SOIL CHARACTERIZATION AND EVALUATION OF SLOW RELEASE UREA FERTILIZER RATES ON YIELD (components?)AND GRAIN YIELDS OF WHEAT AND TEFF ON VERTISOLS OF JAMMA DISTRICT OF SOUTH WOLLO ZONE, AMHARA REGION

MSc THESIS

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Soil Characterization and Evaluation of Slow Release Urea Fertilizer Rates on Yield Traits and Grain Yields of Wheat and Teff on Vertisols of Jamma District of South Wollo Zone, Amhara Region

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MASTER OF SCIENCE IN AGRICULTURE (SOIL SCENCE)

By
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As thesis research advisor, I hereby certify that I have read and evaluated the Thesis entitled "Soil Characterization and Evaluation of Slow Release Urea Fertilizer Rates on Grain Yields and Yield Traits of Wheat and Teff on Vertisols of Jamma District of South Wollo Zone, Amhara Region" prepared under my guidance by Abebe Getu, and recommend it to be submitted as fulfilling the thesis requirement.

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This thesis manuscript is dedicated to his father Getu Asfaw and his brother Misganaew Getu who helped and encouraged him during his educational careers but were not destined to see the fruits of their efforts.

STATEMENT OF THE AUTHOR

First of all, I declare that this thesis is a result of my genuine work and that I have duly acknowledged all sources of materials I referred to for writing it. I submit this thesis to Haramaya University in partial fulfilment for the Degree of Master of Science. The thesis is deposited at the library of the University to be made available to borrowers for reference. I solemnly declare that I have not submitted this thesis to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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BIOGRAPHICAL SKETCH

The author, Abebe Getu, was born on 02 October 1982 in Gondar town, North Gondar Zone, Amhara National Regional State. He attended his primary school education at the Andinet Elementary School. In the subsequent years, he enrolled at the Azezo Senior Secondary School (Grade 7-12) in Gondar town and finally passed the Ethiopian Schools Leaving Certificate Examination in the summer of the 2001.

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LIST OF ABBREVIATIONS AND ACRONYMS

AE	Agronomic Efficiency
AAPFCO	American Association of Plant Food Control Officials
AR	Apparent Fertilizer Recovery Efficiency
AWHC	Available Water Holding Capacity
BW	Biomass Weight
C:N	Carbon to Nitrogen Ratio
CEC	Cation Exchange Capacity
CSA	Central Statistical Authority
CV	Coefficient of Variation
CU	Conventional Urea
DF	Days to Flowering
DH	Days to Heading
DM	Days to Maturity
E	East
EEF	Enhanced Efficiency Fertilizer
FC	Field Capacity
FAO	Food and Agriculture Organization of the United Nations
GNU	Grain Nitrogen Uptake
GY	Grain Yield
G_n	Grain Yield of Fertilized at '*n*' Rates of Fertilizer
Go	Grain Yield of Unfertilized
GDP	Gross Domestic Product
ha	Hectare
IFDC	International Fertilizer Development Center
LSD	Least Significant Difference
masl	Meters above Sea Level
NHI	Nitrogen Harvest Index
NUE	Nitrogen Use Efficiency
ns	Non Significant
N	North
NK	Number of Kernels per Spike
Ns	Nutrient Supplied
U_n	Nutrient Uptake at '*n*' Rate of Fertilizer
U_o	Nutrient Uptake of the Control
OC	Organic Carbon
OM	Organic Matter
PFP	Partial Factor Productivity
PBS	Percent Base Saturation
PWP	Permanent Wilting Point
PE	Physiological Efficiency
Av. P	Plant Available Soil Phosphorus
PH	Plant Height
PU	Prilled Urea

LIST OF ABBREVIATIONS AND ACRONYMS (*CONTINUED*)

P	Probability Level
Rf	Rainfall
n	Rates (Levels) of Fertilizer
SRUF	Slow Release Urea Fertilizer
SL	Spike Length
SN	Spike Number per Plant
SAS	Statistical Analysis Software
STU	Straw Nitrogen Uptake
SY	Straw Yield
TKW	Thousand Kernel Weight
t	Ton
Nt	Total above Ground Nutrient
TN	Total Nitrogen
TNU	Total Nitrogen Uptake (Grain + Straw)
TSP	Triple Super Phosphate
USDA	United States Department of Agriculture
USA	United States of America
USG	Urea Super Granule

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Soil Characterization and Evaluation of Slow Release Urea Fertilizer Rates on Yield Traits and Grain Yields of Wheat and Teff on Vertisols of Jamma District of South Wollo Zone, Amhara Region

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ABSTRACT

An on-farm experiment was conducted in Jamma district of South Wollo zone of the Amhara regional state in 2011 main cropping season. The objectives of the experiment were to characterize the soil of the study area and evaluate the efficiency of slow release nitrogen fertilizer (urea super granule, USG) against the conventional urea fertilizer (CU) in increasing yield and yield traits of wheat and teff crops. Soil pedons were opened on both experimental fields and surface soil samples teken at a depth of 0-20 cm and soil samples from different soil layers in the pedons were collected from both experimental fields prior to planting to characterize the soil and study the fertility status of the study area. Surface soil samples were also collected at a depth of 0-20 cm after harvesting to study the residual effects of USG fertilizer on soil nitrogen. The test crops used in the study were improved wheat variety (HAR 1685) and local teff variety (Wajera), which were widely adopted and produced by the farmers in the study area. The study comprised of three rates of USG (50, 100 and 150% of the recommended N), a single rate of CU (100% of the recommended N) and control (without nitrogen). The treatments were laid in a randomized complete block design with three replications. The aforementioned three rates of USG were applied at 10 cm distance in a row in between the rows of the plants and placed at 10 cm soil depth with placement spacings of 96, 48 and 32 cms, respectively. The full recommended level of phosphorus (46 kg P_2O_5 *ha*$^{-1}$*) was applied all as basal in the form of triple super phosphate (TSP) to all experimental plots. The surface soil sample analyses and soil profile description results indicated that the soil is in a conducive ranges of pH for most crops and clayey in texture with low to medium organic matter, total nitrogen and available phosphorus content. The percent base saturation of both experimental fields was high with Ca and Mg dominating the cation exchangeable sites. The soil pedons opened in both experimental fields had four soil layers and soil depths were found between 1 and 1.5 m in both soil pedons. Soil structure of the soil layers of both study fields were massive blocks and some weak prismatic like soil structure with shiny pressure faces of slickensides. Clayey soil texture was dominant in all soil layers of both soil profiles and increased along with depth. Accordingly, high moisture content at FC and PWP and high available water holding capacity and total porosity were measured from the soils layers of both fields. Low bulk densities were measured in all soil layers. In the bottom soil layers calcium carbonate containing coarse sands were observed and the pH of the soil layers were in a slightly acidic to slightly alkaline ranges and increased along with depth. The organic matter, total nitrogen and available phosphorus content of the soil layers were in the low to medium ranges and showed a decreasing trend as depth increased on both fields. The percent base saturation of both fields was high, dominated by calcium and* *magnesium. The soil profiles physical and chemical properties analyzed indicated that the soil on both fields was presumably formed from a sedimentary lime stone parent material. The agronomic analysis results of the test crops revealed that there was a significant difference ($P \leq 0.01$) in all the agronomic parameters measured in both test crops. The highest yield traits of wheat (plant height, spike no. per plant, spike length and no. of kernels per spike, 1000 kernel weight and straw yield) and teff (plant height and straw yield) were obtained from the application of 150% of the recommended N as USG. The highest grain and total biomass yields of both test crops were obtained from the application of 150% of the recommended N as USG followed with significant difference ($P \leq 0.05$) by application of 100% of the recommended N as CU and USG, respectively. The least grain, straw, and biomass yields in both test crops among the treatments which received N were obtained from the application of 50% of the recommended N as USG. Although there is no statistically significant difference, application of 100% of the recommended N as CU gave grain and total biomass yield advantages of 4.2 and 6.7%, respectively (in the test crop, wheat) and 7.9 and 2.8%, respectively (in the test crop, teff) over application of USG at the same rate. Therefore, from the results obtained in this experiment it is possible to conclude that application of conventional urea fertilizer is preferred from urea super granule at the application rate of the existing full recommendation rate of N for economically beneficial yields of wheat and teff crops.*

1. INTRODUCTION

Agriculture is the core driver of Ethiopia's economic development and long-term food security. It contributes 43% to the gross domestic product (GDP); employs nearly 85% of the total labor force and contributes about 90% of the national export earnings. The agricultural sector is dominated by small-scale farmers, accounting for 95% of the total area under crop cultivation and more than 93% of the total agricultural output (CSA, 2010).

Crops are the major agricultural commodities on which Ethiopians depend for their daily food. There are no substitutes for cereals, pulses and oil crops for the Ethiopian masses. However, given the poor performance of the agricultural sector vis-à-vis the growing population, which is estimated at over 70 million and growing at a rate of 2.7% per annum, intensification of agriculture is very critical (CSA, 2010). As a result, there has been an overall effort in the country to increase agricultural productivity to meet the growing demand for food and agricultural raw materials.

Among the major cereal crops, wheat and teff are the most widely consumed crops in the country. Wheat is the third important cereal crop after teff (*Eragrostis tef*) and maize (*Zea mays*) in area coverage. Among the major cereal crops in the country, wheat ranks second after maize in productivity and accounts for 21.7% of the total cereal output (CSA, 2010). The total area under both durum (*Triticum turgidum var. durum*) and bread wheat (*Triticum aestivum* L.) was about 1.75 million hectares (ha) in 2009/2010 main cropping season, grown primarily as a highland rain-fed crop. Mean wheat yields are around 1.86 tons (t) ha^{-1}, well below experimental yields of over 5 t ha^{-1}. Ethiopia's current annual wheat production of approximately 3.24 million tons is insufficient to meet the domestic needs (CSA, 2010).

The other most important food crop in Ethiopia is teff. Ethiopia is the center of origin and diversity for teff (Seyfu, 1997). The crop is highly adapted to diverse agroecological zones including conditions marginal to the production of most other crops. It is adapted to environments ranging from drought-stressed to waterlogged soil conditions (Seyfu, 1997). Accordingly, teff is the most preferred and important cereal crop by the farmers and it takes the lion's share of the cultivated land of cereals in Ethiopia. Covering 2.57 million ha of the cultivated land in Ethiopia, teff accounts for 21.4% of the total cereal production in 2009/2010 main cropping season (CSA, 2010). However, the existing national production and productivity of teff with an average yield of 1.24 t ha^{-1} and annual yields of about 3.19 million tons is inadequate to satisfy/meet the national food demand.

Vertisols are considered suitable for cereals production like wheat and teff. Vertisols cover about 12.61 million ha of land in Ethiopia and the country ranks third in Vertisols abundance in Africa after Sudan and Chad (Berhanu, 1985). Of the total coverage of Vertisols in Ethiopia, about 8 million ha, including the present study area, are in the Ethiopian highlands and these account for 63% of all Vertisols in the country (Berhanu, 1985). However, only about two million ha (25%) of the Vertisols in the Ethiopian highlands are presently cultivated. This cultivated Vertisols area accounts for about 23% of the total currently cultivated area in the country. As the rest of the Vertisols are mostly in bottom lands, they get flooded and waterlogged during the wet season and, therefore, remain uncultivated and used mainly for dry-season grazing.

The Vertisols in the present study area, Jamma, are extensively cultivated. Over 90% of the potentially arable Vertisols exist in the area is cultivated (Getachew, 1991). However, their meager organic matter (OM) content and low nitrogen (N) supply capacity coupled with their inherent characteristics of intense waterlogging and drainage problems limit their productivity. Moreover, continuous cultivation with nutrient-depleting crops and complete removal of crop residues from farmlands, absence of crop rotation and no fertilizer (organic or inorganic) inputs results in irreversible nutrient mining by plant uptake (Heluf, 2005). As a consequence of these and other factors, Heluf (2005) also stressed that declining soil fertility is a fundamental impediment to agricultural development and the major reason for the slow growth rate in food production and food insecurity both at household and national levels in Ethiopia.

Most soils in the semi-arid areas of northeastern Ethiopia, where the present study district lies, are heavily depleted of plant nutrient elements and are characterized by low total N, available phosphorus (P) and organic carbon (OC) leading to substantial decline in crop productivity (Hailu and Kidane, 1988; Asnakew, 1994). Studies have shown that application of N fertilizer enhanced the productivity of Vertisols with the economic optimum rates of 64 kg N ha^{-1} for durum wheat (Workneh and Mwangi, 1992) and 55 kg N ha^{-1} for teff (Tekalign *et al*., 1996).

