

# Soil Fertility Characterization and Response of Local Wheat Variety to Nitrogen Fertilization at Tembaro District, South Ethiopia

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## ABSTRACT

The selected physico-chemical properties of the soil at Sigazo testing site was diagnosed to characterize the soil fertility status of the study area. In addition, a field experiment was conducted during the main rainy season of the 2009 at the testing site to determine the optimum rates of N fertilizer for local wheat variety production and to evaluate its effects on yield and yield components of the examination crop. The field experiment involved factorial combinations of five rates of N (0, 25, 50, 75 and 100 kg ha<sup>-1</sup>) laid down in randomized complete block design with five replications. Soil samples were collected from freshly opened soil profile on genetic horizon bases and from the experimental plot (0-30 cm depth) before planting and after harvest to study those chosen soil properties. The moist soil color of the profile was very dark grayish brown (10YR 3/2) at the surface and brownish gray (2.5Y 6/2) at the bottom and with clay-loam texture. The bulk density values varied inconsistently with depth of the profile ranging from 1.14 g cm<sup>-3</sup> at the surface layer to 1.27 g cm<sup>-3</sup> at the third layer. Available water holding capacity of the horizons ranged from 109 to 128 mm m<sup>-1</sup> showing a decreasing trend with soil depth. Both the profile and the composite surface soil sample indicated that the soil of the site was slightly acidic to moderately alkaline in reaction (6.38 to 8.31), very low in OM (0.08 to 2.34%), very low in its total N (0.011 to 0.092%). The soil exchangeable bases was mainly dominated by Ca and Mg where the order of occurrence was Ca > Mg > Na > K. The CEC values were very high ranging from 62.7 to 75.6 cmolc kg<sup>-1</sup>. Application of different rates of N fertilizer significantly ( $P \leq 0.01$ ) influenced the whole crop parameters tested except stand count and grain filling period. The significantly different and maximum plant height (65.52 cm), fertile tillers (381), spike number (412), spikelets per spike (10.0) and spike length (6.52cm) were obtained from application of the highest N rate (100 Kg N ha<sup>-1</sup>) whereas the minimum records were obtained from the control plot. Similarly, the maximum grain yield (2584.5 kg ha<sup>-1</sup>), straw yield (3576.30 kg ha<sup>-1</sup>), total biomass yield (6127.4 kg ha<sup>-1</sup>) and 1000 grains weight (49.35 gm) were gained from application of the highest N rate showing a decreasing trend with declining N rate and the lowest records were obtained from the control plot. The grain and straw N contents and total N uptake were affected by the application of N fertilizer. They showed increasing trend with increasing N rate where the maximum records (2.45%, 0.45% and 79.08 kg ha<sup>-1</sup>), respectively, were obtained at the highest N rate. The apparent recovery (AR) and agronomic efficiency (AE) of N responded positively to increasing N rate whereas the physiological efficiency (PE) of N exhibited decreasing trend with the increasing application of N, the highest PE was observed at the lowest N rate and vice versa.

**Keywords:** Soil fertility, Local wheat variety, N-fertilizer, Characterization

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## 1. Introduction

Human beings are dependent on soils and, conversely, high-quality soils are dependent on Human beings and the uses they make of the land (Brady and Weil, 2002). Declining soil fertility has continued to be a major difficult problem to food production in many parts of the world. Low soil fertility in tropical regions has been attributed to the low natural soil nutrient content and loss of nutrient through erosion and crop harvests (Mureithiet *al.*, 2000). The loss of nutrients in most smallholder farms thus exceeds inflows. To deal with these problems, several technological involvement, especially those geared towards nutrient management and soil moisture conservation, have been recommended (Mureithiet *al.*, 2000). Besides, the productivity of some soils is constrained by some limiting factors even-though they have high potential productivity or are naturally fertile.

Many soils in the highlands of Ethiopia are inherently poor in available plant nutrients and organic matter (OM) content (Tekalign *et al.*, 1988; Asnakew *et al.*, 1991). Tekalign *et al.* (1996) also reported that the

Ethiopian highland Vertisols tend to exhibit low total nitrogen (N) and OM contents, and application of N fertilizer is considered essential to improve cereal crops production. Though, in cereal-dominated cropping systems, planned at full filing the subsistence necessities, linked with low usage of chemical fertilizers have led to widespread reduction of soil nutrients in the major cereal crops growing regions of the country. Heavy rains during the early part of the main cropping season (June to August) also cause substantial soil nutrient losses due to intense leaching and erosion on Nitisols and de-nitrification on frequently water-logged Alfisols (Asnakew *et al.*, 1991).

Hence, series of experiments have been carried out on different soils especially on Alfisols to study the effects of N and phosphorus (P) fertilizers on crop yield and it has been found that substantial yield increment was recorded with proper management of these nutrient elements (Desta, 1986).

The major crops that are commonly grown on Vertisols and Alfisols in Ethiopia are *teff*, barley, durum wheat, chickpea, lentil and noug (Desta, 1986). According to CSA (2007), the total wheat cultivated area in Ethiopia in the Meher season of the 2006/2007 was 1,473,917 ha. The total production was 2,463,063 tons, whereas the mean wheat yield was around 1.67 tons ha<sup>-1</sup> which is still considerably below the yield obtained from experimental fields. Therefore, the yield gap suggests that there is a potential for increasing wheat production and productivity through improved crop management practices, particularly by means of increased use of different minerals and/or organic fertilizers (Hailu, 1991).

Wheat is usually planted on heavy black clay soils (Vertisols) and heavy black clay-clay loam soils (Alfisols) of the highlands with altitudes between 1800 and 2800 masl. However, recently the area under local wheat variety production has been decreasing due to competition from *teff* and other wheat variety released from research centers and due to its low average yield, which results from severe biotic, abiotic and socio-economic factors. The low yield of wheat in Ethiopia is primarily due to depleted soil fertility and low rates of chemical fertilizer usage (Amsal *et al.*, 1997; CSA, 2007). Thus, managing soil fertility is very crucial for improving wheat crop productivity.

As reported by Fischer (1989) that genotype and soil fertility are important factors affecting the production of wheat with high yield and protein content when soil moisture and weather conditions are favorable. He point out those fertilizers, mainly those containing N is the major inputs affecting wheat grain yield and quality. In line with this, Tilahun (1994) and Amsal *et al.* (2000) revealed that N is the most essential plant nutrient often limiting the yield and growth of wheat crop. Under most field conditions, the amounts of soluble and readily mineralized soil N are insufficient to meet the crop requirement. Therefore, to obtain better growth of high yielding crops, N as chemical fertilizer, manure, crop residue, or other source, must be added. Asnakew *et al.* (1991) also reported that increased usage of N fertilizer is considered as one of the primary means of increasing wheat grain yield in Ethiopia.

## 1.2. Objectives of the study

### 1.2.1. General objective

- The general objective of this study is to characterize soil fertility and to see the response of local wheat variety to N fertilizer.

### 1.2.2. Specific objectives

The specific objectives of the study are the following:

- To characterize the fertility of soils of the study area on the basis of some selected chemical and physical properties,
- To assess the effects of N fertilizer applications on yield and yield components of local wheat variety and
- To find out the optimum rates of N fertilizer for local wheat variety production.

## 2. RESEARCH METHODOLOGY

### 2.1. Location of the study area

This study was conducted in Tembaro district, Kembata Tembaro Zone in the Southern Nation, Nationalist and Peoples Regional State (SNNPRS). Tembaro District consist of 21 administrative Kebeles and bordered by Omo River in the south, Hadero and Tunto Zuria woreda in the east, Soro woreda in the west and Duna woreda in the north. Geographically, it is located between 32°08' E to 34°29'E and 8°08'N to 8°09'N. The total area of the district is about 27,917 hectares (BoARD, 2007). The altitude of the woreda ranges from 800 to 2600 masl and the slope ranges from intermediate (3%) to very steep slope (above30%) as indicated by Disrict agricultural office.

### 2.2. The climate

The study area consists of three distinct agro-climatic zones, Kolla (30%), Weynadega (60%) and Dega (10%). The average minimum and maximum temperature of the study area ranges between 20°C -33°C. The mean

annual rainfall varies between 800 - 1800mm (TWA0, 2011). It has bimodal rainfall distribution such as short rainy season “Belg” and long rainy season “Kiremt”. “Belg” is the short rainy season that lasts between March and May. During this period, the area receives total average rainfall of about 170 mm. The “Kiremt” season, which is the longest rainy season, lasts between June and September. Rain that occurs during the “Kiremt” season is very intensive and long. Although the rainfall has bimodal distribution, most of the crop production takes place during the “Kiremt” (May to September) season. The dry months in the area extends from middle of October to end of March and May is also included in dry season. (TWA0, 2011).

### 2.3. Soils

The dominant soil of the district is Alfisols (SNNPR BoFED, 2004). As reported from many researchers, Alfisols are among the best agricultural soils with clay-to-clay loam texture and imperfect drainage effective depth of greater than 150cm with the pH value from 5.5 to 6.7.

### 2.4. The vegetation

The district was once known by its dense natural forest mainly found in the periphery of Omo River and near to the main town of Mudula and the plantation forest in the degraded areas of the woreda until the down fall of the Derge regime. Nowadays the small patches of the area is sparsely occupied by some tree species like *Cordia africana*, *Prunus africana*, *Albizia gummifera*, *Croton macrostachyus*, *Grevillea robusta*, *Eucalyptus spp.*, *Ficus spp.*, *Acacia spp.*, and other various native vegetations.

### 2.5. Population

The total population of the study area is 145,946 (CSA, 2007). The area is characterized by high population densities. Although it is not common currently, past polygamous marriage system in the area has contributed to the high population growth. As a result, land holding is as low as an average of 0.5 hectare per household (BoARD, 2007). Apparently, the continuous rise of population puts huge pressure on the remaining forest (natural and plantation) fragments and cultivation of marginal lands.

