.7	14.6	14.5	14	12.6	11.1	10.5	
Maximum	29.7	30.7	31.1	30.8	28.6	25.9	23.9	24.1	25.1	27.2	28.5	29.1	
Mean	20.4	21.6	22.7	22.8	21.8	20.3	19.3	19.3	19.6	19.9	19.8	19.8	
Rainfall (mm)	Gudar												
1990-1999	27.6	2.6	62.7	87.8	111.4	150.4	258.5	163.3	100.7	74.6	14.7	14.7	1069.0
2000	0.0	0.0	9.2	81.2	109.9	123.8	207.5	237.5	166.6	19.4	21.7	17.6	994.4
2001	13.2	8.7	55.8	73.4	194	166.6	301.5	209.7	61.0	17.8	14.5	23.2	1139.4
2002	106.9	7.4	59.4	52.8	29.5	216.2	211.6	131	30.2	17.8	2.1	16.9	881.8
2003	84.3	112.3	41.6	158.1	2.0	185.9	167.3	153.2	55.9	7.5	0.0	7.8	975.9
2004	42.8	13.2	17.7	88.9	37.4	110	293.5	172.1	147	28.9	0.0	0.0	951.5
2000-2004	49.4	28.3	36.7	90.9	74.6	160.5	236.3	180.7	92.1	18.3	7.7	13.1	988.6
Temp. (^{O}C)													
Minimum	9.8	10.6	11.8	11.7	11.6	11.1	11.1	11.2	10.3	9.6	9.0	9.1	
Maximum	26.8	27.7	28.3	27.9	28.4	25.3	23.1	22.6	24.5	25.7	27.6	26.5	
Mean	18.3	19.2	20.1	19.8	20	18.2	17.1	16.9	17.4	17.7	18.3	17.8	

Table 3.2 Some physical and chemical characteristics of the Nitisols at the study sites

Sites	Depth (cm)	Horizon	Sand (%)	Silt (%)	Clay (%)	pH (H_2O)	OC (%)	Total N (%)	*P (ppm)	K (ppm)
Bako	0-25	A	35.1	31.6	33.3	5.59	1.77	0.15	12.6	192
	25-70	Bt1	35.5	23.4	41.1	5.64	0.96	0.09	11.4	146
	70-130	Bt2	24.2	21.3	54.5	5.61	0.66	0.07	8.5	131
	130-200$^+$	Bt3	28.8	11.1	60.1	5.73	0.55	0.06	5.3	103
Shoboka	0-40	A	34.7	23.3	42.0	5.52	1.65	0.14	11.5	155
	40-80	Bt1	27.1	26.1	46.8	5.60	1.11	0.10	8.7	148
	80-120	Bt2	40.6	10.3	49.1	5.84	0.86	0.08	8.9	119
	120-160$^+$	Bt3	33.4	14.2	52.4	6.03	0.68	0.07	6.5	95
Tibe	0-20	Ap	26.7	35.2	38.1	5.41	1.46	0.12	8.7	146
	20-90	Ab	15.3	21.0	63.7	5.49	0.99	0.09	6.8	120
	90-140	Bt1	23.0	18.1	58.9	5.67	0.65	0.07	5.7	103
	140-160$^+$	Bt2	25.6	17.2	57.2	5.86	0.45	0.05	4.3	86
Ijaji	0-30	A	44.7	32.3	23.0	5.69	1.93	0.16	10.3	231
	30-65	Bt1	39.5	19.3	41.2	5.74	1.07	0.10	7.8	204
	65-95	Bt2	33.5	23.7	42.8	5.92	0.85	0.09	8.3	176
	95-140	Bt3	35.4	20.4	44.2	6.03	0.76	0.08	6.5	143
	140-165$^+$	BC	36.0	15.3	48.7	5.87	0.58	0.06	4.1	138
Gudar	0-50	A	18.8	42.5	38.7	6.02	1.69	0.14	9.6	159
	50-110	B	25.8	39.1	35.1	6.64	0.91	0.09	7.5	113
	110-135	C	31.7	37.7	30.6	6.81	0.75	0.08	4.4	91

*Bray II extraction procedure

application. The recommended weed control practice for CT in Ethiopia is hand weeding at 30 and 55 days after sowing followed by slashing at milk stage. Urea and triple super phosphate (TSP) were used as the sources of N and P, respectively. Application of urea was split, viz. half at sowing and half at 35 days after sowing when maize is knee-height, while all TSP was applied in a band at sowing. All treatments received the recommended phosphorus rate of 20 kg ha^{-1} annually.

The standard cultural practices as commonly recommended to the farmers were adopted for the study. Therefore, from 2000 to 2004 the planting dates varied from 5 May to 5 June at all the sites. A late maturing commercial maize hybrid, BH-660 was planted. The plant density aimed for was 50000 plants per hectare as the plots consisted of six rows, 5.0 m in length and the inter- and intra-row spacing were 0.8 and 0.25 m, respectively.

3.2.4 Data collection

Data on yield, yield components and growth parameters were obtained from the central 4 rows of each plot. Maize grain yield was adjusted to the standard moisture content of 12.5%. Total biomass was calculated as the sum of grain and stover yields, and harvest index was the ratio of grain yield to total biomass and expressed in percentage. The plant density of every plot was counted. Plant height was recorded from the base of the plant at ground level to the base of tassel for five randomly selected plants. On five representative cobs the rows per cob and seeds per row was counted. These cobs' length was measured from the base to the tip of the cob and their diameter at the thickest portion of the cob. The averages for either the five plants or cobs were calculated with respect to each parameter.

3.2.5 Statistical analysis

Experimental data were analyzed through analyses of variance using the MSTATC statistical package (Michigan State University, 1989). Means for each parameter were separated by the least significant difference (LSD) test at P = 0.05.

3.3 Results and discussion

A summary on the analyses of variance indicating the effect of treatment factors on selected crop parameters is given in Table 3.3. Inspection of the results shows that there was a significant difference among sites, years, tillage systems and N applications with regard to most of the parameters. Significant interactions between the treatment factors on some of the parameters were mainly restricted to that of either year by site or year by tillage system. This is an indication that prevailing weather conditions at the sites had profound effects on tillage systems but not on N applications. The fact that no significant differences were detected for the parameters between the interactions of either site by tillage system or N application reveals that the tillage systems and N applications performed similarly at all sites. It is interesting that both year and tillage system interacted significantly with N application to affect thousand seed weight (TSW) only.

This statistical information proved that the best way to show the effects of tillage system and N application on yield, yield components and growth parameters is per site for every year. Grain yield was therefore correlated with the other crop parameters for the different sites and years irrespective of tillage systems and N applications. The results are displayed in Table 3.4 and as could be expected grain yield correlated significantly with most of the parameters. The exceptions were plant height and density in few instances. Neither tillage system nor N fertilizer application had any significant influence on plant density at all the five sites and years. Based on these positive correlations only the response of grain yield to the different tillage systems and N applications will be dealt with in detail.

3.3.1 Effect of tillage system on grain yield

In most years the tillage systems and concomitant crop residue management significantly affected grain yield at the five sites (Table 3.5). However, grain yield response to tillage varied substantially across years and this could be ascribed to the prevailing weather conditions, particularly the rainfall in specific growing seasons (Table 3.1).

Table 3.3 Summary on analyses of variance indicating the effect of treatment factors on selected crop parameters

Factors	Grain yield	Stover yield	Total biomass	Harvest index	TSW	Rows per cob	Seeds per row	Cob length	Cob diameter	Plant height	Plant density
Site (S)	*	*	*	*	*	*	*	*	*	*	ns
Year (Y)	*	*	*	*	*	*	*	*	ns	*	*
Tillage (T)	*	*	*	*	*	*	*	*	*	*	ns
Nitrogen (N)	*	*	*	*	*	*	*	ns	ns	ns	ns
S x Y	*	*	*	ns	*	ns	ns	ns	ns	ns	ns
S x T	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
S x N	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Y x T	*	*	*	*	*	*	*	ns	ns	ns	ns
Y x N	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns
T x N	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns
Y x T x N	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
S x Y x T	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
S x Y x N	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
S x Y x T x N	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

* - $P \leq 0.05$
ns - not significant

Table 3.4 Correlations of grain yield with the other crop parameters for different sites and years irrespective of tillage system and nitrogen application treatments

Years	Stover yield	Total biomass	Harvest index	TSW	Rows per cob	Seeds per row	Cob length	Cob diameter	Plant height	Plant density
					Sites					
Bako	0.74*	0.93*	0.54*	0.94*	0.76*	0.83**	0.88*	0.60*	0.41*	0.38*
Shoboka	0.76*	0.93*	0.55*	0.95*	0.89*	0.84*	0.87*	0.63*	0.52*	0.31*
Tibe	0.74*	0.91*	0.43*	0.93*	0.86*	0.81*	0.72*	0.60*	0.04	0.38*
Ijaji	0.72*	0.92*	0.49*	0.94*	0.87*	0.84*	0.86*	0.64*	0.45*	0.46*
Gudar	0.74*	0.91*	0.42*	0.93*	0.84*	0.82*	0.70*	0.68*	0.11	0.36*
					Years					
2000	0.57*	0.89*	0.64*	0.93*	0.84*	0.88*	0.83*	0.63*	0.29*	0.20
2001	0.52*	0.85*	0.57*	0.95*	0.82*	0.88*	0.86*	0.66*	0.09	0.10
2002	0.73*	0.91*	0.37*	0.89*	0.78*	0.88*	0.86*	0.73*	0.05	0.25*
2003	0.72*	0.90*	0.41*	0.86*	0.79*	0.89*	0.74*	0.73*	0.12	0.40*
2004	0.58*	0.87*	0.53*	0.97*	0.76*	0.88*	0.84*	0.74*	0.16	0.29*

Significant at $P \leq 0.05$

The grain yield decreased from 2000 to 2003 for all tillage systems practiced, and slightly increased in 2004. This reduction in grain yield was due to late onset of rain which delayed sowing and early cessation of rain which decreased grain filling. In 2000 and 2001 the rainfall during May adequately wetted the soil and promoted early planting, where after the rainfall extended to September and resulted in favorable conditions for grain filling. In contrast to the 2000 and 2001 growing seasons, little rainfall occurred in May of 2002, 2003 and 2004 which caused late sowing of maize. This late sowing predisposed the maize crop to adverse environmental conditions such as early onset of water stress and desiccating winds in September and October during the anthesis and grain filling stages. These factors caused premature termination of growth which is reflected in the low grain yields. Furthermore, the low grain yield obtained in 2003 could be explained also by excessive rainfall during July and August that might have retarded vegetative growth. Therefore, the grain yield obtained in 2003 was approximately 500 – 1500 kg ha^{-1} lower than that of a normal growing season primarily due to poor distribution of rainfall and insufficient plant available water during grain filling. The rate of decline in grain yield from 2000 to 2003 was 350 kg ha^{-1} year^{-1}.

In 2000 and 2001 the grain yield of CT was similar or lower than the grain yield of either MTRR or MTRV (Table 3.5). Interestingly, no significant difference in grain yield was recorded between MTRR and MTRV at all sites during the first two years, except at Bako in 2001. In 2003 and 2004 the grain yield of CT and MTRV was similar at all sites, except at Gudar in 2004. However, for the last two years the grain yield of MTRR was in most instances significantly higher than the grain yield of CT and MTRV. Therefore, when crop residues are removed, it takes at least three years before adverse effects on grain yield reductions become evident in the study area. Similarly, when crop residues are retained on the surface, it requires at least three years before the beneficial influence on grain yields are obtained. As reported by some researchers (Lal, 1976a; Kang and Yunusa, 1977) grain yield response to minimum tillage when the residues are retained depends on the gradual build-up of soil fertility.

Table 3.5 Effect of tillage system (MTRR = minimum tillage with residue retention, MTRV = minimum tillage with residue removal and CT = conventional tillage) on grain yield of maize for the different sites and years. Means within in a column for each site followed by the same letter(s) are not significantly different at 5% probability

Sites	Tillage system	Grain yield (kg ha^{-1})					
		2000	2001	2002	2003	2004	Mean
Bako	MTRR	7984a	6622b	6736a	6266a	7119a	6945a
	MTRV	8019a	7166a	6593a	5265b	6055b	6620ab
	CT	7200b	6454b	5916b	5487b	6066b	6225b
Shoboka	MTRR	8030a	6508a	6307a	5868a	6706a	6684a
	MTRV	7867a	6729a	5407b	5036b	5826b	6173b
	CT	6852b	6023a	5593b	5131b	5635b	5847b
Tibe	MTRR	6922a	6148a	6071a	5604a	5878a	6125a
	MTRV	6982a	6255a	5528ab	4649b	5367a	5756b
	CT	6323a	5462b	4978b	4858b	5556a	5435b
Ijaji	MTRR	7877a	6463a	6371a	6050a	6790a	6710a
	MTRV	7777a	6565a	6035a	5069b	5951b	6279b
	CT	7013b	6222a	5358b	5298b	6174b	6013b
Gudar	MTRR	6875a	5505ab	6048a	5703a	5375a	5901a
	MTRV	6850a	6009a	5375b	4756b	4687b	5535ab
	CT	6233a	5001b	5207b	4851b	5331a	5325b

The mean grain yield of the five sites as affected by the three tillage systems in five consecutive years is illustrated in Figure 3.1. In 2002, 2003 and 2004 when the maize crop faced terminal drought in September and October, MTRR resulted in higher grain yield than both MTRV and CT. This is attributed to the fact that in drier years surface crop residues provided a better soil environment by reducing the temperature and conserving water, resulting in better grain filling and hence yield.

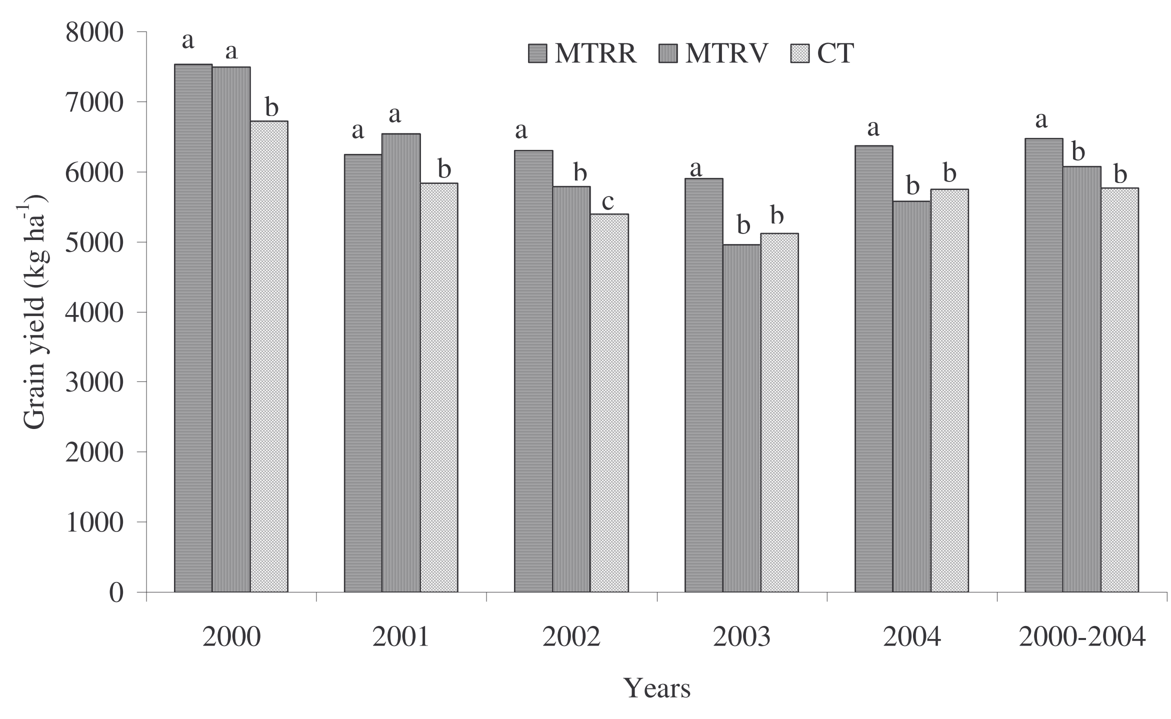


Figure 3.1 Mean grain yield of five sites as affected by tillage systems (MTRR = minimum tillage with residue retention, MTRV = minimum tillage with residue removal and CT = conventional tillage). Bars for each year with the same letter are not significantly different at 5% probability.

Other researchers reported that under conditions of low soil water and high soil temperature during the growing season that higher grain yields realized with minimum tillage where residues are retained and not removed or incorporated with conventional tillage. This phenomenon is attributed to increased water conservation as a result of reduced evaporation (Blevins *et al.*, 1971; Lal 1976a; Phillips *et al.*, 1980), more favorable soil temperatures for root growth (Lal 1974a) and microbial processes (Doran 1980) like soil N mineralization (Rice *et al.*, 1986). Soils prone to water erosion and hence nutrient loss inevitably benefit from minimum tillage that coincide with residue retention as these processes are reduced and therefore higher grain yields resulted which is not the case with other tillage systems (Triplett and Van Doren, 1977; Phillips *et al.*, 1980; Rasmussen and Collins, 1991). Moreover, it is important to recall that minimum tillage has been proposed as an alternative for conventional tillage to combat erosion (Triplett *et al.*, 1968; Harold and Edwards 1972; Lal, 1976b; Triplett and Van Doren, 1977; Langdale *et al.,* 1992; Uri, 1999), to reduce evaporation and enhance the water content in drier environments (Blevins *et al.*, 1971; Phillips *et al.*, 1980; Griffith *et al.*, 1986).

3.3.2 Effect of nitrogen fertilization on grain yield

Nitrogen fertilizer application significantly affected the grain yield at all sites each year except in 2002 at Tibe and Ijaji, and in 2003 at Gudar (Table 3.6). In general a progressive increase in grain yield was measured with incremental levels of N applied. Grain yields were therefore without exception the highest at the 115 kg N ha^{-1} level. However, the response of grain yield was as expected more pronounced with the first than the second increment of N application.

The mean grain yield of the five sites as affected by the three N levels in five consecutive years is displayed in Figure 3.2. It is clear that the response of grain yield to the N levels was similar for every year despite that grain yields varied from year to year. The application of 69 kg N ha^{-1} was significantly inferior to 92 kg N ha^{-1}, and 92 kg N ha^{-1} was on par with the 115 kg N ha^{-1}application. Thus, the recommended fertilization rate of 92 kg N ha^{-1} for conventional tilled maize seemed also adequate for minimum tilled maize in the study area.

Several researchers reported that similar amounts of N fertilizer application are required for optimum crop production with both tillage systems (Triplett and Van Doren, 1969; Baeumer, 1970; Moschler *et al.,* 1972; Reeves and Ellington, 1974; Legg *et al.,* 1979; Thomas and Frye, 1984). They are of opinion that in some instances the immobilization of

Table 3.6 Effect of nitrogen fertilization on grain yield of maize for the different sites and years. Means within in a column for each site followed by the same letter(s) are not significantly different at 5% probability

Sites	N levels	Grain yield (kg ha^{-1})					
	(kg ha^{-1})	2000	2001	2002	2003	2004	Mean
Bako	69	7057a	6139a	5958a	5114a	5910a	6036a
	92	7817b	6831b	6479b	5765b	6502b	6679b
	115	8329b	7272b	6807b	6140b	6828b	7075b
Shoboka	69	6896a	5868a	5332a	4826a	5539a	5692a
	92	7683b	6506ab	5825b	5423b	6165b	6320b
	115	8170b	6885b	6150b	5787b	6463b	6691b
Tibe	69	6034a	5409a	5168a	4601a	5113a	5265a
	92	6824b	6012b	5585a	5091ab	5699b	5842b
	115	7369b	6443b	5824a	5418b	5989b	6209b
Ijaji	69	6886a	5865a	5524a	4924a	5762a	5792a
	92	7657b	6499b	5995a	5585b	6384b	6424b
	115	8123b	6886b	6211a	5875b	6768b	6773b
Gudar	69	6008a	5016a	5156a	4769a	4684a	5127a
	92	6746b	5561ab	5612ab	5153a	5218ab	5658ab
	115	7203b	5939b	5829b	5388a	5491b	5970b

fertilizer N that coincide with minimum tillage may be counteracted by the mineralization of organic N. Fox and Bandel (1986) stated that under dryland cropping mineralization activity peaks in conventional tilled soil immediately after plowing when it is better aerated than minimum tilled soil, while in minimum tilled soil it peaks later in the growing season when it is wetter than conventional tilled soil. Furthermore, Moschler and Martens (1975) as well as Phillips *et al.* (1980) showed that N fertilizer is used more efficiently by minimum than conventional tilled maize when properly fertilized. In addition minimum tillage reduced N losses through runoff and erosion compared to conventional tillage (Phillips *et al.,* 1980).

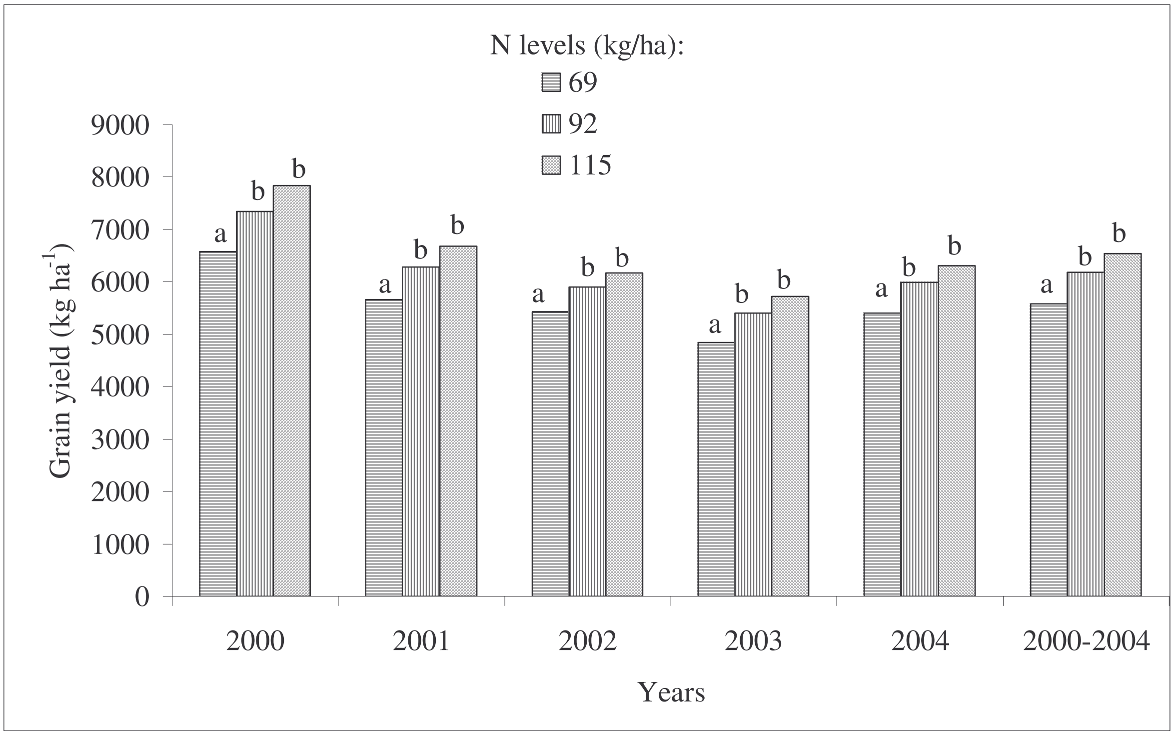


Figure 3.2 Mean grain yield of five sites as affected by N fertilization. Bars for each year with the same letter are not significantly different at 5% probability.

The effect of tillage system and N fertilization on grain yield over sites and years is given in Table 3.7 for a better perspective despite the interaction between the two treatments was not significant. Irrespective of N level, the grain yield was the lowest with CT, followed by MTRV and then MTRR. The grain yield of MTRR was on average 400 and 705 kg ha^{-1} higher than that of MTRV and CT, viz. 6.6 and 12.2%, respectively. These findings are in agreement with that of Triplet and Van Doren (1969), Moschler *et al.* (1972), Meisinger *et al.* (1985) and Wilhelm *et al.* (1986). Regardless of tillage system, the grain yield increased from the lowest to highest N level. The grain yield at the 115 kg N ha^{-1} level was on average 358 and 957 kg ha^{-1} more than that at the 92 and 69 kg N ha^{-1} levels, viz. 5.8 and 17.1%, respectively.