Wheat and teff are also the most important food crops in the present study area (Jamma District), produced by 99.1 and 86.2% of the local farmers and covering 50.4 and 21.0% of the total cultivated land in the District, respectively (Getachew, 1991). Recently, different improved high yielding wheat and teff varieties have been released by different agricultural research centers and higher learning institutions in the country. Some of these improved varieties are adopted by the farmers in Jamma district. However, these high yielding improved varieties are high input-responsive, and N and P deficiencies are the major constraints to such crops production in the Ethiopian highland Vertisols (Kamara and Haque, 1988; Tekalign *et al*, 1988).

Accordingly, there is an encouraging growing demand and utilization of fertilizers in the country and in the study area as well (Getachew, 1991). As a result, the use of chemical fertilizers in Ethiopia have made a contribution to crop yield growth to date, although there is potential for further improvement (Asnakew *et al.*, 1991). Nevertheless, fertilizer is applied by less than 45% of farmers, on about 40% of the area under crop in the country, and most likely at below-optimal dosage levels (Dercon and Hill, 2009). While application rates are higher than the average for sub-Saharan Africa (Heisey and Mwangi, 1996; Dercon and Hill, 2009), there is evidence to suggest that fertilizer applied in Ethiopia is not as effective as could be hoped.

Urea is a nitrogenous fertilizer commonly used in the world agriculture including Ethiopia (Workneh and Mwangi, 1992; Tekalign *et al*., 1996). After being applied to soil, it can be rapidly hydrolyzed to NH_3 and CO_2 by soil urease (Gioacchini *et al*., 2002), followed by NO_3 formation through nitrification. Thus, worldwide N use efficiency (NUE) for cereal production is approximately 33% (Raun and Johnson, 1999) and ammonia loss by volatilization and nitrate (NO_3^-) leaching are environmental concerns in regions where urea is applied. Accordingly, improvement of nutrient use efficiency of crops, that will maximize crop yield, minimize N losses, and eventually improve crop production profitability, in wheat and teff cropping systems can be achieved either by adopting more efficient crop management practices (such as nutrient rate, timing, source, placement and soil-water-crop management practices) or producing more nutrient use efficient cultivars through breeding.

The N fertilizer recovery and N use efficiency of both local and improved varieties, however, hinges upon the soil physical and chemical properties and climatic conditions, to mention some; soil texture, porosity, OM content, clay mineralogy, rainfall, and temperature of which the aggregate effects lead to loss of the added N fertilizer and subsequent low production and economic loss (Tekalign *et al*., 1996). Thus, the development of high yielding varieties and its use solely are not enough to guarantee the desired goal of food security. Therefore, in order to sustainably increase wheat and teff production and productivity, there has to be a research intervention to develop appropriate agronomic practices and in due course improve their fertilizer recovery efficiency.

In order to sustain the production system, it is essential that the nutrient demand of a crop to produce a target yield and the amount removed from the soil be perfectly matched. Nutrient losses due to leaching, volatilization and fixation and the activated risk of NO_3-N leaching after fertilizer addition to the soil may be, however, reduced through the use of enhanced efficiency fertilizers (EEFs) such as, slow release urea fertilizers (SLUFs), which can increase nutrient availability by either slowing release or altering reactions that lead to losses (Kathrine, 2011). Adequate and consistent nutrient availability reduces plant stress and may result in better yield (Hall, 2005). Matching N released with N uptake rather than having high levels of N in the soil solution immediately after fertilization can reduce the risk of excessive vegetative growth and lodging in teff and wheat. It also increases the chance that N will be available during grain filling to increase grain protein.

Among the SLUFs, urea super granule (USG) is designed to slowly release N into the soil. These fertilizers have been proved to increase crop N use efficiency, yield and protein levels, and to reduce unnecessary losses of applied N fertilizer in to the environment (Kathrine, 2011). However, agronomic performance, competency and economic profitability of these N sources with the existing conventional urea fertilizers for small grains crop production must first be evaluated relative to their potential benefits before it can be recommended to farmers. However, little researches have been conducted so far on these slow release urea fertilizers in Ethiopia. This study was, therefore, initiated to characterize the fertility status of the soils in the study area based on selected soil physico-chemical properties and evaluate the efficiency of different rates of urea super granules against the conventional urea fertilizer on the grain yields and yield components of wheat and teff crops.

2. LITERATURE REVIEW

2.1. Production of Wheat in Ethiopia

Wheat (*Triticum aestivum* L.) is one of the major cereal crops of the world ranking second after paddy rice both in acreage and production among the cereal crops. It provides more nourishment for the nations of the world than any other food crops. It supplies carbohydrate, protein, minerals and vitamins and is more preferable to rice for its higher seed protein content (about 12%), 1.72% fat, 69.60% carbohydrates and 27.20% mineral matter (FAO, 2010).

Ethiopia is one of the largest wheat producers among the countries in the Sub-Saharan Africa (Hailu, 1991) and it is one of the most important cereal crops in Ethiopia. Wheat is grown in the highlands of the country at altitudes ranging from 1500 to 3000 meters above sea level (masl). Currently, wheat is one of the major cereals dominating food habits and dietary practices and is known to be a major source of energy and protein for the highland population in Ethiopia (Abera, 1991) and it is the most widely produced crop following teff on the Vertisols of Ethiopian highlands (Getachew, 1991).

The two principal economic wheat species grown widely in Ethiopia are durum wheat (*Triticum turgidum var.durum*) and bread wheat (*Triticum aestivum*). However, recently the area under bread wheat has surpassed the durum wheat (Fasil *et al.*, 2000) because of its significance as a cash crop, a high level of production per unit area, and its role in supplying the dietary requirements of peasant farmers (Asafa *et al.*, 1996). Assefa?

Ethiopia’s current annual wheat production of approximately 3.24 million tons is insufficient to meet domestic needs (CSA, 2010). The low mean national yield for wheat is primarily due to depleted soil fertility, low fertilizer usage, and the unavailability of other improved crop management inputs (Asnakew *et al.*, 1991; Getachew, 1991). There are a number high yielder improved bread wheat varieties which have been released by different agricultural research centers in Ethiopia.

The bread wheat variety HAR 1685 has been verified to be one of the most productive varieties in Ethiopia among the recently released improved bread wheat varieties (Solomon *et al.,* 1995) and it is one of the bread wheat varieties which have been widely adopted by the majority of wheat growing farmers in the present study area. However, according to Tanner *et al*. (1993) and Amsal *et al*. (1995), recently-released bread wheat cultivars are highly responsive to improved management systems, and, relative to older wheat lines, exhibit an economic response to higher rates of nutrient application.

It is evident that application of fertilizer greatly increases grain yields, and facilitates the adoption of improved high-yielding varieties, and hence greater usage of chemical fertilizer has been advocated as a primary means of increasing wheat grain yield in Ethiopia (Tanner *et al*., 1993; Amsal *et al*., 1997). Asnakew *et al.* (1991) reported that the use of chemical fertilizers in Ethiopia have made a contribution to crop yield growth to date although there is potential for further improvement.

2.2. Production of Teff in Ethiopia

Ethiopia is the center of origin and diversity of teff. Teff is an important cereal crop in Ethiopia cultivated on more than 2.57 million hectares (ha) of land covering about 32% of the area under cereals (Fufa *et al*., 2001; CSA, 2010). According to Roseberg (2005), the crop is highly adapted to diverse agro-ecological zones including conditions marginal to the production of most other crops. It can grow from sea level up to 3000 masl and performs well between 1700 and 2400 masl. Teff is cultivated in high rainfall areas with long growing periods and drought prone areas characterized by protracted growing seasons and frequent terminal moisture stress. It tolerates reasonable levels of both drought and waterlogging better than most other cereals.

Vertisols are considered potentially suitable for cereal crop production like wheat and teff. However, proper management on Vertisols calls for the use of different seedbed preparation methods to overcome the problem of poor stand establishment that is encountered either because of soil crusting and cracking during growing seasons with low moisture or because of waterlogging during excessively wet planting and seedling establishment periods..

Despite the aforementioned importance for the Ethiopian mass and extensive coverage, productivity of teff is very low; the national average yield being less than 1.3 t ha^{-1} (CSA, 2010). Some of the factors contributing to the low yield of teff are lack of high yielding cultivars, lodging, weed infestation, waterlogging, low moisture and low soil fertility conditions (Seyfu, 1997; Fufa, 1998). According to Hailu *et al.* (1995), lack of improved cultural practices is among the major production limitations that contribute to the low productivity of teff in the country. The productivity of teff in the study area and in the country in general is, therefore, heavily constrained by inadequate supply of growth limiting nutrients from the soil.

2.3. Role of Nitrogen in Plant Nutrition

Plants contain more N than any other essential elements derived from the soil. Plants take up N from the time the roots begin to function until all uptake of nutrients ceases with maturity. Nitrogen is critically important to plants because of its presences in the structure of protein, the most important building substances from which the living material or protoplasm of every cell is made. In addition, N is also found in chlorophyll, which enables the plant to transfer energy from sunlight by photosynthesis. Therefore, the N supply to the plant will influence the amount of protein, protoplasm and chlorophyll formed, which in turn influence cell size and leaf area, and photosynthetic activity (Mengel and Kirkby, 1996).

Nitrogen is closely linked to control the vegetative growth of plant and hence determine the fate of reproductive cycle. Mengel and Kirkby (1996) stated that N is an integral component of many essential plant compounds such as nucleic acids, amino acid, all protein, including enzymes, and chlorophyll. Therefore, a low supply of N has a profound influence on crop growth and may lead to a great loss in grain yield (Miller and Donahue, 1997). On the other hand, excess nitrogen supply causes higher photosynthetic activities, vigorous growth, weak stem, lodging, dark green color, reduced product quality; delayed in maturity, increase in susceptibility to insect pests and diseases and building up of nitrate in foliage which is harmful to animals (Mengel and Kirkby, 1996).

2.4. Nitrogen Availability in Soils

The vast portion (about 98%) of the total N of the Earth is found in the lithosphere and 2% is in the atmosphere, with the portions in the hydrosphere and biosphere being insignificant relative to that in the lithosphere and atmosphere (Stevenson, 1982). Most of the N of the Earth, including the N in the rocks and in the atmosphere, is not available for plant nutrition. Plants obtain most of their N nutrition from the soil which is a negligible component of the total N content of the world and more than 90% of this N in most soils is in the form of OM, which is not available to crop plants (Stevenson, 1982).

Nitrate and exchangeable ammonium are important in plant nutrition. The other forms of N are generally not available for plant nutrition. Fixed ammonium, entrapped in clays, is a principal nitrogenous constituent of subsoils and is resistant to removal from clay lattices and has little importance in plant nutrition. Exchangeable or dissolved ammonium is available to plants, but ammonium concentration in soils is low, usually in a magnitude of a few mg kg^{-1}. According to (Brady and Weil, 2004why change the form for ref?, in well-aerated soils, ammonium is oxidized rapidly to nitrate by nitrification, so that nitrate is the major source of plant-available N in the soil.

Most plants cannot tap into the large reserve of N in the atmosphere. Biological N fixation is the principal means of adding N to the soil from the atmosphere (Stevenson, 1982). More than 70% of the atmospheric N added or returned to soils is by biological fixation, and can exceed 100 kg of N ha^{-1} addition per year by N-fixing legumes. Most of this N enters into the organic fraction of the soils. Unless N-fixing legumes are grown, the addition of N to soils by biological fixation, averaging about 9.2 kg ha^{-1} annually, is too small to support crop production. The remainder is from atmospheric precipitation of NH_4^+, NO_3^-, NO_2^- and organically bound N (terrestrial dust).

The plant available soil N fractions are vulnerable to different routes of losses; immobilization, denitrification, leaching, surface runoff and erosion, depending on the soil and climatic conditions (Bohn *et al.,* 2001). He or the same author also stated that soils have little capacity to retain oxidized forms of N, and NH_4 accumulation in soils is small; consequently, most of the soil N is associated with OM. Release of N from OM is slow and unpredictable. If soil OM is depleted, as occurs in cultivated soils, N for plant growth is limited. Nitrogen is, therefore, usually the most deficient nutrient in cultivated soils of the world, and fertilization of these soils with N is required. To maintain or increase productivity of soils, worldwide consumption of N fertilizers continues to increase with time.

2.5. Response of Wheat and Teff Crops to Nitrogen Fertilizers

Nitrogen is the nutrient element applied in the largest quantity for most annual crops (Huber and Thompson, 2007). Except for legumes, which have the ability to fix their own N, it must be supplied to plants for growth. Use of inorganic N fertilizers has had its most substantial beneficial effect on human health by increasing the yield of field crops and nutritional quality of foods needed to meet dietary requirements and food preferences for growing world populations (Galloway and Cowling, 2002; Galloway *et al*., 2002).

