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Research Article

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

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ABSTRACT

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. 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 62.7to 75.6 cmolc kg^{1}. 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 (6.52 cm) were obtained from application of the highest N rate (100 Kg N ha^{-1}) whereas the minimum records were obtained from the control plot. Similarly, the maximum grain yield (2584.5 kg ha^{-1}), straw yield (3576.30 kg ha^{-1}), total biomass yield (6127.4 kg ha^{-1}) 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 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

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 [1,2]. 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 [3]. 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 [4]. 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 [5,6] 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 [7].

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

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nutrient elements [8].

The major crops that are commonly grown on Vertisols and Alfisols in Ethiopia are teff, barley, durum wheat, chickpea, lentil and noug. 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^{-1} 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 [9].

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 [10,11]. Thus, managing soil fertility is very crucial for improving wheat crop productivity.

As reported 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 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 also reported that increased usage of N fertilizer is considered as one of the primary means of increasing wheat grain yield in Ethiopia.

MATERIALS AND METHODS

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 32098' E to 34029'E and 8008'N to 809'N. The total area of the district is about 27,917 hectares [12,13]. The altitude of the woreda ranges from 800 to 2600 masl and the slope ranges from intermediate (3%) to very steep slope (above 30%) as indicated by Disrict agricultural office.

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^{o}C-33^{o}C. The mean annual rainfall varies between 800-1800 mm. 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.

Soils: The dominant soil of the district is Alfisols [14,15]. 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 150 cm with the pH value from 5.5 to 6.7.

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.

Population: The total population of the study area is 145,946. 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. Apparently, the continuous rise of population puts huge pressure on the remaining forest (natural and plantation) fragments and cultivation of marginal lands.

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 ventricossum*) and some other root crops such as sweet potato, taro and yam are also some common staple food whereas coffee and gingers 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.

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^{-1}). 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 3 m wide and 4 m long (12 m^2) accommodating 1 wheat plant rows spaced 20 cm apart. The plot size for planting was 1.5 m × 2 m (3 m^2) 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^{-1} 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 35th day after planting. During the different growth stages of the crop, all the necessary cultural and/or recommended agronomic management practices were carried out.

Soil sampling and sample preparation

A fresh soil profile pit with 1 m width by 2 m 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 physic-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 $CaCO_3$ 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 samples 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.

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 0C [16,17]. 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^{-3}. The formula used to estimate total porosity derived from the bulk density and particle density.

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

Soil pH was measured potentiometrically using a pH meter with combined glass electrode in 1: 2.5 soils: water ratio as described. Organic carbon was determined using the wet oxidation method [18,19] 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^{4+} as ammonium sulfate [20,21].

Calcium carbonate ($CaCO_3$) 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. The exchangeable bases (Ca, Mg, K and Na) in the soil were determined from the leachate of 1 molar ammonium acetate (NH4OAc) solution at pH 7.0. Exchangeable Ca and Mg were measured by atomic absorption spectrophotometer and K and Na were read using flame photometer [22,23]. Similarly, CEC were measured after leaching the NH4OAc 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 [24].

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^2) 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^2, number of spikes per 2.25 m^2, 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^2). The number of spikes per 2.25 m^2 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 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.

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_3, H_2SO_4 and $HClO_4$. 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:

$[(U_n-U_o)/n] \times 100$

Where U_n stands for nutrient uptake at 'n' level of fertilizer nutrient and U_o 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 Croswell and Godwin (1984) as:

$AE=[(G_n-G_o)/n]$

$PE=[(G_n-G_o)/(U_n-U_o)]$

Where G_n stands for grain yield of the plot fertilized with 'n' fertilizer rate and G_o for grain yield of unfertilized plot. The notations U_n and U_o stand for nutrient uptake in the two cases as described earlier.

Statistical analysis

The agronomic data was subjected to analysis of variance (GLM procedure) using SAS software program version 8.2 [25-28]. 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 [29,30]. Correlation analysis was carried out by calculating simple linear correlation coefficients between yield and yield components.

RESULTS AND DISCUSSION

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.