Table 3.7 Effect of tillage system (MTRR = minimum tillage with residue retention, MTRV = minimum tillage with residue removal and CT = conventional tillage) and nitrogen fertilization on maize grain yield over sites and years

N level	Tillage system (T)			Mean
(kg ha^{-1})	MTRR	MTRV	CT	
69	5953	5595	5210	5586
92	6513	6173	5868	6185
115	6953	6450	6227	6543
Mean	6473	6073	5768	
LSD$_{(0.05)}$	T or N = 394	T x N = ns		

3.4 Conclusions

Only the response of grain yield to tillage systems and N fertilization was reported in detail since grain yield correlated positively with yield components and growth parameters. In the study the average grain yield over sites and years varied from 5210 kg ha^{-1} with CT at 69 kg N ha^{-1} application to 6953 kg ha^{-1} with MTRR at 115 kg N ha^{-1} application. The grain yield was not affected significantly by the interaction of tillage system and N fertilization. However, grain yield was the lowest with CT, followed by MTRV and then MTRR regardless of the N levels. Irrespective of tillage system, the grain yield increased from the 69 kg N ha^{-1} level to the 115 kg N ha^{-1} level. These results proved that MTRR can be introduced successfully in the study area when it coincides with fertilization of at least 92 kg N ha^{-1}. The replacement of CT with MTRR should contribute to sustainable maize production in western Ethiopia.

CHAPTER 4

EFFECT OF TILLAGE SYSTEM, RESIDUE MANAGEMENT AND NITROGEN FERTILIZATION ON SOME PHYSICAL AND CHEMICAL PROPERTIES OF NITISOLS

4.1 Introduction

A variety of tillage systems are used for crop production of which minimum and conventional tillage are the two extremes. Conventional tillage is usually regarded as moldboard plowing followed by disking one ore more times to obtain a loose friable seedbed. In the case of minimum tillage however the crop is planted with just sufficient tillage to allow placement and coverage of the seed for germination and emergence (Phillips *et al.,* 1980).

Griffith *et al.* (1986) is of opinion that the placement of crop residues often has a greater influence on soil properties than the degree of pulverization. In comparison with conventional tillage, minimum tillage generally retains most of the residues from previous crops on the soil surface by minimizing mechanical manipulation and mixing of the soil. In some instances therefore the reduced soil mixing combined with the retention of crop residues on the surface markedly change physical, chemical and biological properties through the soil profile over time (Lal, 1976a; Doran, 1980; Blevins *et al*, 1983a; Mahboubi *et al.*, 1993; Ismail *et al.*, 1994). These soil properties are inter alia water content, bulk density, structure stability, penetrometer resistance, pH, organic matter content and plant nutrient availability (Lal, 1974b; Lal, 1976a; Blevins *et al,* 1983b; Griffith *et al.*, 1986; White 1990; Mahboubi *et. al.,* 1993).

In many studies it was shown that minimum tillage where crop residues remain on the soil surface decreases evaporation losses, increases rainfall infiltration and reduces water runoff as compared to conventional tillage where crop residues are incorporated into the soil (Lal, 1974b; Lal, 1976a; Griffith *et al.,* 1986). Hence, the net effect is less variation in soil water content during the crop growing period and more plant available water that usually manifested in better crop yields.

Penetrometer resistance is another soil physical property modified by tillage systems through their effects on water content, bulk density and structure (Cassel, 1983; Unger, 1996). In the majority of studies researchers (Lal, 1976a; Bauder *et al.,* 1981; Mahli and O'Sullivan, 1990; Epperlein, 2001) reported higher penetrometer resistance in minimum than conventional tilled soils.

The replacement of conventional tillage by minimum tillage resulted after a few years usually in a higher organic matter content near the soil surface (Blevins *et al,* 1983b; White, 1990; Ismail *et al,* 1994). More C is therefore sequestered in the minimum than conventional tilled soils which may have a long-term beneficial effect (Reicosky, 2001). Minimum tilled soils are also less harmful to the environment through erosion and nutrient losses than conventional tilled soils on account of the higher organic matter content and associated biological activity which enhances structural development and stability (Phillips *et al.,* 1980).

Accordingly, it has also been found that minimum tillage in comparison with conventional tillage increased the concentration of plant nutrients like N, P and K in the surface soil layer (Blevins *et al.*, 1983a; White 1990; Ismail, *et al.*, 1994). The effects of this nutrient accumulation in minimum tilled soils on crop response is not clear yet as the availability of nutrients are influenced by the water content of the soil surface layer. In regions where the soil surface is not frequently wetted by rain the nutrients in the soil may no be in an available form for long periods.

In western Ethiopia the integrated effects of tillage systems, residue management and N fertilization on the properties of Nitisols were not investigated previously. Thus, the objective of this study was to examine the effects of tillage systems, residue management and N fertilization on some physical and chemical properties of the Nitisols.

4.2 Materials and methods

This study was conducted on the maize experiments described earlier and details on them can be found in Section 3.2.1 to 3.3.3. However, for the sake of convenience a concise description is given. The experiments were conducted on Nitisols at Bako, Shoboka, Tibe, Ijaji and Gudar in western Ethiopia from 2000 until 2004. At each of the five sites an experiment was laid out in a randomized complete block design with three replications. Three tillage systems (MTRR = minimum tillage with residue retention, MTRV = minimum tillage with residue removal and CT = conventional tillage) and three N fertilization levels (recommended rate of 92 kg N ha^{-1} and 25% less and 25% more than this rate) were combined in complete factorial arrangement. The experimental plots were kept permanent to observe the carry-over effects of the treatments for the five cropping seasons.

Only penetrometer resistance as a physical property and pH, organic C, total N, extractable P and exchangeable K as chemical properties were quantified to establish the treatment effects on the Nitisols. The procedures implemented for the quantification of these soil properties will be elucidated briefly.

The penetrometer resistance of the soil in each plot of all the five sites was measured during the middle of the 2004 growing season. At this stage the water content of the soils was in all cases approximately at field capacity. A slide cone penetrometer of Eijkelkamp with a base area of 5 cm^2 was used. The penetrometer was pushed manually into the soil at a randomly selected spot per plot. Readings were taken at 5 cm intervals from the surface to 30 cm depth.

After harvesting soil samples were collected from all the plots at each site for analysis of the mentioned chemical properties. One depth interval, viz. 0-30 cm was sampled every year. In addition four depth intervals, viz. 0-7.5, 7.5-15. 15-22.5 and 22.5-30 cm were sampled in the final year. A 2 cm diameter auger was used to sample five randomly selected spots per plot. The soil of these sub-samples were thoroughly mixed, dried at room temperature, sieved through a 2 mm screen and stored until analysis. Standard procedures (The Non-affiliated Soil Analysis Work Committee, 1990) were used to determine the pH (1:2.5 water), organic

C (Walkley-Black), total N (Kjeldahl), extractable P (Bray II) and exchangeable K (NH_4OAc) of these composite soil samples.

The data were analyzed using the MSTATC statistical package (Michigan State University, 1989). Means for each parameter were separated by the least significant difference (LSD) test at $P = 0.05$.

4.3 Results and discussion

4.3.1 Physical properties

As mentioned earlier the only physical property measured to establish the effect of treatment factors was penetrometer resistance. A summary on the analysis of variance indicating the effect of treatment factors on this property is given in Table 4.1. The results showed that there was a significant difference in penetrometer resistance among sites, tillage systems and depth intervals. Significant interactions between treatment factors were restricted to either that of depth intervals by site or tillage systems. The most logical way to present the data on penetrometer resistance is therefore per site for every depth interval.

Table 4.1 Summary of analysis of variance indicating the effects of site, tillage system, N fertilization and depth intervals on penetrometer resistance

Factors	Penetrometer resistance	Factors	Penetrometer resistance
Site (S)	*	D x T	*
Tillage (T)	*	D x N	ns
Nitrogen (N)	ns	T x N	ns
Depth (D)	*	Y x T x N	ns
S x D	*	S x Y x T	ns
S x T	ns	S x Y x N	ns
S x N	ns	S x Y x T x N	ns

*Significant at $P \leq 0.05$

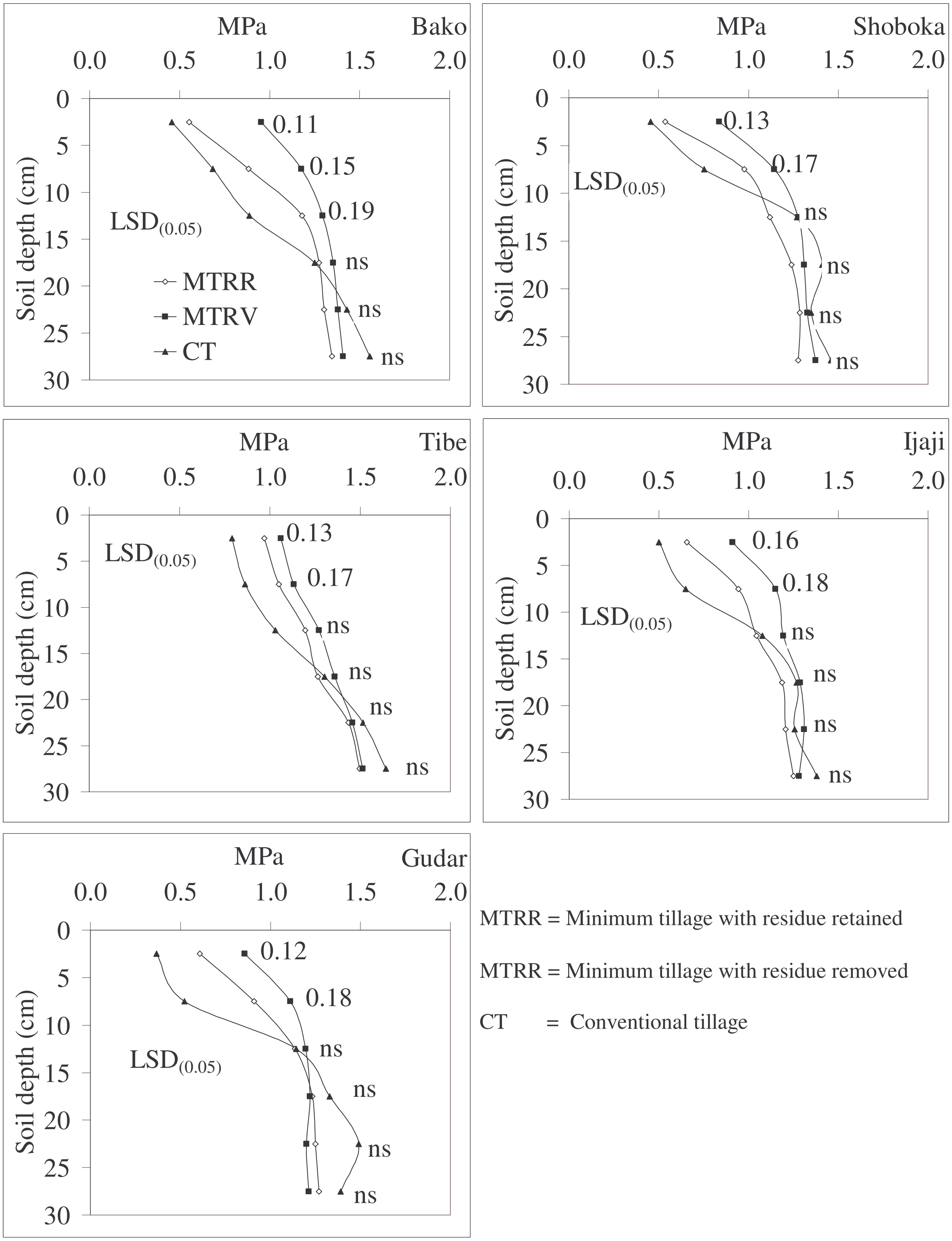
ns - not significant

The penetrometer resistance of the Nitisols at the five sites as measured in the middle of the 2004 growing season is displayed in Figure 4.1. It is clear that the penetrometer resistance increased with depth irrespective of site or tillage system. However penetrometer resistance differed significantly between tillage systems to a depth of 15 cm at Bako and to only 10 cm at Shoboka, Tibe, Ijaji and Gudar. In this upper 0-15 cm soil layer the lowest penetrometer resistance was recorded in the CT soils, followed by the MTRR and then the MTRV soils. Below 15 cm the penetrometer resistance of the CT soils tended to be slightly higher than that of the MTRV and MTRR soils.

The pattern of penetrometer resistance that evolved from this study is in line with what one would be expected based on the findings of other studies (Lal, 1976a; Bauder *et al.,* 1981; Mahli *et al.,* 1992; Epperlein, 2001) of this nature. However, soil water content at the time of measuring could contributed to some of the differences as it was not necessarily comparable in the CT, MTRV and MTRR soils when the findings of other researchers (Doran *et al.,* 1984; Griffith *et al.,* 1986; Unger *et al.,* 1991; Unger 1996) on this aspect are considered. It is well established that penetrometer resistance increased with a decline in soil water content and vice versa.

The penetrometer resistance of 2 MPa or higher at field capacity usually impeded crop root penetration (Taylor and Gardner, 1963; Voorhees *et al.,* 1975; Gupta and Larson, 1982). This threshold value was not reached at all sites in this study. It can be therefore assumed that root penetration of maize in these Nitisols would not be negatively affected by soil penetration resistance regardless of the practice of CT, MTRV and MTRR.

The increase in penetrometer resistance in the upper 0-15 cm soil layer on account of MTRV and MTRR when CT serves as reference manifested according to Lal (1974b) not in grain yield. This was also the case in this study since the grain yield was the highest with MTRR followed by MTRV and CT as reported in the previous chapter.



MTRR = Minimum tillage with residue retained

MTRR = Minimum tillage with residue removed

CT = Conventional tillage

Figure 4.1 Effect of tillage system on the penetrometer resistance of Nitisols as measured at six depth intervals in 2004 at five sites.

4.3.2 Chemical properties

The procedure according to which soil samples were collected for the determination of pH, organic C, total N, extractable P and exchangeable K allows analyses of variance to establish the effect of tillage system and N fertilization on these properties over sites and years as displayed in Table 4.2, as well as over sites and depth intervals as displayed in Table 4.3. The results showed that there were significant differences among sites, years, tillage systems and depth intervals with regard to all five soil chemical properties. Nitrogen fertilization significantly affected pH, organic C and total N but not extractable P and exchangeable K. The significant interactions were only those of site by year on organic C and total N (Table 4.2), site by depth interval on organic C and extractable P, tillage system by depth interval on organic C, total N and extractable P (Table 4.3).

Table 4.2 Summary of analyses of variance indicating the effects of site, year, tillage system and N fertilization on soil chemical properties

Factors	Soil pH	Organic C	Total N	Extractable P	Exchangeable K
Site (S)	*	*	*	*	*
Year (Y)	*	*	*	*	*
Tillage (T)	*	*	*	*	*
Nitrogen (N)	*	*	*	ns	ns
S x Y	ns	ns	ns	ns	ns
S x T	ns	ns	ns	ns	ns
S x N	ns	ns	ns	ns	ns
Y x T	ns	*	*	ns	ns
Y x N	ns	ns	ns	ns	ns
T x N	ns	ns	ns	ns	ns
Y x T x N	ns	ns	ns	ns	ns
S x Y x T	ns	ns	ns	ns	ns
S x Y x N	ns	ns	ns	ns	ns
S x Y x T x N	ns	ns	ns	ns	ns

*Significant at $P \leq 0.05$, ns - not significant

Table 4.3 Summary of analyses of variance indicating the effects of site, tillage system, N fertilization and depth intervals on soil chemical properties

Factors	Soil pH	Organic C	Total N	Extractable P	Exchangeable K
Site (S)	*	*	*	*	*
Tillage (T)	*	*	*	*	*
Nitrogen (N)	ns	*	*	ns	ns
Depth (D)	*	*	*	*	*
S x D	ns	*	ns	*	ns
S x T	ns	ns	ns	ns	ns
S x N	ns	ns	ns	ns	ns
D x T	ns	*	*	*	ns
D x N	ns	ns	ns	ns	ns
T x N	ns	ns	ns	ns	ns
D x T x N	ns	ns	ns	ns	ns
S x D x T	ns	ns	ns	ns	ns
S x D x N	ns	ns	ns	ns	ns
S x D x T x N	ns	ns	ns	ns	ns

*Significant at $P \leq 0.05$, ns - not significant

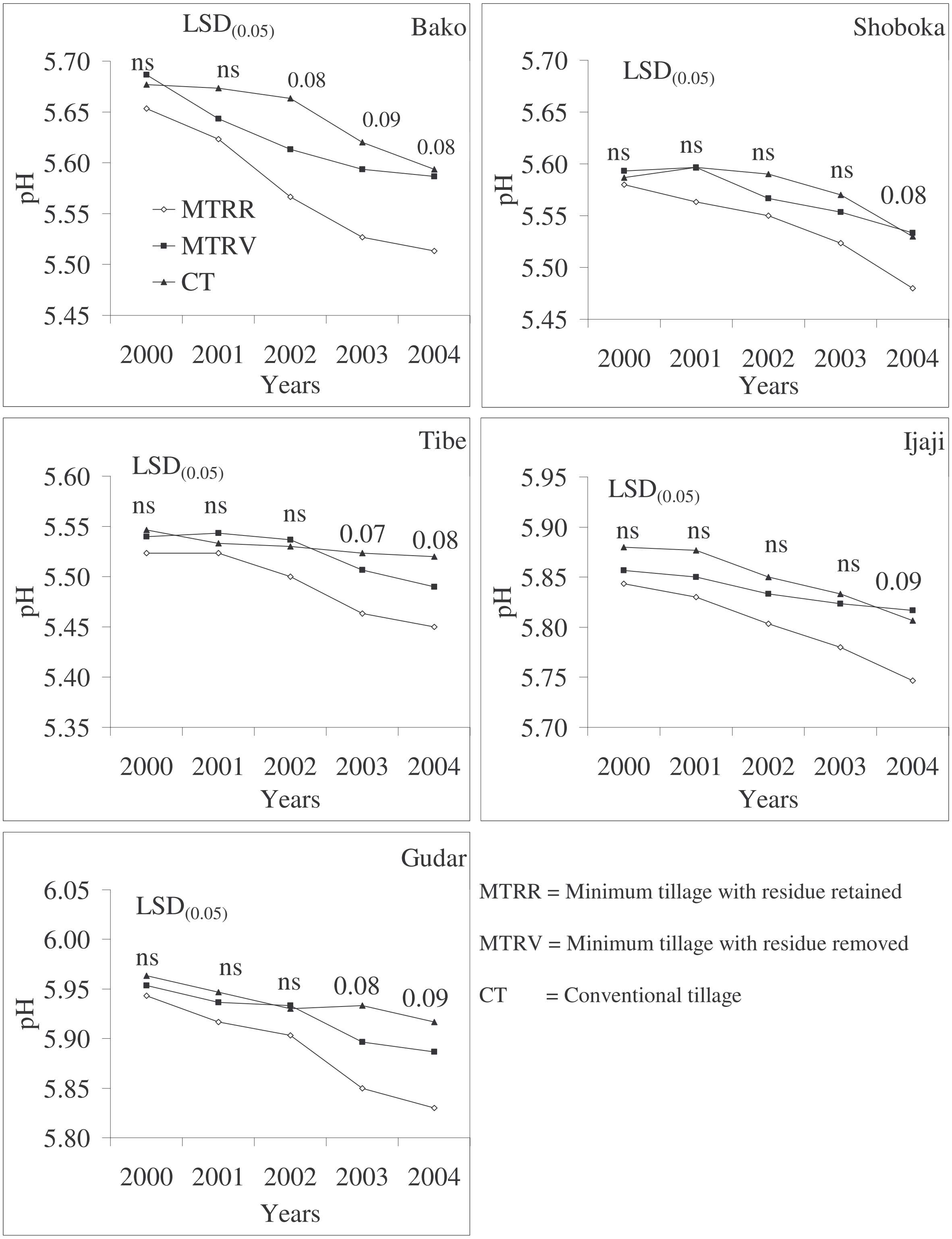
4.3.2.1 Soil pH

Both tillage system and N fertilization had a significant effect on the pH of the 0-30 cm soil layer but there was no significant interaction between the two treatments (Table 4.2). The effect of tillage system on pH in this soil layer is illustrated in Figure 4.2 for the year 2000 to 2004. At all five sites pH decreased over the experimental period regardless of the tillage system applied. This decrease in pH was least severe with CT, followed by MTRV and then MTRR. Differences in pH between tillage systems were therefore initially small and inconsistent but as the experiments progressed it become more apparent.

The pH of the 0-30 cm soil layer as affected by the application of N fertilizer is shown in Figure 4.3 for the year 2000 to 2004. At every site firstly, lower pH values were obtained with higher N application levels and secondly, the pH values decreased over time. These differences in pH between the three N application rates were only significant from the year 2003.

As shown in Figure 4.4 the pH differences that evolved in the upper 30 cm of the Nitisols from either tillage system or N fertilization are attributable to their effects in the 0-7.5 cm layer. In this layer the highest pH was recorded in the CT soil, followed by the MTRV soil and then the MTRR soil. At the five sites the difference in pH between the CT and MTRR soils ranged from 0.15 to 0.25 units. The pH of the next three soil layers was not affected significantly by the three tillage systems at any of the sites.

The increase of pH with depth is common in the Nitisols of the study area. However, acidification of the upper 7.5 cm of these soils at all the sites appeared to be occurring faster with MTRR than with MTRV or CT. This phenomenon could be attributed to the nitrification of NH_4^+ released from either the fertilizer or residues at or near the soil surface (Blevins *et al.*, 1977; Ismail *et al.,* 1994) since the process producing acidifying hydrogen ions (Fox and Bandel, 1986). Similar changes in pH on account of tillage systems were reported by other researchers (Shear and Moschler, 1969; Bleveins *et al.,* 1977; White, 1990).



MTRR = Minimum tillage with residue retained

MTRV = Minimum tillage with residue removed

CT = Conventional tillage

Figure 4.2 Effect of tillage system on the pH of Nitisols as measured during 2000 to 2004 in the 0-30 cm layer at five sites.