### 2.6. Economic Activities

The livelihood of the district depends mainly on mixed agriculture (crop-livestock, crop-tree or crop-tree-livestock production) characterized by subsistence production. The most commonly cultivated crops in the study sites include maize (*Zea mays L.*) followed by teff (*Eragrostis teff*). Enset (*Enset ventricosum*) and some other root crops such as sweet potato, taro and yam are also some common staple food whereas coffee and ginger are cash crops in the area. Fruits such as avocado (*Persea americana*), mango (*Mangifera indica*), banana (*Musa paradisiaca*), papaya (*Carica papaya*), Casimir (*Casimiroa edulis*) and citrus species are also cultivated for household consumption and to some extent income generation.

### 2.7. Experimental Treatments, Design and Procedures

Local wheat variety that was obtained from the study area and was used as a test crop. The treatments were laid in factorial combinations of five levels of N (0, 25, 50, 75 and 100 kg N ha<sup>-1</sup>). The treatment combinations were arranged in factorial experiment and lay down in randomized complete block design with five replications. Urea (46% N) was used as sources of N.

The experimental field was prepared first by local plow (Maresha) according to farmers’ conventional plowing practice. In accordance with the specification of the design, a field layout was prepared and then each treatment was assigned randomly to the experimental units within a block. The blocks and the plots within a block were separated by 1 m wide-open space from each other. The gross plot size was 3m wide and 4m long (12m<sup>2</sup>) accommodating 1 wheat plant rows spaced 20 cm apart. The plot size for planting was 1.5m x 2m (3m<sup>2</sup>) leaving 30 cm wide furrow in the middle of the plot for draining excess rain-water.

The test crop was drilled by hand at the recommended rate of 150 kg ha<sup>-1</sup> on 11 July, 2009. The half dose of N fertilizer of the respective treatments was applied as basal application at planting time and the remaining half N was side dressed at the mid tillering stage on the 35<sup>th</sup> day after planting. During the different growth stages of the crop, all the necessary cultural and/or recommended agronomic management practices were carried out.

### 2.8. Soil Sampling and Sample Preparation

A fresh soil profile pit with 1 m width by 2m length / depth was excavated based on preliminary inspection of the augur soil samples. The soil profile was described at the field for its morphological properties and sampled on genetic horizon basis for characterization of selected physico-chemical properties. The soil properties that were studied include soil color, particle size distribution (texture), bulk density (BD), soil moisture contents at field capacity (FC) and at permanent wilting point (PWP), pH, organic carbon (OC), total N, available P, exchangeable bases (Ca, Mg, K and Na), cation exchange capacity (CEC) and CaCO<sub>3</sub> content.

Moreover, three composite surface soil samples (0-30 cm depth) were collected from each replication of the experimental plot before planting to determine the different soil physical and chemical properties listed above. Similarly, surface soil samples were collected from each plot after harvesting the crop and then composited by replication to obtain one representative sample per treatment for the determinations of soil total N content. Moreover, duplicate undisturbed soil samples were taken using core samplers from the experimental site and from each identified horizon of the profile for determinations of bulk density and moisture contents at FC and PWP.

The surface and profile soil samples collected from the study area were bagged, labeled and transported to the laboratory for preparation and analysis of selected soil properties following standard laboratory procedures. In preparation for laboratory analysis, the soil samples were air dried, crushed and made to pass through a 2 mm size sieve for the analysis of soil pH, texture, exchangeable bases and CEC; whereas for the determinations of OC and total N, the soil samples were passed through 0.5 mm sieve.

## 2.9. Soil Physical and Chemical Analysis

Soil color (dry and moist) determination was done by the Munsell soil color chart. Soil particle size distribution (texture) was analyzed by the hydrometer method following the procedure described by Day (1965). Water content at FC was determined in the laboratory by draining an initially wet sample using a pressure plate apparatus adjusted at -1/3 bar and that at PWP was also measured in the same way but the pressure was set at -15 bars. Bulk density (BD) was determined from undisturbed (core) soil samples collected using core samplers, weighed at FC and then dried in an oven at 105 0<sup>c</sup> (Baruah and Barthakur, 1997). The soil particle density (PD) especially for mineral soils was expected as the PD of the soil in average measures of 2.65 g cm<sup>-3</sup>. The formula used to estimate total porosity derived from the bulk density and particle density.

$$\text{Total porosity (\%)} = \left[1 - \frac{\text{BD}}{\text{PD}}\right] \times 100$$

Soil pH was measured potentiometrically using a pH meter with combined glass electrode in 1: 2.5 soils: water ratio as described by Carter (1993). Organic carbon was determined using the wet oxidation method (Walkley and Black, 1934) where the carbon was oxidized under standard conditions with potassium dichromate in sulfuric acid solution. Finally, the organic matter (OM) content of the soil was calculated by multiplying the percent OC by 1.724. The total N content was determined using the Kjeldahl method by oxidizing the OM with sulfuric acid and converting the N into NH<sub>4</sub><sup>+</sup> as ammonium sulfate (Dewis and Freitans, 1970).

Calcium carbonate (CaCO<sub>3</sub>) content of the soil was estimated by the acid neutralization method in which the soil carbonate was decomposed by excess standard HCl solution and back titrated with standard NaOH after filtration (Sahlemehdin and Taye, 2000). The exchangeable bases (Ca, Mg, K and Na) in the soil were determined from the leachate of 1 molar ammonium acetate (NH<sub>4</sub>OAc) solution at pH 7.0. Exchangeable Ca and Mg were measured by atomic absorption spectrophotometer and K and Na were read using flame photometer (Rowell, 1994). Similarly, CEC were measured after leaching the NH<sub>4</sub>OAc extracted soil samples with 10% NaCl solution. The amount of ammonium ion in the percolate was determined by the usual Kjeldahl procedure and reported as CEC (Hesse, 1972).

## 2.10. Agronomic Data Collection

Data on plant basis was recorded from randomly taken 15 plants per plot, while the middle five (5) wheat plant rows (2.25 m<sup>2</sup>) were used for data collected on plot basis. The crop data that were collected include stand count, plant height, days to heading, days to maturity, grain-filling period, number of fertile tillers per 2.25 m<sup>2</sup>, number of spikes per 2.25 m<sup>2</sup>, number of spikelets per spike, spike length, 1000 grain weight, grain yield, straw yield and total aboveground biomass yield.

Data on stand count at 4 weeks after sowing was taken from the middle five rows of each plot. Plant height was measured from randomly sampled 15 plants per plot at the late flowering stage. Days to heading (the number of days from planting till when 50% of the spikes in the plot have fully emerged) were also recorded. Days to maturity were determined as the number of days from planting until when 50% of the plants have physiologically matured.

Grain filling period was determined by counting the number of days taken from heading to maturity. The number of fertile tillers per plot was determined by taking tiller samples from 15 plants in the net plot area at the late tillering stage and then extrapolated for the total number of plants in the net plot area (2.25 m<sup>2</sup>). The number of spikes per 2.25 m<sup>2</sup> was counted at maturity by taking the total number of spikes within the middle 5 rows of the net plot. The number of spikelets per spike and spike length was averaged over 15 spikes taken from the net plot area.

Thousand grains weight were determined by taking 1000 grains randomly from the net plot area harvested. Grain yield and straw yields was also determined from the harvested four (5) middle rows of the net plot area. The yields were measured after leaving the harvested plants in open air for about 10 days so that they attained

constant weight. The above ground total biomass yield was calculated as the sum of the grain and straw yields. Harvest index (HI) per plot was calculated as the ratio of the grain yield to the total above ground biomass yield.

### 2.11. Plant Sampling for N

Plant samples collected at harvest were partitioned into vegetative and grain for the determinations of N concentration in grain and straw and calculation of N fertilizer recoveries and use efficiencies. The straw and grain samples were grounded and sieved through 0.5 mm size sieve and saved for laboratory analysis of N content. The N content of the grain and straw samples were determined using the wet digestion method, which involves the decomposition of the plant tissues using various combinations of HNO<sub>3</sub>, H<sub>2</sub>SO<sub>4</sub> and HClO<sub>4</sub>. The method used for N analysis was the usual Kjeldahl procedure.

Total N uptakes in straw and grains were calculated by multiplying the N content by the respective straw and grain yields per hectare. Total N uptake, by the whole plant was determined by summation of the respective grain and straw N uptake on hectare basis. Apparent fertilizer N recoveries were calculated by the procedure described by Pal (1991) as:

$$\left[ \frac{U_n - U_o}{n} \right] \times 100$$

Where U<sub>n</sub> stands for nutrient uptake at 'n' level of fertilizer nutrient and U<sub>o</sub> stands for nutrient uptake of the control or 'no fertilizer'. Agronomic efficiencies (AE) and physiological efficiencies (PE) of N fertilizer was calculated using the procedures described by Crosswell and Godwin (1984) as:

$$AE = \left[ \frac{G_n - G_o}{n} \right]$$

$$PE = \left[ \frac{G_n - G_o}{U_n - U_o} \right]$$

Where G<sub>n</sub> stands for grain yield of the plot fertilized with 'n' fertilizer rate and G<sub>o</sub> for grain yield of unfertilized plot. The notations U<sub>n</sub> and U<sub>o</sub> stand for nutrient uptake in the two cases as described earlier.

### 2.12. Statistical Analysis

The agronomic data was subjected to analysis of variance (GLM procedure) using SAS software program version 8.2 (SAS Institute, 2000). The analysis results of the soil and tissue samples were interpreted using descriptive statistics. Duncan's multiple range test (DMRT) at 0.05 probability level was employed to separate treatments means where significant differences exist (Gomez and Gomez, 1984). Correlation analysis was carried out by calculating simple linear correlation coefficients between yield and yield components.

## 3. RESULTS AND DISCUSSION

### 3.1. Characterization of the Soil of the Study Area

The soil silhouette or profile of the study site and the composite surface soil samples collected before planting from the experimental plot area were described morphologically. Furthermore, they were analyzed chemically and physically in the laboratory following standard laboratory procedures and the results were presented and discussed in the following sections.

#### 3.1.1. Physical Properties of the Soil

Particle size distribution has important bearing in water movement, aeration, oxidation-reduction processes, root extension, and nutrient and OM contents as well as composition of the soil reported by (Fisseha, 1992). In the present study, the soil textural class of both the profile and the composite surface soil samples were Alfisols and did not differ with profile depth except for the bottom horizon (H<sub>6</sub>), which was sandy loam (Table 1).