Crop response to N fertilizer is influenced by factors such as N fertilizer management, rate and time of application in relation to plant development, soil type, crop sequence and supply of residual and mineralized N (Lory *et al.,* 1995). For winter wheat grown at temperate latitudes and tropical continental environments, grain yields response is generally maximized, when N is applied prior to stem elongation. This common response has been linked to observations that crop-N demand increases sharply just prior to stem elongation (Mossedaq and Smith, 1994). As reported by different scholars, increased in N did increase number of spikes, grain weight (Ragheb *et al*., 1993; Geleto *et al*., 1995) and grain yield in wheat (Ragheb *et al*., 1993; Khan *et al*., 2009).

Nitrogen affects crop performance through its ability to determine photosynthetic capacity. For winter wheat grown at temperate latitudes and tropical continental environments, grain yields response is generally maximized, when N is applied prior to stem elongation. This common response has been linked to observations that crop-N demand increases sharply just prior to stem elongation (Mossedaq and Smith, 1994). Most of N uptake by wheat plants occurs before anthesis and grain N in wheat is translocated primarily from vegetative parts after anthesis (Schulthess and Jutzi, 1997).

Nitrogen is important in determining the final grain yield of wheat during the rapid phase of crop development because it is required for high rates of spikelet initiation, improvement of spikelet fertility, and increasing grains per fertile spikelet and for biomass formation (Frank and Bauer, 1982). According to Walia *et al.* (1980), higher correlation existed between grain yields and the concentration of N in plants at tillering, jointing and dough stages and they indicated that the amount in plant at jointing gave the best estimate of the grain. Increasing levels of N under different soils and management conditions increase grain and dry matter yields, number of kernels per head and plant height of wheat (Amsal *et al.,* 2000).

Nitrogen nutrition stimulates tillering probably due to its effect on cytokinin synthesis (Botella *et al.,* 1993). Increasing N fertilizer rates can result in higher grain protein content (Vaughan *et al*., 1990; Kelley, 1995) in cereals, including wheat and teff. The report by Eylachew (1996) elucidated that increasing levels of N under different soil and management conditions increases grain yield, dry matter yields, number of kernels per head and plant height of wheat.

2.6. Nitrogen Use Efficiency and Its Components

Nitrogen use efficiency (NUE) is a complex term with many components. To measure or quantify NUE, the term most widely used is a ratio that considers an output (biological yield or economic yield) as the numerator and input (N supply) as the denominator. The biological yield can include either total aboveground plant dry matter or total plant N, whereas the economic yield includes either grain yield or total grain N. The N supply can be from soil, fertilizer (organic or inorganic), or soil plus fertilizer.

Some affiliated scholars divided nutrient use efficiency into two components (Moll *et al*., 1982): uptake, or the ability of the plant to extract the nutrient from the soil, and utilization efficiency, or the ability of the plant to convert the absorbed nutrient into grain yield. Hence, nutrient use efficiency is the product of nutrient uptake efficiency and utilization efficiency.

Nitrogen use efficiency in crop plants can be expressed in several ways as described by (Fageria and Baligar, 2005): agronomic efficiency of nitrogen (AE), which, in economic terms, is also referred to as partial factor productivity (PFP), measures overall efficiency or an integrative index of total economic outputs relative to the use of all sources of N (indigenous soil N and applied fertilizer N); apparent nitrogen recovery (AR) takes the efficiency of the plant to take up N into account or is the quantity of nutrient uptake per unit of nutrient applied; and physiological N-use efficiency (PE) considers the efficiency with which the plant uses N from acquired available N to produce grain or total plant dry matter.

2.7. Improving Nitrogen Use Efficiencies of Wheat and Teff

Nitrogen fertilizer is one of the main inputs for cereals production systems. About 50% of the human population relies on N fertilizer for food production (FAO, 2004). However, compared with other nutrients, N is highly soluble and may be lost from the soil-plant system by leaching, denitrification, volatilization and erosion (Vaughan *et al*., 1990), and substantial quantities of N may also be immobilized in organic forms that are not readily available to crops. Generally, more than 50% of the N applied is not assimilated by plants (Tilman *et al.*, 2002; Dobermann and Cassman, 2004) and is a potential source of environmental pollution.

Therefore, improvement of N uptake, translocation and assimilation towards a desirable outcome has been a long-term goal in agricultural research. While the amount of N available to the plant can be improved by using sustained-release fertilizers, split applications, minimizing fertilizer losses and other nutrient management and crop management strategies, the inherent efficiency of the plant to utilize available N for higher productivity needs to be tackled biologically (Abrol *et al*., 1999; Abdin *et al*., 2005; Raghuram *et al.*, 2006).

Plant use efficiency of N depends on several factors including application time, rate of N applied, type of fertilizer, cultivar and climatic conditions (Moll *et al.*, 1982). The rate and number of N fertilizer applications affect both yield and grain quality (Subedy *et al*., 2007). Most researchers reported split application as superior to application of all N at sowing, particularly in areas of high seasonal precipitation. Split application increases N management flexibility and potentially reduces N losses (Vaughan *et al*., 1990; Alcoz *et al.*, 1993).

In practice, the optimal strategy for applying N to rain-fed cereals depends on the interaction between soil N, amount and distribution of rainfall, and crop N uptake over time (Anderson, 1985. Rajput and Verma, 1994) have shown that yield of wheat increased significantly by splitting the N applied at the critical crop growth stages. Generally, early fertilization increased wheat grain yield, and late fertilizations increase grain protein concentration (Fowler & Brydon, 1989) and yield mostly depends on N accumulated in wheat at anthesis and on N translocation efficiency to grain (Sarandon *et al*., 1990).

A study on time of N application in central highlands of Ethiopia on Nitisols at Holetta and Vertisols at Ghinchi showed application of 50% of the total N at sowing and the rest at full tillering stage significantly increased grain yield as well as the protein content of wheat (Asnakew *et al*., 1991). Teff is considered a low input crop, requiring minimal fertilization. Excessive single applications of nitrogen may result in lodging. Split applications of nitrogen throughout the growing season will enhance productivity of teff.

Plants nutrient use efficiency can also be maximized by using EEF products that can minimize the potential of nutrient loss to the environment, as compared to reference soluble sources (Hall, 2005). Slow and controlled-release fertilizers are fertilizers containing a plant nutrient in a form which either delays its availability for plant uptake and use after application or which is available to the plant significantly longer than a reference ‘rapidly available nutrient fertilizers’ such as ammonium nitrate, urea or ammonium phosphate (Shaviv, 2005).

Among the slow release N fertilizers, compacted urea super granule (USG) with 1-3 g granules, have been proved to be an effective N source (Savant and Stangel, 1998) among the slow release N fertilizers. Deep placement of USG essentially cuts off NH_3 volatilization and also significantly reduces denitrification N loss compared to surface application of conventional prilled urea (PU). Use of USG has one great advantage in that it requires only one-time application after rice transplanting, whereas surface application of PU requires two to three split applications that can still result in significant N loss through NH_3 volatilization.

According to Chien *et al.* (2009), in contrast to flooded rice, little study has been done on the use of USG for upland crops, presumably due to difficulty in deep placement of USG in upland soils. Slow-control release urea fertilizers are practically efficient under the growing conditions where soils are coarse, warm climate, high moisture content, high rainfall/irrigation, high potential volatilization and high leaching losses (Clain, 2009).

However, application of USG is a labor-intensive practice that some rice farmers in developing countries are not willing to adopt, for example, China. Also, it is not an alternative to commercial rice farms in the USA, Europe, and Latin America due to high labor costs. On top of that, the scarce availability of plant available N around the very time the slow release fertilizers has been applied, has impacted poor root development, emergency, growth and eventually poor yield in small grain crops. However, the use of USG has been successfully promoted in several Asian countries, notably in Vietnam and Bangladesh. The Government of Bangladesh has announced that it will expand the use of USG to almost 1 million hectares of rice land, reaching about 1.6 million farm families (IFDC, 2007).

2.8. Soil Fertility Characteristics Affecting Crop Production

2.8.1. An Overview of Soil Fertility and Productivity

The potential of a given site to produce is referred to as productivity, whereas the contribution of soil to productivity is called fertility, which is a function of its physical, biological and chemical properties. Soil productivity encompasses soil fertility plus all other factors affecting plant growth, including soil management and there is a strong positive correlation in productive soils between fertility and physical properties so that highly productive soils have desirable physical properties as well as high fertility (Foth and Ellis, 1997).

Low soil fertility is recognized as an important constraint to increased food production and farm incomes in many parts of Sub-Saharan Africa (Shepherd and Soule, 1998). Ethiopia is one of the Sub-Saharan countries with highest rates of nutrient depletion due to lack of adequate synthetic-fertilizer input, limited return of organic residues and manure to, and high biomass removal from farm lands, high soil erosion rate, and leaching loss of nutrient elements. The annual nutrient deficit in the country is estimated at 41 kg N, 6 kg P, and 26 kg K per ha per year (Stoorvogel and Smaling, 1993).

Soil fertility and plant nutrition are important components of plant production. Productive capacity of soils requires the provision of adequate and balanced amounts of nutrients to ensure proper growth of the plants. The fact on the ground is that soil nutrient status of most farming systems is widely constrained by the limited use of inorganic and organic fertilizers and by nutrient loss mainly due to erosion and leaching (Balesh *et al.*, 2007).

2.8.2. Soil Physical Properties

2.8.2.1. Soil texture

The texture of a soil refers to the size-composition of elementary grains in a soil. The texture affects productivity in several ways. It determines the amount of pores and the pore size distribution (Brady and Weil, 2004) which in turn affects the aeration status and water holding capacity of the soil. Sandy soils have large pores so that infiltration rates and permeabilities to water are high, and they retain little water. In contrast, clays have low infiltration rates, low permeabilities, retain much water in available as well as in unavailable forms, and may be poorly drained. Soils of intermediate textures such as loams are intermediate in porosity, water retention, and drainage.

The general tendency for productivity is better on medium-textured soils consisting of proportional a mixture of sand, silt, and clay than on soils that are light, heavy or mainly silty. Specific surfaces and cation exchange capacities (CEC) of sands are low as compared to clays although clay mineralogy is another factor to be considered for the CEC (Wakene, 2001; Ward, 2008).

Ethiopian Vertisols, which are the dominant soil types in the study area, generally contain more than 40% clay in the surface horizons and close to 75% in the middle part of the profiles. The sand fraction is low, often less than 20%, and is found in the bottom and the surface (plow layer) horizons. Workability of these soils is hampered by their stickiness when wet and hardness when dry, and waterlogging and erosion greatly affect crop production. In the highland Vertisols where soil burning (guie) is practiced, the sand fraction is normally high in the surface horizon because the clay bakes into sand-size particles (Berhanu, 1985).

2.8.2.2. Bulk density and total porosity

Bulk density is a measure of the weight of the soil per unit volume, usually given on an oven dry basis (Birkland, 1999). Bulk density and compaction of soils have been recognized as a major physical threat to soil fertility throughout the world (Soane and Ouwerkerk, 1994). Studies showed that an increase in soil bulk density resulted in decreased aeration and increased penetration resistance, which in turn resulted in impeded root development (Batey, 2009). A common response of the root system to increasing bulk density is to decrease its length, concentrating roots in the top layer and decreasing rooting depth (Jurcova and Zrubec 1989; Medvedev *et al.,* 2000).

Variation in bulk density is attributable to the variation in the relative proportion and specific gravity of solid organic and inorganic particles and to the porosity of the soil. Consequently, bulk density of soils is influenced by soil texture, structure, OM content and soil management practices. The greater development of structure in the fine-textured surface soils and relatively higher OM content accounts for their lower bulk density as compared to the more sandy soils with less structural differentiation (Foth, 1990). Low bulk density values (generally below 1.3

gm cm^{-3}) indicate a porous soil condition (FAO, 2006). Increase in OM content lowers bulk density while compaction increases bulk density. In swelling soils, bulk density decreases with increase in moisture content and vice versa. Bulk density is generally higher in lower profile layers (Indian Society of Soil Science, 2002).

Reports showed that Vertisol bulk density is usually high, 1.5-1.8 g cm^{-3}, and may reach 2.05-2.1 g cm^{-3} (Murthy *et al.*, 1982). These variations in bulk density are caused by swelling and shrinking with changes in soil moisture content. The soils have high bulk density when dry and low density when wet (Virmani *et al.,* 1982).

The soil total porosity is a function of the total volume of the soil and the volume of pore spaces. Coarse textured soils tend to be less porous than fine-textured soils, though the mean size of individual pores is greater in coarse-textured soils. Furthermore, in clayey soils, the porosity is highly variable as the soil alternately swells, shrinks, aggregates, disperses, compacts and cracks (Brady and Weil, 2004; Indian Society of Soil Science, 2002).

2.8.2.3. Soil-water characteristics

The soil-water properties of soils are of great importance to soil fertility because soil water promotes innumerable chemical, physical, and biological activities and reactions, and dissolves and carries plant nutrients and is a nutrient itself (Brady and Weil, 2004). Soil water is the chemically uncombined water contained in soil pores and adsorbed on soil particles and it is commonly classified as gravitational, plant (readily) available, and plant unavailable water (Gregorich *et al.*, 2001).