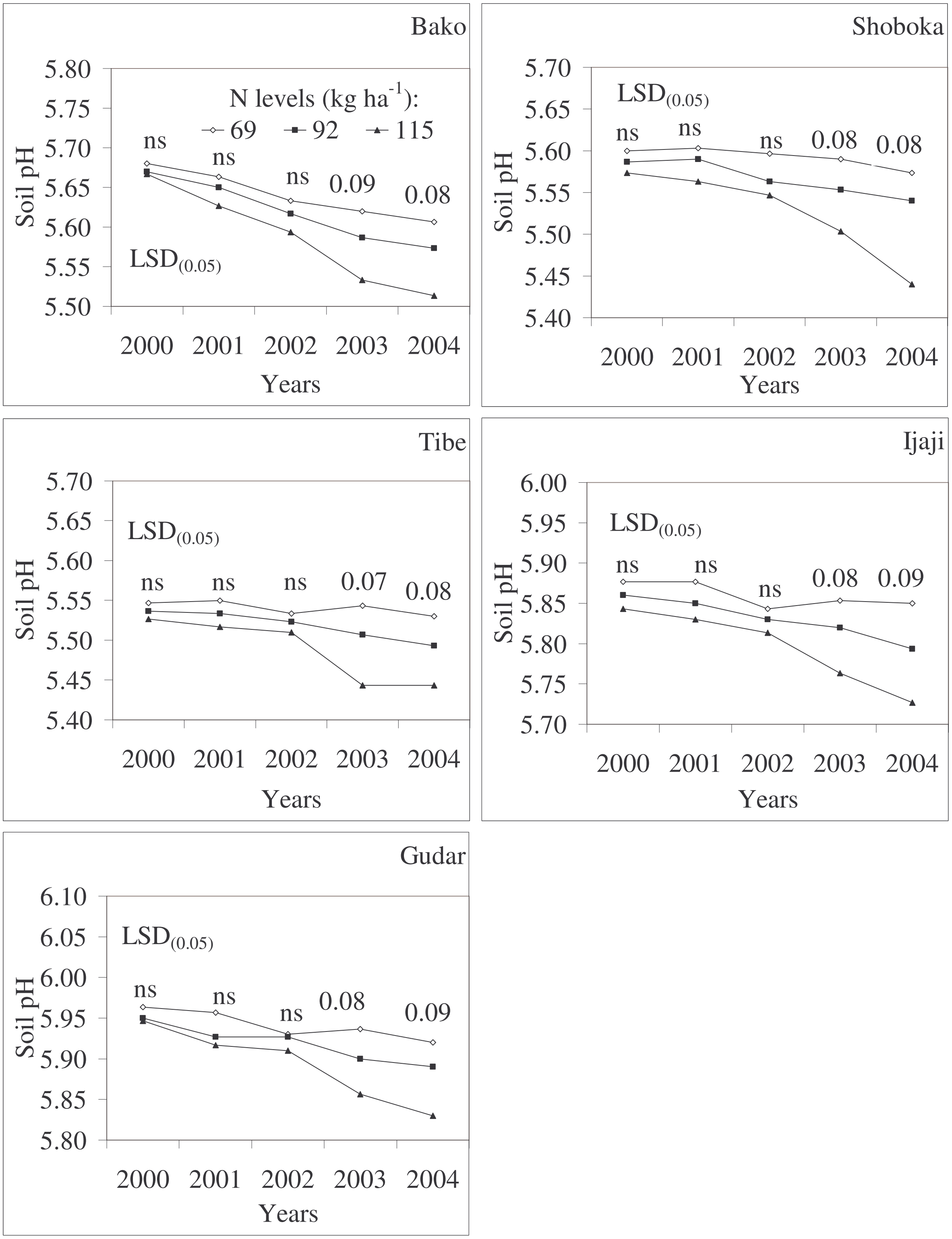
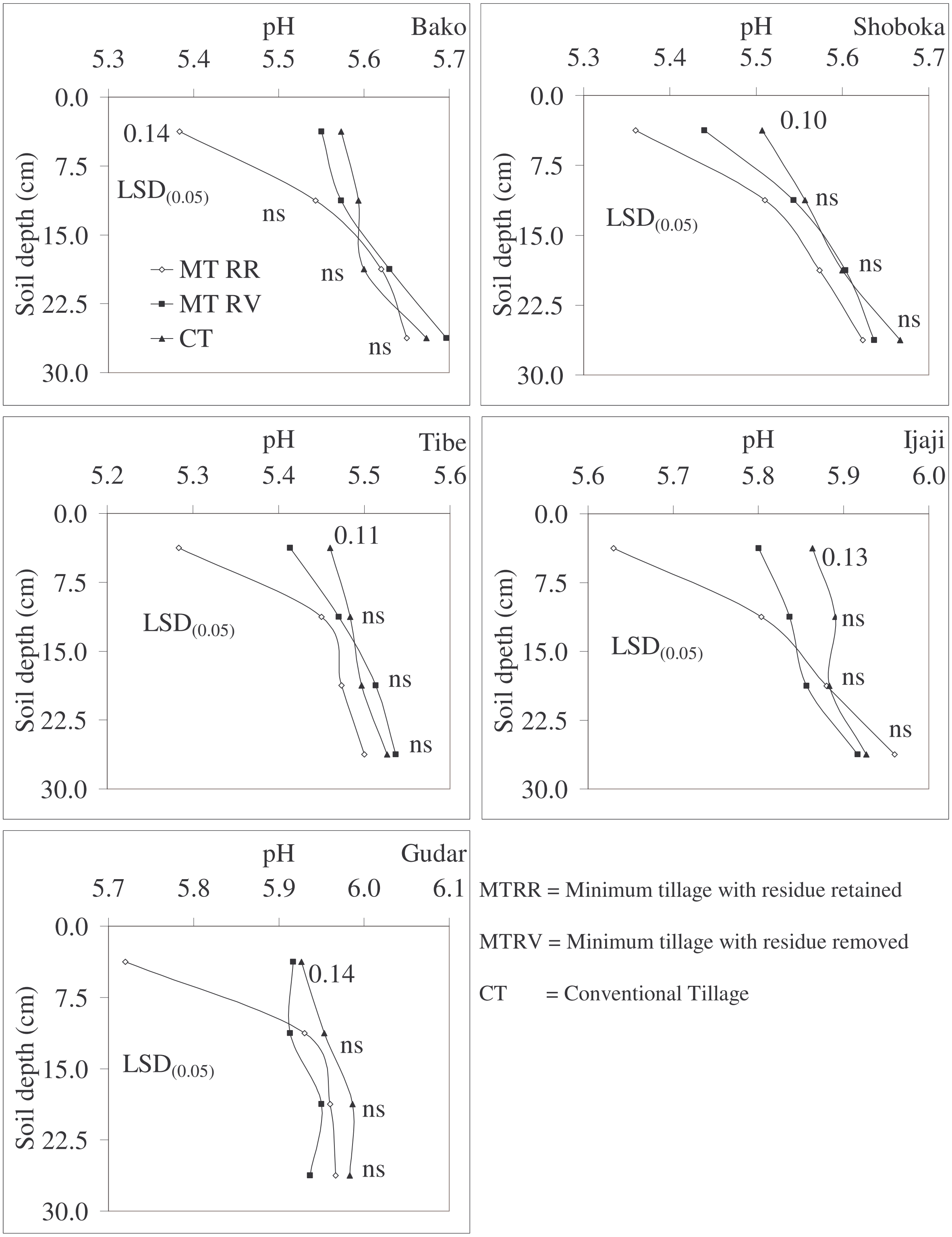


Figure 4.3 Effect of N fertilization on the pH of Nitisols as measured during 2000 to 2004 in the 0-30 cm layer at five sites.



MTRR = Minimum tillage with residue retained

MTRV = Minimum tillage with residue removed

CT = Conventional Tillage

Figure 4.4 Effect of tillage system on the pH of Nitisols as measured at four depth intervals in 2004 at five sites.

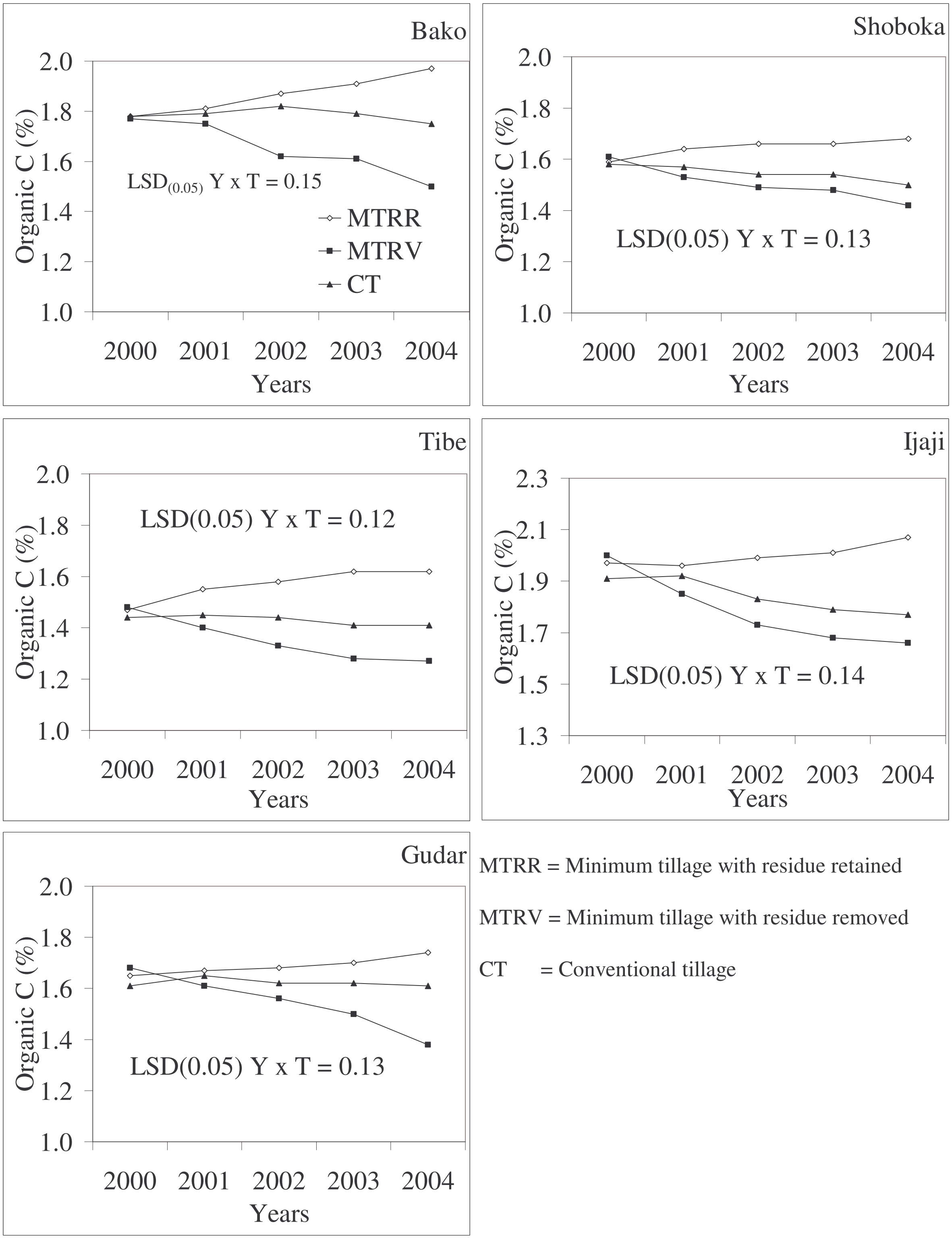
4.3.2.2 Organic C

As shown in Table 4.2 both tillage system and N fertilization significantly influenced organic C in the 0-30 cm soil layer. The effect of tillage system on organic C in this soil layer is displayed in Figure 4.5 for the year 2000 to 2004. Very clear differences in the organic C development on account of the three tillage systems as the experiments progressed from 2000 to 2004. This phenomenon is attributed to the fact that organic C increased with MTRR and decreased with MTRV. In the case of CT the organic C at Tibe and Gudar remained almost constant, and at Bako, Shoboka and Ijaji it declined but to a lesser degree as compared to MTRV.

The change of organic C in the 0-30 cm layer resulting from the application of N fertilization at different levels is illustrated in Figure 4.6. Organic C increased with higher levels of N application though not significant in many instances. These differences in organic C become more apparent as the experimental period progressed from 2000 to 2004.

The organic C differences evolved in the upper 30 cm of the Nitisols from tillage system and N fertilization had their origin mainly in the upper 0-7.5 cm layer as shown in Figures 4.7 and 4.8. In general the highest organic C in this layer was recorded with MTRR, followed by CT and then MTRV. Organic C increased also with higher levels of N application significantly at three of the five sites, viz. Bako, Ijaji and Gudar.

The application of the particular three tillage systems on the Nitisols for five consecutive years caused tremendous changes of organic C in the upper 7.5 cm layer. Organic C in this layer was on average for all sites with MTRR 17 and 25% more than with CT and MTRV, respectively. This finding is consistent with results reported by several other researchers (Baeumer and Bakermans, 1973; Blevins *et al.,* 1977; Hamblin and Tennants, 1979; Griffith *et al.,* 1986; Mahboubi *et al.,* 1993). They attributed the difference in organic C between MTRR and CT to the fact that crop residues and the organic matter originated from it are oxidized faster in CT than MTRR soils due a higher microbial activity. The significance of



MTRR = Minimum tillage with residue retained

MTRV = Minimum tillage with residue removed

CT = Conventional tillage

Figure 4.5 Effect of tillage system on the organic C of Nitisols as measured during 2000 to 2004 in the 0-30 cm layer at five sites.

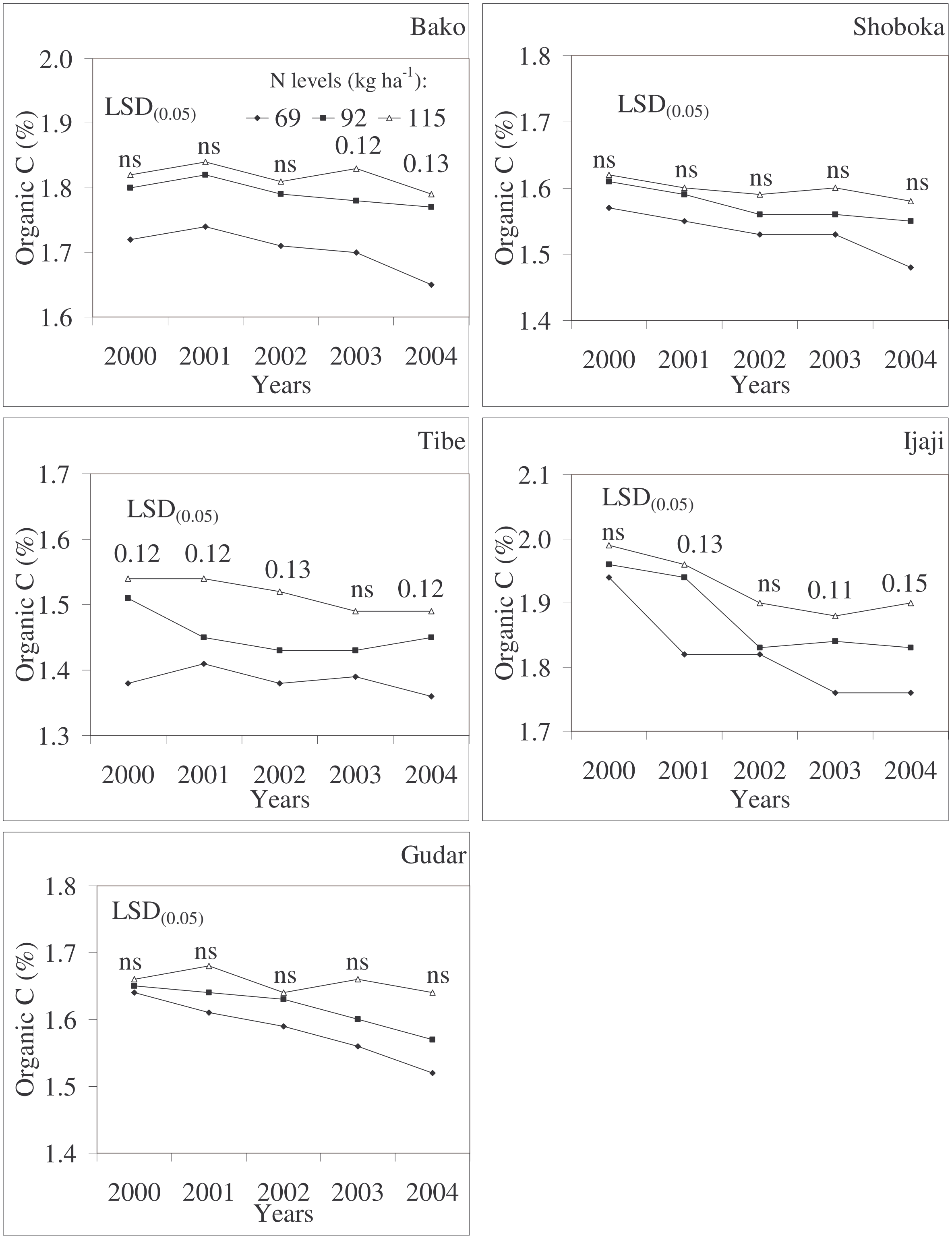
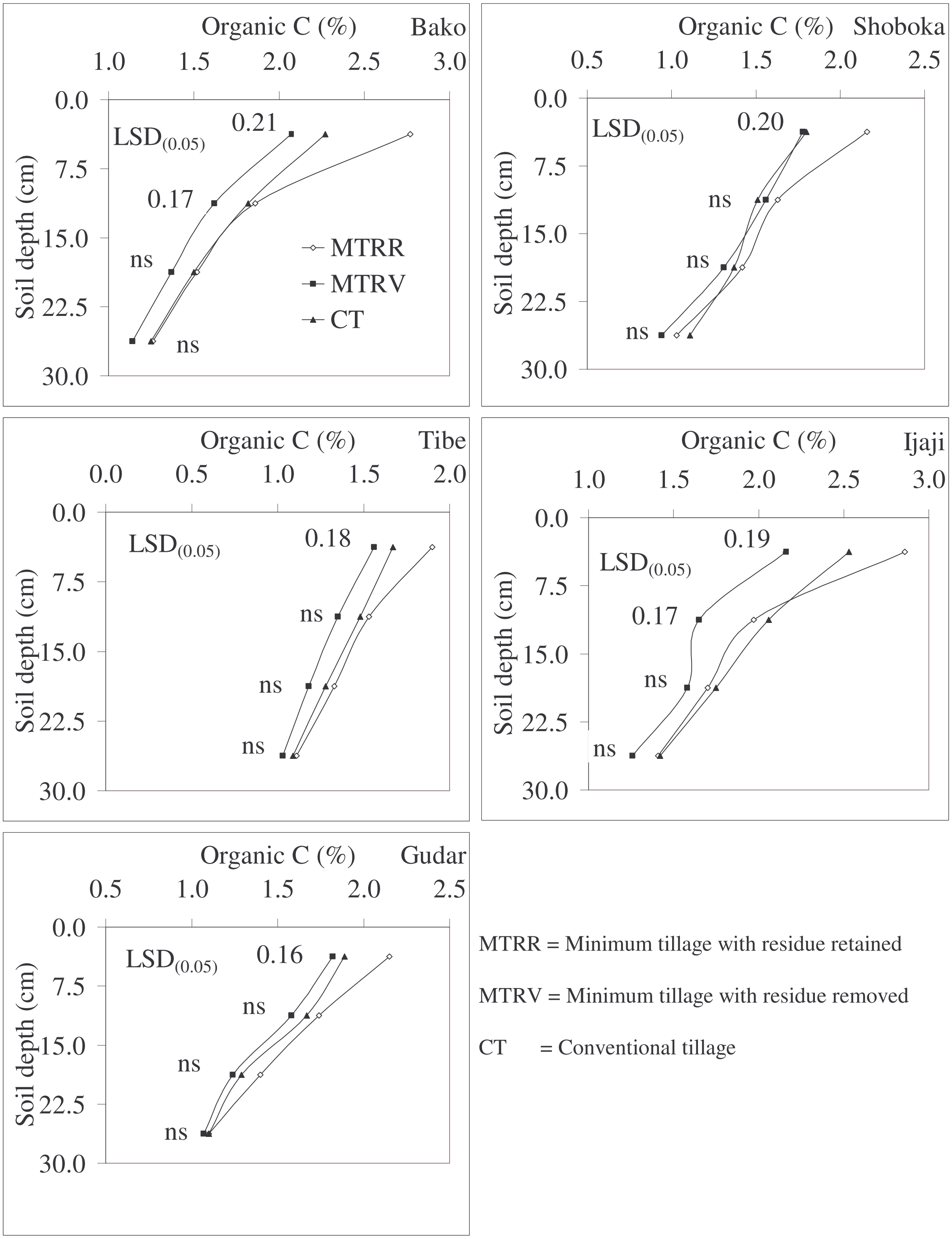


Figure 4.6 Effect of N fertilization on the organic C of Nitisols as measured during 2000 to 2004 in the 0-30 cm layer at five sites.



MTRR = Minimum tillage with residue retained

MTRV = Minimum tillage with residue removed

CT = Conventional tillage

Figure 4.7 Effect of tillage system on the organic C of Nitisols as measured at four depth intervals in 2004 at five sites.

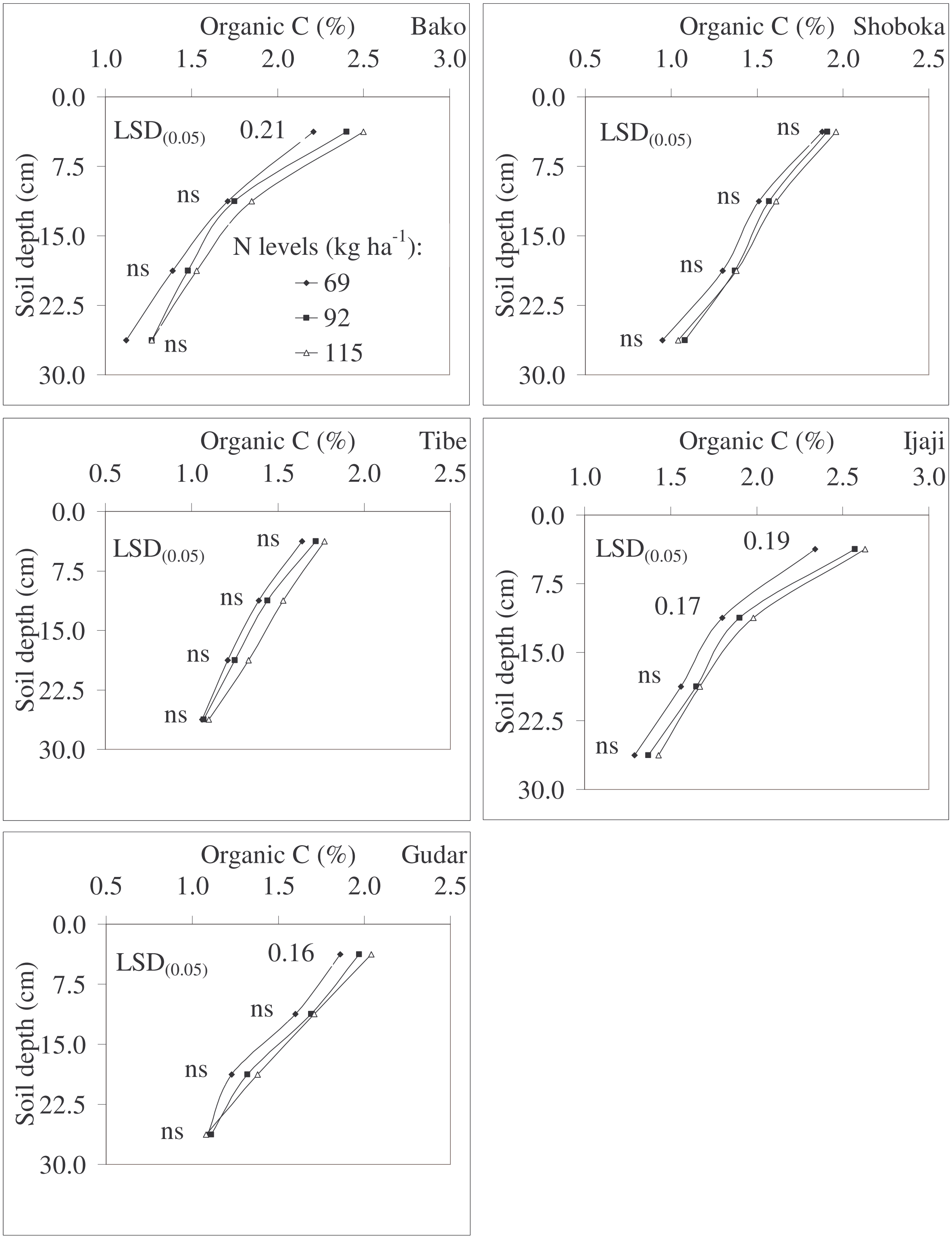


Figure 4.8 Effect of N fertilization on the organic C of Nitisols as measured at four depth intervals in 2004 at five sites.

retaining crop residues was emphasized by the difference of organic C between the MTRR and MTRV soils. Sufficient crop residues for retention to ensure organic C maintenance or increase can only realized with proper N fertilization as was the case in this study.

4.3.2.3 Total N

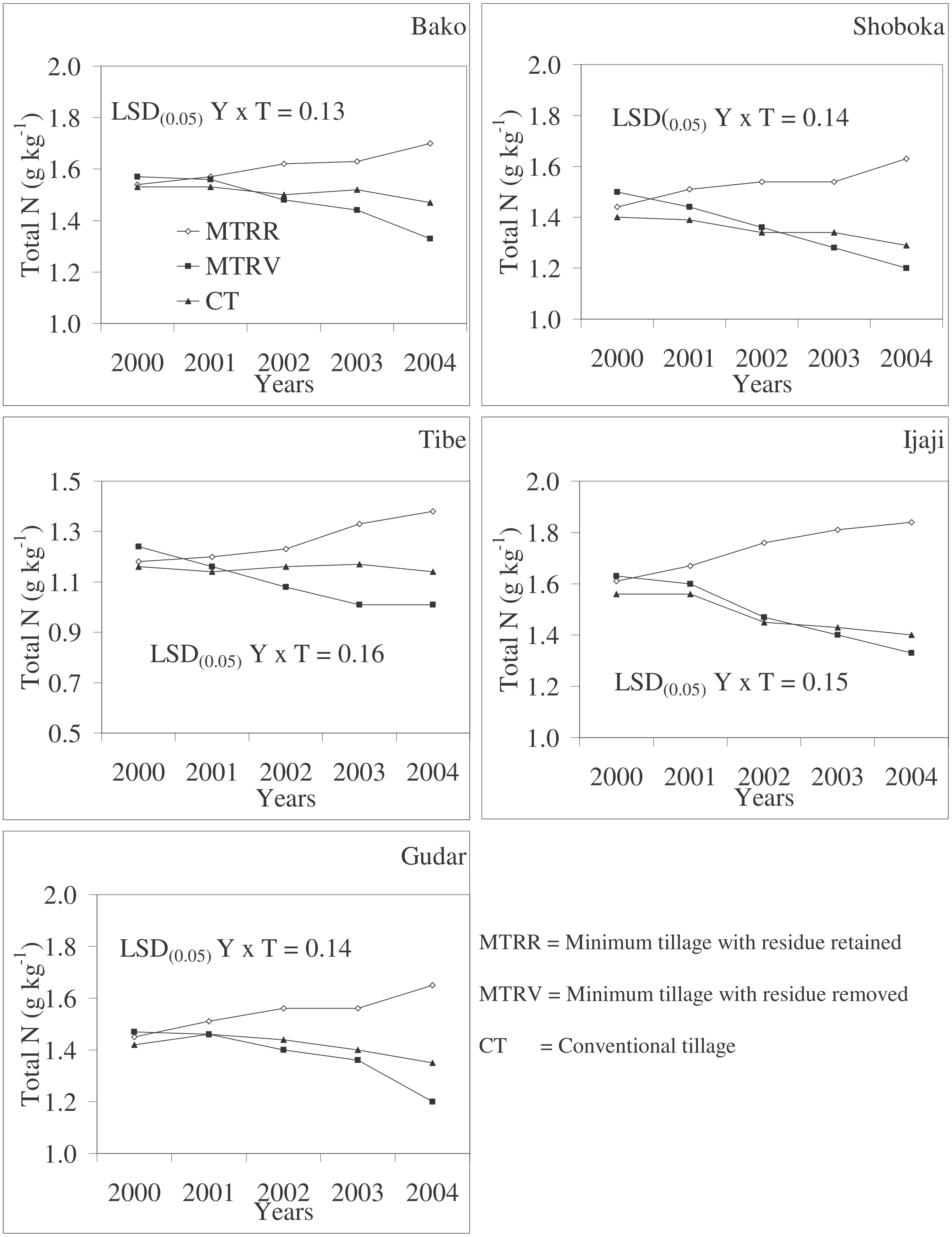
Total N was significantly influenced by tillage system and N fertilization in the 0-30 cm layer (Table 4.2). As could be expected the effect of tillage system on total N (Figure 4.9) was almost similar to that of organic C (Figure 4.5). The total N increased with MTRR and decreased with MTRV resulting in large differences after five years. In the case of CT the total N also decreased but to a lesser degree as with MTRV.