The proportions of clay and silt ranged from 19 to 51% and from 26.4 to 52%, respectively, with no distinct pattern of variation with profile depth except the relatively lower clay content at the extreme bottom (155-200 cm depth) horizon (Table 1). On the other hand, the sand content increased consistently with soil depth from 11% at the surface horizon to 54.6% at the bottom layer of the profile.

The silt to clay ratio of the soil ranged from 0.74 to 1.58 for the profile and from 0.74 to 0.78 for the composite surface soil samples (Table 1). This ratio is one of the indices used to assess the rate of weathering and determine the relative stage of development of a given soil. According to Young (1976), a ratio of silt to clay below 0.15 is considered as low and indicates of a progressive stage of weathering and/or soil development while greater than 0.15 indicates that the soil contains simply weatherable minerals and young enough. Therefore, the silt to clay proportion of the soil detected in the current research is generally greater than 0.15 both for the profile and the composite surface soils (Table 1) suggesting little degree of weathering and soil growth phases.

The bulk density (BD) values of the horizons in the profile varied inconsistently with depth ranging from 1.14 g cm<sup>-3</sup> at the surface layer (H<sub>1</sub> horizon) to 1.27 g cm<sup>-3</sup> at the third layer (H<sub>3</sub> horizon) (Table 1). Therefore, the values are closer to the normal range of BD for mineral soils which is 1.3 - 1.4 g cm<sup>-3</sup> as indicated by Bohn *et al.* (2001). The data in Table 1 indicate that the relatively low BD value at the surface layer could be due to the relatively high OM and/or clay contents which resulted in high total porosity (56.98%). On the other hand, the

relatively high BD values in the layers from 55-80 and 80-115 cm could be due to compaction caused by the weight of the overlying soil material and reduced root penetration (Brady and Weil, 2002). However, the unusual lower BD value that was observed in the bottom ( $H_6$ ) horizon may suggest that the process of inversion, which is a common phenomenon in profiles of Alfisols, is not sufficient enough to homogenize the horizons.

Table 1: Selected physical properties of the soil profile and composite surface soil samples of the study area

Depth (cm)	Horizon	Particle size (%)			Textural Class	Silt/Clay	*BD (g cm <sup>-3</sup> )	TP (%)	Water content		
		Sand	Silt	Clay					FC (%)	PWP (%)	AWHC (mm m <sup>-1</sup> )
0-25	H <sub>1</sub>	11	38	51	Clay-loam	0.75	1.14	56.98	42	27	128.00
25-55	H <sub>2</sub>	13	37	50	Clay-loam	0.74	1.23	53.58	39	25	125.00
55-80	H <sub>3</sub>	15	40	45	Clay-loam	0.89	1.27	52.07	37	22	123.60
80-115	H <sub>4</sub>	15	52	33	Silty-loam	1.58	1.26	52.45	37	22	123.60
115-155	H <sub>5</sub>	45	30	25	Sandy-loam	1.20	1.21	50.34	29	16	110.50
155-200	H <sub>6</sub>	54.6	26.4	19	Sandy loam	1.39	1.16	51.98	25	14	109.00
Composite surface (0 – 30 cm) soil samples before planting (from experimental nearby profile)											
Block 1	-	11	38	51	Clay-loam	0.75	-	-	-	-	-
Block 2	-	12	37	49	Clay-loam	0.76	-	-	-	-	-
Block 3	-	11	39	50	Clay-loam	0.78	-	-	-	-	-
Block 4	-	11	38	51	Clay-loam	0.75	-	-	-	-	-
Block 5	-	13	37	50	Clay-loam	0.74	-	-	-	-	-
Block 6	-	12	37	49	Clay-loam	0.76	-	-	-	-	-
Mean		12	38	50	Clay-loam	0.76	-	-	-	-	-

\*BD = Bulk density; TP = Total porosity; FC = Field capacity; PWP = Permanent wilting point; AWHC = Available water holding capacity;

In most of the horizons, the soil water contents both at FC and PWP were both high ascribed to the high clay contents. These parameters showed a decreasing pattern with depth of the profile (Table 1) which may be due to the relatively higher OM content at the surface and its decreasing trend with the soil depth. The available water holding capacity (AWHC) of the horizons ranged from 109 to 128 mm m<sup>-1</sup> where the lowest value was recorded at the bottom ( $H_6$ ) horizon and the highest value was at the surface layer ( $H_1$  horizon). Likewise, Virmani *et al.* (1982) had reported that Alfisols have a relatively higher water storage capacity in the root zone because of their soil depth and high clay content. They reported AWHC ranging from 110-250 mm for the top 1 meter of the soil profile. The same authors observed that the moisture content in the deeper layers of the soil profile is lower, apparently due to compression effects on matric potential which is in agreement with the result obtained in the present study.

On the other hand, Mukanda and Mapiki (2001) reported that Alfisols investigated in Zambia had high water content due to their high clay content. Most of this water, however, was not available to plants because both the FC and PWP were high and hence the AWHC was generally low (120 to 160 mm m<sup>-1</sup> soil depth) in contrast to other soils with high clay content.

Total porosity of the soil profile varied inconsistently with depth ranging from 52.07% (at the  $H_3$  horizon) to 56.98% (at the  $H_1$  horizon). The highest total porosity at the  $H_1$  horizon corresponds to the relatively higher OM content and the lowest BD value, whereas the lowest total porosity corresponds to the highest BD value of the  $H_5$  horizon and  $H_3$  respectively (Table 1). According to Brady and Weil (2002), the decrease in OM and increase in clay that occur with depth in many profiles are associated with a shift from macropores to micropores. Thus, the current result presented in Tables 1 and 2 is in agreement with the above statement and it justifies the dominance of micropores in the soil profile studied. As indicated in Landon (1991), sandy soils with a total pore space of less than about 40% are liable to restrict root growth due to excessive strength, whilst in clay soils total porosities of less than 50% can be taken as the corresponding limiting value.

### 3.2. Chemical Properties of the Soil

#### 3.2.1. Soil Reaction (pH)

The data show that the pH of the profile varied from slightly acidic (pH = 6.38) at the surface layer (0-25 cm depth) to strongly alkaline (pH = 8.22) at the  $H_6$  horizon (Table 2). The mean pH of the composite sample was also slightly acidic (pH = 6.32). Except for the extreme bottom layer ( $H_5$  horizon), the pH of the profile increased consistently with depth. This increase in pH may be due to observed increase in basic cations with depth and hence, percent base saturation. The increase in basic cations concentration with depth, in turn, may suggest the existence of downward movement of these constituents within the profile. Therefore, a high pH value in the lower horizons of the profile corresponds to high values of exchangeable Ca, Mg and to some extent

Na (Table 2).

### 3.2.2. Calcium Carbonate

The content of calcium carbonate ( $\text{CaCO}_3$ ) in the soil profile ranged from 0.21% at the surface horizon to 10.78% at the  $H_5$  horizon (Table 2). Generally, there are no precise ratings for levels of free carbonates, but values of over about 40% can be considered as extremely calcareous (Avery, 1964). On the other hand, values as high as 70% or more can occur in horizons of arid zones. According to FAO (1990), a soil horizon having  $\text{CaCO}_3$  equivalent of > 15% within 100 cm from the soil surface qualifies for a calcic horizon and such high carbonate levels affect both the physical and the chemical properties of soils. Hence, in the current study, the level of  $\text{CaCO}_3$  is generally low (< 15%) and it showed an increasing trend down the profile depth which cannot bring any significant problem in crop production.

### 3.2.3. Organic Matter and Total Nitrogen

The organic matter content of the profile (Table 2) decreased consistently with depth ranging from 2.34% at the surface layer ( $H_1$  horizon) to 0.08% at the extreme bottom layer ( $H_6$  horizon). On the other hand, the composite surface soil samples collected from the experimental plot had a mean OM content of 2.412%. According to the OM content rating established by Landon (1991), both the profile and the composite surface soil samples had very low OM content (Appendix 2). The reasons for the very low content of OM could be intensive cultivation of the land and the total removal of crop residues for animal feed and source of energy. Moreover, there is no practice of organic fertilizers addition, such as animal manure and green manure that would have contributed to the soil OM pool in the study area. In other soils of Ethiopia, variability of soil OM has also been related to land use history and pattern. It is generally low in cultivated soils than those under natural vegetation (Eylachew, 1999; Dawit *et al.*, 2002). Moreover, very low OM content of 3.07 and 2.07% were reported for soil samples collected from the plow layer from Gojjam and Amaressa, respectively (Mesfin, 1998).

The total N contents of the soil profile varied from 0.011% at the  $H_6$  horizon to 0.092% at the surface ( $H_1$  horizon) layer (Table 2). The total N content of the surface layer of the profile (0.092%) and the mean total N content of the composite surface soil samples (0.091%) of the study area are normally rated as very low based on the classification of Landon (1991). However, the relatively higher value of total N (0.092%) corresponds to the layer of the profile having higher value of OM (2.34%) and the lowest amount of total N (0.011%) was recorded in the subsurface layer with the lowest OM content (0.08%). In line with OM contents of the profile, the contents of the total N also decreased consistently with depth suggesting the strong correlation between the two soil parameters. The low total N contents indicate that the soils of the study area are deficient in N to support proper growth and development of crops, which confirms that the site must be fertilized with external N inputs.