However, under the influence of gravity much of that water freely drains from the soil after water application ceases, provided that drainage is not restricted by compacted or impermeable layers. Rapid drainage stops in one to three days in coarse-textured soils, whereas fine-textured soils drain more slowly. The soil water content at which free drainage stops is called the field capacity of the soil. It is considered the upper limit of a soil’s capacity to store water for plant use. The lower limit of available water is at the permanent wilting point, which is the largest soil water content at which indicator plants growing in a particular soil wilt and then fails to recover turgidity when placed in a humid chamber.

Soil water contents at field capacity (FC), permanent wilting point (PWP) and available water holding capacity (AWHC) increased with depth for the soils under different management practices (Wakene, 2001; Ahmed, 2002). The increases of these three components of soil moisture holding capacity of soils with depth were positively and significantly correlated with the increase of the clay fractions of the soil with profile depth.

Vertisols have a relatively high water storage capacity in the root zone because of their depth and high clay content. The high water-storage capacity of Vertisols is important in regions with uncertain rainfall. The moisture content in deeper layers of the soil profile is lower, apparently due to compression effects on matric potential (Virmani *et al,* 1982). The growing season on deep Vertisols is usually longer than on other soils. Farmers practice late-season planting to avoid the serious drainage problems characteristic of these soils during the rainy season.

2.8.3. Soil Chemical Properties

2.8.3.1. Soil reaction (pH)

Soil pH is one of the most valuable indicators of soil fertility. Soil reaction (pH) is mostly related to the nature of the parent material, climate, OM and topographic situations (Tamirat, 1992). Practically all soils fall in the pH range of very strongly acid (pH 3) to strongly basic (pH 9) with rare extremes as low as 2 and as high as 11 (Brady and Weil, 2004).

Developments of soil reaction conditions, which are not conducive for plant growth, are mostly associated with the climatic conditions, particularly rainfall. Where there is high precipitation there is high tendency of soils to be acidic, which is attributed to the substantial loss of basic cations such as, Ca^{2+}, K^{+}, Mg^{2+} and Na^{+} below the root zone and accumulation of acidic cations like H^{+}, Al^{3+}, and to some extent Fe^{+3} in the soil surface (Smith *et al.*, 1995).

Soil pH increased with depth of soil profile and relatively high pH was observed at subsoil horizons in Vertisols of the central highlands of Ethiopia (Tamirat, 1992). On the contrary, soil pH tends to rise particularly in the low lands where evapo-transpiration exceeds the amount of precipitation which leads to accumulation of salts in the soil. Both extreme rises and lowering of soil pH, as Miller and Donahue (1995) reported, affect either directly or indirectly the biological, physical and chemical properties of the soil thereby affecting plant production by disrupting the activity of soil microorganisms and altering the solubility and availability of most of the essential plant nutrients and infusing toxicity of some elements.

2.8.3.2. Soil organic matter

Soil organic matter is the most important indicator of soil quality and productivity and it is one of the most important components of soil that affects most of the soil biological, physical and chemical properties. It increases the water holding capacity of soils improves aggregate stability and structure of soils and is the primary source of N, P and sulfur and a temporary sink for most plant nutrients (Prasad and Power, 1997).

According to Lal (2001), soil OM is important in maintaining soil tilth aiding water and air circulation and increasing soil porosity, thereby improving infiltration and water-holding capacity of the soil, providing more water availability for plants and less potentially erosive runoff and agro-chemical contamination. However, most cultivated soils of Ethiopia are poor in OM contents due to low amount of organic materials applied to the soil and complete removal of the biomass from the field (Yihenew, 2002; Tesfaye and Sahlemedhin, 2002). This has lead to drastic decline of crop productivity in most of intensively cultivated highland areas of Ethiopia.

2.8.3.3. Total nitrogen

Nitrogen occurs in soils in both organic and inorganic compounds of which plants absorb N in its cationic form (NH_4^+) and anionic form (NO_3^-), and obtain readily available N forms from different sources. The major sources include biological N fixation by soil microorganisms, mineralization of organic matter and industrial fixation of N gas and fixation as oxides of N by atmospheric electrical discharge . The availability of N through biological N fixation is influenced by soil pH and its mineral nutrient status, photosynthesis, climate and crop management Similarly, mineralization of organic N to inorganic forms depends on temperature, level of soil moisture and supply of oxygen (Tisdale *et al.,* 1995). No need for repetition.You can just cite him once at the end.

Soils have little capacity to retain oxidized forms of N, and ammonium accumulation in soils is small; consequently, most of the soil N is associated with soil OM. Release of N from soil OM is slow and unpredictable. If soil OM is depleted, as occurs in cultivated soils, N for plant growth is limited (Brady and Weil, 2004). The N content is lower in continuously and intensively cultivated and highly weathered soils of the humid and sub humid tropics due to leaching and in highly saline and sodic soils of semi- arid and arid regions due to low OM content (Tisdale *et al*., 1995).

Because of their low OM content, most of the Vertisols in Ethiopian highlands have low total N content and there is a high crop response to N fertilizers in these areas (Desta, 1986). On account of rapid nitrification, most of the N added as fertilizer containing NH_4 or NH_2 is subject to leaching or denitrification soon after application. Ammonia fixation also affects fertilizer efficiency in heavy Vertisols (Finck and Venkateswarlu, 1982).

2.8.3.4. Available phosphorus

Phosphorus is among the most limiting nutrients for food production in the sub-humid and humid tropical highlands of East Africa (Sanchez *et al.,* 1997). Next to N, P is the most limiting nutrient in Vertisols (Finck and Venkateswarlu, 1982) and this holds true for Ethiopian soils and the problem in Ethiopia is further exacerbated by nutrient mining due to the prevailing low-input agriculture.

Phosphorus is unique among the anions in that it has low mobility and availability, which is determined by soil pH and the consequent reactions of P with Al^{3+}, Fe^{3+} and Ca^{3+}. It is difficult to manage because it reacts so strongly with both solution and solid phases of the soil. While P occurs in a multitude of inorganic and organic forms in the soil, the plant available forms of P are limited primarily to solution HPO_4^{-2} and $H_2PO_4^-$, with the dominant forms determined by the soil pH (Tisdale *et al.*, 1995).

Studies show that the total P status of some representative major soil types in Ethiopia is low (Picolo and Huluka, 1985). Most of the Vertisols in the Ethiopian highlands, 70% of the cases, are reported low in available P content, below 5 ppm (Hubble, 1984; Berhanu, 1985). Phosphorus fractionation results show low levels of the available forms in the Ethiopian highland Vertisols. Phosphorus sorption studies indicated high sorption capacity of Vertisols and other soils in Ethiopia which is mainly controlled by content of Fe and Al oxides (Tekalign and Haque, 1987).

2.8.3.5. Cation exchanging capacity (CEC)

Cation-exchange capacity is the sum of exchangeable cations that a soil or other material can absorb at a specific pH (Foth and Ellis, 1997). Isomorphous substitution produces a constant negative charge for cation adsorption giving rise to constant CEC. Whereas, the negative charge resulting from deprotonation gives rise to variable CEC, and ion exchange in soils, occurs on surfaces of clay minerals, inorganic compounds, organic matter, and plant roots. The amount of negative charges on the soil exchange sites determine the cation retaining capacity of the soil which intern is related to potential reserve of soil for plant nutrients (Foth, 1990).

Soils that have a low CEC hold fewer cations and may require more frequent applications of fertilizer than soils that have a high CEC. Soils that have a high CEC have the potential to retain cations, which reduces the risk of the pollution of ground water. Vertisols are characterized by their high content of expanding smectite clay minerals, which are known for their substantial cation exchanging permanent negative charge sites. Berhanu (1985) stated that nearly all of the Vertisols in Ethiopia have CEC of 35-70 cmol kg^{-1} soil, which falls above the high CEC range of soils.

2.8.3.6. Exchangeable acidity

Exchangeable acidity is acidity associated with cation exchange sites on mineral or organic colloids. It is the sum of the concentrations of hydrogen (H) and aluminum (Al) ions in the soil exchange complex. Hydrolysis of the Al^{3+} ion produces a moderately strong acidic environment in the soil solution and thus, many of the properties of acid soils are controlled by the chemistry of Al. Soil acidity affects the growth of crops because acidic soils contain toxic levels of aluminum and manganese and characterized by deficiency of essential plant nutrients such as, P, Ca, K, Mg and Mo (Tisdale *et al*., 1995).

Soils may become acidic in the long term as a result of several natural processes; as rainfall exceeds evapotranspiration which leads to leaching of soluble salts, more readily soluble minerals, and basic cations such as, Ca^{+2}, Mg^{+2}, Na^{+} and K^{+}. Consequently, the leached surface soil becomes slightly to moderately acid although the sub soil may remain neutral or alkaline. In the short term, however, soil acidity develops mainly due to application NH_4 of N fertilizers or manure, primarily those having high concentrations of or urea because nitrification releases hydrogen (H^{+}) ions, and decomposition of organic wastes or plant residues in to organic acids under somewhat reducing conditions (Bohn *et al.*, 2001).

2.8.3.7. Exchangeable bases

The base-exchange properties of soils influence plant nutrition and the desirability of the soil as a growth medium. Nutrient cations held as exchangeable bases are in a readily available state, but are not readily leached from soils. The levels of exchangeable cations in a soil are usually of more immediate value in advisory work than the CEC, because they not only indicate existing nutrient status, but can also be used to assess balances amongst cations.

According to Landon (1991), the levels of exchangeable cations is of great importance because many effects, for example soil structure and nutrient uptake by crops, are influenced by the relative concentrations of cations as well as their absolute levels. Soils in high rainfall areas and under continuous cultivation and fertilization with inorganic N containing fertilizers are characterized by low contents of exchangeable bases and the subsequent deficiencies of Ca, Mg and K (Saikh *et al.*, 1998). However, Vertisols and high OM containing soils retain more basic cations, which are mainly dominated by exchangeable Ca and Mg (Eylachew, 2001). The predominant exchangeable cation, which accounts for up to 80% of the exchange complex, is Ca, followed by Mg: K and Na contribute nearly equal proportions (Berhanu, 1985).

The cations in productive agricultural soils are present in the order, $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$. Deviations from this order can create ion imbalance problems for plants. High Mg, for example, in soils formed from serpentine rocks inhibits Ca uptake by plants (Malpas, 1992). High Na occurs in soils where drainage is poor and evaporation rates exceed rainfall. High Na creates problems of low water flow in soils and availability for plants (Bohn *et al.,* 2001).

3. MATERIALS AND METHODS

3.1. Experimental Site Description

3.1.1. Location

The study was conducted in 2011 main cropping season on two farmers' fields in Jamma District, which lies between the geographical coordinates 10^{o} 23' to 10^{o} 27' N latitudes and 39^{o} 07' to 39^{o} 24' E longitudes in South Wollo Zone of the Amhara National Regional State (Figure 1). The experimental site is located in Jamma District about 260 km away from the capital city, Addis Ababa, in the north east direction and at geographical coordinates of 10^{o} 27' N latitude and 39^{o} 15' E longitude at an altitude of 2630 masl. The dominant soil type of the study District is Vertisols, and the area is characterized by poor drainage or waterlogging, difficulty to work in and low soil fertility but high potential for wheat and teff crops production (Getachew, 1991).