The change of total N in the 0-30 cm soil layer resulting from the application of N fertilizer at different rates is shown in Figure 4.10. Total N increased with higher rates of N application though not always significant.

Inspection of Figure 4.11 and 4.12 show that the differences of total N in the 0-30 cm layer which resulted from tillage system and N fertilization are mainly attributable to changes in the 0-7.5 cm layer. At all sites the lowest total N was recorded in this layer with MTRV, followed by CT and then MTRR. Total N increased also with higher rates of N application though only significant at Bako and Ijaji.

After five consecutive years of application the three tillage systems resulted in large changes of total N in the upper 7.5 cm layer of the Nitisols. The total N in this layer was on average for all sites with MTRR 20 and 29% more than with CT and MTRV, respectively. Similar results were reported by various other researchers (Tripplet and Van Doren, 1969; Phillips and Young, 1973; Lal, 1976a; Blevins *et al.,* 1983b; White, 1990).

The fate of total N was therefore almost similar to that of organic C for the same reasons given earlier. This phenomenon is not surprising since organic C and total N are both used as indices of organic matter.



MTRR = Minimum tillage with residue retained

MTRV = Minimum tillage with residue removed

CT = Conventional tillage

Figure 4.9 Effect of tillage system on the total N of Nitisols as measured during 2000 to 2004 in the 0-30 cm layer at five sites.

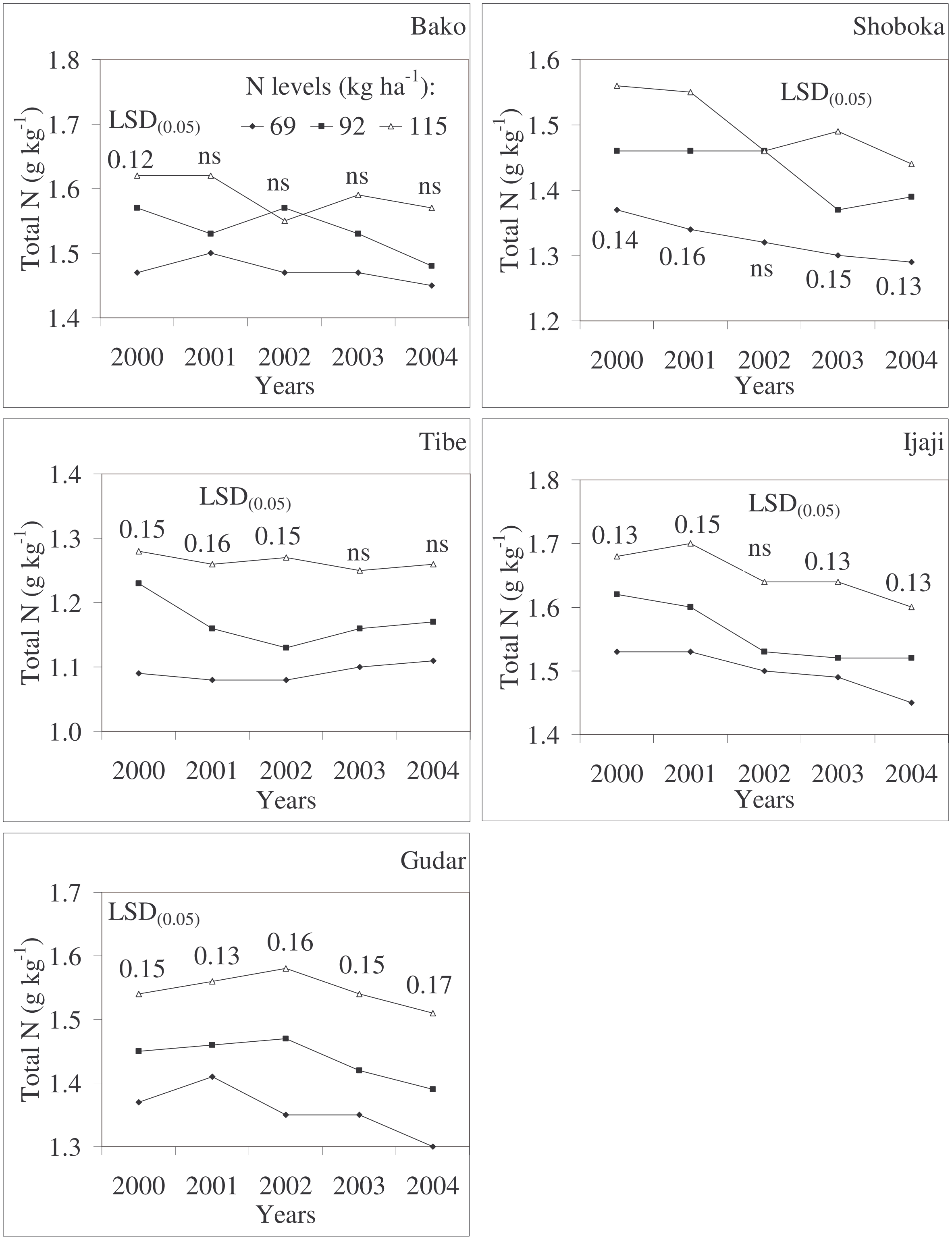
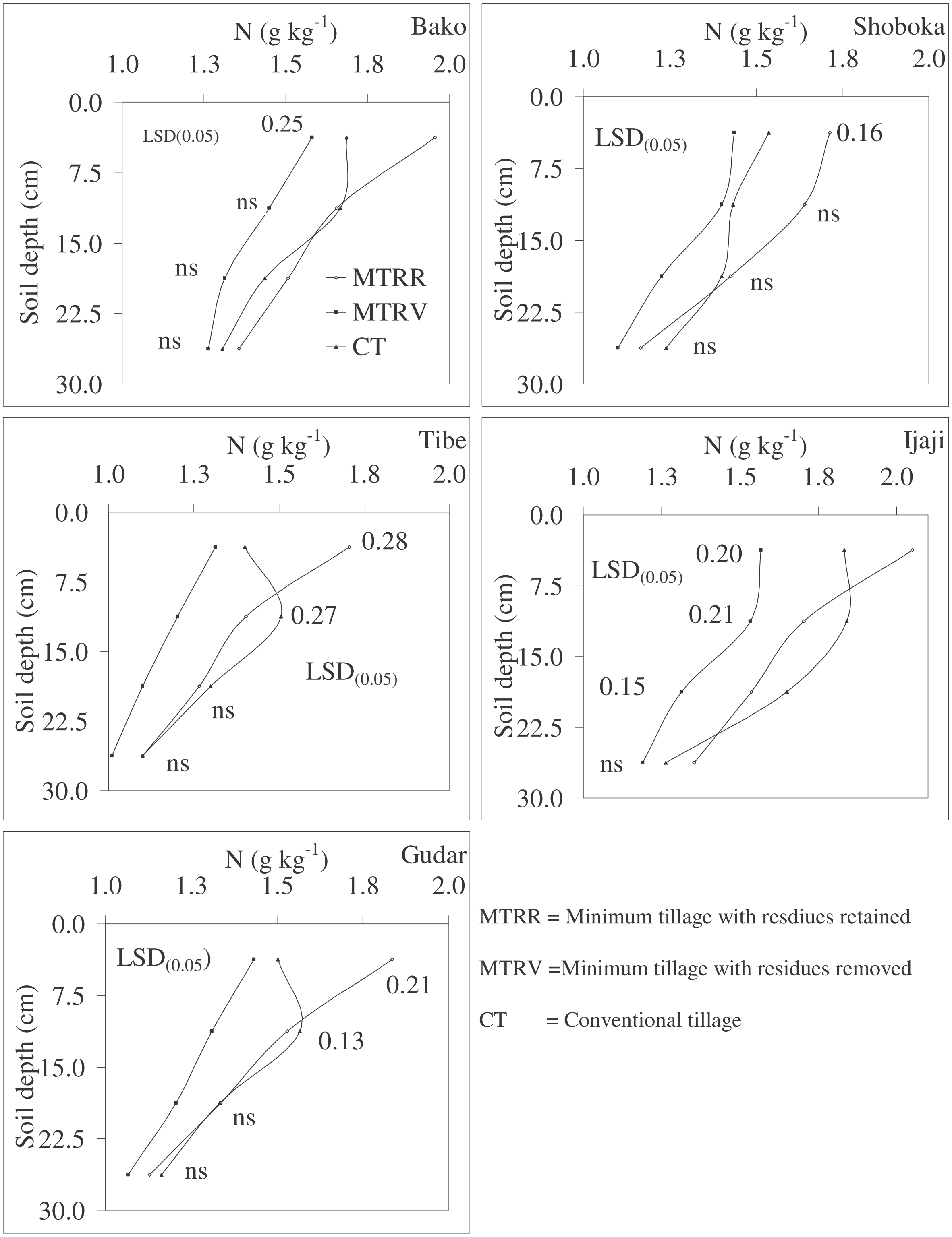


Figure 4.10 Effect of N fertilization on the total N of Nitisols as measured during 2000 to 2004 in the 0-30 cm layer at five sites.



MTRR = Minimum tillage with resdiues retained

MTRV =Minimum tillage with residues removed

CT = Conventional tillage

Figure 4.11 Effect of tillage system on the total N of Nitisols as measured at four depth intervals in 2004 at five sites.

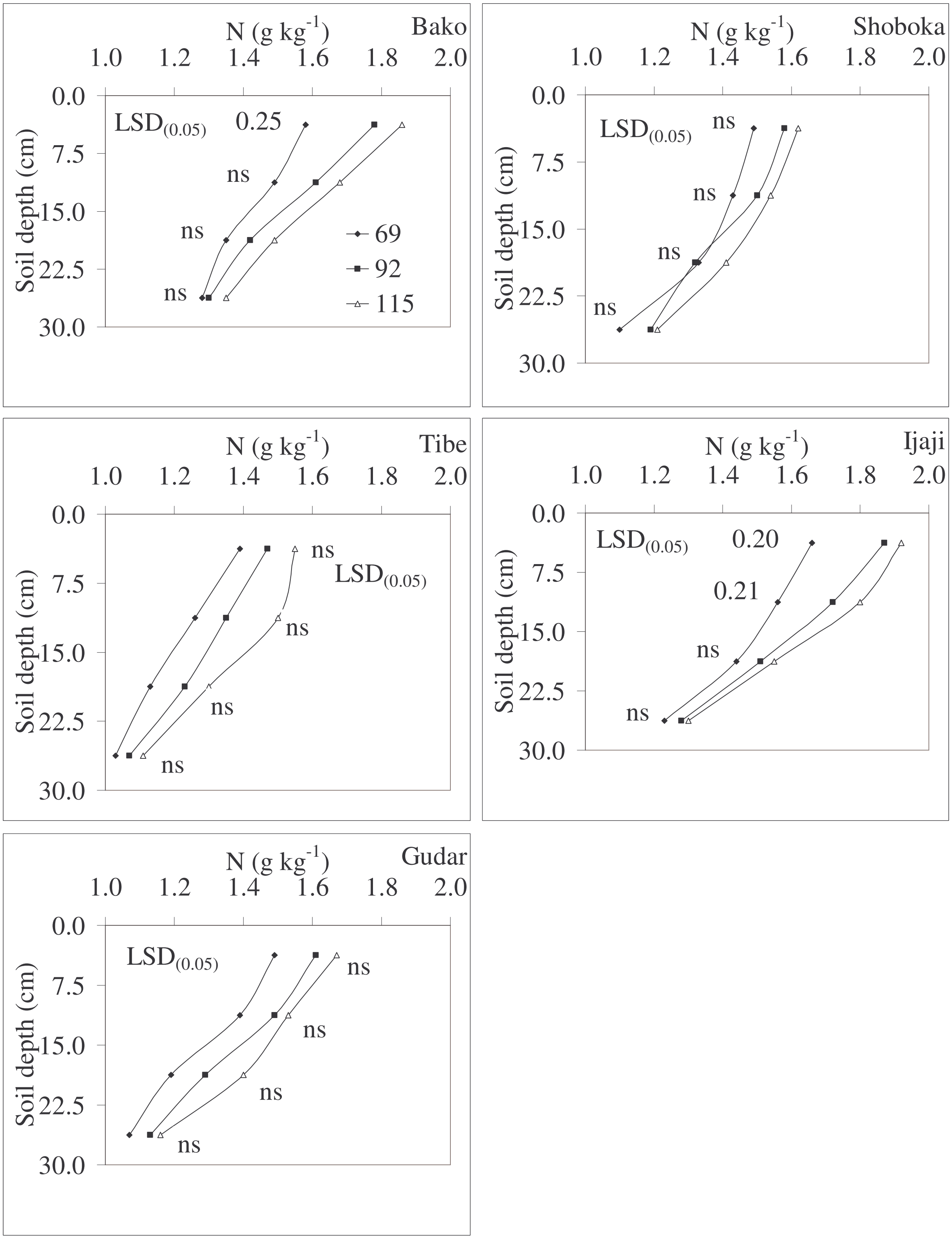


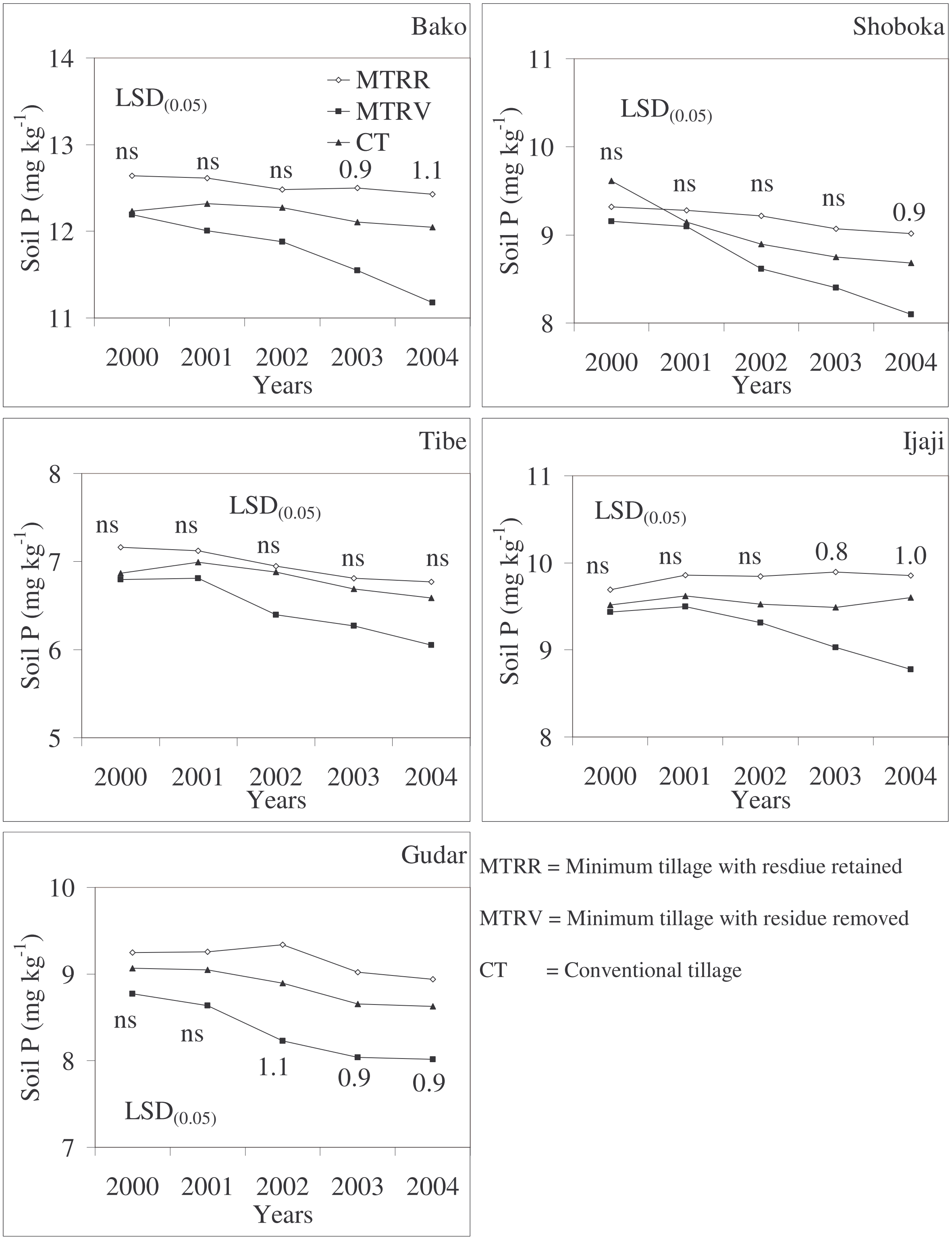
Figure 4.12 Effect of N fertilization on the total N of Nitisols as measured at four depth intervals in 2004 at five sites.

4.3.2.4 Extractable P

As shown in Table 4.2 extractable P of the 0-30 cm soil layer was significantly affected by tillage system and not by N fertilization. The effect of tillage system on extractable P in this soil layer is displayed in Figure 4.13 for the year 2000 to 2004. Regardless of year MTRR exhibited a higher extractable P level than MTRV with CT intermediate. These differences in extractable P levels between tillage systems were only significant from 2003 at Bako and Ijaji, 2004 at Shoboka and 2002 at Gudar.

As shown in Figure 4.14 the above mentioned differences in extractable P levels originated in the upper 15 cm soil layer as no significant differences were found below this depth. In 2004 irrespective of site, the extractable P level of the 0-7.5 cm layer was significantly higher in the MTRR soil than in either the MTRV or CT soils. However, the extractable P level of the 7.5-15 cm layer was higher in the CT soil than in either the MTRV or MTRR soils although not significant at all sites.

The higher extractable P levels recorded especially in the 0-7.5 cm soil layer and to a lesser extent in the 7.5-15 cm layer of the Nitisols regardless of the tillage system can be attributed to the immobility of this nutrient. However, as indicated the tillage systems caused after five consecutive years of practice different extractable P levels in the upper 7.5 cm layer. The higher extractable P levels in this layer of the MTRR than the CT soils can be attributed to the applied P fertilizer and the retained maize residues which were not mixed with the soil to the same degree due to the nature of the two tillage systems. It seems however that the retention of maize residues contributed largely to this phenomenon as the extractable P levels in the upper 7.5 cm layer of the MTRV and CT soils were almost similar. The retained maize residues on the soil surface enhanced organic matter formation and in this process some of the P taken up by the crop from deeper layers is released in an inorganic form (Ismail *et al.,* 1994). This released inorganic P is probably less subject to fixation as organic matter can protected it to some degree (El-Baruni and Olsen, 1979).

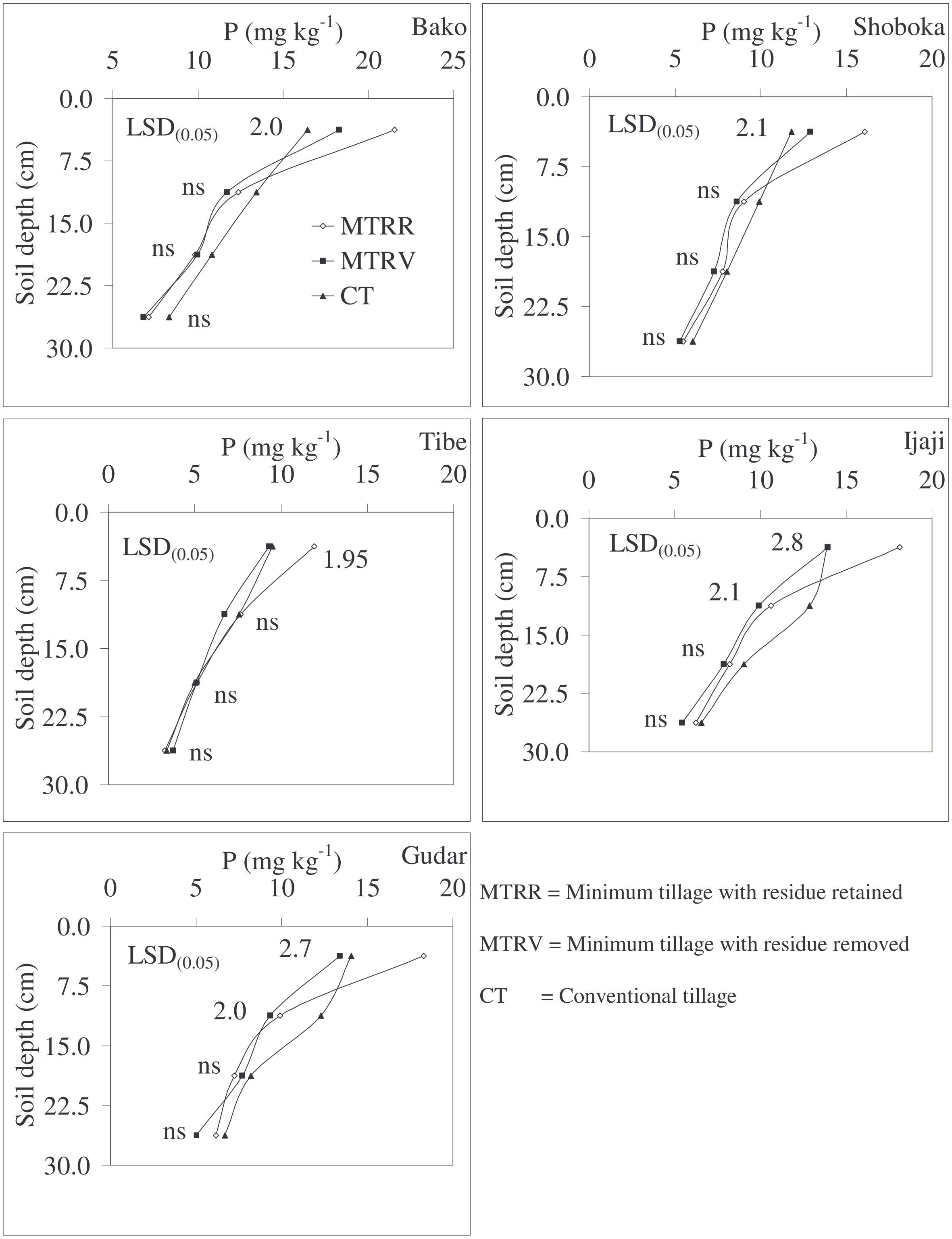


MTRR = Minimum tillage with resdiue retained

MTRV = Minimum tillage with residue removed

CT = Conventional tillage

Figure 4.13 Effect of tillage system on the extractable P of Nitisols as measured during 2000 to 2004 in the 30 cm layer at five sites.