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. 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_6), 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. 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. 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 weather able 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 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^{-3} at the surface layer (H_1 horizon) to 1.27 g cm^{-3} at the third layer (H_3 horizon). Therefore, the values are closer to the normal range of BD for mineral soils which is 1.3-1.4 g cm^{-3} as indicated. 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 [31-33]. 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 ($g\ cm^{-3}$)	TP (%)	Water content		
		Sand	Silt	Clay					FC (%)	PWP (%)	AWHC ($mm\ m^{-1}$)
0-25	H_1	11	38	51	Clay-loam	0.75	1.14	56.98	42	27	128
25-55	H_2	13	37	50	Clay-loam	0.74	1.23	53.58	39	25	125
55-80	H_3	15	40	45	Clay-loam	0.89	1.27	52.07	37	22	123.6
80-115	H_4	15	52	33	Silty-loam	1.58	1.26	52.45	37	22	123.6
115-155	H_5	45	30	25	Sandy-loam	1.2	1.21	50.34	29	16	110.5
155-200	H_6	54.6	26.4	19	Sandy loam	1.39	1.16	51.98	25	14	109
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	-	-	-	-	-

Note: *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 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^{-1} 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, 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 reported that Alfisols investigated in Zambia had high water content due to their high clay content [34,35]. 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^{-1} soil depth) in contrast to other soils with high clay content [36-39].

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). 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.

Chemical properties of the soil

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. 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).

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

Depth (cm)	Horizon	pH (H_20)	$CaCO_3$ (%)	*OM (%)	C:N	Total N (%)	Exchangeable bases and CEC soil (cmolc kg^{-1})					PBS
			0				Na	K	Mg	Ca	CEC	
0-25	H_1	6.38	0.21	2.34	9.34	0.092	0.3	0.7	9.4	41	70.1	82
25-55	H_2	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_3	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_4	7.79	0.35	0.89	10.17	0.053	0.8	0.8	9.04	48	58.4	111
115-155	H_5	8.31	10.78	0.45	4.34	0.024	0.9	0.3	9.61	78.5	75.2	152
155-200	H_6	8.22	3.15	0.08	3.95	0.011	1.3	0.31	10.8	61	62.7	137
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	9.6	40	73.1	78
Block 2	-	6.15	0.23	2.402	9.25	0.096	0.3	0.95	10.28	41.3	65.5	69.5
Block 3	-	6.49	0.24	2.39	8.95	0.089	0.3	1.01	10.23	39.9	61.6	71.7
Block 4	-	6.55	0.25	2.46	8.97	0.083	0.3	1.03	9.54	41.4	59.4	70.5
Block 5	-	6.05	0.22	2.37	9.21	0.094	0.3	0.98	9.61	38.5	62.2	62.4
Block 6	-	6.27	0.25	2.44	9.05	0.091	0.3	0.97	10.8	36.8	62.8	59.8
Mean	-	6.32	0.23	2.412	9.13	0.091	0.3	0.998	10.01	39.6	64.1	68.7

Note: *OM: Organic Matter; C-N: Carbon to Nitrogen ratio; CEC: Cation Exchange Capacity; PBS: Percent Base Saturation.

Calcium carbonate: The content of calcium carbonate ($CaCO_3$) in the soil profile ranged from 0.21% at the surface horizon to 10.78% at the H_5 horizon. Generally, there are no precise ratings for levels of free carbonates, but values of over about 40% can be considered as extremely calcareous. 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 $CaCO_3$ 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 $CaCO_3$ is generally low (<15%) and it showed an increasing trend down the profile depth which cannot bring any significant problem in crop production.

Organic matter and total nitrogen: The organic matter content of the profile 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. 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 [40-42]. 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 (H1 horizon) layer. 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.

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. 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^{-1} at the H_1 and H_3 horizons respectively to 78.5 cmolc kg^{-1} 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^{-1} at the H_5 to 10.8 cmolc kg^{-1} at H_6 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 [43] and in soils of Jelo micro-catchment [44]. 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 $CaCO_3$ that the maximum value of $CaCO_3$ (10.78%) was observed at the H_5 horizon which coincided with the highest exchangeable Ca (78.5 cmolc kg^{-1}) [45].

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_2 and H4 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 [46-48].

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 [49].

Therefore, the range suggests the presence of 2:1 clay minerals and can be expected to have more nutrient reserves 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 indicate that the soil has high buffering volume when compared to the induced alterations [50].

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 [51].

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 [51].

Response of wheat to applied N fertilizer: Analysis of variance for crop agronomic parameters 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).

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^{-1}) headed and matured more rapidly (though no significant difference was observed among themselves) than the plots receiving 25 kg N ha^{-1} and the control plot (Table 5). The coefficients of correlation for days to heading and maturity were also found negative and significant 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. Abundant supply of N might delays plant maturity. Contrary to the current finding, however, reported that N fertilization at the rate of 92 kg N ha^{-1} and above 92 Kg N ha^{-1} significantly ($P \leq 0.01$) delayed physiological maturity of wheat crop.