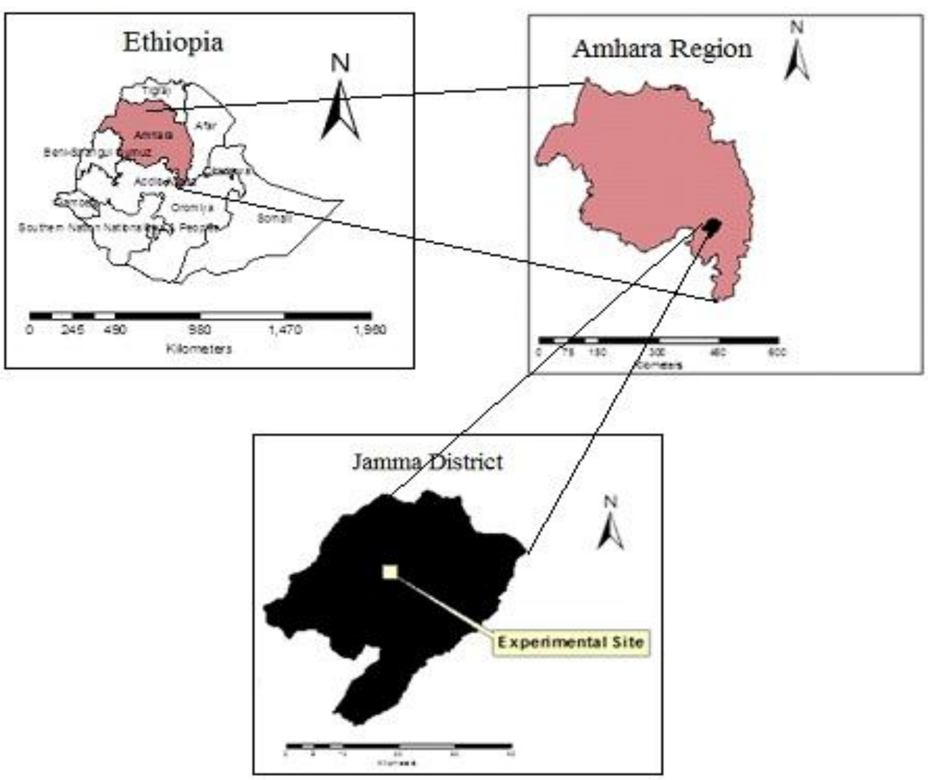

Figure 1. Location map of the study area

3.1.2. Climate

According to the weather record from the Kombolcha Meteorology Station, the mean annual rainfall and annual mean minimum and maximum temperatures of the study area based on the last 10 years (2002-2011) rainfall and minimum and maximum temperature data records were 868.2 mm and 9 and 21.6 ^{o}C, respectively. The total rainfall of the study area during the growing season (June - December 2011) was 720.5 mm and the minimum and maximum temperatures were 10.0 and 21.1 ^{o}C, respectively (Figures 2). The weather data between the years 2002-2011 is presented comprehensively in Appendix Tables 1 and 2.

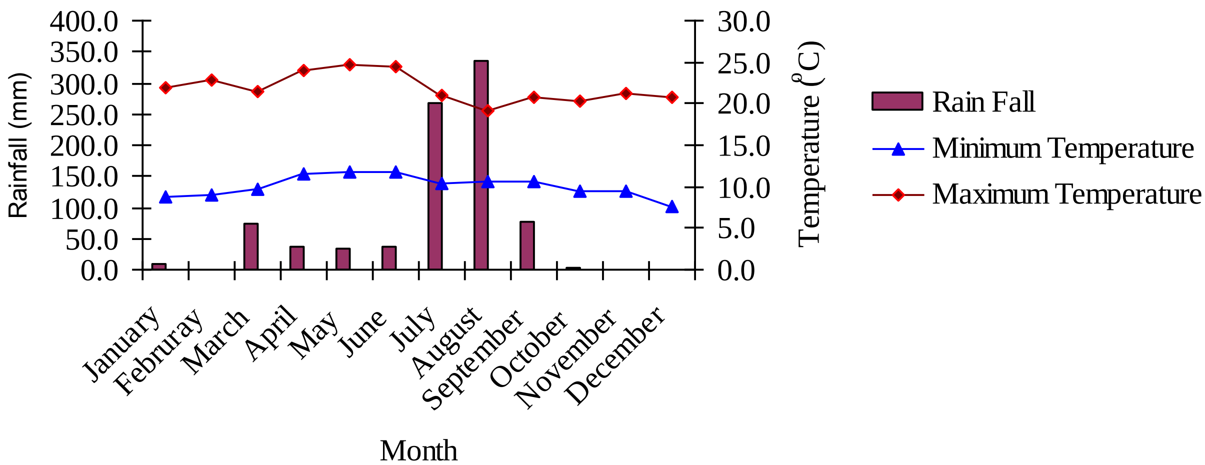

Figure 2. Monthly total rainfall and monthly mean minimum and maximum temperature of the study area in the year 2011

3.2. Treatments and Experimental Design

There were two separate experiments; one experiment on wheat and the other on teff. Both experiments comprised of five treatments; three rates of N as urea super granule (50, 100 and 150% of the recommended N), 100% of the recommended N (46 kg N ha^{-1}) as conventional urea fertilizer and control (without nitrogen). These five treatments were laid down in a randomized complete block design with three replications.

The gross plot size of both experiments was 4 m x 3 m accommodating 15 rows, spaced 20 cm, apart of 3 m lengths. The net plot size was 2.2 m x 4.0 m (11 rows of plants) leaving two outermost rows on both of sides of each plot. The blocks and plots were separated by 1m wide-open spaces.

3.3. Experimental Materials and Procedures

The experimental fields were prepared using local plow (maresha) according to farmers' conventional farming practices. The fields were ploughed four times, and following the seed bed preparation, a field layout was prepared on both experimental fields in accordance with the specifications of the design, and each treatment was assigned randomly to experimental units within a block.

The test varieties used in the study were improved bread wheat variety (HAR 1685) and the local teff variety (*Wajera*), which have been widely produced by the farmers in the study area. Urea super granule, as a source of slow release urea fertilizer (SRUF), and the conventional prilled urea as a source of conventional urea fertilizer, were used in the experiments. The full recommended rate of phosphorus (46 kg P_2O_5 ha^{-1}) in triple super phosphate (TSP) form was applied all at basal to all experimental plots.

The USG tablets with test rates of 50% of the recommended N (23 kg N ha^{-1}), 100% of the recommended N (46 kg N ha^{-1}) and 150% of the recommended N (69 kg N ha^{-1}) were applied at spacings of 96 cm, 48 cm and 32 cm, respectively all at planting in 10 cm space distance in between the rows of the test crops. The USG tablets were then incorporated in to the soil at a depth of 10 cm. Half of the full recommendation rate of CU fertilizer was applied at planting by side banding, and the remaining half was side-dressed at tillering.

3.4. Soil Sampling and Analysis

3.4.1. Profile and Surface Soil Sampling

Soil pedons (2 m depth, 1.5 m length, and 1.5 m width) were opened in both experimental farm fields to characterize the soils of the study areas. Soil samples were collected from each soil layers and were analysed for texture, bulk density, particle density, field capacity (FC), permanent wilting point (PWP), available water holding capacity (AWHC), pH, OM, TN, available phosphorus, exchangeable bases and CEC.

For the surface soil fertility assessment, three composite surface soil samples, one per a block, were taken from each experiment at a depth of 20 cm before planting. To make the composite soil samples, five soil sub-samples were collected systematically within the replication and mixed thoroughly. The soil samples collected were analyzed for texture, pH, OM, TN, available phosphorus, exchangeable bases and CEC. Similarly, soil samples at a depth of 20 cm were collected after harvesting from each experimental plot to investigate the residual effects of the slow release urea fertilizer applied on soil total N content.

3.4.2. Analysis of Soil Physical Properties

Particle size distribution (soil texture) was determined in the laboratory by the modified Bouyoucos hydrometer method (Bouyoucos, 1962) using sodium hexametaphasphate as dispersing agent. Soil textural class names were assigned based on the relative contents of the percent sand, silt, and clay separates using the soil textural triangle of the USDA. Soil bulk density was determined on undisturbed soil samples following the core sampling method while particle density was estimated by the pycnometer method (Blake, 1965). Finally, total soil porosity was estimated from the values of bulk density and particle density as:

$$\text{Total porosity (\%)} = [1-(\text{Bulk density}/\text{Particle density})] \times 100$$

The soil-water potential was measured at -1/3 bar for field capacity (FC) and -15 bars for permanent wilting point (PWP) with pressure plate apparatus and plant available water holding capacity was calculated as the difference between water potentials at FC (-1/3 bar) and PWP (-15 bars) as suggested by Klute (1965).

3.4.3. Analysis of Soil Chemical Properties

Soil pH was measured potentiometrically using a digital pH meter in a 1:2.5 soil water suspension (Van Reeuwijk, 1992). Organic carbon (OC) was determined by wet digestion method, and following the assumptions that OM is composed of 58% carbon, the conversion factor, 1.724 was used to convert the OC in to OM (Walkley and Black, 1934). Determination of total N of the soil was carried out through Kjeldahl digestion, distillation and titration procedures of the wet digestion method (Black, 1965). Available phosphorus was determined colorimetrically using Olsen's method (Olsen, 1952). Exchangeable acidity was determined by saturating the soil samples with potassium chloride solution and titrated with sodium hydroxide as described by Mclean (1965).

Exchangeable bases were extracted with 1M buffered ammonium acetate extractant; K and Na was then measured using flame photometer and Ca and Mg were measured using absorption spectrophotometer (Chapman, 1965). The soil samples CEC was determined by 1M buffered ammonium acetate extraction method and distillation of the ammonium saturated soil in a kjeldahl distillation apparatus while receiving the distillate in boric acid and then titrating with sulfuric acid (Chapman, 1965). The percent base saturations of the soil samples were calculated as the percentage of the sum of the basic exchangeable cations (Ca, Mg, K and Na) to the CEC.

3.5. Crop Data Collection

3.5.1. Phenological Parameters

Days to emergence, days to flowering, days to heading and days to maturity for wheat were recorded when more than 50% of the plants in each plot emerged, 50% of the plant population in each plot produced flowers, 75% of the spikes fully emerged and 90% of the plants in a plot reached physiological maturity, respectively. Similarly, days to emergence, days to flowering, days to heading and days to maturity for teff were measured when 50% of the plants in each plot emerged, 50% of the plant population in each plot produced flowers, 50% of the plants in the plots headed and 50% of the plants in the plot reached physiological maturity, respectively.

3.5.2. Growth, Yield Components and Grain Yield

For the experiment on wheat, plant height was measured at maturity, from ten random plant samples of the harvestable rows, from the ground level to the tip of the spike including the awns using a measuring tape. Spike length was measured by calculating the average spike length of ten random plant samples in the harvestable rows, following the measurement from its base to the tip excluding awns. Spike number was determined by counting the number of fertile spikes per plant from ten random plant samples of the harvestable rows including tillers and taking the average. Number of kernels per spike was measured as the average number of kernels per spike from ten random plant spikes in the net plot area.

Grain yield was measured by taking the weight of the grains threshed from the central 11 rows of each plot and converted to kilograms per hectare after adjusting the grain moisture content to 12.5%. Straw yield was obtained as the difference of the total above ground plant biomass and grain yield. 1000 kernels weight was measured by weighing 1000 seeds from the harvest. Biomass or biological yield was measured by weighing the total above ground plant biomass within the 11 central rows and harvest index was calculated by dividing the grain yield to the total dry biomass weight.

For the experiment where teff was used as the test crop, plant height was determined from the average height of pre-tagged ten plant samples. Shoot biomass was measured by weighing the total above ground biomass of the entire harvestable area. Grain yield was measured by weighing the seed harvested from the harvestable area and the straw yield was obtained as the difference of total above ground biomass and grain yield.

3.6. Plant Tissue Sampling and Analysis for Nitrogen Content

Plant samples were collected randomly from plants at maturity from each harvestable row and bulked over replication and partitioned into vegetative and grains for the determination of N in aboveground vegetative parts (straw) and grains using standard procedures. Nitrogen was determined by treating the plant material with concentrated sulfuric acid to convert the N into ammonium sulfate during oxidation. Finally, the ammonium liberated by distilling with NaOH was absorbed in boric acid and back titrated with standard H_2SO_4. Total N uptake in the plant vegetative parts and the grains were calculated by multiplying N content with respective straw and grain yield ha^{-1}. Total N uptake by whole plant was calculated by summing up the N uptakes by grains and straw.

Apparent fertilizer N recovery efficiency (RE) was calculated as:

$$\text{RE (\%)} = [(\mathrm{Un} - \mathrm{Uo})/\mathrm{n}] \times 100$$

where Un stands for nutrient uptake at '*n*' rate of fertilizer nutrient and Uo stands for nutrient uptake at control 'no fertilizer nutrient'. Agronomic (AE) and physiological (PE) efficiencies were calculated as follows:

$$\mathrm{AE} = [(\mathrm{Gn} - \mathrm{G0})/\mathrm{n}] \text{ and } \mathrm{PE} = [(\mathrm{Gn} - \mathrm{Go})/(\mathrm{Un} - \mathrm{Uo})]$$

where G*n* and G*o* stand for grain yield of fertilized at '*n'* rates of fertilizer and grain yield unfertilized, respectively and U*n* and U*o* stand for nutrient uptake at '*n*' rate of fertilizer and uptake at control (no fertilizer nutrient), respectively. Nitrogen harvest index (NHI) was calculated as;

$$\text{NHI (\%)} = (\text{GNU}/\text{TNU}) \times 100$$

where GNU and TNU stand for N uptake by the grain and total N uptake by the grain and straw.

3.7. Statistical Analysis

The crop yield and yield related traits data were subjected to analysis of variance using statistical procedures described by Gomez and Gomez (1984) with the help of SAS statistical software. The Fisher's LSD mean comparison method at 5% level of significance was used to separate the treatment means and compare the effects of different rates of USG with the CU on grain yields and yield related traits of wheat and teff experiments separately. Using the same statistical software (SAS), simple correlation analysis was carried out to investigate associations among grain yield, yield traits and phenological parameters of the test crops.