Table 2: Selected soil chemical properties of the soil profile and composite surface soils of the study area

Depth (cm)	Horizon	pH (H <sub>2</sub> O)	CaCO <sub>3</sub> (%)	*OM (%)	C:N	Total N (%)	Exchangeable bases and CEC soil (cmolc kg <sup>-1</sup> )					PBS
							Na	K	Mg	Ca	CEC	
0-25	H <sub>1</sub>	6.38	0.21	2.34	9.34	0.092	0.3	0.7	9.4	41	70.1	82.00
25-55	H <sub>2</sub>	6.65	0.24	2.12	9.05	0.086	0.5	0.8	10.24	42.3	60.5	90.5
55-80	H <sub>3</sub>	6.98	0.24	1.53	7.25	0.089	0.7	0.7	9.1	42.9	75.6	86.7
80-115	H <sub>4</sub>	7.79	0.35	0.89	10.17	0.053	0.8	0.8	9.04	48	58.4	110.5
115-155	H <sub>5</sub>	8.31	10.78	0.45	4.34	0.024	0.9	0.3	9.61	78.5	75.2	152.4
155-200	H <sub>6</sub>	8.22	3.15	0.08	3.95	0.011	1.3	0.31	10.8	61	62.7	136.8
Composite surface (0 – 30 cm) soil samples before planting (from experimental nearby profile)												
Block 1	-	6.38	0.21	2.41	9.34	0.092	0.3	1.05	9.60	40.00	73.10	78.00
Block 2	-	6.15	0.23	2.402	9.25	0.096	0.3	0.95	10.28	41.30	65.50	69.50
Block 3	-	6.49	0.24	2.39	8.95	0.089	0.3	1.01	10.23	39.90	61.60	71.70
Block 4	-	6.55	0.25	2.46	8.97	0.083	0.3	1.03	9.54	41.40	59.40	70.50
Block 5	-	6.05	0.22	2.37	9.21	0.094	0.3	0.98	9.61	38.50	62.20	62.40
Block 6	-	6.27	0.25	2.44	9.05	0.091	0.3	0.97	10.80	36.75	62.75	59.84
Mean	-	6.32	0.23	2.412	9.13	0.091	0.3	0.998	10.01	39.64	64.09	68.66

\*OM = Organic matter; C: N = Carbon to nitrogen ratio; CEC = Cation exchange capacity; PBS = Percent base saturation

### 3.2.4. Exchangeable Bases

Exchangeable Ca followed by Mg was the predominant cation in the exchange sites of both the profile and the composite surface soil colloidal materials (Table 2). The exchangeable Ca increased with soil depth except for the extreme bottom layer in exactly the same pattern as observed in soil pH. Exchangeable calcium content varied from 41 and 42.9 cmolc kg<sup>-1</sup> at the  $H_1$  and  $H_3$  horizons respectively to 78.5 cmolc kg<sup>-1</sup> at the  $H_5$  horizon. On the other hand, exchangeable Mg did not show any consistent trend with depth and varied from 9.61 cmolc

kg<sup>-1</sup> at the H<sub>5</sub> to 10.8 cmolc kg<sup>-1</sup> at H<sub>6</sub> horizon. This shows that the soil parent material primarily releases divalent cations. A high content of these two cations has also been reported in Alfisols of Bichena and Woreta areas (Yihenew, 2002) and in soils of Jelo micro-catchment (Mohammed *et al.*, 2005). Hence, the concentration of these two cations is rated as very high where they fully saturated the soil exchange complex. In some of the subsurface layers, the sum of these cations was remarkably very high even exceeding CEC values. This may be attributed to the analytical method used where ammonium acetate at pH 7 dissolves the free carbonates of Ca and Mg which overestimates the values of the respective cations and then the PBS. It is also clearly observed from the level of CaCO<sub>3</sub> that the maximum value of CaCO<sub>3</sub> (10.78%) was observed at the H<sub>5</sub> horizon which coincided with the highest exchangeable Ca (78.5 cmolc kg<sup>-1</sup>).

In most of the horizons of the profile and composite surface soil, the proportions of the cations were in the order of Ca > Mg > Na > K. This might be related to the parent material from which the soils have been developed *i.e.* basalt rock. Nevertheless, according to Landon (1991), the observed exchangeable K value was high at the H<sub>2</sub> and H<sub>4</sub> horizon where it generally showed a decreasing trend with depth of the profile. This indicates that the potential supply of K for crop growth largely lies in the surface horizon and hence, calls for protection and maintenance of the surface soil to ensure crop production in sustainable manner without any excess application of K fertilizers. The content of exchangeable Na in the soil relative to the CEC was below the critical value and, hence, Na toxicity was unlikely to occur. Yet, the content of exchangeable Na showed an increasing trend with soil depth.

### 3.2.5. Cation Exchange Capacity and Percent Base Saturation

The soil CEC values were normally very high throughout the profile and did not show any clear pattern of variability among horizons of the profile (Table 2). Although the OM content of the soil is low, the amount and type of clay might have been very important in contributing to CEC values. The type of clay is shrinking / swelling type with extensive internal and external surfaces. These surfaces can attract or adsorb many cations. This is in line with the findings of Mebit (2006) who reported very high CEC on Alfisols and that varied inconsistently with soil depth.

Therefore, the range suggests the presence of 2:1 clay minerals and can be expected to have more nutrient reserves (Landon, 1991). Mohammed *et al.* (2005) also indicated that the CEC to clay ratios of the soils of Jelo catchment were over 0.67 reaching 2.05 in some horizons which predicted the presence of smectite clay mineralogy in all of the soil horizons. This shows that inorganic material is the predominant contributing factor to CEC. Additionally, the great CEC standards indicates that the soil has high buffering volume when compared to the induced alterations.

The percent base saturation (PBS) of the profile was very high throughout the horizons and varied from 82.0 to 136.8%. The high values of PBS for the bottom 3 horizons, which were greater than 100%, could be attributed to the very high contents of exchangeable Ca and Mg that go beyond CEC value for the reason already mentioned in the previous section.

### 3.3. Effects of Applied N on Total N of the Soil

The data in Table 3 show that application of different levels of N fertilizer had no effect on the total N contents of the soils after harvest. Nevertheless, the entire N content of the sample from the control plot after harvest (0.068%) was somewhat reduced as compared to the total N of the soil before planting (0.079%). This might be due to the utilization of applied N by wheat crop as well as N losses through different mechanisms such as leaching and denitrification.

Table 3: Effects of different levels of applied N on total N of the soil after crop harvest

Applied N rate (kg ha <sup>-1</sup> )	Total N available (%)					Mean
0	0.070	0.068	0.066	0.067	0.069	0.068
25	0.075	0.070	0.072	0.075	0.073	0.073
50	0.074	0.074	0.069	0.074	0.071	0.072
75	0.078	0.073	0.075	0.078	0.076	0.076
100	0.073	0.071	0.073	0.073	0.074	0.073
Mean	0.074	0.071	0.071	0.073	0.073	

### 3.4. Response of Wheat to Applied N Fertilizer

Analysis of variance for crop agronomic parameters and yield and yield components showed that application of different rates of N fertilizer significantly ( $P \leq 0.01$ ) influenced all of the crop parameters tested except stand count and grain filling period (Table 4).

#### 3.4.1. Effects of N on Crop Phenological Parameters

Examination of the Phenological records showed that the application of different rates of N fertilizer had significant effect ( $P \leq 0.01$ ) on days to 50% heading and days to 50% maturity (Table 4). In addition, the effect of N application was more significant on days to heading than to maturity. It was observed that the plots which



received higher rates of N fertilizer (50, 75 and 100 kg N ha<sup>-1</sup>) headed and matured more rapidly (though no significant difference was observed among themselves) than the plots receiving 25 kg N ha<sup>-1</sup> and the control plot (Table 5). The coefficients of correlation for days to heading and maturity were also found negative and significant (Table 8) suggesting that with increasing the rates of N fertilizer, the crop took shorter period to head and mature than the treatments receiving either no or lower rates of N.

These results are in line with Cock and Ellis (1992) that an adequate supply of N is related with vigorous and rapid growth and accelerate maturity. On the other hand, too little N results in slow growth and delays maturity while excessive N promotes vegetative growth and delays maturity. Brady and Weil (2002) also pointed out that abundant supply of N might delays plant maturity. Contrary to the current finding, however, Gurmessa (2002) and Getachew (2004) reported that N fertilization at the rate of 92 kg N ha<sup>-1</sup> and above 92 Kg N ha<sup>-1</sup> significantly ( $P \leq 0.01$ ) delayed physiological maturity of wheat crop.

Table 4: Mean square estimates for wheat agronomic parameters, yield and yield components as affected by application of N fertilizers

Parameters to be considered	Mean squares for source of variation	
	N (5)	Error
Stand count	632.454545 <sup>ns</sup>	956.4527
Plant height (cm)	609.4722258**	4.5784523
Days to heading	105.6525554**	1.0576243
Days to maturity	112.5477851**	2.1624753
Grain filling period	6.3647771 <sup>ns</sup>	3.0578231
Number of fertile tillers	192750.254**	7251.612
Number of spikes 2.4 m <sup>-2</sup>	23547.5671**	1547.256
Spike length (cm)	13.4586222**	0.175421
Spikelets per spike	10.8954234**	0.194586
Thousand grain weight (g)	84.2475621**	2.5463218
Grain yield (kg ha-1)	6547621.56**	52761.52
Straw yield (kg ha-1)	9754628.54**	142357.24
Total biomass yield (kg ha-1)	33591264.8**	258653.51
Harvest index (%)	0.0095468**	0.0010458

\*Statistics in parentheses are values for degrees of freedom for respective source of variation; \*\* = Significant at  $P \leq 0.01$ ; ns = Non-significant.

Table 5: Main effects of N on wheat phenology

N (kg ha-1)	Days to 50% heading	Days to 50% maturity	Grain filling (days)
0	89 <sub>a</sub>	152 <sub>a</sub>	56
25	86 <sub>b</sub>	145 <sub>b</sub>	54
50	83 <sub>c</sub>	139 <sub>c</sub>	54
75	78 <sub>c</sub>	139 <sub>c</sub>	55
100	80 <sub>d</sub>	135 <sub>d</sub>	55
LSD (0.05)	0.92	1.62	Ns
SE ( $\pm$ )	0.37	0.52	0.53
CV (%)	1.12	1.06	2.64

\*Means within a column sharing common letter(s) are not significantly different at  $P < 0.05$ ; ns = Non significant; CV values of the respective parameters are main effects N fertilizer rates

### 3.4.2. Effects of N Fertilization on Wheat Growth Parameters

Application of different rates of N had no significant effect on stand count data at 4 weeks after sowing (Tables 4 and 6). The probable reason for this might be that stand count data was taken before top dressing of the remaining half rate of N. Therefore, the rate of N applied at planting period might not be sufficient enough to bring significant differences in stand count among treatment means. Furthermore, as N is very mobile, some of the applied N fertilizer at planting might have been lost through different mechanisms, such as leaching, volatilization and denitrification and, hence, its contribution for the crop growth might have been limited.