MTRR = Minimum tillage with residue retained

MTRV = Minimum tillage with residue removed

CT = Conventional tillage

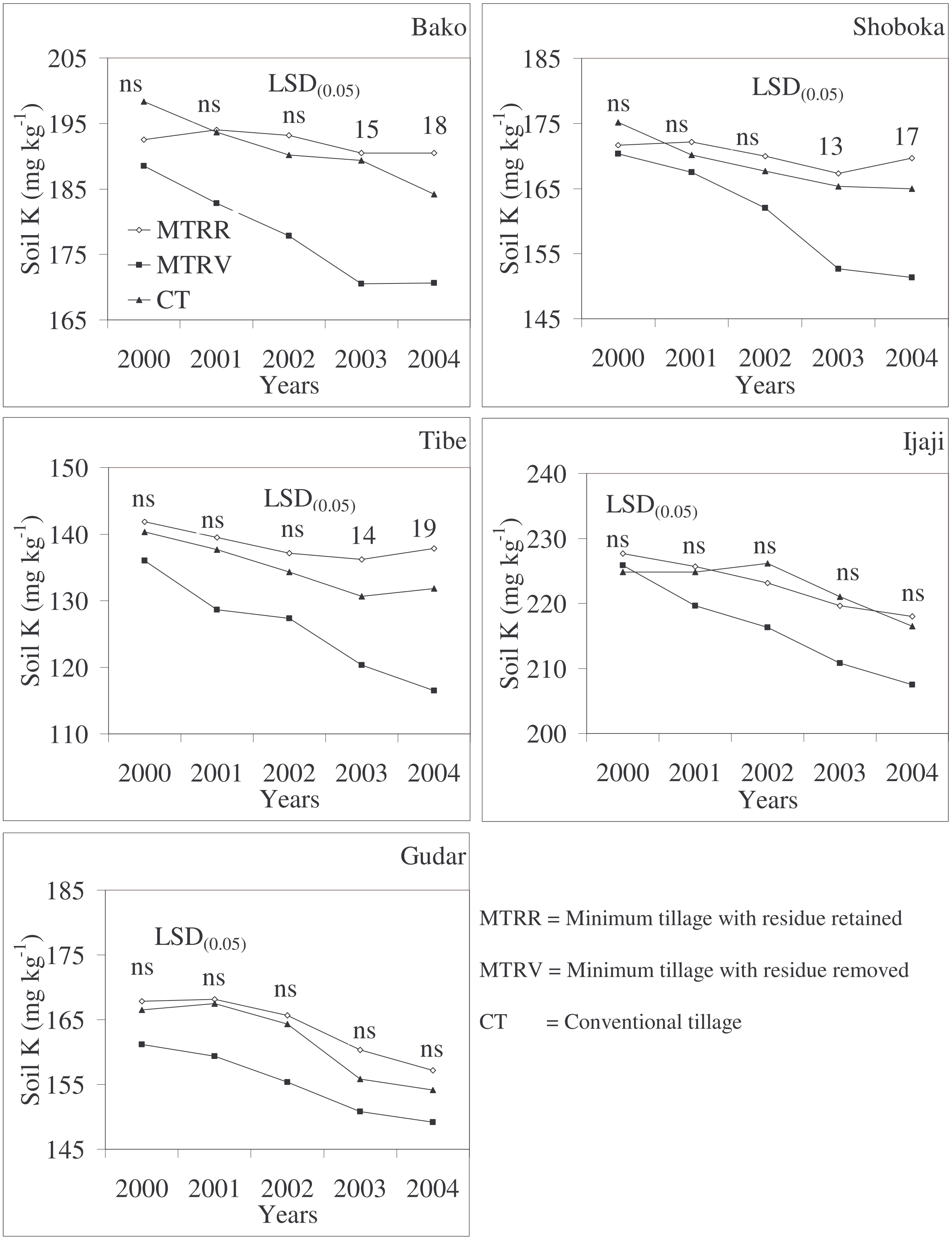
Figure 4.14 Effect of tillage system on the extractable P of Nitisols as measured at four depth intervals in 2004 at five sites.

4.3.2.5 Exchangeable K

Exchangeable K of the 0-30 cm layer was significantly affected by tillage system and not by N fertilization (Table 4.2). The effect of tillage system on exchangeable K in this soil layer is shown in Figure 4.15 for the year 2000 to 2004. During the first three years exchangeable K differed not significantly among the three tillage systems which was not the case in the last two years at Bako, Shoboka, and Tibe when significantly higher levels of exchangeable K were recorded in the MTRR than MTRV and CT soils. However, throughout the experimental period the MTRR soils and to a lesser extent also the CT soils exhibited higher levels of exchangeable K than the MTRV soils.

The above mentioned differences in the exchangeable K originated in the upper 15 cm soil as no significant differences were recorded below this depth (Figure 4.16). In 2004 after five consecutive years of practice, MTRR resulted in the highest exchangeable K level in the 0-7.5 cm soil layer at all sites, followed by MTRV and CT. However, in the 7.5-15 cm soil layer at all sites, the exchangeable K levels as a result of MTRR and CT were almost similar but higher than that of MTRV.

A decline of exchangeable K with depth in the Nitisols is common to the study area. However, the differences in exchangeable K that evolved in the upper 15 cm of the Nitisols on account of tillage systems are a consequence of the concomitant residue management since no K fertilizer was applied. Several researchers (e.g. Triplett *et al.,* 1969; Fink and Wesley, 1974) showed that the fate of maize residues had a large influence on exchangeable K in soils as the residues contain a large amount of K.

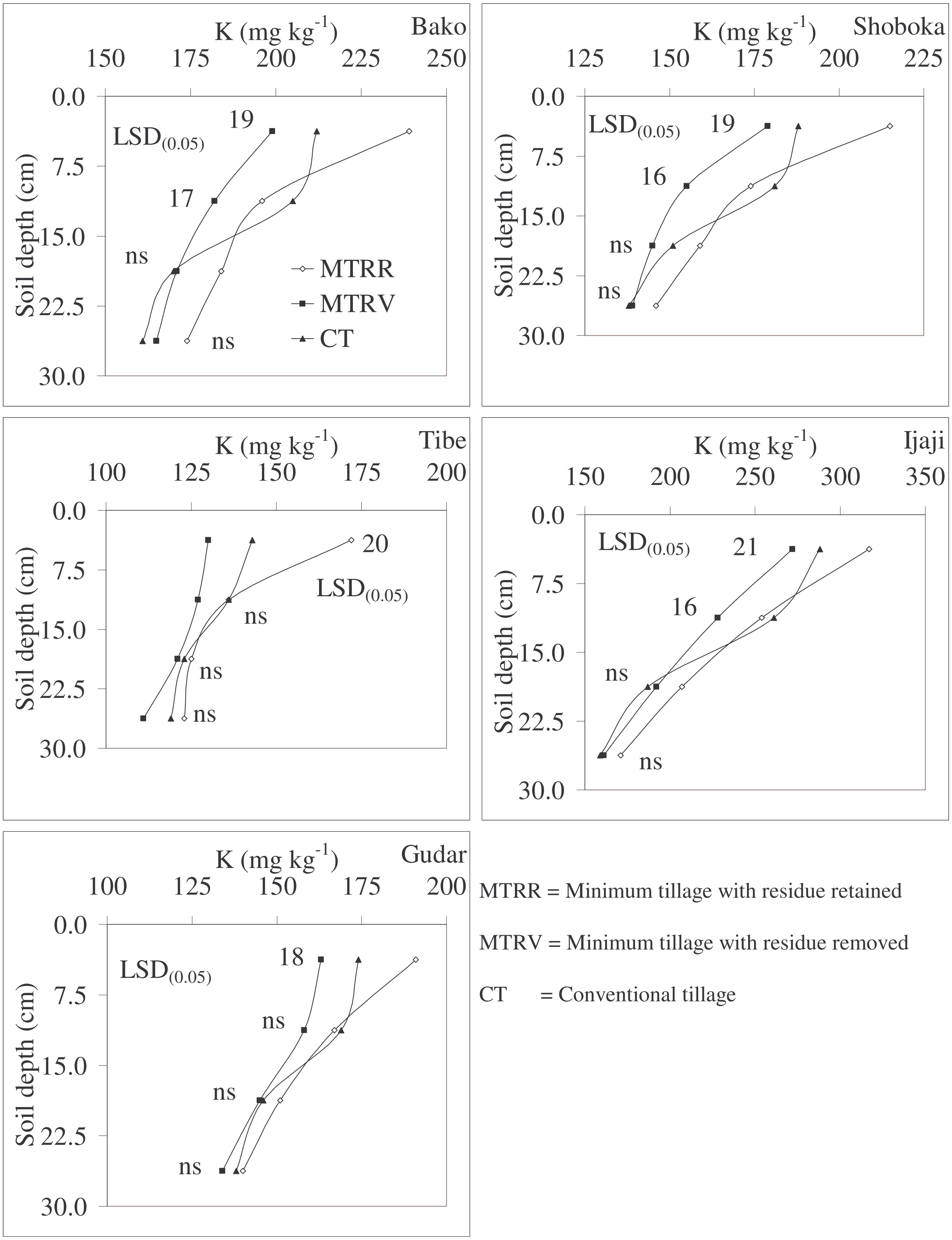


MTRR = Minimum tillage with residue retained

MTRV = Minimum tillage with residue removed

CT = Conventional tillage

Figure 4.15 Effect of tillage system on the exchangeable K of Nitisols as measured during 2000 to 2004 in the 0-30 cm layer at five sites.



MTRR = Minimum tillage with residue retained

MTRV = Minimum tillage with residue removed

CT = Conventional tillage

Figure 4.16 Effect of tillage system on the exchangeable K of Nitisols as measured at four depth intervals in 2004 at five sites.

4.4 Conclusions

Three contrasting tillage systems, viz. MTRR, MTRV and CT were applied for five consecutive years to study their effects on some physical and chemical properties of Nitisols. After five years the influence of the tillage systems on penetrometer resistance, pH, organic C, total N, extractable P and exchangeable K was confined to the upper 0-15cm which is the plow layer. In comparison with CT, MTRR resulted in a higher penetrometer resistance and lower pH which is alarming since both of them should be managed carefully for sustainable cropping. However, MTRR resulted in higher contents of organic C, total N, extractable P and exchangeable K which is reassuring since all of them can be very beneficial to sustainable cropping.

Application of N fertilization at three rates, viz. 69, 92 and 115 kg ha^{-1} for five consecutive years showed profound effects on pH, organic C and total N. Increasing levels of N application decreased pH and increased both organic C and total N irrespective of tillage system.

Based on these results replacement of CT with MTRR should be beneficial to soil quality in the study area if care is taken of the acidification that coincide with it. In addition proper fertilization of N, P and K is of utmost importance to benefit from the introduction of MTRR. However, MTRV is not an option at all to replace CT from a soil quality point of view.

CHAPTER 5

EFFECT OF TILLAGE SYSTEM, RESIDUE MANAGEMENT AND NITROGEN FERTILIZATION ON USAGE OF APPLIED NITROGEN BY MAIZE

5.1 Introduction

The physical mixing of soil, residues and fertilizers with moldboard plowing resulting in a homogenous plow layer is typical of conventional tillage. In comparison minimum tillage is characterized by almost undisturbed topsoil with abundant residues and hence nutrients near the surface. Several studies showed therefore that these two extreme tillage systems had a significant influence on the dynamics of nutrients and hence their availability to crops (Blevins *et al.*, 1983b; Hargrove, 1985; White, 1990; Ismail *et al.*, 1994).

The retention of residues on the surface as with minimum tillage usually enhances the maintenance of organic matter in soils. This is due to the fact that the micro-environment in the residue-covered soils is less oxidative than where residues are removed. However, organic matter through its positive influence on several soil properties is of great importance for soil and water conservation. The resulting effect is better conditions for crop growth and therefore more efficient usage of nutrients like N by crops (Hooker and Schepers, 1984; Thomas and Frye, 1984; Fox and Bandel, 1986; Griffith *et al.,* 1986).

Nitrogen is probably the nutrient most affected by tillage systems and the concomitant management of residues and fertilizers. The disturbance of soil and incorporation of residues that coincide with conventional tillage promote the mineralization of organic N resulting in more plant available N (Arnon, 1975; Dowdell and Cannell, 1975; Powlson, 1980; House *et al.,* 1984). On the long-term therefore, a depletion of the soil N reservoir is often observed with conventional tillage while the opposite is observed with minimum tillage (Lal, 1976a; Blevins *et al.*, 1977; Rice *et al.,* 1986; White, 1990; Ismail *et al.,* 1994).

In several studies it has been shown that tillage systems affect N uptake by maize. Kitur *et al.* (1984) and Meisinger *et al.* (1985) reported greater N uptake by conventional than minimum tilled maize at low N fertilization rates but the reverse at high N fertilization rates. The lower N uptake by minimum tilled maize at low N fertilization rates was attributed to increased immobilization in the minimum tilled soils and/or increased mineralization in the conventional tilled soils. In a three year study Moschler and Martens (1975) found that N uptake by maize correlated well with yield regardless of tillage system. However, at low N fertilization rates more N was removed by conventional tilled maize than was applied. Based on grain yield, minimum tillage increased the efficiency of applied N by 19.1% at high N fertilization rates. Researchers like Hargrove (1985) showed the N status of maize grown under minimum tillage was equal or superior to those grown under conventional tillage. Similarly, Thomas and Frye (1984) reported that the actual N uptake by maize grown under conventional and minimum tillage does not vary except with yield. If the yields are matching, there will be no difference in the N requirement of maize between the two systems. It seems therefore that N is used more efficiently by minimum than conventional tilled maize when properly fertilized (Bennett *et al.,* 1975; Moschler and Martens, 1975; Phillips *et al.*, 1980).

However, the efficiency of applied N by crops remains low throughout the world and ranges from 30 to 76 % with an approximate average of 50% (Kundler, 1970; Legg *et al.*, 1979; Meisinger *et al.*, 1985; Simonis, 1988; Rao, *et al.*, 1993). Thus, any effort to increase the efficacy of applied N in cropping systems would be advantageous for food security and environmental well being.

In western Ethiopia the integrated effects of tillage systems, residue management and N fertilization on the usage of applied N have not been studied. Hence, this study was initiated to examine these effects in particular when maize is planted on Nitisols.

5.2 Materials and methods

This study was conducted on the maize experiments described earlier and details on them can be found in Section 3.2.1 to 3.3.3. However, for the sake of convenience a concise description is given. The experiments were conducted on Nitisols at Bako, Shoboka, Tibe, Ijaji and Gudar in western Ethiopia from 2000 until 2004. At each of the five sites an experiment was laid out in a randomized complete block design with three replications. Three tillage systems (MTRR = minimum tillage with residue retention, MTRV = minimum tillage with residue removal and CT = conventional tillage) and three N fertilization levels (recommended rate of 92 kg N ha^{-1} and 25% less and 25% more than this rate) were combined in complete factorial arrangement. The experimental plots were kept permanent to observe the carry-over effects of the treatments for the five cropping seasons.

Representative grain and stover samples from the harvest area of all plots at every site were collected to determine their N contents. The stover was chopped into smaller pieces before the grain and stover were dried, powdered and stored for analysis. A standard steam distillation procedure was used for the determination of N after the samples were digested in sulfuric acid (Hesse, 1971).

The N uptake by grain (GNU) and stover (SNU) for all plots at every site were calculated using the relevant yields and N contents and hence that of total biomass by summation of GNU and SNU. Then the N agronomic efficiency (NAE), N recover efficiency (NRE) and N physiological efficiency (NPE) were calculated as noted by Bock (1984):

$$NAE = \frac{(Y_i - Y_{i-1})}{(N_i - N_{i-1})} \tag{5.1}$$

$$NRE = \frac{(NR_i - NR_{i-1})}{(N_i - N_{i-1})} \quad * \quad 100 \tag{5.2}$$

$$NPE = \frac{(Y_i - Y_{i-1})}{(NR_i - NR_{i-1})} \tag{5.3}$$

where, Y_i and Y_{i-1} represent grain dry matter yield and NR_i and NR_{i-1} N uptake by total biomass at Ni and Ni-1 levels of fertilizer N application.

The data were analyzed using the MSTATC statistical package (Michigan State University, 1989). Means for each parameter were separated by the least significant difference (LSD) test at P = 0.05.

5.3 Results and discussion

A summary on the analyses of variance indicating the effects of the treatment factors on the N content and uptake of maize is presented in Table 5.1. The results showed that there were in some instances significant differences among sites, years, tillage systems and N fertilization regarding grain and stover N content as well as grain, stover and total biomass N uptake. Significant interactions were almost absent and therefore the effects of tillage system and N fertilization will be presented for every site and year.

Table 5.1 Summary of analyses of variance indicating the effects of the treatment factors on the content and uptake of N by maize

Factors	Grain N	Stover N	GNU	SNU	TNU
Site (S)	ns	*	*	*	*
Year (Y)	*	ns	*	ns	*
Tillage (T)	*	ns	*	*	*
Nitrogen (N)	ns	ns	*	ns	*
S x Y	ns	ns	ns	ns	*
S x T	ns	ns	ns	ns	ns
S x N	ns	ns	ns	ns	ns
Y x T	ns	ns	ns	ns	*
Y x N	ns	ns	ns	ns	ns
T x N	ns	ns	ns	ns	ns
Y x T x N	ns	ns	ns	ns	ns
S x Y x T	ns	ns	ns	ns	ns
S x Y x N	ns	ns	ns	ns	ns
S x Y x T x N	ns	ns	ns	ns	ns

5.3.1 Nitrogen content of grain and stover

As shown in Table 5.1 tillage systems significantly influenced the N content of the grain but not that of the stover. Neither the N content of the grain nor that of the stover was significantly affected by N fertilization. However, all of these data are presented in Tables 5.2 to 5.5 since firstly, it forms the basis for the calculation of N uptake and use efficiency and secondly, there were definite trends due to the treatments.

5.3.1.1 Effect of tillage systems

The N content of the grain was consistently greater with MTRR than with either CT or MTRV during the five year period, with significant differences occurring in 14 out of 25 instances (Table 5.2). On average across years, the N content of the grain was between 5.4% at Gudar to 9.8% at Bako higher in the MTRR than CT system. This result suggests that more N was mineralized with MTRR than with CT since similar rates of N were applied.

In several studies it was found that the grain N content is much higher with crops grown under minimum tillage than with crops grown under conventional tillage (Angle *et al.,* 1993). Other studies showed that minimum tillage increased the grain N content only slightly compared to conventional tillage (Halvorson *et al.*, 2001; Sainju and Singh, 2001), while Olson and Kurtz (1982) and Mehdi *et al.* (1999) reported a higher grain N content under conventional than minimum tillage system. These discrepancies are attributed by Fox and Bandel (1986) to the fact that there is usually a peak of mineralization in conventional tilled soil immediately after plowing when the soil has been disturbed and aerated. However, during the latter part of the growing season mineralization is more prominent in minimum tilled soil due to greater water availability.

Generally as in this study also, minimum tillage with residue retention in comparison with conventional tillage has been shown to produce higher concentrations of total N in the surface layer of soil, which may enhance availability and uptake of N by plants. The uptake of N by plants from soil is also enhanced by a higher water content that is maintained with minimum tillage (Griffith *et al.,* 1986). Doran *et al.* (1984) and Linn and Doran (1984) reported that especially mineralization and hence nitrification benefit from the higher water content in minimum tilled soil.

Table 5.2 Effect of tillage system (MTRR = minimum tillage with residue retention, MTRV = minimum tillage with residue removal and CT = conventional tillage) on grain N content (%) of maize for the different sites and years. Means within a column for each site followed by the same or no letter(s) are not significantly different at 5% probability

Sites	Tillage system	Years					
		2000	2001	2002	2003	2004	Mean
Bako	MTRR	1.36a	1.50a	1.39a	1.52a	1.53a	1.46a
	MTRV	1.27ab	1.40b	1.26b	1.40b	1.39b	1.35ab
	CT	1.25b	1.36b	1.27b	1.40b	1.38b	1.33b
Shoboka	MTRR	1.32	1.46a	1.35a	1.49	1.46a	1.42a
	MTRV	1.28	1.37ab	1.22b	1.39	1.35b	1.32b
	CT	1.26	1.33b	1.22b	1.37	1.37ab	1.31b
Tibe	MTRR	1.29	1.40	1.39a	1.49a	1.46a	1.41a
	MTRV	1.21	1.31	1.26b	1.34b	1.32b	1.29b
	CT	1.24	1.35	1.24b	1.39ab	1.35b	1.31ab
Ijaji	MTRR	1.33	1.46a	1.38a	1.44	1.43	1.41
	MTRV	1.25	1.37ab	1.27b	1.33	1.36	1.32
	CT	1.25	1.33b	1.24b	1.39	1.35	1.31
Gudar	MTRR	1.28	1.37	1.32	1.48a	1.38	1.37
	MTRV	1.19	1.38	1.22	1.36b	1.29	1.29
	CT	1.21	1.31	1.26	1.41ab	1.30	1.30

Inspection of Table 5.3 shows that with the exception of Gudar in 2002 no significant differences were obtained in stover N content as a result of the tillage systems applied. Unlike grain N, stover N was enhanced by MTRV and CT as compared to MTRR. This observation suggests that in the case of CT and MTRV there was sufficient N supply for vegetative growth but the translocation of N from the vegetative to reproductive tissue was inhibited during the grain filling period probably due to water stress.

Table 5.3 Effect of tillage system (MTRR = minimum tillage with residue retention, MTRV = minimum tillage with residue removal and CT = conventional tillage) on stover N content (%) of maize for the different sites and years. Means within a column for each site followed by the same or no letter(s) are not significantly different at 5% probability

Sites	Tillage system	Years					
		2000	2001	2002	2003	2004	Mean
Bako	MTRR	0.45	0.48	0.56	0.52	0.52	0.51
	MTRV	0.47	0.53	0.59	0.58	0.54	0.54
	CT	0.49	0.47	0.56	0.54	0.50	0.51
Shoboka	MTRR	0.46	0.45	0.52	0.49	0.54	0.49
	MTRV	0.53	0.44	0.55	0.51	0.58	0.52
	CT	0.51	0.45	0.51	0.47	0.54	0.50
Tibe	MTRR	0.53	0.51	0.59	0.62	0.61	0.57
	MTRV	0.60	0.57	0.64	0.69	0.69	0.64
	CT	0.62	0.57	0.58	0.65	0.58	0.60
Ijaji	MTRR	0.52	0.53	0.58	0.62	0.57	0.56
	MTRV	0.55	0.61	0.63	0.65	0.65	0.62
	CT	0.55	0.54	0.60	0.64	0.58	0.58
Gudar	MTRR	0.63	0.58	0.55b	0.62	0.60	0.59
	MTRV	0.64	0.67	0.68a	0.65	0.66	0.66
	CT	0.65	0.64	0.69a	0.69	0.63	0.66

Chevalier and Schrader (1977) stated that maize plants accumulate a large amount of N in the stover during the vegetative growth phase and during grain filling this stored N is translocated to the developing seeds. Any stress that the plants experienced during grain filling would inhibit the translocation of the stored N which is the main source of N in the seeds. The N taken up by maize plants after anthesis usually provide a minor contribution to the N content of seeds although it is generally mobilized directly to seeds (Hanway, 1962a,b; Beauchamp *et al.,* 1976).

5.3.1.2 Effect of N fertilization

The effect of N fertilization on the N content of grain and stover is displayed in Tables 5.4 and 5.5, respectively. Irrespective of site or year, increasing levels of N application resulted in higher grain N contents though not significant. A similar trend was also observed for stover N content.

5.3.2 Nitrogen uptake by grain, stover and total biomass

The uptake of N by grain, stover and total biomass was significantly influenced by tillage systems (Table 5.1). However, N fertilization affected only grain and total biomass N uptake significantly.

5.3.2.1 Effect of tillage system

Grain N uptake (Table 5.6), stover N uptake (Table 5.7) and total biomass N uptake (Table 5.8) were from 2002 consistently greater with MTRR than with either MTRV or CT though not significant in all instances. The difference in the N uptake recorded between MTRR and CT every year at all sites can be attributed in the case of grain to a higher yield and N content and in the case of stover to a higher yield only. This observation suggests in the case of MTRR a more favourable soil environment leading to more vigorous vegetative growth and hence a higher N demand by the maize crop. However, N uptake varied over years regardless of tillage system due to prevailing climate (Table 3.1). In the more favourable years for maize production, namely 2000 and 2004 N uptake was larger than the other three years.