4. RESULTS AND DISCUSSION

4.1. Texture and Chemical Properties of Surface Soil of the Experimental Sites

The laboratory analysis results, as presented in Table 1, indicated that the particle size distribution of the surface (0-20 cm depth) layers of the experimental fields soils was dominated by clay fraction (above 60%). Berhanu (1985) also reported that Vertisols in Ethiopia generally contain more than 40% clay in the surface horizons.

Soil pH of the surface soil samples of both experimental fields was in the range favourable for most crops (Tekalign, 1991) as most Ethiopian Vertisols do (Berhanu, 1985). The soil OM, total N and available P contents (Table 1), however, were in the low, low to medium and low ranges, respectively according to the ratings given by Sahlemedhin (1999) and Olsen *et al.* (1954). The carbon to nitrogen ratio (C/N ratio) values were in the average under 10, which signify a relatively high rate of mineralization and low rate of N immobilization.

Table 1. Some physico-chemical properties of the surface soils of the study area

Field	Block	Sand (%)	Silt (%)	Clay (%)	Textural class	pH (H_2O)	OM (%)	Total N (%)	C/N ratio	Av. P (mg kg^{-1})
Wheat	1	12.50	25.00	62.50	Clay	6.57	1.09	0.08	7.80	4.66
	2	12.50	22.50	65.00	Clay	6.75	1.02	0.08	7.30	4.20
	3	12.50	22.50	65.00	Clay	6.78	1.63	0.08	11.80	6.82
Mean		12.50	23.33	64.17	Clay	6.70	1.25	0.08	8.97	5.23
Teff	1	10.00	25.00	65.00	Clay	6.63	1.31	0.08	9.70	8.46
	2	17.50	20.00	62.50	Clay	6.51	1.18	0.08	8.90	5.22
	3	20.00	20.00	60.00	Clay	6.52	1.29	0.11	6.70	6.08
Mean		15.83	21.67	62.50	Clay	6.55	1.26	0.09	8.43	6.59

OM = Organic matter; C/N ratio = Carbon to nitrogen ratio; Av. P = Available phosphorus

Exchangeable Ca followed by Mg was the dominant cation in the surface soils of both experimental fields (Table 2). Calcium comprised of 73.7 and 68.0% of the soil cation exchange sites of the wheat and teff experimental fields, respectively. Similarly, Mg constituted 24.6 and 29.7% of the soil cation exchange sites of the wheat and teff experimental fields, respectively. Sodium had the lowest concentration (0.3-0.4 $cmol_C$ kg^{-1} of soil) among the base forming cations found in the soil cation exchange complex of the top soils of both experimental fields (Table 2).

As it is presented in Table 2, the CEC of the surface soils of the experimental fields of wheat and teff were in the ranges of 49.7-55.4 $cmol_C\ kg^{-1}$ and 50.1-51.6 $cmol_C\ kg^{-1}$, respectively. The CEC of the study area can be termed as very high according to the ratings given by Hazelton and Murphy (2007). These high CEC values might presumably be resulted from the dominant smectite clay mineral constituents of the Vertisols of the study area (Berhanu, 1985). The base saturation of the surface soil of the study area is in the very high range based on the ratings given by Hazelton and Murphy (2007), which is accounted for the very low rate of leaching due to the very low hydraulic conductivity and low infiltration rates of Vertisols.

Table 2. Exchangeable basic cations and CEC of the surface soil of the study area

		Ca	Mg	K	Na	CEC	
Field	Block	($cmol_C\ kg^{-1}$)					PBS (%)
Wheat	1	35.00	13.10	0.60	0.30	52.12	94.00
	2	39.90	13.20	0.60	0.30	49.66	108.80
	3	43.70	13.20	0.60	0.30	55.35	104.50
Mean		39.53	13.17	0.60	0.30	52.38	102.43
Teff	1	35.80	14.80	0.90	0.40	51.60	100.50
	2	33.60	15.00	0.80	0.30	50.05	99.40
	3	33.00	14.90	0.80	0.30	51.56	95.10
Mean		34.13	14.90	0.83	0.33	51.07	98.33

CEC = Cation exchange capacity; PBS = Percent base saturation

4.2. Morphological and Physical Characteristics of the Soil Profiles

In the soil pedons opened on both experimental fields, clear soil horizon differentiation and boundaries could not be obtained. It is worth-mentioning that Vertisols exhibit minimal horizon differentiation as a result of pedoturbation and reports from different scholars (Probert *et al.*, 1987; Kamara and Haque, 1988; Mitiku, 1987, 1991) revealed similar findings. Soil depths were found to be between 1.0 and 1.5 m in both experimental fields, beyond which was found light grayish colored parent material. Reports by Mitiku (1987) and Kamara and Haque (1988) from studies involving characterization of Vertisols in the Ethiopian highlands showed that soil depths of the Vertisol at Jamma (the present study area) ranges from 60-150 cm.

Four soil layers with some hazy boundaries could be observed in both sites. The soils of the upper three soil layers were plastic and sticky in consistence when wet with massive blocks and some weak prismatic like soil structure and shiny pressure faces of slickensides in the subsoil (Appendix Tables 4 and 5). The texture of all the soil layers of both soil pedons was dominated by the clay fraction being more that 60% of the total particle size distribution (Table 3).

Table 3. Soil physical properties of the soil profiles on the experimental fields of wheat and teff

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural class	BD (g cm^{-3})	PD (g cm^{-3})	TP (%)	Soil water at; FC (%)	PWP (%)	AWHC (%)
Soil profile on the wheat experimental field										
0-30	17.5	20.0	62.5	Clay	1.03	2.58	60.1	56.1	34.9	21.2
30-90	21.3	11.3	67.5	Clay	1.14	2.59	56.0	61.5	39.3	22.2
90-130	18.8	23.8	57.5	Clay	1.29	2.33	44.6	65.8	43.7	22.1
130-150	26.3	6.3	67.5	Clay	-	2.32	-	61.5	38.1	23.5
Soil profile on the teff experimental field										
0-30	16.3	21.3	62.5	Clay	1.14	2.38	49.2	54.6	31.2	23.4
30-70	8.8	26.3	65.0	Clay	1.21	2.36	51.7	59.8	37.4	22.4
70-100	16.3	18.8	65.0	Clay	1.31	2.1	37.6	64.4	41.0	23.4
100-120	27.5	7.0	65.5	Clay	-	2.35	-	60.0	32.0	28.0

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

The bulk densities of the soil layers increased with increasing soil depth owing to the compactions imposed by the increasing mass of overlying soil layers, the relatively higher mineral and lower organic matter contents of the underlying soil layers. Vertisols are characterized by their wide range of bulk densities; high bulk densities when dry due to the shrinking of the bulk soil volume and when wet like the condition at which the soil samples of the present study were collected, low bulk densities (as low as 1.03 g cm^{-3}) could be recorded due the swelling property and the subsequent rise in volume of the bulk soil (Virmani *et al.*, 1982).

Total porosity decreased downwards in the soil profile owing to an increase in the bulk density. The water content of the soil layers at field capacity (FC) and permanent wilting point (PWP) increased with depth up to 130 cm in the wheat field and up to 100 cm depth in the profile on the teff field (Table 3). The available water holding capacity (AWHC) of the soil at the experimental sites was high, which is one of the attributes of Vertisols (Virmani *et al.,* 1982). In accordance with the soil water content at FC and PWP, the available water holding capacity of the soil layers also increased as depth increased. Similar results were reported by Wakene (2001) and Ahmed (2002) based on the researches conducted in Bako area of western part of Ethiopia and in western slopes of Mount Chilalo in Arsi, respectively. However, in contrast to this result, a report from Virmani *et al.* (1982), stated that the moisture content in deeper layers of the soil profile is lower, apparently due to compression effects on metric potential.

4.3. Chemical Properties of the Soil Profiles of the Experimental Sites

The chemical analysis results of the soil samples collected at different soil layers of the pedons of both experimental fields (Table 4) showed pH ranges (6.5-7.5) conducive for most crops, based on the ratings given by Tekalign (1991). As it is shown in Table 4, the soil pH increased as depth increased due to an increase in the concentrations of base forming cations such as Ca, Mg and Na (Özsoy and Aksoy, 2007) and a decrease in the soil OM. However, exchangeable K decreased with an increase in depth, which might be attributed to an increase in the K fixing capacity of the expanding clay minerals of Vertisols and the tendency of K to move downwards in the soil profile along with the infiltrating water due to the high rate of mobility of K.

Organic matter, total N and available P decreased significantly with increasing soil depth in both soil profiles (Table 4). The decrease in total N and available P with soil depth is apparently due to the decrease in the total OM content down wards in the soil. The C:N ratio of the soil layers, however, increased as soil depth increased owing to the decrease in microbial biomass and low mineralization rate of the available soil OM. These results are in agreement with the observation of Sahlemedhin (1999) who reported that N and P are tied to humus content of the soil and their value decrease along with a decline in soil OM content.

By virtue of the high smectite content in the Vertisols (Dixon, 1982; Berhanu, 1985), soil CEC of the soil layers was high and showed an increasing trend along with an increase in soil depth except in the last soil layers of both soil profiles, in which the lowest CECs were measured. The increase in the CEC of the soil layers along with the increase in soil depths up to 130 and 100 cm in the soil profiles on wheat and teff experimental fields, respectively, might be attributed to an increase in the soil minerals content bearing high surface negative charges. The increment of soil surface negative charges could be confirmed by the rise in the percent base saturation and clay particle size fractions of the soil layers down with depth.

Table 4. Soil chemical properties of the soil profiles of the experimental fields of wheat and teff

Depth (cm)	pH (H_2O)	OM (%)	Total N (%)	C/N ratio	Av. P (mg kg^{-1})	Ca	Mg	K	Na	CEC	PBS
						cmol$_C$ kg^{-1}					
Soil profile on the wheat experimental field											
0-30	6.8	1.36	0.11	7.3	3.1	46.3	12.9	0.6	0.3	58.0	103.8
30-90	6.9	1.60	0.07	14.1	7.5	50.7	13.4	0.6	0.5	59.4	109.9
90-130	7.2	1.23	0.06	11.3	2.0	53.7	14.8	0.5	0.9	59.5	117.5
130-150	7.5	1.06	0.03	24.5	0.7	54.7	14.3	0.4	1.1	55.4	127.3
Soil profile on the teff experimental field											
0-30	6.49	1.75	0.10	10.7	5.20	30.6	9.9	0.7	0.4	50.8	81.9
30-70	6.50	1.55	0.06	15.0	5.32	30.8	9.9	0.6	1.0	53.0	79.8
70-100	6.65	1.50	0.06	14.5	2.74	31.0	10.1	0.5	1.0	55.9	76.2
100-120	6.61	1.15	0.04	16.7	1.46	25.5	9.4	0.5	1.1	47.8	76.4

OM = Organic matter; C/N ratio = Carbon to nitrogen ratio; Av. P = Available phosphorus; CEC = Cation exchange capacity; PBS = Percent base saturation

Generally, the soil physical and chemical analyses results indicated that the soils of the experimental fields are potentially productive from the perspectives of chemical properties of soils for plant growth and had optimum pH condition for plant growth and had a potential to respond to fertilizer application. The soil profile morphological, physical and chemical properties, particularly the increase in pH and Ca content of the soil layers down to the bottom of the pedons and the light grayish parent material indicated that the parent material beneath the solum was presumably of sedimentary (limestone) origin.

4.4. Residual Effects of USG and CU Fertilizers on Soil N Content

The soil samples collected after harvesting were analysed for total N content to investigate the residual effect of urea super granule (USG) and conventional urea (CU) fertilizers applied at planting. The laboratory result revealed that there was no residual deposition of N in the soil after harvesting due to the applied fertilizers. As it is presented in Table 5, the total N content of the soil of both experimental fields decreased after harvesting due to uptake of N by plants and losses of N via different processes such as leaching and subsurface lateral movement along with infiltrating water, and dinitrification due to waterlogging.

Table 5. Residual effects of USG and CU fertilizers on total N (%) of the surface (0-20 cm) soils of the study fields

	Wheat experiment		Teff experiment	
Treatment	At planting	After harvesting	At planting	After harvesting
Control	0.08	0.05	0.09	0.05
23 kg N (USG) ha^{-1}	0.08	0.05	0.09	0.05
46 kg N (USG) ha^{-1}	0.08	0.07	0.09	0.05
69 kg N (USG) ha^{-1}	0.08	0.05	0.09	0.05
46 kg N (CU) ha^{-1}	0.08	0.04	0.09	0.05

USG = Urea super granule; CU = Conventional urea

4.5. Growth, Yield Traits, Yield and Nitrogen Use Efficiency of Wheat and Teff Crops

Urea super granule (USG) fertilizer, which has got a special merit of releasing N slowly in plant available form and alleviating N loss, was evaluated with the conventional prilled urea fertilizer for its benefit in increasing the yield components, grain yield and N use efficiency (NUE) of wheat and teff crops. The results obtained in this study are presented in detail in the following subsections.