Table 6: Main effects of N on wheat growth parameters

N (kg ha <sup>-1</sup> )	Stand count (number)	Plant height (cm)	Tillers 3m <sup>-2</sup>
Effects of N fertilizer*			
0	291	49.26 <sub>d</sub>	95 <sub>d</sub>
25	283	55.64 <sub>c</sub>	169 <sub>c</sub>
50	312	56.14 <sub>c</sub>	275 <sub>b</sub>
75	301	61.05 <sub>b</sub>	315 <sub>b</sub>
100	288	65.52 <sub>a</sub>	381 <sub>a</sub>
LSD (0.05)	Ns	1.32	63.51
SE (±)	7.32	0.64	19.53
CV (%)	9.56	3.57	26.54

\*Means within a column sharing common letter(s) are not significantly different at  $P < 0.05$ ; ns = Non-significant; CV values of the respective parameters are main effects N fertilizer rates

The effect of N fertilization on wheat plant height was found to be highly significant (Table 4). The plots which received N fertilizer had increased plant height significantly as compared the control plot. The plant height was increased consistently with rates of N where the maximum plant height (65.52 cm) was obtained from the application of the highest N rate (100 kg N ha<sup>-1</sup>) followed by 61.05 cm which was obtained from 75 kg N ha<sup>-1</sup> and the minimum (49.26 cm) was from for the control plot (Table 6). Simple correlation coefficient also showed that N was strongly and positively correlated to plant height (Table 8). In agreement with this result, Amsal *et al.* (2000) reported a positive and linear response of plant height to N fertilizer application in the central highlands of Ethiopia. Several other studies (Zewdu *et al.*, 1992; Tilahun *et al.*, 1996a; Minale *et al.*, 2005) have also revealed remarkable plant height enhancement in reaction to each incremental dose of N fertilizer.

Nevertheless, the effect of applied N on the number of productive tillers was statistically significant ( $P \leq 0.01$ ). The number of tillers per 3m<sup>2</sup> was increased linearly with increasing rate of applied N from 95 in the control (no N) to 381 in the plots supplied with 100 kg N ha<sup>-1</sup> (Table 6). The differences in mean number of tillers obtained due to the different rates of applied N were significant  $P \leq 0.01$  between each other except between 50 and 75 kg N ha<sup>-1</sup>. It can also be observed from the highly significant and positive correlation coefficient (Table 8) that increasing the N rate had enhanced the development and growth of new productive tillers.

As reported by (Botella *et al.*, 1993) that N stimulates tillering probably due to its effect on cytokinin synthesis. Batey (1984), Archer (1988) and Mossedaq and Smith (1994) revealed that tillering is enhanced by increased light and N availability during the vegetative growing stage and wheat reacts to N application by producing more tillers per plant and by exhibiting a higher percentage endurance of tillers. Ayoub *et al.* (1994) and Minale *et al.* (1999) also reported that the spike population of wheat increased with increasing level of N fertilization which is mainly because of increased fertile tillers than the control plots.

### 3.5. Effects of N Fertilizers on Wheat Yield and Yield Components

#### 3.5.1. Number of Spikes, Spikelets per Spike and Spike Length

On the other hand, the number of spikes showed significant response ( $P < 0.01$ ) to application of N. In this case, the maximum number of spikes (410) was recorded from application of 100 kg N ha<sup>-1</sup> followed by 405 and 386 due to applications of 75 and 50 kg N ha<sup>-1</sup> respectively, where there were no significant differences among themselves (Table 7). However, all were significantly different from the spike count at 25 kg N ha<sup>-1</sup> and the control plot.

Table 7: The main effects of N fertilizers on wheat yield components

N (kg ha <sup>-1</sup> )	Spikes per 3 m <sup>2</sup>	Spike length (cm)	Spikelets per spike
Effects of N fertilizer*			
0	204 <sub>d</sub>	3.26 <sub>d</sub>	4.0 <sub>d</sub>
25	325 <sub>c</sub>	4.64 <sub>c</sub>	6 <sub>c</sub>
50	386 <sub>b</sub>	5.14 <sub>b</sub>	8 <sub>b</sub>
75	405 <sub>b</sub>	6.05 <sub>a</sub>	10 <sub>a</sub>
100	412 <sub>a</sub>	6.52 <sub>a</sub>	10 <sub>a</sub>
LSD (0.05)	32.24	0.31	0.51
SE (±)	6.35	0.14	0.53
CV (%)	10.12	6.57	7.54

\*Means within a column sharing common letter(s) are not significantly different at  $P < 0.05$ ; ns = Non significant; CV values of the respective parameters are main effects N fertilizer rates

More than a few researchers (Zewdu *et al.*, 1992; Tilahun *et al.*, 1996a) also reported the enhancement of

fertile spikes per unit area with increasing rates of N fertilizer. Power and Alessi (1978) also reported that for wheat, one spike is produced per main stem; thus, the number of heads per unit area is highly dependent on the use of high N rates to promote the initiation, survival, and development of secondary tillers. Correspondingly, Alcoz *et al.* (1993) reported that the N fertilized treatments doubled grain yield as compared with control plots due to significantly more and heavier spikes produced. High and positive correlation coefficient observed between applied N and spike number (Table 8) also suggests that N fertilization affected the development and growth of spike in wheat crop.

The two parameters (*i.e.*, Spike length and spikelet per spike) were also significantly ( $P < 0.01$ ) affected by the application of different rates of N fertilizer (Table 7) and exhibited strong linear relationship with fertilizer N (Table 8). For both yield components, the maximum and the minimum records were obtained at the highest and the lowest N rates, respectively.

Table 8: Correlation matrix of N fertilizer, crop yield and growth parameters

	N	GY	SY	TBY	TGW	HI	SC	PH	DH	DPM	DGF	FT	SN	SL	SPS
N	1.00	0.95**	0.89**	0.92**	0.801**	0.08	0.13	0.90**	-0.80**	-0.85**	0.00	0.76**	0.61**	0.88**	0.77**
GY		1.00	0.94**	0.93**	0.81**	0.27*	0.18	0.80**	-0.82**	-0.77**	0.15	0.72**	0.67**	0.80**	0.68**
SY			1.00	0.92**	0.71**	-0.13	0.19	0.76**	-0.85**	-0.85**	0.01	0.70**	0.65**	0.73**	0.74**
TBY				1.00	0.72	0.02	0.17	0.85**	-0.84**	-0.82**	0.04	0.78**	0.72**	0.85**	0.75**
TGW					1.00	0.30*	0.06	0.2*	-0.78**	-0.70**	0.13	0.61**	0.51**	0.72**	0.65**
HI						1.00	0.05	0.03	0.06	0.25	0.54*	0.08	0.18	0.00	-0.02
SC							1.00	0.02	-0.36	-0.37	0.06	0.20	0.57**	0.15	0.15
PH								1.00	-0.91**	-0.92**	-0.05	-0.74**	0.55**	0.86**	0.73**
DH									1.00	0.96**	-0.16	-0.73**	-0.72**	-0.30**	-0.71**
DPM										1.00	0.18	-0.68**	-0.48**	-0.71**	-0.63**
DGF											1.00	0.01	0.34*	0.05	0.02
FT												1.00	0.65**	0.68**	0.64**
SN													1.00	0.54**	0.58**
SL														1.00	0.93**
SPS															1.00

\* = Significant at  $P \leq 0.05$ ; \*\* = Significant at  $P \leq 0.01$ ; N = Nitrogen rate; GY = Grain yield; SY = Straw yield; TBY = Total biomass yield; TGW = Thousand grain weight; HI = Harvest index; SC = Stand count; PH = Plant height; DH = Days to heading; DPM = Days to physiological maturity; DGF = Days to grain filling; FT = Fertile tiller per 3m<sup>2</sup>; SN = Spike number per 3m<sup>2</sup>; SL = Spike length; SPS = Spikelet per spike

### 3.5.2. Thousand Grains Weight

Thousand grains weight responded significantly ( $P < 0.01$ ) to the application of increasing rates of N and increased consistently with the increase in N except at 25 kg N ha<sup>-1</sup> where it was not significantly different from the control plot (Table 9). Moreover, highly significant and positive coefficient of correlation ( $r = 0.801^{**}$ ) was observed between 1000 grains weight and applied N rate (Table 8) indicating an increase in the rate of N resulted in a more weight of wheat grain. This result is in line with the findings of Tilahun *et al.* (1996a) who indicated that 2.2 to 10% higher grain weights were obtained from 120 over 60 kg N ha<sup>-1</sup> depending on the location and climatic condition of the growing season. Amsal *et al.* (2000) also reported a positive and linear response of 1000 grains weight to N fertilization where the subsequent decline in grains weight was attributed to sub-optimal absorption of nutrients and, hence, shriveled seeds of wheat. In contrast, other reports (Mooleki and Foster, 1993; Gooding and Davis, 1997) have shown either no improvement or reduced kernel weight due to N fertilization even when yields increased. Zewdu *et al.* (1992) has also reported non-significant response of 1000 grains weight to application of N fertilizer in the highlands of Ethiopia.