Table 5.4 Effect of N fertilization on grain N content (%) of maize for the different sites and years. Means within a column for each site followed by the same or no letter(s) are not significantly different at 5% probability

Sites	N levels (kg/ha)	Years 2000	2001	2002	2003A	2004	Mean
Bako	69	1.28	1.39	1.27	1.42	1.40	1.35
	92	1.28	1.42	1.33	1.44	1.44	1.38
	115	1.32	1.45	1.33	1.47	1.46	1.40
Shoboka	69	1.26	1.35	1.21	1.37	1.34	1.30
	92	1.29	1.39	1.26	1.41	1.39	1.35
	115	1.32	1.42	1.33	1.46	1.44	1.39
Tibe	69	1.23	1.31	1.25	1.32	1.33	1.29
	92	1.24	1.35	1.29	1.41	1.39	1.34
	115	1.27	1.40	1.34	1.49	1.41	1.38
Ijaji	69	1.26	1.35	1.24	1.34	1.33	1.30
	92	1.28	1.40	1.30	1.38	1.38	1.35
	115	1.29	1.42	1.34	1.44	1.42	1.38
Gudar	69	1.21	1.32	1.21	1.39	1.26	1.28
	92	1.22	1.34	1.27	1.40	1.32	1.31
	115	1.26	1.39	1.31	1.46	1.40	1.36

Table 5.5 Effect of N fertilization on stover N content (%) of maize for the different sites and years. Means within a column for each site followed by the same or no letter(s) are not significantly different at 5% probability

Sites	N levels	Years					
	(kg/ha)	2000	2001	2002	2003	2004	Mean
Bako	69	0.45	0.47	0.55	0.54	0.49	0.50
	92	0.47	0.49	0.56	0.54	0.54	0.52
	115	0.49	0.52	0.60	0.56	0.54	0.54
Shoboka	69	0.49	0.41	0.51	0.47	0.51	0.48
	92	0.49	0.46	0.53	0.49	0.56	0.51
	115	0.52	0.48	0.54	0.51	0.59	0.53
Tibe	69	0.55	0.52	0.56	0.63	0.60	0.57
	92	0.59	0.55	0.61	0.65	0.62	0.60
	115	0.61	0.58	0.64	0.68	0.65	0.63
Ijaji	69	0.52	0.52	0.58	0.61	0.56	0.56
	92	0.53	0.56	0.60	0.63	0.60	0.59
	115	0.56	0.60	0.63	0.67	0.64	0.62
Gudar	69	0.62	0.60	0.61	0.61	0.58	0.60
	92	0.64	0.62	0.64	0.66	0.64	0.64
	115	0.66	0.67	0.67	0.69	0.66	0.67

Table 5.6 Effect of tillage system (MTRR = minimum tillage with residue retention, MTRV = minimum tillage with residue removal and CT = conventional tillage) on grain N uptake (kg ha^{-1}) of maize for the different sites and years. Means within a column for each site followed by the same or no letter(s) are not significantly different at 5% probability

Sites	Tillage system	Years					Mean
		2000	2001	2002	2003	2004	
Bako	MTRR	95.4a	86.5	82.0a	83.1a	95.5a	88.49a
	MTRV	89.1ab	85.0	72.9ab	64.9b	73.7b	77.7ab
	CT	78.8b	77.0	65.9b	67.4b	73.2b	72.5b
Shoboka	MTRR	92.9a	82.9a	75.0a	76.4a	85.7a	82.6a
	MTRV	88.0a	80.7a	58.0b	61.6b	68.9b	71.4b
	CT	75.4b	70.2b	60.1b	61.5b	67.3b	66.9b
Tibe	MTRR	78.2a	75.6	73.8a	73.2a	75.0a	75.2a
	MTRV	73.7ab	71.9	60.9b	54.6b	62.1b	64.6ab
	CT	68.5b	64.3	54.5b	59.8b	65.4b	62.5b
Ijaji	MTRR	91.3a	82.6a	76.9a	76.6a	84.8a	82.4a
	MTRV	84.8ab	78.9ab	66.9ab	59.1b	71.1b	72.2ab
	CT	76.4b	72.3b	58.5b	64.4b	72.8b	68.9b
Gudar	MTRR	77.1	66.1ab	69.9a	73.6a	65.1a	70.4
	MTRV	71.4	72.6a	57.2b	56.9b	53.0b	62.2
	CT	65.9	57.3b	57.6b	60.0b	60.8ba	60.3

Table 5.7 Effect of tillage system (MTRR = minimum tillage with residue retention, MTRV = minimum tillage with residue removal and CT = conventional tillage) on stover N uptake (kg ha^{-1}) of maize for the different sites and years. Means within a column for each site followed by the same or no letter(s) are not significantly different at 5%

Sites	Tillage system	Years					Mean
		2000	2001	2002	2003	2004	
Bako	MTRR	39.6	37.8ab	44.0	39.6	41.5	40.5
	MTRV	40.1	43.2a	41.8	36.3	34.4	39.1
	CT	37.2	31.0b	36.0	35.9	36.2	35.3
Shoboka	MTRR	40.0	34.2	39.8	37.0	40.6a	38.3a
	MTRV	44.3	35.2	36.5	30.2	35.3ab	36.3ab
	CT	38.2	28.9	30.8	29.7	26.8b	30.9b
Tibe	MTRR	42.3	37.6	40.8	42.8	47.1	42.1
	MTRV	48.9	42.9	38.5	38.8	42.8	42.4
	CT	46.9	37.1	31.0	42.4	39.8	39.5
Ijaji	MTRR	44.4	41.0ab	42.8	43.1	43.5	43.0
	MTRV	47.1	47.9a	42.3	37.5	40.4	43.1
	CT	39.7	34.6b	37.6	42.1	39.1	38.6
Gudar	MTRR	51.4	42.1	40.4	43.7	41.2	43.8
	MTRV	52.0	50.9	44.9	36.6	34.8	43.8
	CT	43.5	39.1	43.0	42.4	40.7	41.8

Table 5.8 Effect of tillage system (MTRR = minimum tillage with residue retention, MTRV = minimum tillage with residue removal and CT = conventional tillage) on total biomass N uptake (kg ha^{-1}) of maize for the different sites and years. Means within a column for each site followed by the same or no letter(s) are not significantly different at 5%

Locations	Tillage system	Years 2000	2001	2002	2003	2004	Mean
Bako	MTRR	135.0a	124.3a	126.0a	122.7a	137.0a	129.0a
	MTRV	129.2a	131.1a	114.7b	101.2b	108.0b	116.9b
	CT	116.0b	107.9b	101.9c	103.3b	109.4b	107.7b
Shoboka	MTRR	132.9a	117.1a	114.8a	113.3a	127.7a	121.2a
	MTRV	132.3a	115.8a	94.5b	91.8b	104.6b	107.8b
	CT	113.6b	99.2b	90.9b	91.2b	104.9b	100.0b
Tibe	MTRR	120.5	113.3	114.6a	116.0a	122.2a	117.3a
	MTRV	122.6	114.8	99.4b	93.4b	104.9b	107.0ab
	CT	115.4	101.4	85.5c	102.1b	105.3b	102.0b
Ijaji	MTRR	135.8a	123.7a	119.6a	119.6a	128.2a	125.4a
	MTRV	131.9a	126.8a	109.2ab	96.6b	111.5b	115.2ab
	CT	116.2b	106.8b	96.1b	106.6ab	111.9b	107.5b
Gudar	MTRR	128.5a	108.2b	110.2	117.3a	106.3a	114.1
	MTRV	123.5a	123.5a	102.1	93.5b	87.8b	106.1
	CT	109.4b	96.4b	100.6	102.5b	101.5a	102.1

Generally, the N uptake by total biomass in this study compares well with those reported by Hargrove (1985) and Gordon *et al.* (1993). The opinion of Legg *et al.* (1979); Hargrove (1985) and Meisinger *et al.* (1985) is that the larger total biomass and higher N uptake under minimum tillage is mainly due to a higher production potential. However, Staley and Perry (1995) feel that this phenomenon is mainly the result of a higher N availability.

In this study it seems that the availability of water and N contributed to the larger total biomass N uptake with MTRR than with either MTRV or CT. During the least favorable years for maize production, namely 2002 and 2003 the reduction in total biomass N uptake was more severe with CT and MTRV than with MTRR. This finding is supported by Gordon *et al.* (1993) who concluded that the availability of water and N are the main determinants of total biomass N uptake.

5.3.2.2 Effects of N fertilization

The effect of N fertilization on the uptake of N by grain, stover and total biomass is displayed in Tables 5.9, 5.10 and 5.11, respectively. In all instances N uptake increased with increasing levels of N application though not always significant. This phenomenon can be attributed mainly to the higher yields of grain and stover at the higher N levels. The N contents of the grain and stover were not affected to the same extent by an increase of N levels.

5.3.3 Nitrogen use efficiencies

As described in Section 5.2 three indices of N use efficiency (NUE) were calculated, viz. N agronomic efficiency (NAE), N recovery efficiency (NRE) and N physiological efficiency (NPE). The results for NAE, NRE and NPE are displayed for every site, year, tillage system and N level range in Table 5.12, 5.13 and 5.14, respectively.

Table 5.9 Effect of N fertilization on grain N uptake (kg ha^{-1}) of maize for the different sites and years. Means within a column for each site followed by the same or no letter(s) are not significantly different at 5% probability

Sites	N levels (kg ha^{-1})	Years					Mean
		2000	2001	2002	2003	2004	
Bako	69	79.2a	74.5a	66.6a	63.6a	72.9a	71.4a
	92	88.0ab	84.8ab	75.1ab	72.8ab	82.0b	80.5ab
	115	96.2b	92.1b	79.1b	79.0b	87.4b	86.7b
Shoboka	69	75.9a	69.1a	56.8a	58.1a	65.3a	65.0a
	92	86.2b	79.2b	64.6ab	67.3ab	75.1b	74.5b
	115	94.1b	85.5b	71.6b	74.1b	81.5b	81.3b
Tibe	69	64.8a	62.0a	57.1a	54.0a	59.3a	59.4a
	92	73.8b	71.1ab	63.3ab	62.9ab	69.4b	68.1ab
	115	81.8b	78.7b	68.8b	70.7b	73.9b	74.8b
Ijaji	69	75.8a	69.0a	61.0a	58.5a	67.4a	66.3a
	92	85.5b	79.3b	68.3ab	67.7ab	77.2b	75.6ab
	115	91.3b	85.5b	73.0b	73.9b	84.1b	81.5b
Gudar	69	63.5a	58.2a	55.4a	58.3a	51.6a	57.4a
	92	71.9ab	65.4ab	62.4ab	63.3ab	60.3ab	64.7ab
	115	79.1b	72.3b	66.9b	68.9b	66.9b	70.8b

Table 5.10 Effect of N fertilization on stover N uptake (kg ha^{-1}) of maize for the different sites and years. Means within a column for each site followed by the same or no letter(s) are not significantly different at 5% probability

Sites	N levels	Years					
	(kg/ha)	2000	2001	2002	2003	2004	Mean
Bako	69	36.1	34.4	37.8	34.4	33.9	35.3
	92	39.3	37.0	40.1	37.7	37.9	38.4
	115	41.6	40.5	43.9	39.6	40.3	41.2
Shoboka	69	38.3	29.2	33.1	29.0	34.7	32.9
	92	40.8	33.5	35.9	33.1	39.0	36.5
	115	43.4	35.6	38.1	34.8	41.6	38.7
Tibe	69	42.1	35.9	33.3	38.6	40.4	38.0
	92	46.8	39.6	37.5	41.6	42.9	41.7
	115	49.3	42.2	39.6	43.8	46.5	44.3
Ijaji	69	40.5	37.2	38.7	36.8	36.8	38.0
	92	43.1	41.0	41.6	41.3	41.1	41.6
	115	47.6	45.3	42.4	44.6	45.1	45.0
Gudar	69	46.2	39.2	39.8	36.7	35.9	39.6
	92	50.0	44.6	42.9	42.1	39.6	43.8
	115	50.7	48.4	45.6	43.8	41.2	46.0

Table 5.11 Effect of N fertilization on total biomass N uptake (kg ha^{-1}) of maize for the different sites and years. Means within a column for each site followed by the same or no letter(s) are not significantly different at 5% probability

Sites	N levels (kg/ha)	Years					Mean
		2000	2001	2002	2003	2004	
Bako	69	115.2a	109.0a	104.4a	98.0a	106.8a	106.7a
	92	127.3b	121.8b	115.3b	110.5b	119.9b	118.9b
	115	137.8b	132.6b	123.0b	118.6b	127.7b	127.9b
Shoboka	69	114.2a	98.3a	89.8a	87.1a	100.0a	97.9a
	92	127.0b	112.8b	100.5ab	100.4b	114.1b	111.0b
	115	137.5b	121.0b	109.8b	108.9b	123.1b	120.1b
Tibe	69	106.8a	97.9a	90.3a	92.6a	99.7a	97.5a
	92	120.6b	110.6b	100.8ab	104.5b	112.3b	109.8b
	115	131.1b	120.9b	108.4b	114.5b	120.3b	119.0b
Ijaji	69	116.3a	106.2a	99.6a	95.3a	104.2a	104.3a
	92	128.6b	120.4b	109.9ab	109.0b	118.3b	117.2b
	115	138.9b	130.8b	115.4b	118.5b	129.2b	126.6b
Gudar	69	109.7a	97.4a	95.2a	95.0a	87.5a	97.0a
	92	121.8b	110.0b	105.3ab	105.5ab	99.9ab	108.5ab
	115	129.8b	120.7b	112.5b	112.8b	108.1b	116.8b

5.3.3.1 Nitrogen agronomic efficiency

At every site NAE was higher at the lower than higher N level range for the same tillage treatment though not always significant (Table 5.12). The largest NAE was recorded with CT at the lower N level range and with MTRR at the higher N level range. Bock (1984) and Simonis (1988) reported a higher NAE for maize at low than at high N application.

In each year the NAE of CT and MTRV was higher at the lower than higher N level range. This trend is observed only from 2003 with MTRR. At the lower N level rangeof the MTRR

NAE differed only in 2002 and 2003 with CT the superior treatment. However, at the higher N level range NAE differed every year with the MTRR treatment superior. The recommended fertilization rate of 92 kg N ha^{-1} for conventional tilled maize is confirmed by the NAE results. This rate seems also sufficient for minimum tilled maize on the Nitisols.

Table 5.12 Effect of tillage system (MTRR = minimum tillage with residue retention, MTRV = minimum tillage with residue removal and CT = conventional tillage) on nitrogen agronomic efficiency (kg grain/kg N applied) for different sites, years and N level ranges

Tillage system	N range (kg ha^{-1})	Sites				
		Bako	Shoboka	Tibe	Ijaji	Gudar
MTRR	69 - 92	22.6	22.3	20.8	22.7	17.6
MTRV	69 - 92	24.6	22.0	18.9	22.5	20.7
CT	69 - 92	26.2	27.1	25.3	25.3	21.3
MTRR	92 - 115	19.4	16.6	16.7	17.3	13.1
MTRV	92 - 115	10.5	11.1	10.0	12.7	10.5
CT	92 - 115	12.6	12.3	13.1	12.2	8.8
LSD$_{(0.05)}$		5.9	7.0	5.8	5.0	6.5
Tillage system	**N range (kg ha^{-1})**	**Years**				
		2000	2001	2002	2003	2004
MTRR	69 - 92	28.6	23.2	15.5	16.5	22.5
MTRV	69 - 92	30.2	23.6	11.6	22.3	22.1
CT	69 - 92	29.0	24.3	25.2	23.8	22.9
MTRR	92 - 115	28.0	22.3	15.6	13.8	16.0
MTRV	92 - 115	11.4	12.0	5.4	13.0	11.3
CT	92 - 115	17.6	12.7	14.1	9.7	9.4
LSD$_{(0.05)}$		3.2	3.4	3.9	3.1	4.2

5.3.3.2 Nitrogen recovery efficiency

As displayed in Table 5.13 NRE was with a few exceptions at every site higher at the lower than higher N level range for the same tillage treatment though not always significant. The exceptions were with MTRR at Bako and Tibe where the NRE was almost similar for the two N level ranges. At the lower N level range the largest NRE was recorded with CT, followed by MTRV and then MTRR. However, at the higher N level range the largest NRE was obtained with MTRR, followed by either MTRV or CT.

In each year the NRE of CT and MTRV was higher at the lower than higher N level range. This trend is observed only from 2003 with MTRR. The largest NRE was recorded in the majority of years with CT at the lower N level range and with MTRR at the higher N level range.

The NRE varied irrespective of the N level range at all sites from 43 to 51% with MTRR, 30 to 55% with MTRV and 29 to 65% with CT. In all years regardless of the N level range the NRE varied from 35 to 56% with MTRR, 27 to 61% with MTRV and from 32 to 62% with CT. These values correspond well with the values reported by other researchers (Legg *et al.*, 1979; Meisinger *et al.*, 1985; Fox and Piekielek, 1993; Staley and Perry, 1995) which varied between 34 to 62% for conventional tillage and between 46 and 76% for minimum tillage.

5.3.3.3 Nitrogen physiological efficiency

The values for NPE are given in Table 5.14. At every site NPE was higher at the lower than higher N level range for the same tillage treatment though not always significant. A strong trend exists at both N level ranges of a larger NPE with MTRR than with MTRV and CT.

In each year NPE was for the same tillage treatment also higher at the lower than higher N level range though not always significant. At both N level ranges NPE tended to be larger with MTRR than with MTRV and CT.

It seems therefore that the translocation of N from the vegetative to reproductive tissue was more efficient in the case of MTRR. This phenomenon can probably be ascribed to a higher availability of water during the grain filling period (Moschler *et al.*, 1972; Bennett *et al.*, 1975; Moschler and Martens, 1975; Phillips *et al.*, 1980).

Table 5.13 Effect of tillage system (MTRR = minimum tillage with residue retention, MTRV = minimum tillage with residue removal and CT = conventional tillage) on nitrogen recovery efficiency (%) for different sites, years and N level ranges

Tillage	N range	Sites				
system	(kg ha^{-1})	Bako	Shoboka	Tibe	Ijaji	Gudar
MTRR	69 - 92	48.6	51.1	45.8	50.2	42.9
MTRV	69 - 92	54.1	55.4	54.0	53.6	51.3
CT	69 - 92	57.1	63.8	60.5	64.6	56.5
MTRR	92 - 115	49.1	44.5	45.6	43.0	35.7
MTRV	92 - 115	29.7	35.8	34.4	35.5	33.1
CT	92 - 115	38.5	38.5	41.2	36.0	29.0
LSD$_{(0.05)}$		14.9	13.9	12.3	9.6	13.2
Tillage	N range	years				
system	(kg ha^{-1})	2000	2001	2002	2003	2004
MTRR	69 - 92	50.3	55.1	36.7	40.1	56.4
MTRV	69 - 92	57.4	57.0	38.6	60.8	54.5
CT	69 - 92	56.9	62.0	61.5	60.5	61.7
MTRR	92 - 115	58.3	57.0	41.3	34.5	46.7
MTRV	92 - 115	31.5	38.9	26.5	36.8	34.8
CT	92 - 115	40.2	35.6	39.5	31.8	33.2
LSD$_{(0.05)}$		7.3	9.4	8.9	9.1	7.3

Table 5.14 Effect of tillage system (MTRR = minimum tillage with residue retention, MTRV = minimum tillage with residue removal and CT = conventional tillage) on nitrogen physiological efficiency (kg grain/kg N uptake) for different sites, years and N level ranges

Tillage system	N range (kg ha^{-1})	Sites				
		Bako	Shoboka	Tibe	Ijaji	Gudar
MTRR	69 - 92	47.0	44.0	45.2	45.3	40.7
MTRV	69 - 92	45.2	39.5	34.8	42.0	40.0
CT	69 - 92	46.2	42.6	41.8	39.3	38.0
MTRR	92 - 115	39.7	36.8	35.9	39.9	36.4
MTRV	92 - 115	34.6	30.4	29.2	35.2	32.0
CT	92 - 115	32.9	32.1	31.5	34.5	29.6
LSD$_{(0.05)}$		8.2	10.3	7.6	ns	8.5
Tillage system	N range (kg ha^{-1})	years				
		2000	2001	2002	2003	2004
MTRR	69 - 92	56.9	42.2	42.1	40.9	39.9
MTRV	69 - 92	53.0	41.2	29.9	36.5	40.8
CT	69 - 92	51.1	39.2	41.1	39.3	37.2
MTRR	92 - 115	48.3	39.4	38.2	39.8	34.0
MTRV	92 - 115	36.2	31.4	21.1	35.4	32.4
CT	92 - 115	44.1	35.3	35.6	30.7	27.9
LSD$_{(0.05)}$		8.9	ns	7.6	ns	6.8

5.4. Conclusions

The N status of maize grown under MTRR, as reflected in the N content of grain or stover, was equal or superior to that of maize grown under CT or MTRV. On account of this trend and the fact that grain and stover yields show a similar trend, uptake of N by the grain, stover and total biomass of maize were larger with MTRR than with either CT or MTRV.

The NAE, NRE and NPE for the same tillage treatment were higher at the lower N level range of 69 – 92 kg ha^{-1} than at the higher N level range of 92 – 115 kg ha^{-1}. At the lower N level range NAE and NRE were larger with CT than with the other two tillage systems. These two indices were larger with MTRR than with the other two tillage systems at the higher N level range. The NPE had a propensity at both N level ranges to be higher with MTRR than with MTRV and CT.

These results showed that the recommended fertilization rate of 92 kg N ha^{-1} for conventional tilled maize is also sufficient for minimum tilled maize in western Ethiopia. It seems that minimum tillage that coincide with residue retention enhanced the translocation of N from the vegetative to reproductive tissue during grain filling probably on account of more favorable soil conditions. The ultimate result was higher grain yield.

CHAPTER 6

FATE OF NITROGEN APPLIED TO MAIZE ON CONVENTIONAL AND MINIMUM TILLED NITISOLS

6.1 Introduction

Nitrogen is an essential nutrient for the growth and development of maize. This nutrient is taken up by maize in the form of either NH_4^+ or NO_3^-. Maize prefers NH_4^+ in the early growth stages and NO_3^- in the later growth stages (Dibb and Welch, 1976).

In most instances only a portion of the N required by maize for optimum yields can be supplied by the soil. The remaining N is therefore supplemented through the application of nitrogenous fertilizers. Unfortunately, recovery of applied N by maize is low and ranges from 30 to 76% with an approximate average of 50% (Kitur *et al.,* 1984; Meisinger *et al.,* 1985; Simonis, 1988).

Accordingly, management of N fertilization to maize has become increasingly important. Nitrogen is an expensive commodity required in large quantities by maize and can easily be lost from the soil-crop system resulting in that the full yield potential is not realized. Losses of N from soil-plant systems are of increasing concern to environmental pollution of both air and water (Thomas *et al.,* 1973; MacMahon and Thomas, 1976; Tyler and Thomas, 1977; Rice and Smith 1982). It is therefore very important to have proper knowledge on the fate of applied N in a soil-crop system for ensuring optimum yields with minimum pollution.

The fate of fertilizer N in a soil-crop system is affected by processes like mineralization, immobilization, nitrification, denitrification, leaching, volatilization and erosion. Conversion from conventional to minimum tillage usually changes the soil environment to such an extent that many of these processes are affected (Doran, 1980; Phillips *et al.,* 1980; Rice and Smith, 1983; Kitur *et al.,* 1984; Mesinger *et al.*, 1985; Fox and Bandel, 1986). It is evident that N recovery can be increased by reducing losses through leaching, denitrification and volatilization. In this regard the source (Balasubramanian and Singh, 1982; Mughogbo *et al.*, 1990; Malhi *et al.*, 1996;), rate (Jokela and Randall, 1997) and time of fertilizer application (Jokela and Randall, 1997; Gerwing *et al.*, 1979; Russelle *et al.*, 1981; Legg and Meisinger, 1982; Mughogbo *et al.*, 1990; Karlen *et al.*, 1996) as well as soil water conditions (Olsen, 1984; Pilbeam *et al.*, 1995) are also of great importance.

The recovery of applied N by a crop can be estimated directly by the isotopic method or indirectly by the difference method. Usually the difference method gives higher estimates of N uptake than the isotopic method (Hauck and Bremner, 1976). It is generally assumed that the isotopic method is the most accurate one (Harmsen and Moraghan, 1988) although very expensive to implement. Therefore, very useful information on the fate of applied N in a soil-plant system can be obtained with the isotopic method.

The fate of N applied to maize on conventional and minimum tilled Nitisols has not been studied in western Ethiopia. Hence, the objective of was to study the fate of applied N in the soil-crop system using labelled urea.

6.2 Materials and methods

This study was conducted on the maize experiments described earlier and details on them can be found in Section 3.2.1 to 3.3.3. However, for the sake of convenience a concise description is given. The experiments were conducted on Nitisols at Bako, Shoboka, Tibe, Ijaji and Gudar in western Ethiopia from 2000 until 2004. At each of the five sites an experiment was laid out in a randomized complete block design with three replications. Three tillage systems (MTRR = minimum tillage with residue retention, MTRV = minimum tillage with residue removal and CT = conventional tillage) and three N fertilization levels (recommended rate of 92 kg N ha^{-1} and 25% less and 25% more than this rate) were combined in complete factorial arrangement. The experimental plots were kept permanent to observe the carry-over effects of the treatments for the five cropping seasons.

The use of labeled N is expensive and therefore only three sites were selected for this study, viz. Bako, Tibe and Gudar. It was also decided to restrict the study to only the CT and MTRR plots fertilized at the recommended rate of 92 kg N ha^{-1}. In 2004 a 2.4 m^2 micro plot was demarcated in the center of every selected 24 m^2 macro plot. Labeled ^{15}N @ 5 atom % urea fertilizer was applied to the micro plots instead of unlabeled urea fertilizer which was applied as usual to the remaining part of the macro plots. The procedure, rate and time of N application were exactly the same as in the previous four years irrespective of the type of fertilizer used for this investigation.

At physiological maturity 0.4 m^2 of a micro plot was harvested for the determination of grain and stover yields. Representative grain and stover samples from the harvest area of every plot at all sites were collected to determine their N contents. The stover was chopped into smaller pieces before the grain and stover were dried, powdered and stored for analysis.

After harvesting a metal frame having the same dimensions as the harvest area of a micro plot was pushed into the soil to facilitate the removal of soil layers from the actual harvest area. Soil layers were removed at 15 cm intervals down to a depth of 90 cm. A core sample was collected for bulk density determination (Blake and Hartge, 1986) before the soil from each layer was spread on a plastic sheet and thoroughly mixed before sub samples were randomly collected to prepare a representative sample for every soil layer from a micro plot. These sub samples were thoroughly mixed, dried at room temperature sieved through a 2 mm screen and stored for analysis.

A standard steam distillation procedure was used for the determination of total N in the grain, stover and soil samples after they were digested in sulfuric acid (Hesse, 1971). The grain, stover and soil samples were also digested in sulfuric acid where after ^{15}N abundance was determined by mass spectrometry (Hauck, 1982).