4.5.1. Crop Phenology and Growth of Wheat

More than 50% of the wheat plants in all the test plots emerged six days after sowing regardless of the difference of treatments. However, there was a significant ($P \leq 0.01$) effect of treatments on the number of days required to heading, flowering and maturity of the crop (Table 6 and Appendix Table 6). Plants treated with the highest level of N (150% of the recommended N) followed by 100% of the recommended N as USG remained green, while the spikes, leaves and stems of plants which received 23 kg N ha^{-1} as USG and the control changed to yellow and matured early. Accordingly, N fertilization at the rate of 150% of the recommended N (69 kg N ha^{-1}) as USG significantly ($P \leq 0.05$) delayed growth stages and physiological maturity.

As it is presented in Table 6, the highest number of days, 84.0, 90.0, 124.0, required to heading, flowering and maturity, respectively were recorded from the application of 150% of the recommended N as USG followed with significant difference ($P \leq 0.05$) by the application of 100% of the recommended N as USG and CU, respectively. This might be accounted for the highest N level and the slowly released plant available N from USG which resulted in highest N uptake, high rate of photosynthesis and the subsequent prolonged vigorous vegetative growth, which in turn delayed the grain filling and maturity period.

Table 6. Effects of different rates and sources of N fertilizers on wheat phenology

Treatment	Days to heading	Days to flowering	Days to maturity
Control (No N)	70.3d	77.0d	110.0d
23 kg N (USG) ha^{-1}	73.7c	82.7c	116.0c
46 kg N (USG) ha^{-1}	79.3b	86.7b	120.7b
69 kg N (USG) ha^{-1}	84.0a	90.0a	124.0a
46 kg N (CU) ha^{-1}	77.7b	84.7bc	118.7bc
Mean	77.0	84.2	117.9
CV (%)	1.8	1.7	1.4
LSD (0.05)	2.6	2.7	3.2

USG = Urea super granule; CU = Conventional urea. CV = Coefficient of variation; LSD = Least significant difference. Means within a column followed by the same letter are not significantly different at $P > 0.05$

The least number of days required to heading, flowering and maturity were recorded from the control treatment. There was no statistically significant difference ($P > 0.05$) in the number of days required to flowering and maturity between application of 100% of the recommended N as CU and application of 50% of the recommended N as USG (Table 6). This might be attributed to the relatively better availability of N from the slowly released N from USG than the CU during and after anthesis, which could lead to the late heading and maturity of the plant.

4.5.2. Yield Traits of Wheat

Plant height, spike number (total number of tillers bearing spikes per plant), spike length, 1000 kernel weight and straw yield were significantly ($P \leq 0.01$) affected by the treatments (Appendix Table 6). As it is shown in Table 7, the highest plant height of 83.6 cm was measured from the application of 150% of the recommended N rate as USG followed by application of 100% of the recommended N as USG with insignificant difference ($P > 0.05$). It was observed that plant height increased with the increasing levels of nitrogen. Similar results were also found by Dhuka *et al.* (1991) who reported that plant height of wheat increased with increasing levels of USG.

The highest spike numbers per plant, spike length and number of kernels per spike were obtained from the application of 150% of the recommended N as USG followed by application of 100% of the recommended N as CU and USG, respectively with insignificant difference ($P > 0.05$). Patel *et al.* (1995) also reported that progressive increase in nitrogen levels enhanced the number of spikes per plant.

Maximum rates of N stimulated tillering, and increased spike numbers per plant maybe due to its effect on cytokinin synthesis (Mengel and Kirkby, 1996). The highest 1000 kernel weight was recorded from the application of 150% of the recommended N as USG followed with significant difference ($P \leq 0.05$) by application of 100% recommended N as USG. However, there was no significant difference ($P > 0.05$) in all yield related traits between application of 100% of the recommended N as USG and CU.

Though there was no statistical difference application of 100% of the recommended N as USG gave higher 1000 kernel weight than application of 100% of the recommended N as CU. This might be accounted for the slow releasing property of USG, which could release N slowly and for prolonged periods and hence N was available for plant uptake in grain filling stage and with resultant higher 1000 kernel weight in the respective treatments. El-Kramany (2001) also found that, slow release nitrogen fertilizer gave the highest 1000 kernel weight of wheat crop as compared to the conventional N fertilizers.

Application of 100% of the recommended N as CU, however, gave higher spike numbers per plant and higher number of kernels per spike than application of 100% of the recommended N as USG, though there was no statistical difference. This was resulted from the fact that the number of spikes per plant/or per unit area is set before stem elongation (Li *et al.*, 2001). So, N fertilization at tillering stage, pretty like the CU fertilizer in this study which was applied in split; half at planting and the remaining half at tillering, had a significant impact on spike numbers per plant and number of kernels per spike. The least spike numbers, spike length and number of kernels per spike were obtained from the control.

As it is indicated in Table 7, the highest straw yield (5.0 t ha^{-1}) was recorded from the application of 150% of the recommended N as USG followed by application of 100% of the recommended N as CU with significant difference ($P \leq 0.01$). Application of 100% of the recommended N as CU gave a significantly higher straw yield (4.3 t ha^{-1}) which exceeded the straw yield obtained from the application of USG at the same rate of N by 9.2%. The lowest straw yield of 2.4 t ha^{-1} was recorded from the control.

Table 7. Effects of different rates of USG and CU fertilizers on yield traits and grain yield of wheat

Treatment	PH (cm)	SL (cm)	SN	NK	TKW (g)	SY (kg ha^{-1})	GY (kg ha^{-1})	BW (kg ha^{-1})	HI
Control	65.0c	5.7c	5.7c	15.7c	35.7c	2416.0e	1207.7d	3731.8d	0.33c
23 kg N (USG) ha^{-1}	77.5b	8.3b	7.1bc	22.2bc	36.8bc	3313.7d	1922.7c	5304.1c	0.37b
46 kg N (USG) ha^{-1}	81.5ab	8.8ab	8.2ab	26.3ab	38.9b	3923.6c	2507.3b	6649.1b	0.39a
69 kg N (USG) ha^{-1}	83.6a	9.3a	9.8a	33.3a	41.8a	5032.4a	3175.5a	8515.0a	0.39a
46 kg N (CU) ha^{-1}	80.1ab	8.8ab	8.7ab	28.7ab	38.5b	4285.5b	2612.5b	7097.8b	0.38ab
Mean	77.5	8.2	7.9	25.2	38.4	3794.2	2285.1	6259.5	0.37
CV (%)	3.8	4.6	12.6	15.8	3.0	4.8	6.6	5.3	2.08
LSD (0.05)	5.6	0.7	1.9	7.5	2.2	342.9	283.5	624.9	0.01

Means within a column followed by the same letter are not significantly different at $P > 0.05$. PH = Plant height; SL = Spike length; SN = Spike number per plant; NK = Number of kernels per spike; TKW = 1000 kernel weight; SY = Straw yield; GY = Grain yield; BW = Biomass weight; HI = Harvest index; USG = Urea super granule; CU = Conventional urea; CV = Coefficient of variation; LSD = Least significant difference

4.5.3. Grain and Total Biomass Yields of Wheat

There was a significant ($P \leq 0.01$) grain and total biomass yields response of wheat crop to the effect of the treatments. The grain and total biomass yields increased with an increase in the application rates of N as USG up to the maximum level of N tested (150% of the recommended N). As it is presented in Table 7, the highest grain and total biomass yields (3.2 and 8.5 t ha^{-1}, respectively) were recorded from the application of 150% of the recommended N as USG followed, with significant difference ($P > 0.05$), by application of 100% of the recommended N as CU. Response of wheat grain yield to the increasing rates of N was also reported by Ma *et al.* (2004), Albert *et al.* (2005) and Martin (2006). The grain yield obtained from the application of 150% of the recommended N as USG has got yield advantages of 21.5 and 26.6% over application of 100% of the recommended N as CU and USG, respectively.

Though there was no significant difference ($P > 0.05$), application of 100% of the recommended N as CU gave a grain yield of 2.6 t ha^{-1} which exceeded the grain yield obtained from the application of USG at the same rate by 4.2%. Though there was no significant difference ($P > 0.05$), the total biomass yield obtained from the application of CU at the rate of 100% of the recommended N surpassed the total biomass yield recorded from USG at the same application rate of N by 6.7%.

By applying 50% of the recommended N as USG, it was possible to increase the total biomass yield by 42.1% over the control. The results are well supported by Bhandarkar *et al.* (1982) and Mahatim *et al.* (1987). The lowest grain yield (1.9 t ha^{-1}) among the treatments which received N was recorded from the application of 50% of the recommended N as USG, which was by 59.2% higher than the grain yield obtained from the control. The lowest grain yield of 1.2 t ha^{-1} was recorded from the control.

There was also a significant difference ($P \leq 0.01$) in the harvest index of wheat crop due to the effect of treatments (Table 7 and Appendix Table 6). The highest harvest index (0.39) was measured from the application of 150 and 100% of the recommended N as USG followed with insignificant difference ($P > 0.05$) by application of 100% of the recommended N as CU (Table 7).

Generally, the study revealed that application of 100% of the recommended N as CU gave higher biological yields than application USG at the same rate of N, though there was no statistically significant difference ($P > 0.05$). Observations of the growth and biomass of the test plant showed USG may had a slower N-releasing rate in the earlier stages, which probably did not supply N adequately for the crop; the conventional urea could, however, release N quickly to soils and became available to plants as required in early growth stages of the crop, which perhaps provided proper development of primordia and tillering.

Welch (1971), Johnson (1987) and Cervato *et al.* (1990) reported that N uptake was more pronounced at the rapid growth stages of wheat, which supports the present findings as obtained higher yields in the treatments, which probably released sufficient N in early growth stages of test crops. Moreover, the low rate of leaching due to impermeability nature of Vertisols, high CEC due to the smectite clay mineralogy (Berhanu, 1985), might have an added advantage for the CU fertilizer to maintain and prolong availability of NH_4^+ and NO_3^--N to the crop. The results are in accordance with the result from Bodruzzaman *et al.* (2002) who reported better growth performance and higher yields from basal application of conventional urea fertilizer than application of USG.

Rajput and Verma (1994) did reveal that yield of wheat increased significantly by splitting the nitrogen applied at the critical crop growth stages. By splitting the N fertilizer application, N available to the plant apparently matched crop needs more closely during the growing period. An adequate supply of N to the crop plants during their early growth period is very important for the initiation of leaves and florets primordia (Tisdale & Nelson, 1995). Some affiliated scholars also found out that band placement of urea solution into the anaerobic soil layer (waterlogged soil condition can be an example) has been as effective as deep placement of USG in reducing volatilization and denitrification losses and improving grain yield (Schnier *et al.*, 1988, 1993).

Application spacings of USG tablets might also have their own impacts for the lower yields obtained from the treatments which received 50 and 100% of the recommended N. There were 96 and 48 cm spacings between each USG placement holes along the row in the test plots which received USG at the rates of 50 and 100% of the recommended N, respectively. This could create a barrier in the mobility of the released N from USG upon dissolution, which probably resulted in non-uniform and inadequate N distribution in to the plant roots at early growth stages.

These effects of placement spacings of USG tablets were confirmed by visual observation of the growth of the test crop. Nitrogen deficiency, which could lead to poor development and relatively stunted growth, was observed in the plants which were far from the USG tablet placement holes; while better growth was observed in the plants which were in the close proximity of the USG tablet placement holes. Accordingly, the cumulative effects of the slow rate of release of N at early growth stages of the crop and the spacings of placement holes of the USG tablets resulted in lower yield returns from the application of 50 and 100% of the recommended N as USG.

The relatively narrower spacing (32 cm between USG pellet placement holes) from the application of 150% of the recommended N, could relatively increase the available N ions better than application of 50 and 100% of the recommended N as USG and subsequently make mobility, arrival and uptake by the plant roots easier. Accordingly, vigorous growth was observed and the highest grain and biomass yields could be recorded from the application of 150% of the recommended N as USG. The highest rate of N from the application of 150% of the recommended N as USG among the rates of N tested in the study and its slow N releasing property and the subsequent better availability and uptake of N by the test crop evidently made it superior in wheat yield response parameters measured. The findings of this study are well supported by Bodruzzaman *et al.* (2002).