Table 9: Major effects of N on yield and harvest index of wheat

N (kg ha <sup>-1</sup> )	Thousand grain weight (gm)	Grain yield (kg ha <sup>-1</sup> )	Straw yield (kg ha <sup>-1</sup> )	Total Biomass yield (kg ha <sup>-1</sup> )	Harvest index (%)
Effects of N fertilizer*					
0	38.35 <sub>c</sub>	856.2 <sub>c</sub>	1134.0 <sub>d</sub>	2104.4 <sub>e</sub>	39.0 <sub>b</sub>
25	41.54 <sub>c</sub>	1097.6 <sub>d</sub>	1857.6 <sub>c</sub>	3043.5 <sub>d</sub>	35 <sub>c</sub>
50	45.14 <sub>b</sub>	1234.3 <sub>c</sub>	2661.8 <sub>b</sub>	4127.6 <sub>c</sub>	36 <sub>c</sub>
75	48.57 <sub>a</sub>	2154.4 <sub>b</sub>	2761.10 <sub>b</sub>	4857.7 <sub>b</sub>	45 <sub>a</sub>
100	49.35 <sub>a</sub>	2584.5 <sub>a</sub>	3576.30 <sub>a</sub>	6127.4 <sub>a</sub>	45 <sub>a</sub>
LSD (0.05)	1.24	213.31	284.51	492.24	2.24
SE (±)	0.45	74.14	112.53	174.35	1.35
CV (%)	3.12	11.57	12.54	12.12	6.12

\*Means within a column sharing common letter(s) are not significantly different at  $P < 0.05$ ; ns = Non-significant; CV values of the respective parameters are main effects N fertilizer

### 3.5.3. Grain Yield

Grain yield responded significantly ( $P < 0.01$ ) to the application of N fertilizer rates (Tables 4 and 9). The highest mean grain yield (2584.5 kg ha<sup>-1</sup>) was obtained from the maximum N rate (100 kg N ha<sup>-1</sup>) with an increment of 19.96% and 201.86% yield advantage over the next higher N rate (75 kg N ha<sup>-1</sup>) and the control plot, respectively (Table 9). The next highest mean grain yield (2154.4 kg ha<sup>-1</sup>) was obtained from 75 kg N ha<sup>-1</sup> and the least yield (856.2 kg ha<sup>-1</sup>) was obtained from the control plot. Generally, grain yield exhibited a linear increase with increasing the rate of N fertilizer.

Strong significant and positive correlation coefficient ( $r = 0.95^{**}$ ) of N fertilizer with grain yield and other yield components of wheat (Table 8) also indicates that N is the principal factor that controls the growth and development of the crop. Moreover, grain yield was highly and positively correlated with most of the growth parameters and yield components such as straw yield ( $r = 0.94^{**}$ ), total biomass yield ( $r = 0.93^{**}$ ), thousand grains weight ( $r = 0.81^{**}$ ), plant height ( $r = 0.80^{**}$ ), fertile tillers ( $r = 0.72$ ), spike number ( $r = 0.67^{**}$ ), spike length ( $r = 0.80^{**}$ ) and spikelet per spike ( $r = 0.68^{**}$ ). Several other studies also indicated positive and linear responses of grain yield to increasing levels of N fertilizer (Tilahun *et al.*, 1996a; Amsal *et al.*, 2000). Tilahun *et al.* (1996a) reported that application of 120 kg N ha<sup>-1</sup> showed yield advantage ranging from 19 to 49% over that obtained from 60 kg N ha<sup>-1</sup> depending on the inherent N status of the soil and the amount and distribution of rainfall during the growing season of the respective locations.

### 3.5.4. Straw and Total Biomass Yields

The consequence of N fertilization on the straw yield was significant at  $P < 0.01$  (Table 4). Highly significant positive relationships were also observed among straw yield and growth parameters and yield components such as plant height ( $r = 0.76^{**}$ ), fertile tillers ( $r = 0.70^{**}$ ), spike number ( $r = 0.65^{**}$ ) and spike length ( $r = 0.73^{**}$ ) (Table 8). Straw yield showed a sharp increase with increasing the rates of N fertilizer, following the same trend as grain yield, except for the non-significant difference observed at N rates of 50 and 75 kg N ha<sup>-1</sup> (Table 9). Application of 100 kg N ha<sup>-1</sup> gave the highest straw yield (3576.30 kg ha<sup>-1</sup>) which was superior by 215.37% and 92.52% as compared to the control and 25 kg N ha<sup>-1</sup> application, respectively.

In concord with this result, Tilahun *et al.* (1996a) showed straw yield increments of 24% to 29% for 120 over 60 kg N ha<sup>-1</sup> from experiments conducted in the central and southeastern Ethiopia. Moreover, the result from the experiment done on Alfisols of the central highlands of Ethiopia by Selamyihun *et al.* (1999) showed that straw yield of durum wheat increased significantly with each incremental dose of N. Other reports (Singh *et al.*, 1992; Amsal *et al.*, 2000; Teklu *et al.*, 2002) also indicated that application of N fertilizer significantly enhanced the straw yield of wheat, since N promotes the vegetative growth of the plant. In addition, Taye *et al.* (2002) reported linear and quadratic responses of straw yield to N rate with mean values ranging from 2324 to 4073 kg ha<sup>-1</sup> during favorable growing seasons.

### 3.5.5. Harvest Index

The main effect of N application on local wheat variety harvest index (HI) was significant ( $P < 0.01$ ) (Table 4). The mean HI values varied from 35.0 to 45% for the effect of N (Table 9). Harvest indices from N rates of 0, 50 and 75 were higher and significantly different, but there is no significance difference between on HI between 75 and 100 Kg of N ha<sup>-1</sup>. On the other hand, the mean harvest indices of 25 and 50 kg N rates were comparable and low. As harvest index is the ratio of grain yield to total above ground biomass, the highest harvest indices recorded from the control plot is the result of low straw yield as compared to the plots which received N fertilizer, whereas for 75 and 100 N rates, it was due to higher grain yield (Table 9). It was also found that HI had increased with successive addition of N except at 25 kg N ha<sup>-1</sup> and was correlated positively and significantly ( $P < 0.05$ ) with grain yield and 1000 grains weight. Mengel and Kirkby (1996) also reported that harvest indices of modern wheat cultivars normally range from 35.0 to 40.0%, whereas older cultivars have indices in the range of 23.0 to 30.0%, which fully agreed with the present observation.

### 3.6. Nitrogen Uptake and Utilization of Wheat Crop

#### 3.6.1. Grain and Straw N Contents and Uptakes of Wheat

The grain and straw N contents and their uptakes were affected by the application of N fertilizer. N contents of the grain and straw augmented with each consecutive addition of N fertilizer. Accordingly, the highest grain N (2.45%) and straw N (0.45%) contents were obtained at the rate of 100 kg N ha<sup>-1</sup> and the least were from the control plot (Table 10). The crop grain N and straw N thus increased by 61.2% and 125%, respectively, in response to the application of 100 kg N ha<sup>-1</sup> relative to the control. This result is in agreement with the findings of Amsal *et al.* (2000) who reported that grain N and straw N contents of wheat had increased by 22% and 57% over the control, respectively, with application of N fertilizer.

Table 10: Effects of applied N on grain and straw N contents and uptake parameters of wheat

N (kg ha <sup>-1</sup> )	Grain N (%)	Straw N (%)	Grain N uptake (kg ha <sup>-1</sup> )	Straw N uptake (kg ha <sup>-1</sup> )	Total N uptake (kg ha <sup>-1</sup> )
Effects of N fertilizer*					
0	1.52	0.20 <sub>e</sub>	13.20	2.40	15.60
25	1.64	0.22	18.40	3.50	21.90
50	1.75	0.34	24.01	7.60	31.61
75	2.09	0.35	37.54	8.10	45.64
100	2.45	0.45	62.57	16.51	79.08

Furthermore, grain N, straw N and total N uptake parameters linearly increased in response to the increased N fertilization where the maximum uptakes were recorded at the highest N rate (100 kg N ha<sup>-1</sup>) and the minimum were at the control (Table 10). The grain N and straw N uptakes were increased by 374.02 and 587.92%, respectively, and total N uptake increased by 406.92% in response to 100 kg N ha<sup>-1</sup> relative to the control. The result obviously showed the positive effects of N on wheat grain and straw yields and the improvement of grain and straw N contents by application of N fertilizer. The grain N uptake of all N rates was much higher than that of the straw uptake due to higher grain N content than the straw. The total N uptake recorded in the present study due to N fertilization is similar with results of the previous studies in Ethiopia, (Tilahun *et al.*, 1996b; Selamyihun *et al.*, 2000), which showed total N uptakes of wheat ranging from 23.3 to 83.4 kg N ha<sup>-1</sup> for Alfisols and Vertisols.

#### 3.6.2. Apparent Recovery, and Agronomic and Physiological Efficiencies of N

The apparent recovery (AR) of N fertilizer was calculated based on the total uptake of the respective nutrients by the aboveground biomass produced in the net plot area. The apparent recovery of applied N showed positive response to N fertilizer application where the maximum (67.21%) and the minimum (27.13%) N recoveries were recorded at the highest N (100 kg N ha<sup>-1</sup>) and the lowest N (25 kg N ha<sup>-1</sup>) rates, respectively (Table 11). The highest AR of N at 100 kg N ha<sup>-1</sup> could be related to the highest total N uptake at this rate, while the least recovery at 25 kg N ha<sup>-1</sup> is also due to its lowest total N uptake, next to the control treatment (Table 11). The AR of N increased by 147.73% in response to the highest N rate relative to the lowest N rate.

Moreover, the mean AR of N (46.92%) was comparable with the previous studies done in Ethiopia which ranged from 46.8% to 65.8% (Salemyihun *et al.*, 2000) on Alfisols. In other studies, low values of crop recovery of applied fertilizer nutrients were reported usually less than 50% N apparent recoveries respectively (Harmsen, 1984). Such low AR of N might be attributed to the susceptibility of N to different losses through leaching or denitrification, and, hence, exhibits low recovery under conditions of high rainfall or impeded drainage as the case of the study area. On the other hand, Sieling *et al.* (1998) reported 59% AR of applied N in bread wheat.

The agronomic efficiency (AE) of applied N showed positive response to N fertilizer application. It ranged from 12.05 to 21.63 kg grain per kg N, where the lowest and highest records were obtained at the minimum and maximum N rates, respectively (Table 11). The AE of N fertilizer had increased by 79.50% at the highest N rate relative to the lowest N rate. The mean AE of N was 16.96 kg grain per kg applied N which is comparable with results of previous studies in the country *i.e.* 22.48 and 20.68 kg grain per kg applied N for the Alfisols, Nitisol zones respectively (Amsal *et al.* (2000).