The data from the micro plots were used in the calculations described below. Firstly, the percentage of labeled N recovery in the maize grain and stover (% $^{15}N\mathit{rm}$) was calculated using Equation 6.1 as described by Weinhold *et al.* (1995):

$$\%\ ^{15}Nrm = \frac{atom\ \ \%\ \ excess\ \ in\ \ sample}{atom\ \ \%\ \ excess\ \ in\ \ fertilizer} \ * \ 100 \qquad 6.1$$

Then the amount of grain and stover N derived from fertilizer (Ndff, kg ha^{-1}) and N derived from soil (Ndfs, kg ha^{-1}) were calculated using Equation 6.2 and 6.3:

$$Ndff = N\ uptake * \frac{\%\ {}^{15}Nrm}{100} \qquad 6.2$$

$$Ndfs = N\ uptake - Ndff \qquad 6.3$$

Lastly, N recovery efficiency (NRE, %) by the grain and stover were calculated using Equation 6.4 which is similar to that of Rao *et al.* (1992);

$$NRE = \%\ {}^{15}Nrm * \frac{N\ uptake}{N\ applied} \qquad 6.4$$

The percentage of labeled N recovery in the soil (% ^{15}N*rs*) was calculated using Equation 6.5 as described by Buresh *et al.* (1982).

$$\%\ {}^{15}Nrs = \frac{atom\ \%\ excess\ in\ sample}{atom\ \%\ excess\ in\ fertilizer} * A * 100 \qquad 6.5$$

$$where \quad A = \left[\frac{total\ soil\ N\ (g\ N\ g^{-1}\ soil) * bulk\ density\ (g\ cm^{-3})}{\%\ N\ in\ fertilizer * g\ fertilizer\ applied\ cm^{-2}}\right] * soil\ depth\ (cm)$$

Then the amount of N fertilizer remained in the soil (Nfrs, kg ha^{-1}) was calculated using Equation 6.6:

$$Nfrs = N\ applied * \frac{\%\ {}^{15}Nrs}{100} \qquad 6.6$$

The unit for N uptake and applied is kg ha^{-1}.

The data were analyzed using the MSTATC statistical package (Michigan State University, 1989). Means for each parameter were separated by the least significant difference (LSD) test at P = 0.05.

6.3 Results and discussion

6.3.1 Maize N derived from fertilizer and soil

A summary on the analysis of variance indicating the effects of the treatment factors on grain, stover and total biomass N derived from fertilizer (Ndff) and N derived from soil (Ndfs) as well as N use efficiency (NUE) by the grain, stover and total biomass is given in Table 6.1. The results show that in all instances but one, there were significant differences among sites and tillage systems regarding the parameters of concern. Significant interactions were almost absent and therefore the effects of tillage systems will be presented per site.

Table 6.1 Summary of analyses of variance indicating the effects of the treatment factors on grain, stover and total biomass N derived from fertilizer (Ndff) and soil (Ndfs) and N recovery efficiency (NRE) by grain, stover and total biomass

Factors	Ndff			Ndfs			NRE		
	Grain	Stover	Total biomass	Grain	Stover	Total biomass	Grain	Stover	Total biomass
Site (S)	ns	*	*	*	*	*	ns	*	*
Tillage (T)	*	*	*	*	*	*	*	ns	*
S x T	ns	ns	ns	*	ns	ns	ns	ns	ns

The amount of grain, stover and total biomass N derived from fertilizer and soil are presented in Table 6.2. Grain, stover and total biomass N derived from fertilizer was consistently larger with CT than MTRR at all three sites. On average for the MTRR and CT systems 28 vs. 32, 15 vs. 18 and 43 vs. 50 kg ha^{-1} fertilizer N were taken up by the grain, stover and total biomass, respectively. In a similar study with maize Kitur *et al.* (1984) found that fertilizer N uptake by grain, stover and total biomass from MTRR and CT systems amounted to 21 vs. 38, 12 vs. 15 and 33 vs. 53 kg ha^{-1}, respectively.

The grain, stover and total biomass N derived from soil was consistently larger with MTRR than CT at all three sites. On average for the CT and MTRR systems 33 vs. 49, 23 vs. 28 and 55 vs. 77 kg ha^{-1} soil N were taken up by the grain, stover and total biomass, respectively. Similar results were reported by Reddy and Reddy (1993).

Table 6.2 Effect of tillage system (MTRR = minimum tillage with residue retention, CT = conventional tillage) on grain, stover and total biomass N derived from fertilizer (Ndff) and soil (Ndfs) at Bako, Tibe and Gudar. Means within a column for each site followed by same or no letter(s) are not significantly different at 5% probability level

Sites	Tillage system	Ndff (kg ha^{-1}) Grain	Ndff (kg ha^{-1}) Stover	Ndff (kg ha^{-1}) Total biomass	Ndfs (kg ha^{-1}) Grain	Ndfs (kg ha^{-1}) Stover	Ndfs (kg ha^{-1}) Total biomass
Bako	MTRR	29.8a	15.9a	45.7a	56.7a	30.6a	87.4a
	CT	34.6b	19.4b	54.0b	36.1b	27.0b	63.1b
Tibe	MTRR	28.4a	15.5a	43.8a	49.9a	29.6a	79.4a
	CT	31.2a	18.9b	50.1b	31.3b	21.3b	52.6b
Gudar	MTRR	25.6a	13.7a	39.2a	41.0a	22.5a	63.6a
	CT	29.7b	16.3b	46.1b	30.4b	19.8a	50.2b

In the case of CT maize utilized 105 kg N ha^{-1} of which 48% was from the fertilizer and 52% from soil. The contribution of fertilizer was 36% and that of soil 64% to the 120 kg N ha^{-1} utilized by maize in the case of MTRR. These results suggest more mineralization of organic N in the MTRR than CT soils which coincide with the findings of Fox and Bandel (1986). The amount of N mineralized is determined to a large extent by the organic matter content of a soil (Rice *et al.,* 1986). On the longer term organic matter usually increases in MTRR soils and decreases in CT soils (Lal, 1976a; Blevins *et al.,* 1977; Blevins *et al.,* 1983b; White, 1990) as was the case in this study. Furthermore, the differences observed between CT and MTRR with regard to the contribution of soil N to maize may be attributed also to the substitution of ^{15}N for ^{14}N in the soil N pools (Varvel and Peterson, 1990; Rao et al., 1991). This effect would be probably more severe in soils with small N pools than in soils with large N pools.

As shown in Table 6.3 the NRE of grain, stover and total biomass was consistently larger with CT than MTRR. The maize grown on CT soils recovered at Bako, Tibe and Gudar respectively 59, 55 and 50% of the fertilizer N applied. Only 50, 48 and 43% of the fertilizer N was recovered by the maize grown on MTRR soils at Bako, Tibe and Gudar, respectively. These values are of the same range as those reported by Kitur *et al.* (1984) and Meisinger *et al.* (1985), viz. 42 to 62 for CT and 36 to 53% for MTRR. The higher recovery of fertilizer N by maize grown on the CT than MTRR soils can be attributed probably to a low N availability in the former soils. A high recovery of fertilizer N by the crop is frequently reported on soils that have a low N availability (Broadbent and Carlton, 1978; Roberts and Janzen, 1990).

Table 6.3 Effect of tillage system (MTRR = minimum tillage with residue retention, CT = conventional tillage) on nitrogen recovery efficiency (%) by maize at Bako, Tibe and Gudar. Means within a column for each site followed by same or no letter(s) are not significantly different at 5% probability level

Sites	Tillage system	Grain	Stover	Total biomass
Bako	MTRR	32.4a	17.3a	49.7a
	CT	37.6b	21.0b	58.6b
Tibe	MTRR	30.8	16.8a	47.6a
	CT	33.9	20.6b	54.5b
Gudar	MTRR	27.8a	14.9	42.7a
	CT	32.3b	17.8	50.1b

6.3.2 Fertilizer N remained in the soil

There was no marked difference between sites with respect to the fertilizer N that remained in the soil (Table 6.4). However, significant differences were recorded among tillage systems and depth intervals and their interaction.

Table 6.4 Summary of analysis of variance indicating the effects of the treatment factors on N fertilizer remained in the soil (Nfrs)

Factors	Nfrs	Factors	Nfrs
Site (S)	ns	S x D	ns
Depth (D)	*	D x T	*
Tillage (T)	*	S x D x T	ns

The amount of fertilizer N measured in the soil after harvesting of maize at Bako, Tibe and Gudar are given in Table 6.5. In the case of MTRR the amount of fertilizer N remained in the soil to 90 cm depth varied from 15.5 kg ha^{-1} at Tibe to 17.5 kg ha^{-1} at Gudar with an average of 16.2 kg ha^{-1}. Less fertilizer N was recorded to the same depth in the case of CT, viz. from 10.6 kg ha^{-1} at Tibe to 11.1 kg ha^{-1} at Bako and Gudar with an average of 10.9 kg ha^{-1}.

Most of this remaining fertilizer N was detected in the 0-15 cm soil layer, viz. 54% for MTRR and 57% for CT. The contribution of the 15-30 cm soil layer declined to 24% for MTRR and 33% for CT and that of 30-45 cm soil layer to 13% for MTRR and 7% for CT.

The remaining fertilizer N which was higher in the MTRR than CT soils was therefore confined to the upper 45 cm. This may be an indication that it was mainly in an organic form (Blevins *et al.,* 1983b, Reddy and Reddy, 1993) which is not much subjected to leaching. As shown in Chapter 4 the organic matter content of the MTRR soils was in 2004 substantially higher in the upper 20 cm than that of the CT soils.

Table 6.5 Effect of tillage system (MTRR = minimum tillage with residue retention, CT = conventional tillage) on N fertilizer remained in soil (Nfrs, kg ha^{-1}) at Bako, Tibe and Gudar. Means within a column for each site followed by same or no letter(s) are not significantly different at 5% probability level

Soil depth	Bako		Tibe		Gudar	
(cm)	MTRR	CT	MTRR	CT	MTRR	CT
0-15	8.7a	6.0a	8.5a	6.2a	9.3a	6.3a
15-30	3.1b	3.8b	3.6b	3.2b	4.7b	3.8b
30-45	1.9c	0.8c	2.3c	1.0c	2.1c	0.7c
45-60	1.0cd	0.3c	0.8d	0.2d	1.0d	0.3c
60-75	0.6d	0.1c	0.3d	0.0d	0.4de	0.0c
75-90	0.4d	0.0c	0.0d	0.0d	0.0e	0.0c
Total	15.6	11.1	15.5	10.6	17.5	11.1

6.3.3 Nitrogen balance of applied urea fertilizer

The N balances of the applied urea fertilizer at Bako, Tibe and Gudar are displayed in Table 6.6. No significant differences were calculated among sites and tillage systems for the N balances. However, there are clear trends worth mentioning.

Inspection of Table 6.6 shows that maize on MTRR soils recovered less fertilizer N than maize on CT soils irrespective of the sites, viz. on average 43 vs. 50 kg N ha^{-1}. As a result of this phenomenon more fertilizer N was detected in the MTRR than CT soils regardless of the site, viz. on average 16 vs. 11 kg N ha^{-1}. Therefore the unaccounted fertilizer N in the MTRR and CT systems was almost similar per site, viz. on average 33 vs. 31 kg N ha^{-1}. The unaccounted fertilizer N is probably lost through volatilization, leaching or denitrification prior to harvesting.

Table 6.6 Effect of tillage system (MTRR = minimum tillage with residue retention, CT = conventional tillage) on the N balance of applied urea fertilizer (kg N ha^{-1}) at Bako, Tibe and Gudar

Tillage system	Components	Bako	Tibe	Gudar
MTRR	Maize	45.7	43.8	39.2
	Soil	15.6	15.5	17.5
	Unaccounted	30.7	32.7	35.3
CT	Maize	53.9	50.1	46.1
	Soil	11.1	10.6	11.1
	Unaccounted	27.0	31.3	34.8

6.4 Conclusions

The fate of N applied to maize on CT and MTRR soils was investigated using labeled urea at a rate of 92 kg N ha^{-1}. Grain, stover and total biomass N derived from fertilizer was larger with CT than MTRR and the reverse was observed with fertilizer N remained in the soil. The fertilizer N remained in the soil after harvesting was higher with MTRR than CT and in both systems mainly confined to the upper 45 cm layer. The fate of fertilizer N was in MTRR: 47% recovered by maize, 17% remained in the soil and 36% unaccounted for and in CT: 54% recovered by maize, 12% remained in soil and 34% unaccounted for.

CHAPTER 7

COMPARISON OF MAIZE GENOTYPES FOR NITROGEN UPTAKE AND USE EFFICIENCY

7.1 Introduction

Nitrogen is the most limiting factor in the production of maize in Ethiopia. In the western part of the country maize is mostly grown by resource-poor farmers on Nitisols low in N. This leads to low and unstable maize production, and consequently reduces income and food security.

Usually, potentially high yielding maize genotypes are selected under well-fertilized conditions where N supply is sufficient. These genotypes may not perform well under poor-fertilized conditions where N supply is insufficient (Lafitte and Edmeades, 1994a; Pixley *et al.*, 1995; Bänziger *et al.*, 1997). The latter conditions are very common where small-scale farmers plant maize.

Until now very little effort was made in developing maize genotypes that suit the needs of small-scale farming systems. Small-scale farmers seldom have the financial resources or available technology to exploit their environmental potential, or to rectify the production constraints such as N deficiencies. Perhaps the most attractive alternative is to select or breed maize genotypes that are efficient in utilizing N at both low and high N levels (Short, 1991; Smith *et al.*, 1995).

Some researchers (Laffite and Edmeades, 1994a; Bänziger *et al.*, 1997) reported that there is sufficient genetic variability to select or breed maize genotypes that can perform well on soils with low N supplying capacities. The use of maize genotypes with such abilities will not only be cost effective but also of sustainable value as pointed out by Coffman and Smith (1991). It is a matter of fitting these genotypes to the environment instead of altering the environment by adding fertilizer N.

In its international maize trials, the International Maize and Wheat Improvement Center (CIMMYT) has developed genotypes that are considered to be able to yield well under both low and high N soil fertility conditions (Bänziger *et al.*, 1997). Small-scale farmers in western Ethiopia can benefit if some of these CIMMYT genotypes are introduced into their farming systems. Unfortunately, detailed information on the N uptake and use efficiency of the CIMMYT genotypes are largely missing.

Hence, this study was conducted firstly to identify maize genotypes that would yield well at both low and high N soil fertility conditions and secondly to compare their N uptake and use efficiency across a range of N levels.

7.2 Materials and methods

The experiments ware conducted on the Nitisols at Bako, Shoboka, Tibe, Ijaji and Gudar in western Ethiopia during the 2004 growing season. Concise descriptions of the five experimental sites regarding their locations, climatic conditions and soil properties are given in Section 3.2.1 and therefore not repeated here.

At every site two experiments viz. one with open-pollinated genotypes and the other with hybrid genotypes were laid out in a randomized complete block design with three replications. In each of these experiments five open-pollinated or hybrid maize genotypes and six N fertilization levels were combined in complete factorial arrangement. The open-pollinated and hybrid genotypes used are listed in Table 7.1. Each group consists of four CIMMYT genotypes and a local genotype as control. Selection of the CIMMYT genotypes was based on their yield response to low and high N conditions at Bako research center in a preliminary study. The fertilization levels ranged from 0 to 230 kg N ha^{-1} with 46 kg N ha^{-1} intervals.

Urea and triple super phosphate were used as N and P sources, respectively. Half of the urea was applied at planting and the remaining half at 35 days after sowing when maize was at knee-height. The triple super phosphate was applied at the recommended rate of 20 kg P ha^{-1} in a band at planting. All other cultural practices like seedbed preparation, planting dates and weed control were standard as described for conventional tillage in Section 3.3.3. The plant density aimed for was 50000 plants per hectare as the plots consisted of six rows of 5.0 m in length and the inter- and intra-row spacing were 0.8 and 0.25 cm, respectively.

Table 7.1 List of open-pollinated and hybrid maize genotypes used in the experiments at the five sites

Open-pollinated	Source	Hybrids	Source
Ecaval 1	CIMMYT	CML388/CML202/CML384	CIMMYT
Ecaval 2	CIMMYT	CML373/CML202/CML384	CIMMYT
Ecaval 5	CIMMYT	LPSC3H44/CML202/CML380	CIMMYT
Ecaval 14str	CIMMYT	TUXPSEQ/CML202/CML384	CIMMYT
Kulani	Local	BH 540	Local

Data on grain and stover yields were obtained from the central four rows of each plot. Grain yield was adjusted to 12.5% moisture content. Total biomass was calculated as the sum of the grain and stover yields.

Representative grain and stover samples from the harvest area of all plots at every site were collected to determine their N contents as described in Section 5.2. The N uptake by the grain (GNU) and stover (SNU) for all plots at every site was calculated using the relevant dry matter yields and N contents and hence that of total biomass by summation of GNU and SNU. Then the N agronomic efficiency (NAE), N recovery efficiency (NRE) and N physiological efficiency (NPE) were calculated for five N level ranges using Equation 5.1, 5.2 and 5.3, respectively.

Experimental data were analyzed using the MSTATC statistical package (Michigan State University, 1989). Means for each parameter were separated by the least significant difference (LSD) test at P = 0.05.

7.3 Results and discussion

Only the results of grain yield and total biomass N uptake will be presented because these two parameters were used in the calculation of NAE, NRE and NPE of the maize genotypes. A summary of analysis of variance indicating the effects of the treatment factors on the mentioned parameters are given in Table 7.2. The parameters differed significantly among sites, genotypes and N applications with a few exceptions. Interactions of site by genotypes as well as genotypes by N application were also significant with regard to most of the parameters.

Table 7.2 Analysis of variance indicating the effects of the treatment factors on grain yield (GY), total biomass N uptake (TBNU), N agronomic efficiency (NAE), N recovery efficiency (NRE) and N physiological efficiency (NPE)

Factors	Open-pollinated					Hybrids				
	GY	TBNU	NAE	NRE	NPE	GY	TBNU	NAE	NRE	NPE
Sites (S)	*	*	ns	*	ns	*	*	*	*	*
Genotype (G)	*	*	*	*	*	*	*	*	*	*
Nitrogen (N)	*	*	*	*	*	*	*	*	*	*
S x G	*	*	*	*	ns	*	*	*	*	ns
G x N	*	*	*	*	ns	*	*	*	ns	ns
S x N	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
S x G x N	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

* - $P \leq 0.05$, ns - not significant

7.3.1 Grain yield

The average grain yields of open-pollinated and hybrid genotypes at the five sites are shown in Table 7.3. Grain yield of all genotypes increased progressively with higher N application rates and the highest yields were recorded at the 230 kg N ha^{-1} level. This effect was most prominent with the first increment of N application and then declined gradually with subsequent increments of N application. These trends in grain yield were similar to that reported by other researchers (Balko and Russel, 1980; Muruli and Paulsen, 1981; Akintoye *et al.*, 1999).

On average the grain yield of the open-pollinated genotypes increased with a factor of 1.78 from 3071 kg ha^{-1} at the 0 kg N ha^{-1} level to 5466 kg ha^{-1} at the 230 kg N ha^{-1} level. The yield increase factor for the local genotype Kulani was 1.70 and that of the CIMMYT genotypes ranged from 1.70 for Ecaval 2 and Ecaval 14str to 1.92 for Ecaval 1. Grain yield of the hybrid genotypes increased on average with a factor of 2.06 from 3092 kg ha^{-1} at the 0 kg N ha^{-1} level to 6355 kg ha^{-1} at the 230 kg N ha^{-1} level. The yield increase factor for the local genotype BH 540 was 2.12 and that of the CIMMYT genotypes ranged from 1.80 for LPSC3H144/CML202/CML380 to 2.31 for TUXPSEQ/CML202/CML384.

Ransom *et al.* (1993) and Pixley *et al.* (1995) stated that N use efficient genotypes are those genotypes that yield well at both low and high N soil fertility conditions, whereas N use inefficient genotypes are those that yield well only at high N soil fertility conditions. Therefore, without considering significant differences the genotypes were ranked based on the grain yield realized at the lowest and highest N levels, viz. 0 and 230 kg N ha^{-1} (Table 7.4). At these two N levels the ranking of seven genotypes were inconsistent. Only the two open-pollinated genotypes Ecaval 5 and Kulani and one hybrid genotypes TUXPSEQ/ CML202/ CML384 ranked similar at the two N levels, viz. either 4 or 5. These low rankings disqualify them for recommendation to resource-poor farmers.

The differential response of maize genotypes to N application is common (Lafitte and Edmeades, 1994a; Bänziger *et al.*, 1997). However, inspection of Table 7.3 shows that at the 0 kg N ha^{-1} level three open-pollinated genotypes as well as three hybrid genotypes yielded the best with no significant differences between them. They are the open-pollinated genotypes Ecaval 1, Ecaval 2 and Ecaval 14str, and the hybrid genotypes CML388/ CML202/CML384, CML373/CML202/CML384 and LPSC3H/CML202/CML380. Of these genotypes Ecaval 1 and CML373/CML202/CML384 yielded significantly the best at the 230 kg N ha^{-1} level. Consequently, only Ecaval 1 and CML373/CML202/CML384 can be regarded as N use efficient genotypes as they were able to perform outstandingly well at both the 0 and 230 kg N ha^{-1} level. These two genotypes yielded on average 5.9% at the lowest N level and 17.5% at the highest N level better than the two local genotypes, viz. Kulani and BH 540. Therefore, these two N use efficient genotypes qualify for recommendation to resource-poor farmers.

Table 7.3 Effect of N fertilization on the grain yield of open-pollinated and hybrid maize genotypes. Means within a column for each group followed by the same or no letter(s) are not significantly different from each other at 5 % probability level.

Genotypes	N levels (kg ha^{-1})					
	0	46	92	138	184	230
Ecaval 1	3145ab	4348b	5158a	5645a	5913a	6051a
Ecaval 2	3363a	4649a	5212a	5520ab	5653ab	5728b
Ecaval 5	2601c	3760c	4309b	4588c	4774c	4873c
Ecaval 14str	3247ab	4343b	4941a	5285b	5484b	5542b
Kulani	2999b	4082b	4576b	4852c	5030c	5107c
CML388/CML202/CML384	3506a	4803a	5667a	6239b	6580b	6667b
CML373/CML202/CML384	3194ab	4674ab	5770a	6636a	7123a	7403a
LPSC3H/CML202/ CML380	3344a	4455bc	5277b	5678c	5901c	6018c
TUXPSEQ/CML202/CML384	2428c	3507d	4322c	4888d	5195d	5335d
BH540	2989b	4142c	5010b	5686c	6110c	6352b

Table 7.4 Ranking of the open-pollinated and hybrid genotypes based on the grain yields realized at the lowest and highest N level

Genotypes	Lowest N	Highest N
Ecaval 1	3	1
Ecaval 2	1	2
Ecaval 5	5	5
Ecaval 14str	2	3
Kulani	4	4
CML388/CML202/CML384	1	2
CML373/CML202/CML384	3	1
LPSC3H/CML202/ CML380	2	4
TUXPSEQ/CML202/CML384	5	5
BH540	4	3

7.3.2 Total biomass N uptake

The average total biomass N uptake of open-pollinated and hybrid genotypes at the five sites is shown in Table 7.5. Similar to the grain yield, total biomass N uptake increased with higher N applications irrespective of the genotypes. Among the open-pollinated genotypes N uptake by the total biomass ranged from 43.2 to 59.4 kg ha^{-1} at 0 kg N ha^{-1} and from 102.8 to 128.3 kg ha^{-1} at 230 kg N ha^{-1} level. Likewise, among the hybrid genotypes N uptake by the total biomass ranged from 42.2 to 59.8 kg ha^{-1} at the 0 kg N ha^{-1} level and from 108.5 to 143.1 kg ha^{-1} at 230 kg N ha^{-1} level.

The total biomass N uptake of the two genotypes identified as N use efficient is interesting to take note of. In the case of open-pollinated Ecaval 1 its N uptake was significantly higher than that of the local genotype Kulani over the entire range of N levels except at the 0 kg N ha^{-1} level. Likewise, the uptake of the hybrid CML373/CML202/ CML384 was significantly higher than that of the local genotype BH 540 over the entire range of N levels except at the 0 kg N ha^{-1} level.

The differential response of maize genotypes in terms of N uptake at similar N levels may be attributed to their genetic traits. In this regard maximum rooting depth and the capacity of the roots to absorb N from different soil layers are of great importance (Lafitte and Edmeades, 1994b; Kling *et al.*, 1996; Oikeh *et al.*, 1999). Baldwin (1975) reported that to maximize N uptake, it is important that the root system of the plant exploit a volume of soil that contain sufficient N to meet the plant's requirement.

Table 7.5 Effect of N fertilization on the total biomass N uptake (kg ha^{-1}) of open-pollinated and hybrid maize genotypes. Means within a column for each group followed by the same or no letter(s) are not significantly different from each other at 5 % probability level

Genotypes	N levels (kg ha^{-1})					
	0	46	92	138	184	230
Ecaval 1	48.9bc	74.4b	95.1a	111.4a	121.8a	128.3a
Ecaval 2	53.6b	79.7a	99.3a	111.6a	119.6a	124.9a
Ecaval 5	43.2d	65.8c	80.8b	90.8b	98.4b	102.8b
Ecaval 14str	59.4a	82.6a	98.8a	111.5a	120.2a	124.0a
Kulani	47.6cd	70.1bc	84.2b	95.0b	102.0b	106.1b
CML388/CML202/CML384	57.2ab	84.6a	106.8a	122.8a	132.7a	135.9b
CML373/CML202/CML384	56.2ab	81.9a	104.3a	123.2a	135.4a	143.1a
LPSC3H/CML202/ CML380	59.8a	82.8a	102.4a	113.0b	119.7b	123.8c
TUXPSEQ/CML202/CML384	42.2c	64.3c	83.1c	96.8d	104.4c	108.5d
BH540	53.0b	74.7b	92.5b	106.9c	116.5b	122.4c

7.3.3 Nitrogen use efficiencies

7.3.3.1 Nitrogen agronomic efficiency

The NAE of each genotype at the different N level ranges is presented in Table 7.6. It is clear that the NAE of all genotypes decreased with higher N applications. However, significant differences were recorded between the genotypes at similar N level ranges. In the open-pollinated group all the CIMMYT genotypes performed better than the local genotype Kulani with regard to the two lower N level ranges. The NAE of Ecaval 1 was the best of CIMMYT genotypes. In the hybrid group only CML373/CML202/CML384 performed consistently better than all the other genotypes through the entire N level ranges.