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

Applied N rate (kg ha^{-1})	Total N available (%)					Mean
0	0.07	0.068	0.066	0.067	0.069	0.068
25	0.075	0.07	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	-

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

	Mean squares for source of variation	
Parameters to be considered	N (5)	Error
Stand count	632.454545^{ns}	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^{ns}	3.0578231
Number of fertile tillers	192750.254**	7251.612
Number of spikes 2.4 m^{-2}	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

Note: *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)
	Effects of N fertilizer*		
0	89	152	56
25	86	145	54
50	83	139	54
75	78	139	55
100	80	135	55
LSD (0.05)	0.92	1.62	Ns
SE (±)	0.37	0.52	0.53
CV (%)	1.12	1.06	2.64

Note: *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.

Table 6: Main effects of N on wheat growth parameters.

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

Note: *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. 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^{-1}) followed by 61.05 cm which was obtained from 75 kg N ha^{-1} and the minimum (49.26 cm) was from for the control plot. Simple correlation coefficient also showed that N was strongly and positively correlated to plant height. In agreement reported a positive and linear response of plant height to N fertilizer application in the central highlands of Ethiopia [52]. Several other studies have also revealed remarkable plant height enhancement in reaction to each incremental dose of N fertilizer [53-55].

Nevertheless, the effect of applied N on the number of productive tillers was statistically significant ($P \leq 0.01$). The number of tillers per $3m^2$ 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^{-1}. 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^{-1}. It can also be observed from the highly significant and positive correlation coefficient that increasing the N rate had enhanced the development and growth of new productive tillers (Table 6).

As reported that N stimulates tillering probably due to its effect on cytokinin synthesis and 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 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 [56].

Effects of N fertilizers on wheat yield and yield components

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^{-1} followed by 405 and 386 due to applications of 75 and 50 kg N ha^{-1} 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^{-1} and the control plot.

More than a few researchers also reported the enhancement of fertile spikes per unit area with increasing rates of N fertilizer 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, 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 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 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.

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^{-1} 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 indicating an increase in the rate of N resulted in a more weight of wheat grain. This result is in line with the findings indicated that 2.2 to 10% higher grain weights were obtained from 120 over 60 kg N ha^{-1} depending on the location and climatic condition of the growing season 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 have shown either no improvement or reduced kerenel weight due to N fertilization even when yields increased also reported non-significant response of 1000 grains weight to application of N fertilizer in the highlands of Ethiopia.

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

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

Note: *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.

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

1	N	GY	SY	TBY	TGW	HI	SC	PH	DH	DPM	DGF	FT	SN	SL	SPS
N	1	0.95**	0.89**	0.92**	0.801**	0	0	0.90**	-0.80**	-0.85**	0	0.76**	0.61**	0.88**	0.77**
GY		1	0.94**	0.93**	0.81**	0.27*	0	0.80**	-0.82**	-0.77**	0	0.72**	0.67**	0.80**	0.68**
SY			1	0.92**	0.71**	0	0	0.76**	0.85**	0.85**	0	0.70**	0.65**	0.73**	0.74**
TBY				1	1	0	0	0.85**	0.84**	0.82**	0	0.78**	0.72**	0.85**	0.75**
TGW					1	0.30*	0	0.2*	0.78**	0.70**	0	0.61**	0.51**	0.72**	0.65**
HI						1	0	0	0.1	0	0.54*	0	0.2	0	0
SC							1	0	0	0	0	0	0.57**	0	0
PH								1	0.91**	0.92**	0	0.74**	0.55**	0.86**	0.73**
DH									1	0.96**	0	0.73**	0.72**	0.30**	0.71**
DPM										1	0	0.68**	0.48**	0.71**	0.63**
DGF											1	0	0.34*	0	0
FT												1	0.65**	0.68**	0.64**
SN													1	0.54**	0.58**
SL														1	0.93**
SPS															1

Note: *:Significant at P ≤ 0.05; **:Significant at P ≤ 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^2; SN: Spike Number per 3m^2; SL: Spike Length; SPS: Spikelet Per Spike.