The physiological efficiency (PE) of N responded to the application of N with an apparent decreasing trend *i.e.* the efficiency declined with each successive addition of N fertilizer rates (Table 11). Thus, the maximum and minimum physiological efficiencies of N (40.18 and 28.17 kg grain per kg total N uptake) were recorded at the lowest and highest N rates, respectively. The mean PE of N was 34.95 kg grain per kg total N uptake and it is comparable with the reports of Amsal *et al.* (2000) *i.e.* 47.33 kg grain per kg total N for bread wheat grown on Alfisols in central Ethiopia. On the other hand, Genee (2003), in the study conducted on bread wheat in southeastern Ethiopia, reported mean PE of N as low as 2.74.

Table 11: Effects of N fertilizer application on N apparent recovery, and agronomic and physiological efficiencies

N (kg ha <sup>-1</sup> )	N		
	AR	AE	PE
0	-	-	-
25	27.13	12.05	41.18
50	40.05	15.02	38.08
75	53.24	19.15	33.36
100	67.21	21.63	28.17

AR = Apparent recovery (%); AE = Agronomic efficiency (kg grain per kg nutrient applied); PE = Physiological efficiency (kg grain per kg total nutrient uptake)

#### 4. Conclusion

A fresh soil profile pit was opened and described in-situ for its morphological properties. Moreover, representative soil samples were collected from the profile on genetic horizon basis and surface soil samples from the experimental area for characterization of selected physicochemical properties. Morphological descriptions of the soil profiles were carried out in the field following the FAO guidelines, whereas analyses of the physical and chemical properties were done in the laboratory following standard laboratory procedures. Furthermore, a field experiment was conducted to determine the optimum rates of N fertilizer for local wheat production and to evaluate the effects of N fertilizer applications on yield and yield components.

The moist soil color of the present study varied from slightly dark grayish brown at the surface horizon to brownish gray at the bottom layer. It was also observed that the soil was imperfectly drained which occurs on almost flat sloping land (1.67% slope). The profile investigated had strong, medium angular blocky structure at the surface to moderate, medium granular structures in the lower subsoil horizon. The soil consistence also varied from hard (dry), firm (moist), very sticky and very plastic (wet) at the surface horizon to very friable (moist) and slightly sticky and slightly plastic (wet) at the bottom layer.

The soil textural class of both the profile and the composite surface soil samples were clay-loam and did not vary with profile depth, except for the bottom two horizons which was sandy loam. The bulk density values of the horizons in the profile varied inconsistently with depth ranging from 1.16 g cm<sup>-3</sup> at the surface layer to 1.27 g cm<sup>-3</sup> at the H<sub>3</sub> horizon. The soil water contents at FC and PWP were high attributed to the high clay content throughout the profile depth, except for the bottom two layers. On the other hand, the soil water contents both at FC and PWP and AWHC throughout the profile decreased with increasing depth which may be attributed to the decreasing trend of OM content with the soil depth.

The pH of the soil profile ranged from 6.38 at the surface layer to 8.31 in the subsurface layers showing an increasing trend with soil depth. The OM and total N contents of both the profile and the composite surface soil samples were very low and consistently declined with soil depth.

The soil exchange bases of both the profile and composite surface soil samples were predominantly occupied by divalent basic cations (exchangeable Ca followed by Mg) where the proportions of the cations were in the order of Ca > Mg > Na > K. The CEC and PBS values were very high throughout the soil depth and did not show any clear pattern of variability among horizons of the profile. In some of the subsurface layers, the PBS was too high (ranging from 82.0 to 152.4%) which might be ascribed to the extraction method used for basic cations.

Application of different rates of N fertilizer had no noticeable effect on the total N contents of the soil after harvest. This was due to the utilization of applied N by wheat crop and might also be due to N losses through different mechanisms such as leaching and denitrification.

Application of N fertilizer rates significantly ( $P \leq 0.01$ ) influenced almost all the crop characters tested such as days to maturity, heading, plant height, fertile tillers, spikes per 3m<sup>2</sup>, spike length, spikelet per spike, 1000 grain weight, grain yield, straw yield, biomass yield and harvest index. The maximum mean grain yield (2584.5 kg ha<sup>-1</sup>) was obtained at the highest N rate (100 kg N ha<sup>-1</sup>) with an increment of 19.97% and 201.86% yield advantage over the next higher N rate (75 kg N ha<sup>-1</sup>) and the control treatments, respectively. This was mainly attributed to the very low OM and total N contents of the soils of the study area which demand for improvement of the soil OM and external N input to support proper growth and development of crops.

Furthermore, the plant total N content and uptakes were linearly increased in response to the application of N fertilizer where the maximum values for grain and straw N contents and uptakes were obtained at the highest N rate. It was also obvious that much of the nutrients applied were assimilated by the grain than that achieved by the straw. Nitrogen AR and AE were increased in response to applied N rates where the maximum records were observed at the highest rate of N. The fact that all the crop yield parameters (grain, straw and biomass yield) being linearly increased with rising N rate, without showing any declining trend on the response curve, confirms

that the biological optimum N rate was not attained yet.

As a general conclusive comment, the result of the present study provide basic information for further research and development efforts in soil fertility management for sustainable utilization of the soil resources in the area. However, it is fairly tricky to develop an actual recommendation since the experiment was conducted only for one season on one crop variety in one location. Hence, studies involving more genotypes, different N rates and for at least 3 to 4 seasons over several locations should be conducted.

## References

- Alcoz, M.M., M.H., Frank, and A.H., Vincent, 1993. Nitrogen fertilization timing effect on wheat production, nitrogen uptake efficiency and residual soil nitrogen. *Agron. J.* 85: 1198- 1203.
- Amsal Tarekegn, D.G. Tanner and Chanyalew Mandefro, 2000. Agronomic and economic evaluation of the farm N and P response of bread wheat grown on two contrasting soil types in central Ethiopia. pp. 239-252. In: The Eleventh Regional Wheat Workshop for Eastern, Central and Southern Africa. CIMMYT. Addis Ababa, Ethiopia.
- Amsal Tarekegn, D.G. Tanner, AmanuelGorfu, Tilahun Geleto, and ZewduYilma, 1997. The effect of several crop management factors in bread wheat yields in the Ethiopian highlands. *African Crop Science Journal.* 5: 161-174.
- Archer, J., 1988. Crop Nutrition and Fertilizer Use. Farming Press Ltd. Suffolk. 265p.
- Asnakew Woldeab, TekalignMamo, MengeshaBekele and TeferaAjema, 1991. Soil fertility management studies on wheat in Ethiopia. pp. 137-172. In: HailuGeberemariam, D.G. Tanner and MengistuHulluka (Eds.). Wheat Research in Ethiopia: A Historical perspective. IAR/CIMMYT, Addis Ababa, Ethiopia.
- Ayoub, M., S. Guertin, S. Lussier and D.L. Smith, 1994. Timing and levels of nitrogen fertility effects on spring wheat. *Crop Sci.* 34: 748-750.
- Baruah, T.C. and H.P. Barthakur, 1997. A text book of soil analyses. Vikas Publishing House Pvt. Ltd. New Delhi. 334p.
- Batey, T. 1984. Plant growth and composition as predictors of N requirements. pp. 227-232. In: Nitrogen Requirement of Cereals. MOA, Fisheries and Food, Reference 385, London.
- BOARD, 2007. Agricultural and rural development planning section report (Unpublished).
- Bohn, H.L., B.L. McNeal and G.A. O'Connor, 2001. Soil Chemistry. 3rd (Ed.). John Willey and Sons Inc. New York.
- Botella, M.A., A.C. Cerda and S.H. Lips, 1993. Dry matter production, yield and allocation of carbon-14 assimilate by wheat as affected by nitrogen source and salinity. *Agron. J.* 85 (5): 1044-1049.
- Brady, N.C. and R.R. Weil, 2002. The nature and properties of soils. 13th (Ed). Person Education Ltd., USA.
- Carter, M.R. (Ed.), 1993. Soil sampling and methods of analysis. *Canadian Soil Science.*
- Cock, R.L. and B.G. Ellis, 1992. Soil management, a world view of conservation Krieger Publishing Company, Malabar, Florida. 413p. Company, Belmont, California.
- Craswell, E.T. and D.C. Godwin, 1984. The efficiency of nitrogen fertilizers applied to cereals in different climates. pp. 1-55. In: Tinker P.B. and A. Lauchli (Eds.). Advances in plant nutrition. Vol. 1. Praeger, New York.
- CSA (Central Statistical Authority), 2007. Agricultural Sample Survey 2006/2007. Reports on area under cultivation, yield and production of major crops for 2004/05-2006/07 main (Meher) season, Ethiopia.
- Dawit Solomon, F. Fritzsche, Tekalign Mamo, J. Lehmann and W. Zech, 2002. Soil organic matter composition in the sub-humid Ethiopian highlands as influenced by deforestation and agricultural management. *Soil Sci. Soc. Am. J.* 66: 68-82.
- Day, P.R., 1965. Hydrometer method of particle size analysis. pp. 562-563. In: C.A. Black (Ed.). Methods of Soil Analysis. Agronomy. Part II, No. 9. *American Society of Agronomy*, Madison, Wisconsin, USA.
- Desta Beyene, 1986. The response of pulse crops to nitrogen and phosphorus fertilizers. Paper Presented at the Workshop on Review of Soil Science Research in Ethiopia, Addis Ababa, Ethiopia, 11-14 February, 1986.
- Dewis, J. and P. Freitans, 1970. Physical and chemical methods of soil and water analysis. Bull. No.10. FAO, Rome, Italy.
- Eylachew Zewdie, 1987. Study on the phosphorous status of different soil types of Charcher highlands, South Eastern Ethiopia. A PhD Dissertation submitted to The University of Jestus Liebig, Germany. 186p.
- FAO (Food and Agriculture Organization), 1990. Guidelines for soil profile description, 3rd (Ed.). Soil Resources, Management and Conservation Service Land and Water Development Division, Rome. 70p.
- Fischer, R.A., 1989. Development in wheat agronomy. pp. 249-269. In: Heyne, E.G. (Ed.). Wheat and Wheat Improvement. Second Edition. *American Society of Agronomy*, Madison, Wisconsin, USA.
- Fisseha Itana, 1992. Macro and micronutrients distributions in Ethiopian Vertisols landscapes. PhD Dissertation, University of Hohenheim, Germany. 201p.
- Gebremariam, 1991. Wheat production and research in Ethiopia. In: HailuGebremariam, D.G. Tanner and