Table 7.6 Effect of N fertilization on the N agronomic efficiency (NAE, kg grain kg^{-1} N applied) of open-pollinated and hybrid maize genotypes. Means within a column for each group followed by the same or no letter(s) are not significantly different from each other at 5 % probability level

Genotypes	N ranges (kg ha^{-1})				
	0-46	46-92	92-138	138-184	184-230
Ecaval 1	22.9ab	15.4a	9.3a	5.1a	2.6
Ecaval 2	24.5a	10.7bc	5.9b	2.5b	1.4
Ecaval 5	22.0bc	10.4bc	5.3b	3.5ab	1.9
Ecaval 14str	20.8c	11.4b	6.5b	3.8ab	1.1
Kulani	20.6c	9.4c	5.3b	3.4b	1.5
CML388/CML202/CML384	24.7a	16.4b	10.9b	6.5bc	1.7c
CML373/CML202/CML384	28.2a	20.8a	16.5a	9.3a	5.3a
LPSC3H/CML202/ CML380	21.1c	15.6b	7.6c	4.2c	2.2c
TUXPSEQ/CML202/CML384	20.5c	15.5b	10.8b	5.8bc	2.7bc
BH540	21.9c	16.5b	12.9b	8.1ab	4.6ab

7.3.3.2 Nitrogen recovery efficiency

The data on the NRE of each genotype at different N ranges is shown in Table 7.7. The NRE of all the genotypes declined with higher N applications. However, at similar N level ranges the genotypes differed significantly in their NRE. The most important aspect to point out is that the two genotypes, namely Ecaval 1 and CML373/CML202/CML384 identified earlier as N efficient genotypes also performed consistently the best over the five N level ranges.

Table 7.7 Effect of N fertilization on the N recovery efficiency (NRE, %) of open-pollinated and hybrid maize genotypes. Means within a column for each group followed by the same or no letter(s) are not significantly different from each other at 5 % probability level

Genotypes	N ranges (kg ha^{-1})				
Open-pollinated	0-46	46-92	92-138	138-184	184-230
Ecaval 1	55.4a	45.0a	35.4a	22.6a	14.1a
Ecaval 2	56.7a	42.6a	26.7b	17.4b	11.5ab
Ecaval 5	49.1b	32.6b	21.7c	16.5b	9.6ab
Ecaval 14str	50.4b	35.2b	27.6b	18.9ab	8.3b
Kulani	48.9b	30.7b	23.5bc	15.2b	8.9b
CML388/CML202/CML384	59.6	48.3	34.8	21.5	7.0
CML373/CML202/CML384	55.9	48.7	41.1	26.5	16.7
LPSC3H/CML202/ CML380	50.0	42.6	23.0	14.6	8.9
TUXPSEQ/CML202/CML384	48.0	40.9	29.8	16.5	8.9
BH540	47.2	38.7	31.3	20.9	12.8

7.3.3.3 Nitrogen physiological efficiency

The NPE of each genotype at the different N level ranges is displayed in Table 7.8. Like NAE and NRE, NPE also decreased with higher N applications. In the open-pollinated group Ecaval 1 performed the best and Ecaval 2 was the worst when all N level ranges are taken into account. The performance of the local genotype Kulani was intermediate. In the hybrid group the CIMMYT genotype CML373/CML202/CML384 and the local genotype BH 540 performed almost similar when all five N level ranges are considered. The performances of these two genotypes were better than the other three CIMMYT genotypes.

Table 7.8 Effect of N fertilization on the N physiological efficiency (NPE, kg grain kg^{-1} N uptake) of open-pollinated and hybrid maize genotypes. Means within a column for each group followed by the same or no letter(s) are not significantly different from each other at 5 % probability level

Genotypes	N ranges (kg ha^{-1})				
	0-46	46-92	92-138	138-184	184-230
Ecaval 1	41.3	34.2	26.1	22.5	18.6
Ecaval 2	43.1	25.1	21.9	14.5	12.4
Ecaval 5	44.9	32.0	24.4	21.4	19.7
Ecaval 14str	41.3	32.3	23.7	20.0	13.4
Kulani	42.1	30.7	22.4	22.3	16.4
CML388/CML202/CML384	41.4	34.1	31.3	30.1	23.8
CML373/CML202/CML384	50.4	42.8	40.1	34.9	31.8
LPSC3H/CML202/ CML380	42.3	36.7	33.1	29.1	25.0
TUXPSEQ/CML202/CML384	42.7	37.9	36.1	35.3	29.9
BH540	46.5	42.7	41.1	38.6	35.9

All the three indices of N use efficiency confirmed the earlier deduction that Ecaval 1 and CML373/CML202/CML384 are N use efficient maize genotypes. The efficiency with which maize genotypes utilize N is affected by several factors including root morphology (Pan *et al.*, 1985; Weisler and Horst, 1994; Engles and Marschner 1995) as well as the genetical, biochemical and physiological mechanisms involved in nitrate assimilation and use (Duncan and Baligar, 1990). Moreover, significant and consistent differences in the efficiency of N uptake and distribution to the various plant parts have been demonstrated among maize genotypes (Chevalier and Schrader, 1977; Pollmer *et al.*, 1979; Muruli and Paulsen, 1981; Moll *et al.*, 1982) and these results indicated the potential of selecting N use efficient maize genotypes. Lafitte and Edmeades (1994b) suggested in their selection study that N use efficient maize genotypes had the ability to develop better root systems. This ability enables these genotypes to extract soil N from greater depths.

The results of this study confirms the findings of Wiesler *et al.* (2001) that the traits of N use efficient maize genotypes are their ability of efficient uptake and utilization of N over a large range of soil fertility conditions. However, other researchers (Kamprath *et al.*, 1982; Moll *et al.*, 1982; Presterl *et al.*, 2002) favored either the efficient uptake or utilization of N.

7.4 Conclusions

The N uptake and use efficiency of five open-pollinated and five hybrid maize genotypes on Nitisols in western Ethiopia were investigated. Generally, the hybrid genotypes performed better than the open-pollinated genotypes with regard to N uptake and use efficiency. Only two genotypes were identified as N use efficient, namely the open-pollinated Ecaval 1 and the hybrid CML373/CML202/CML384. These two CIMMYT genotypes performed better with respect to N uptake and use efficiency than the two local genotypes included in the study viz. the open-pollinated Kulani and hybrid BH 540. The introduction of these two N use efficient genotypes into the farming systems of the resource-poor farmers could lead to better food and income security.

CHAPTER 8

ECONOMIC EVALUATION OF TILLAGE SYSTEMS AND NITROGEN FERTILIZATION FOR MAIZE PRODUCTION

8.1 Introduction

The health of Ethiopia's economy is highly influenced by the performance of the agricultural sector. Despite Ethiopia's long agricultural tradition and its importance in the national economy, the growth of the sector has remained very low mainly due to a poor natural resource base and unfavorable socio-economic conditions. The poor natural resource base is an even more limiting factor than the interlinked socio-economic conditions and nutrient mining of soils aggravates the situation and significantly contribute to the stagnant economy of the country.

Careful management of cropping systems offers a possible reduction in the trade-off between maintaining profitability and reducing dependence on external inputs. Reduction of external inputs can be achieved inter alia by selecting tillage systems that coincide with residue retention. This approach usually resulted in the maintenance of long-term productivity and profitability of the land by gradual build-up of the soil fertility status through the internal cycling of nutrients (Philips *et al.*, 1980; Uri, 1999).

The magnitude of economic returns for various tillage systems is the most important evidence of the viability and superiority of one tillage system over another. Acceptance of minimum tillage for maize production instead of conventional tillage depends more on its profitability than just the grain yields which realized. In general it is known that minimum tillage reduced costs of labor, fuel and machinery but increased costs of herbicides to maintain or increase grain yields (Phillips *et al.*, 1980; Smart and Bradford, 1999).

The acceptance of minimum tillage by Ethiopian farmers is low due to lack of knowledge on the economic benefits of the system. In western Ethiopia no economic evaluation of tillage systems and N fertilization on maize production has been done. Therefore, this study was carried out with experimental data to compare the profitability of three tillage systems, verify which N fertilization rate is most appropriate for these tillage systems and select an appropriate N fertilization rate for the two identified N use efficient maize genotypes.

8.2 Materials and methods

The grain yield data from two sets of maize experiments reported in the previous chapters were used for this study and details on them can be found in Section 3.2 and 7.2. In the first set of the experiments the effect of three tillage systems (MTRR = minimum tillage with residue retention, MTRV = minimum tillage with residue removal and CT = conventional tillage) and three levels of N fertilization (recommended rate of 92 kg N ha^{-1} and 25% less and 25% more than this rate) on maize yield was investigated at five sites for five consecutive years. In the second set of experiments the N uptake and use efficiency of five open-pollinated and five hybrid maize genotypes were compared at six N fertilization levels at five sites.

The economic evaluation was done on the grain yield data that was significantly affected by the tillage and N fertilization treatments to consolidate the statistical analysis thereon. This evaluation comprised of a partial budget with dominance, marginal and sensitivity analysis as described by CIMMYT (1988). The minimum acceptable rate of return was set at 100% and grain yield were adjusted downwards by 10% to minimize bias.

Field prices used in the analysis were collected from local markets during January to December 2004. To estimate economic parameters, maize was valued at an average open market price of 1.02 Ethiopian Birr (EB) per kg grain and fertilizer was valued at a fixed official price of 5.80 EB per kg N. A wage rate of 4.5 EB per work-day and oxen rate of 18.0 EB per work-day were used. Round-up and lasso-atrazine were valued at 75 and 60 EB per L, respectively. Since maize residue has no monetary value in the study area, it was not considered in the economic evaluation.

Some of the concepts used in the partial budget analysis are given below:

- Mean grain yield (kg ha^{-1}): Average yield of each treatment across sites and years.
- Gross field benefit (GFB) ha^{-1}: Product of real price of maize and the mean yield for each treatment.
- Total variable cost (TVC): Sum of costs of all variable inputs and management practices.
- Net benefit (NB) ha^{-1}: Difference between the GFB and the TVC.

The dominance analysis procedure was used to select potentially profitable treatments from the range that was tested. Treatments were ranked in order of ascending TVC from the lowest to the highest cost to eliminate those treatments costing more but producing a lower NB than the next lowest cost treatment. The selected and rejected treatments by using this technique are referred to as undominated and dominated treatments, respectively. For each pair of ranked undominated treatments, a percentage marginal rate of return (% MRR) was calculated. The % MRR between any pair of undominated treatments denotes the return per unit of investment in crop management practices or inputs expressed as percentage. The % MRR is given by Equation by 8.1:

$$\% MRR = \frac{\Delta NB}{\Delta TVC} \quad * \quad 100 \tag{8.1}$$

Thus, a MRR of 100% implies a return of one Birr on every Birr of expenditure in the given variable inputs.

8.3 Results and discussion

8.3.1 Economic viability of tillage systems

The result of the partial budget and the data used in the development of this partial budget is given in Table 8.1. Ranking of treatments in order of increasing TVC revealed that MTRR costs less than either MTRV or CT. It is clear that MTRR has considerably reduced cost of labor and oxen, but increased cost of herbicides compared to CT. The reduction of labor and oxen-power cost that coincides with minimum tillage can be attributed to less cultivation in preparing the seedbed and virtually no labor was used to control weeds. Consequently, the farmers would save some time for other farm activities. The highest NB was obtained with MTRR, followed by MTRV and then CT. The dominance analysis also indicated the superiority of MTRR to MTRV and CT.

Table 8.1 Partial budget with dominance and marginal analysis to establish the profitability of maize production with the three tillage systems (MTRR = minimum tillage with residue retention, MTRV = minimum tillage with residue removal and CT = conventional tillage)

Tillage system	Yield ($kg\ ha^{-1}$)	GFB ($EB\ ha^{-1}$)	Costs ($EB\ ha^{-1}$) labor	oxen	herbicides	TVC ($EB\ ha^{-1}$)	NB ($EB\ ha^{-1}$)	MRR (%)
MTRR	5664	5199.6	71.5	133.2	525	729.7	4469.9	--
MTRV	5314	4878.3	125.8	111.6	525	762.4	4115.9	D
CT	5048	4634.1	264.15	590.4	0.0	854.6	3779.5	D

GFB = gross field benefit, TVC = total variable cost, NB = net benefit, MRR = marginal rate of return and D = dominated treatment.

The input and output prices used in the economic evaluation were those prevailing during the period of the experiments. Market prices are ever changing and as such a recalculation of the partial budget with a set of likely future prices is important to establish whether a tillage system is likely to remain stable and hence sustain acceptable returns for farmers despite price fluctuations. A sensitivity analysis was done therefore in which an increase in the field price of herbicides and a drop in the price of grain were assumed. The change in the prices of herbicides and grain is borne out of experience and represents a realistic fluctuation of liberal market conditions prevailing in the study area at that time.

The sensitivity analysis indicated that MTRR remained the most economic tillage system when the maize price decreased by 20% and herbicide cost increased by 20% (Table 8.2). However, with the concurrent changes in field prices of grain and herbicides the profitability of MTRR has become marginal. These results agree with Smart and Bradford (1999) whose findings showed that minimum tillage resulted in greater economic returns and lower production costs as compared with conventional tillage.

Table 8.2 Sensitivity analysis to establish the stability of maize production with the three tillage systems (MTRR = minimum tillage with residue retention, MTRV = minimum tillage with residue removal and CT = conventional tillage)

Tillage system	GFB (EB ha^{-1})	TVC (EB ha^{-1})	NB (EB ha^{-1})	MRR (%)*
MTRR	4159.6	834.7	3324.9	--
MTRV	3902.6	867.4	3035.2	D
CT	3707.3	854.6	2852.7	D

*Denotes 20% increase in herbicide cost and 20% decrease in grain price. GFB = gross field benefit, TVC = total variable cost, NB = net benefit, MRR = marginal rate of return and D = dominated treatment.

8.3.2 Economic viability of N levels for tillage systems

In this case the partial budget indicated that the highest TVC and NB were obtained at an application rate of 115 kg N ha^{-1} (Table 8.3). The dominance analysis showed that none of the N fertilization levels were dominant. However, the sensitivity analysis indicated that an application of 92 kg N ha^{-1} remained profitable, but the profitability of an application of 115 kg N ha^{-1} was well below the minimum acceptable rate and was therefore eliminated (Table 8.4).

Table 8.3 Partial budget with dominance and marginal analysis to compare the profitability of maize production with N fertilization

N level (kg ha^{-1})	TVC (EB ha^{-1})	NB (EB ha^{-1})	MRR (%)
69	400.2	4727.7	--
92	533.6	5144.2	312.2
115	667.0	5339.5	146.4

TVC = total variable cost, NB = net benefit, MRR = marginal rate of return

Table 8.4 Sensitivity analysis to establish the stability of maize production with N fertilization

N levels (kg ha^{-1})	TVC (EB ha^{-1})	NB (EB ha^{-1})	MRR (%)*
69	480.2	3622.1	--
92	640.3	3901.9	174.8
115	800.4	4004.8	64.2

*Denotes 20% increase fertilizer N cost, and 20% decrease in grain price.
TVC = total variable costs, NB = net benefit, MRR = marginal rate of return

8.3.3 Economic viability of N levels for maize genotypes

Two maize genotypes were identified as N use efficient. They were the open-pollinated Ecaval 1 and the hybrid CML373/CML202/CML384. The partial budget showed that among the N levels with which these genotypes were tested, the highest NB was obtained at an application of 138 kg N ha^{-1} with Ecaval 1 and 184 kg N ha^{-1} with CML373/CML202/CML384 (Table 8.5). However, an application of 46 kg N ha^{-1} gave the highest MRR for both genotypes. The dominance analysis lead to the selection of the 46, 92 and 138 kg N ha^{-1} levels for Ecaval 1 and the 46, 92, 138 and 184 kg N ha^{-1} levels for

CML373/CML202/CML384 ranked in increasing order of TVC. A MRR of below 100% is considered low and unacceptable to farmers (CIMMYT, 1988). Such a return would not offset the cost of capital and other related transaction costs while still giving an attractive profit margin to serve as an incentive. Based on this guideline the 138 kg N ha^{-1} level for Ecaval 1 and the 184 kg N ha^{-1} level for CML373/CML202/CML384 are eliminated.

Table 8.5 Partial budget with dominance and marginal analysis to establish the profitability of maize production for the two N use efficient genotypes

	N level	TVC	NB	MRR
Genotype	(kg ha^{-1})	(EB ha^{-1})		(%)
Ecaval 1	0	0	2887.1	--
	46	266.8	3724.7	313.9
	92	533.6	4201.4	178.7
	138	800.4	4381.7	65.6
	184	1067.2	4360.9	D
	230	1334.0	4220.8	D
CML373/CML202/CML384	0	0	2932.1	--
	46	266.8	4023.9	409.2
	92	533.6	4763.3	277.1
	138	800.4	5291.4	198.0
	184	1067.2	5471.7	67.6
	230	1334.0	5462.0	D

TVC = total variable costs, NB = net benefit, MRR = marginal rate of return,
D = dominated treatment

The sensitivity analysis indicated that even the 92 kg N ha^{-1} level for Ecaval 1 and the 138 kg N ha^{-1} level for CML373/CML202/CML384 are not conducive to stable production. However, the 46 kg N ha^{-1} level for Ecaval 1 and the 92 kg N ha^{-1} level for CML373/CML202/CML384 are well above the minimum acceptable threshold. These results agree with the findings of Tolessa (1999) in western Ethiopia that an application of 92 kg N ha^{-1} to maize gave acceptable economic returns.

Table 8.6 Sensitivity analysis to establish the stability of maize production for the two N use efficient genotypes

	N level	TVC	NB	MRR
Genotype	(kg ha^{-1})	(EB ha^{-1})		(%)*
Ecaval 1	0	0	2309.7	--
	46	320.2	2873.0	176.0
	92	640.3	3147.7	85.8
CML373/CML202/CML384	0	0	2345.7	--
	46	320.2	3112.4	239.5
	92	640.3	3597.2	151.4
	138	960.5	3913.0	98.6

*Denotes 20% increase in fertilizer cost and 20% decrease in grain price. TVC = total variable cost, NB = net benefit and MRR = marginal rate of return

8.4 Conclusions

The partial budget analysis with experimental data revealed that the highest net benefit with maize in western Ethiopia was obtained with MTRR, followed by MTRV and then CT. MTRR would still be the most economical tillage system when the maize price decreases by 20% and the herbicide cost increases by 20%. An application of 92 kg N ha^{-1} remains economical for MTRR and CT with a 20% decrease in maize price and a 20% increase in fertilizer cost. In the case of the two N use efficient maize genotypes it was found that an application of 46 kg N ha^{-1} for the open-pollinated Ecaval 1 and 92 kg N ha^{-1} for the hybrid CML373/CML202/CML384 were economically sound and remained superior within a price variability of 20%.

CHAPTER 9

SUMMARY AND RECOMMENDATIONS

The sustainability of maize production in western Ethiopia is in question despite of favorable environmental conditions. A major reason for this phenomenon is severe soil degradation in maize fields. This soil degradation manifested often in low soil N fertility which inhibited maize yields. The situation is worsened by the financial inability of most farmers to purchase N fertilizer for supplementation.

In these conditions two basic approaches can be followed to improve maize productivity in a sustainable way. Firstly, integrated cropping practices can be developed for maize to make better use of N from organic and inorganic sources. Secondly, maize genotypes can be selected that are superior in the utilization of available N, either due to enhanced uptake efficiency or because of more efficient use of the absorbed N. In this context, experiments were conducted to determine the integrated effects of tillage system, residue management and N fertilization on the productivity of maize, and to evaluate different maize genotypes for N uptake and use efficiency.

The experiments on integrated cropping practices were done from 2000 to 2004 at five sites viz. Bako, Shoboka, Tibe, Ijaji and Gudar in western Ethiopia. They were laid out in a randomized complete block design with three replications. Three tillage systems (MTRR = minimum tillage with residue retention, MTRV = minimum tillage with residue removal and CT = conventional tillage) and three N levels (the recommended rate and 25% less and 25% more than this rate) were combined in factorial arrangement. Every year yield response, usage of applied N and changes of some soil properties were measured. In 2004 the same experiments were used to monitor the fate of applied N in the soil-crop system. Labeled urea was applied at the recommended rate to micro plots within the MTRR and CT plots for this purpose.

During the initial two years of the experiments, there was no significant difference in grain yield between MTRR and MTRV and both were significantly superior to CT. However, during the final two years of the experiments, there was no significant difference between MTRV and CT and both were significantly inferior to MTRR. On average, the grain yield of MTRR was 400 and 705 kg ha^{-1} higher than that of MTRV and CT, resulting in consequent increases of 6.6 and 12.2%, respectively. The application of N increased the grain yield regardless of tillage system. An application of 92 kg N ha^{-1} was significantly superior to 69 kg N ha^{-1}, but on par with the 115 kg N ha^{-1} application. Hence, the recommended fertilization rate of 92 kg N ha^{-1} for conventional tilled maize was also found adequate for minimum tilled maize in western Ethiopia. This rate remained economically optimum with a 20% decrease in the maize price and a 20% increase in fertilizer cost.

The grain differences resulted from the tillage systems and concomitant residue management were attributed to significant changes in some soil fertility parameters, especially in the 0-7.5 cm layer. After five years both indices of organic matter, viz. the organic C and total N contents were significantly higher in the MTRR soils when the CT soils serve as reference. Similarly, the extractable P and exchangeable K contents of the MTRR soils were also higher than that of the CT soils. The only negative aspect of MTRR in comparison with CT was a decline in soil pH.

A significantly higher grain N content was recorded with MTRR than with MTRV and CT. The stover N content was not significantly affected by the three tillage systems. However, grain, stover and total N uptake were consistently superior with MTRR compared to MTRV and CT. The NAE, NRE and NPE of maize for the same tillage system were consistently higher at the lower N level range of 69-92 kg ha^{-1} than at the higher N level range of 92-115 kg ha^{-1}. At the lower N level range NAE and NRE were larger with CT than with the other two tillage systems. Both indices were higher with MTRR than with the other two tillage systems at the higher N level range. The NPE was not significantly affected by the tillage systems. However, the trend at both N level ranges was higher with MTRR than with MTRV and CT.

The labeled urea study showed that the grain, stover and total biomass N derived from fertilizer was consistently higher for CT than MTRR. Conversely, grain, stover and total biomass N derived from soil was consistently higher with MTRR than CT. Therefore, the fertilizer N recorded in the MTRR soils was higher with MTRR than CT and mainly confined to the upper 45 cm. The fate of fertilizer N was in MTRR: 47% recovered by maize, 17% remained in the soil and 36% unaccounted for and in CT: 54% recovered by maize, 12% remained in the soil and 34% unaccounted for.

The experiments on genotype comparison for N uptake and use efficiency were also done at Bako, Shoboka, Tibe, Ijaji and Gudar. In 2004 the response of five open-pollinated and five hybrid genotypes were evaluated at six N levels from 0 to 230 kg ha^{-1} with 46 kg ha^{-1} intervals.

Only two out of the ten genotypes evaluated qualify as N use efficient. They were the open-pollinated Ecaval 1 and the hybrid CML373/CML202/CML384. These two CIMMYT genotypes showed consistently higher NAE, NRE and NPE at low and high N applications as required. This was not the case with the two local genotypes that were included, viz. the open-pollinated Kulani and the hybrid BH 540.

Based on the results that evolved from this study it is clear that:

1. Farmers should be encouraged to practice MTRR instead of CT since this change in tillage system could improve the productivity of maize on Nitisols in western Ethiopia.

2. On these Nitisols the conversion from CT to MTRR need not coincide with an adaptation in the recommended fertilization rate of 92 kg N ha^{-1}.

3. The planting of N use efficient maize genotypes on Nitisols must be advocated to farmers, especially those who can not afford proper fertilization.

Aspects that need to be investigated in future are:

1. Quantification of N mineralization and immobilization in the Nitisols when subject to MTRR and CT for maize production.
2. Losses of fertilizer N through volatilization, leaching and denitrification from the Nitisols when subject to MTRR and CT for maize production.
3. Suitability of other soil types which are used for maize production in western Ethiopia for MTRR instead of CT.
4. Performance of the N use efficient genotypes on other soil types which are used for maize production in western Ethiopia.
5. Crop rotation with N fixing crops.

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