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

N (kg ha-1)	Thousand grain weight (gm)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Total Biomass yield (kg ha^{-1})	Harvest index (%)
Effects of N fertilizer*					
0	38.35	856.2	1134.0	2104.4	39.0
25	41.54	1097.6	1857.6	3043.5	35
50	45.14	1234.3	2661.8	4127.6	36
75	48.57	2154.4	2761.10	4857.7	45
100	49.35	2584.5	3576.30	6127.4	45
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

Note: *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.

Grain yield: Grain yield responded significantly (P<0.01) to the application of N fertilizer rates. The highest mean grain yield (2584.5 kg ha^{-1}) was obtained from the maximum N rate (100 kg N ha^{-1}) with an increment of 19.96% and 201.86% yield advantage over the next higher N rate (75 kg N ha^{-1}) and the control plot, respectively. The next highest mean grain yield (2154.4 kg ha^{-1}) was obtained from 75 kg N ha^{-1} and the least yield (856.2 kg ha^{-1}) 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 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 reported that application of 120 kg N ha^{-1} showed yield advantage ranging from 19 to 49% over that obtained from 60 kg N ha^{-1} depending on the inherent N status of the soil and the amount and distribution of rainfall during the growing season of the respective locations.

Straw and total biomass yields: The consequence of N fertilization on the straw yield was significant at P<0.01). 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**). 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^{-1}. Application of 100 kg N ha^{-1} gave the highest straw yield (3576.30 kg ha^{-1}) which was superior by 215.37% and 92.52% as compared to the control and 25 kg N ha^{-1} application, respectively [57].

In concord with this result showed straw yield increments of 24% to 29% for 120 over 60 kg N ha^{-1} from experiments conducted in the central and southeastern Ethiopia. Moreover, the result from the experiment done on Alfisols of the central highlands of Ethiopia showed that straw yield of durum wheat increased significantly with each incremental dose of N. Other reports 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, reported linear and quadratic responses of straw yield to N rate with mean values ranging from 2324 to 4073 kg ha^{-1} during favorable growing seasons [58].

Harvest index: The main effect of N application on local wheat verity harvest index (HI) was significant (P<0.01). The mean HI values varied from 35.0 to 45% for the effect of N. 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^{-1}. 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. It was also found that HI had increased with successive addition of N except at 25 kg N ha^{-1} and was correlated positively and significantly (P<0.05) with grain yield and 1000 grains weight and 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.

Nitrogen uptake and utilization of wheat crop

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^{-1} and the least were from the control plot. 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^{-1} relative to the control. This result is in agreement with the findings 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 [59]. 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^{-1}) 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^{-1} 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, which showed total N uptakes of wheat ranging from 23.3 to 83.4 kg N ha^{-1} for Alfisols and Vertisols.

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^{-1}) and the lowest N (25 kg N ha^{-1}) rates, respectively. The highest AR of N at 100 kg N ha^{-1} could be related to the highest total N uptake at this rate, while the least recovery at 25 kg N ha^{-1} is also due to its lowest total N uptake, next to the control treatment. The AR of N increased by 147.73% in response to the highest N rate relative to the lowest N rate [60-62].

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% on Alfisols. In other studies, low values of crop recovery of applied fertilizer nutrients were reported usually less than 50% N apparent recoveries respectively. 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 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. 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 [63].

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 [64]. The mean PE of N was 34.95 kg grain per kg total N uptake and it is comparable with the reports of 47.33 kg grain per kg total N for bread wheat grown on Alfisols in central Ethiopia. On the other hand, in the study conducted on bread wheat in southeastern Ethiopia, reported mean PE of N as low as 2.74.

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

N (kg ha^{-1})	Grain N (%)	Straw N (%)	Grain N uptake (kg ha^{-1})	Straw N uptake (kg ha^{-1})	Total N uptake (kg ha^{-1})
			Effects of N fertilizer*		
0	1.52	0.20$_e$	13.2	2.4	15.6
25	1.64	0.22	18.4	3.5	21.9
50	1.75	0.34	24.01	7.6	31.61
75	2.09	0.35	37.54	8.1	45.64
100	2.45	0.45	62.57	16.51	79.08

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

N (kg ha^{-1})		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

Note: AR: Apparent Recovery (%); AE: Agronomic Efficiency (kg grain per kg nutrient applied); PE: Physiological Efficiency (kg grain per kg total nutrient uptake).

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^{-3} at the surface layer to 1.27 g cm^{-3} at the H_3 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^2, 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^{-1}) was obtained at the highest N rate (100 kg N ha^{-1}) with an increment of 19.97% and 201.86% yield advantage over the next higher N rate (75 kg N ha^{-1}) 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.

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