- Mengistu Hulluka (Eds.). Wheat Research in Ethiopia: A Historical Perspective. Addis Ababa, IAR/CIMMYT.
- Genene Gezu, 2003. Yield and quality responses of bread wheat varieties to rate and time of nitrogen fertilizer application in Kulumsa, Southeastern Ethiopia. An MSc Thesis presented to the School of Graduate Studies of Alemaya University, Ethiopia. 112p.
- Getachew Fisseha, 2004. Soil characterization and bread wheat response to nitrogen and phosphorus fertilization on Nitosol at Ayehu Research substation in Northwestern Ethiopia. An MSc Thesis presented to the School of Graduate Studies of Alemaya University, Ethiopia. 71p.
- Gomez, A.K. and A.A. Gomez, 1984. Statistical procedure for agricultural research 2nd (Ed.). A Wiley Inter-Science Publication, New York.
- Gooding, M.J. and W.P. Davies, 1997. Wheat Production and Utilization. CAB Int., Wallingford, UK.
- Gurmessa Lelissa, 2002. Response of wheat to fertilizer nitrogen and phosphorus in Borana Zone, Ethiopia. MSc Thesis presented to the School of Graduate Studies of Alemaya University, Ethiopia. 87p.
- Hesse, P.R., 1972. A textbook of soil chemical analysis. John Murry Limited, London, Great Britain. 470p.
- Landon, J.R. (Ed.). 1991. Booker tropical soil manual: A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics. Longman Scientific and Technical, Essex, New York. 474p.
- Mebit Kebede, 2006. Physico-chemical properties and classification of soils along the toposequence at Woreta Agricultural Technical Vocational Education and Training College research farm, Ethiopia. MSc Thesis presented to the School of Graduate Studies of Alemaya University, Ethiopia. 65p.
- Mengel, K. and E.A. Kirkby, 1996. Principles of plant nutrition. Panima Publishing Corporation. New Delhi, India.
- Mesfin Abebe, 1998. Nature and management of Ethiopian soils. Alemaya University, Ethiopia. 272p.
- Minale Liben, Alemayahu Assefa, D.G. Tanner and Tilahun Tadesse, 1999. The response of bread wheat to nitrogen and phosphorus application under improved drainage on Bichena Vertisols in northwestern Ethiopia. pp. 298-308. In: The Tenth Regional Wheat Workshop for Eastern, Central and Southern Africa. Addis Ababa, Ethiopia.
- Minale Liben, Alemayehu Assefa and Tilahun Tadesse, 2005. The response of bread wheat to nitrogen and phosphorous fertilizer at different agro-ecologies of North Western Ethiopia In: M.G. Kinyua, J. Kamwaga, J.O. Owuoche, A.C. Ndiema, P.N. Njau, D.K. Friesen, D. Ouyal (Eds.). 2005. Proceedings of Twelfth Regional Wheat Workshop for Eastern, Central and Southern Africa, 22-26 Nov. 2004. CIMMYT and KARI, Nakuru, Kenya.
- Mohammed Assen, P.A.L. Le Roux, C.H. Barker and Heluf Gebrekidan, 2005. Soils of Jelo micro-catchment in the Chercher highlands of Ethiopia: I Morphological and physicochemical properties. *Ethiopian Journal of Natural Resources*. 7(1): 55-81.
- Mooleki, S.P. and R.K. Foster, 1993. Effects of nitrogen and phosphorus rates and proportional timing of N application on rainfed wheat in Zambia. *Plant and Soil* 149: 73-86.
- Mossedaq, F., and D.H. Smith, 1994. Time of nitrogen fertilizer application to enhance spring wheat yields in a Mediterranean climate. *Agron. J.* 86(2): 221-226.
- Mukanda, N. and A. Mapiki, 2001. Vertisol management in Zambia. pp. 129-137. In: Syers, J.K., F.W.T. Penning de Veris and P. Nyamudeza (Eds.). The sustainable management of Vertisols. Proceedings of the 20th International Board for Soil Research and Management (IBSRAM). CABI Publishing, Wallingford, UK.
- Mureithi, J.G., P.M. Mwaura and C.O. Nekesa, 2000. Introduction of legume cover crops to smallholder farms in Gatanga, Central Kenya. pp. 98-102. In: Proceedings of the Second Scientific Conference of the Soil Management and Legume Research Network Projects. Mombasa, Kenya.
- Pal, U.R., 1991. Effect of source and rate of nitrogen and phosphorous on yield and nutrient uptake and apparent fertilizer recovery by maize in Southern Guinea Savanna. *Journal of Agricultural Science Technology* 1: 21-24.
- Power, I.F. and A. Alessi, 1978. Tiller development and yield standard and semi-dwarf spring wheat varieties as affected by N fertilizer. *J. Agric. Sci.* 90: 97-108.
- Sahlemedhin Sertsu and Taye Bekele, 2000. Procedures for soil and plant analysis. National Soil Laboratory Research Center: Ethiopian Agricultural Research Organization, Addis Ababa, Ethiopia. 110p.
- SAS Institute, 2000. SAS User's Guide, Statistics version 8.2 (Ed.). SAS Inst., Cary, NC, USA.
- Selamyihun Kidanu, D.G. Tanner and Tekalign Mamo, 1999. Effect of nitrogen fertilizer applied to *teff* on the yield and N response of succeeding *teff* and durum wheat on a highland Vertisol. *African J. Crop Sci.* 7 (1): 35-46.
- Selamyihun Kidanu, D.G. Tanner and Tekalign Mamo, 2000. Residual effects of nitrogen fertilizer on the yield and N composition of succeeding cereal crops and on soil chemical properties of an Ethiopian highland Vertisol. *Can. J. Soil Sci.* 80: 63-69.



- Sieling, K., H. Schroder, M. Finck and H. Manus, 1998. Yield, nitrogen uptake and apparent nitrogen use efficiency of winter wheat and winter barley grown in different cropping systems. *Journal of Agricultural Science, Cambridge*. 131: 375-387.
- Singh, P. and R.A. Khan, 2000. Long term effects of fertilizer practices on yield and profitability of rice-wheat cropping system. pp. 7-13. In: Abrol, I.P., K.F. Bronson, J.M. Duxbury, and R.K. Gupta (Eds.). Rice-Wheat Consortium Paper Series 6. New Delhi, India.
- SNNPR, BoFED, 2004. Regional atlas.Southern Nation, Nationalist People Regional State, Bureau of Finance and Economics Development, Hawassa, Ethiopia.
- Taye Bekele, Yesuf Assen, Sahlemedhin Sertsu, Amanuel Gorfu, Mohammed Hassen, D.G. Tanner, Tesfaye Tesemma and Takele Gebre, 2002. Optimizing fertilizer use in Ethiopia:
- Tekalign Mamo and I. Haque, 1996. Phosphorus status of some Ethiopian soils.*East African Agricultural and Forestry Journal*.53(3): 123-130.
- Tekalign Mamo, I. Haque, and C.S. Kamara, 1988. Phosphorus status of Ethiopian Vertisols: Management of Vertisols in Sub-Saharan Africa. pp. 232-252. In: Proceeding of the conference held at International Livestock Centre for Africa (ILCA), 31 August - 4 September 1987.
- Teklu Erkosa, Tekalign Mamo, Selamyihun Kidanu and Mesfin Abebe, 2000. Response of some durum wheat landraces to nitrogen application in Ethiopian Vertisols. pp. 229-238. In: The Tenth Regional Wheat Workshop for Eastern, Central and Southern Africa. Addis Ababa, Ethiopia.
- Tilahun Geleto, 1994. The effect of nitrogen fertilizer sources, rates and time of application on nitrogen uptake, grain yield and yield components of wheat. MSc Thesis presented to the School of Graduate Studies of Alemaya University of Agriculture, Ethiopia.
- Tilahun Geleto, D.G. Tanner, Tekalign Mamo and Getnet Gebeyehu, 1996a. Response of rainfed bread and durum wheat to source, level and timing of nitrogen fertilizer at two Vertisol sites. pp. 127-147. In: The Ninth Regional Wheat Workshop for Eastern, Central and Southern Africa. Addis Ababa, Ethiopia.
- Tilahun Geleto, D.G. Tanner, Tekalign Mamo and Getnet Gebeyehu, 1995. Response of rain fed bread and durum wheat to source level and timing of nitrogen fertilizer on two Ethiopian Vertisol sites. *Comm. in Soil Sci. and Plant Analysis*. 26: 1773-1794.
- TWAO, .2011. Tembaro Woreda Agricultural Office planning section report (Unpublished).
- Virmani S.M, K.L. Sahrawat and J.R. Burford, 1982. Physical and chemical properties of Vertisols and their management. pp. 80-93. In: Vertisols and rice soils of the tropics. Twelfth International Congress of Soil Science, 8-16 February 1982. New Delhi, India.
- Walkley, A. and C.A. Black, 1934.Determination of organic matter in the soil by chromic acid digestion. *Soil Sci.*, 63: 251-264.
- Yihene Gebreselassie, 2002. Selected chemical and physical characteristics of soils of Adet Research Centre and its testing sites in Northwestern Ethiopia. *Ethiopian Journal of Natural Resources*. 4 (2): 199-215.
- Young, A., 1976. Tropical soils and soil survey. Cambridge University Press, London. 468p.
- Zewdu Yilma, Lemma Zewdie and D.G. Tanner. 1992. A study of several factors limiting wheat yields on farmers' fields and on-station in Bale region of Ethiopia. pp. 510-516. In: Tanner, D.G. and W. Mwangi (Eds.). The Seventh Regional Wheat Workshop for Eastern, Central and Southern Africa. Nakuru, Kenya: CIMMYT.