4.5.4. Nitrogen Use Efficiency Indices of Wheat

The grain and straw N content increased with increasing rates of N. The maximum grain N uptake (95.3 kg ha^{-1}) was obtained from the application of 150% of the recommended N as USG followed by application of 100% of the recommended N as USG with a grain N uptake of 69.5 kg ha^{-1} (Table 8). Halvorson *et al.* (2004) indicated that grain protein content in wheat generally increased with increasing N rate. The percentage of N in the straw and grain increased in line with the increase in grain yield, which means that more N was required per unit of dry weight as yield increases, which in turn was responsible for the increase in the grain and straw N uptake from the increasing levels of N fertilizer. This was in accordance with the report made by Hobbs *et al.* (1998).

Table 8. Effect of USG and CU on grain, straw and total N uptake (TNU) and NUE indices of wheat

Treatment	GNU	SNU (kg ha^{-1})	TNU	RE (%)	PE	AE (kg kg^{-1})	NUE	NHI (%)
Control (No N)	22.1	16.9	39.0	-	-	-	-	56.7
23 kg N (USG) ha^{-1}	50.3	14.8	65.2	113.8	61.6	31.09	83.6	77.2
46 kg N (USG) ha^{-1}	69.5	15.1	84.6	99.1	61.6	28.25	54.5	82.1
69 kg N (USG) ha^{-1}	95.3	12.6	107.8	99.8	66.6	28.52	46.0	88.3
46 kg N (CU) ha^{-1}	55.6	25.7	81.4	92.1	77.3	30.54	56.8	68.4

GNU = Grain N uptake; SNU = Straw N uptake; TNU = Total (Grain + Straw) N uptake; RE = Apparent fertilizer recovery efficiency; PE = Physiological efficiency; AE = Agronomic efficiency; NUE = Nitrogen use efficiency; NHI = Nitrogen harvest index; USG = Urea super granule; CU = Conventional urea

The maximum total (grain + straw) N uptake (107.8 kg ha^{-1}) was obtained from the application of 150% of the recommended N as USG followed by application of 100% of the recommended N as USG (Table 8). The highest total N uptake from both application of 150 and 100% of the recommended N as USG was attributable to the higher rates of N and slow releasing nature of USG and the subsequent prolonged maintenance of available N in the soil for the crop. The lowest total N uptake (39.0 kg ha^{-1}) was recorded from the control due to the inadequate plant available N in the soil and the subsequent less crop uptake of N.

All the N indices except PE and NHI, showed a decreasing trend with the increasing rates of N. These results agree with those of Lopez-Bellido and Lopez-Bellido (2001) and Zhao *et al.* (2006), who found that NUE decreased with an increase in N use rates. Lopez-Bellido and Lopez-Bellido (2001) indicated that a decrease in NUE with increasing fertilizer rates is because grain yield rises less than the N supply in soil and fertilizer. The maximum RE (113.8%), AE (31.1 kg kg^{-1}), NUE (83.6 kg kg^{-1}) were recorded from the application of 50% of the recommended N as USG while the lowest RE (92.1%) was obtained from the application of 100% of the recommended N as CU. The lowest RE recorded from the application of 100% of the recommended N as CU was due to the lowest total crop N uptake on account of the relative susceptibility of CU fertilizer to losses as compared to the USG fertilizer.

According to Sowers *et al.* (1994), application of high N rates may result in poor N uptake relative to the amount supplied, low RE and NUE due to excessive N losses. However, due to the slow releasing property of USG and less loss of N relative to the higher loss of N from CU, RE from the application of 150% of the recommended N as USG was higher than application of 100% of the recommended N as CU.

The highest N harvest index (NHI) of 88.3% was obtained from the application of 150% of the recommended N as USG followed by application of 100% of the recommended N as USG. This was attributable to the fact that N was available in all the growth stages of wheat crop due to the slow release and supply of N to the crop by the USG fertilizer, which led to higher translocation of N to the grains in these treatments. Consequently, the proportion of the grain N uptake to the total N uptake was more in these treatments. The lowest NHI (56.7%) was obtained from the control which was resulted from the lowest mobilization of N to the grains relative to the total N (grain + straw) uptake due to the lowest N uptake and the subsequent less production of metabolites necessary for the translocation of nutrients to the grains.

4.5.5. Correlation between Phenological and Agronomic Parameters of Wheat

Correlation analysis between growth parameters, yield related traits and grain yield is presented in Table 9. The correlation analyses revealed that there was a significant ($P \leq 0.01$) positive correlation between grain yield and yield related traits of wheat. Grain yield was significantly and positively correlated with straw yield ($r = 0.988$), biomass yield ($r = 0.996$), plant height ($r = 0.895$) and 1000 kernel weight ($r = 0.869$). Different studies indicated positive associations of grain yield with yield related traits (Kinyua and Kirigwi, 1994 and Jaglan *et al.,* 1997). This is promising result to find an optimum N fertilizer recommendation rate which can give maximum economic grain yield along with maximum total biological yield.

Biomass and straw yields were also found significantly ($P \leq 0.01$) and positively associated with spike number (number of tillers bearing spikes) per plant, 1000 kernel weight, number of kernels per spike and spike length (Table 9). However, there was no significant correlation ($P > 0.05$) between grain yield and yield traits of wheat with the number of days required to acquire different physiological stages (heading, flowering and maturity).

Table 9. Correlation coefficients among phenological parameters, yield traits and grain yield of wheat

	DH	DF	DM	PH	SL	SN	NK	TKW	SY	GY	BW
DH		0.973**	0.877**	-0.135ns	-0.017ns	0.051ns	-0.159ns	0.116ns	0.087ns	0.055ns	0.071ns
DF	0.974**		0.903**	-0.141ns	-0.009ns	0.063ns	-0.108ns	0.147ns	0.114ns	0.077ns	0.098ns
DM	0.877**	0.903**		-0.226ns	-0.108ns	-0.013ns	-0.255ns	-0.001ns	0.022ns	0.013ns	0.019ns
PH	-0.135ns	-0.141ns	-0.226ns		0.958**	0.709**	0.859**	0.687**	0.888**	0.895**	0.887**
SL	-0.017ns	-0.009ns	-0.108ns	0.958**		0.809**	0.844**	0.761**	0.933**	0.936**	0.930**
SN	0.051ns	0.063ns	-0.013ns	0.707**	0.809**		0.722**	0.748**	0.803**	0.798**	0.805**
NK	-0.159ns	-0.108ns	-0.255ns	0.859**	0.844**	0.722**		0.799**	0.891**	0.879**	0.889**
TKW	0.116ns	0.147ns	-0.001ns	0.687**	0.761**	0.748**	0.799**		0.864**	0.869**	0.873**
SY	0.087ns	0.114ns	0.022ns	0.888**	0.933**	0.803**	0.891**	0.864**		0.988**	0.997**
GY	0.055ns	0.077ns	0.013ns	0.895**	0.936**	0.798**	0.879**	0.869**	0.988**		0.996**
BW	0.071ns	0.098ns	0.019ns	0.887**	0.930**	0.805**	0.889**	0.873**	0.997**	0.996**	

DH = Days to heading; DF = Days to flowering; DM = Days to maturity; PH = Plant height (cm); SL = Spike length (cm); SN = Spike number per plant; NK = Number of kernels per spike; TKW = 1000 kernel weight (g); SY = Straw yield (kg ha^{-1}); GY = Grain yield (kg ha^{-1}); BW = Biomass weight (kg ha^{-1}), ** and ns indicate significance at P < 0.01 and non significant at P > 0.05

4.6. Effects of USG and CU on Growth, Yield Traits and Yield of Teff

4.6.1. Crop Phenology and Growth Parameters of Teff

The crop phenolgy of teff was significantly (P $\leq$ 0.01) affected by the effect of treatments (Appendix Table 6). The maximum number of days of 80.7, 90.0 and 150.0 required to heading, flowering and maturity, respectively were recorded from the application of 150% of the recommended N as USG followed with insignificant difference (P > 0.05) by application of 100% of the recommended N as USG. As it is presented in Table 10, the minimum number of days to heading, flowering and maturity were recorded from the control. The maximum number of growing days recorded from the application of higher N rates of 150 and 100% of the recommended N as USG might be attributed to the slow release of N and the subsequent continuous uptake of N and photosynthesis, of which cumulative effects imposed relatively prolonged vegetative growth period, grain filling and maturity stages.

Table 10. Effect of USG and CU on growth phenology of teff

Treatment	Days to heading	Days to flowering	Days to maturity
Control (No N)	68.7d	76.7d	139.0d
23 kg N as USG ha^{-1}	72.0c	81.3c	142.3c
46 kg N as USG ha^{-1}	76.0b	85.0b	146.3b
69 kg N as USG ha^{-1}	80.7a	90.0a	150.0a
46 kg N as CU ha^{-1}	74.0bc	83.3bc	145.0b
Mean	74.3	83.3	144.5
CV (%)	2.4	1.7	0.9
LSD (0.05)	3.3	2.7	2.7

Means within a column followed by the same letter are not significantly different at P > 0.05, USG = Urea super granule; CU = Conventional urea; CV = Coefficient of variation; LSD = Least significant difference

4.6.2. Yield Traits and Grain Yield of Teff

As it is summarized in Table 11, similar trend of response and results like wheat were obtained in the study on teff. Plant height, straw yield, grain yield, total biomass and harvest index of teff were affected significantly (P $\leq$ 0.01) by the effect of treatments. The highest plant height (74.2 cm) was recorded from the application of 100% of the recommended N as

USG followed with insignificant difference (P > 0.05) by application of 100% of the recommended N as CU. The lowest plant height (47.0 cm) was measured from the control.

Application of 100% of the recommended N as CU could also gave higher straw and biomass yields, which are important parameters for increased grain yield, than application of USG with the same application rate of N. The lowest straw and biomass yields were obtained from the control. However, among the treatments which received N, the lowest straw and biomass yields were obtained from application of 50% recommended N as USG.

The highest grain yield of 2.5 t ha^{-1} was recorded from the application of 150% of the recommended N as USG followed with significant difference ($P \leq 0.05$) by application of 100% of the recommended N as CU and USG, respectively. Although there is no statistical significant difference (P > 0.05), application of 100% of the recommended N as CU could give grain yield advantage of 7.9% over application of 100% of the recommended N as USG.

Table 11. Effects of USG and CU fertilizers on yield traits and grain yield of teff

Treatment	Plant height (cm)	Straw yield ($kg\ ha^{-1}$)	Grain yield ($kg\ ha^{-1}$)	Biomass weight ($kg\ ha^{-1}$)	Harvest index
Control (No N)	46.9b	1437.1d	759.5d	2206.8d	0.34c
23 kg N (USG) ha^{-1}	69.0a	2011.9c	1157.8c	3349.7c	0.36bc
46 kg N (USG) ha^{-1}	74.2a	3044.5b	1962.8b	5352.9b	0.39ab
69 kg N (USG) ha^{-1}	68.2a	4354.9a	2539.4a	6922.2a	0.37bc
46 kg N (USG) ha^{-1}	73.3a	3058.9b	2117.6b	5504.7b	0.41a
Mean	66.3	2781.5	1707.4	4667.2	0.38
CV (%)	4.8	7.8	6.1	5.0	4.58
LSD (0.05)	6.0	406.3	197.4	439.4	0.03

Means within a column followed by the same letters are not significantly different at P > 0.05, USG = Urea super granule; CU = Conventional urea; CV = Coefficient of variation; LSD = Least significant difference

Similar to the study on the wheat experiment, plant growth observations and the crop biomass of teff showed USG might not release N soon enough to meet plant needs, which probably did not supply N adequately for the crop. The CU fertilizer, however, could release N quickly to soils and became available to plants as required in early growth stages of wheat, which perhaps provided proper development during and after emergency and tillering, which eventually could lead to higher yields.

The lowest grain yield (1.1 t ha^{-1}) among the treatments which received N was measured from the application 50% of the recommended N as USG. The control treatment gave the lowest grain yield (0.8 t ha^{-1}) of all the treatments. The highest harvest index (HI) was measured from the application of 100% of the recommended N as CU followed with insignificant difference ($P > 0.05$) by the same rate of application of N as USG (Table 11). This was accounted for the relatively better availability of N from the application of CU at early growth and peak N demanding stages of the crop which imposed higher grain yields as compared to the total biomass.

4.6.3. Nitrogen Use Efficiency Indices of Teff

The grain and straw N content showed increasing response to the increasing rates of N applied as it is presented in Table 12, The maximum grain N uptake was recorded from the application of 150% of the recommended N as USG followed by application of 100% of the recommended N as USG. Maximum grain N uptake from these USG receiving treatments were resulted from the high rate of N and the slow releasing and prolonged maintenance and supply of N from USG fertilizer after anthesis which eventually led to maximum mobilization of N to the grains. The maximum straw N uptake was also obtained from the application 150% of the recommended N as USG followed by application of 100% of the recommended N as CU.

In the treatment which received 100% of the recommended N as CU, the higher N uptake during early and later vegetative growth stages than during grain filling stage was responsible for the low translocation of N to the grains and subsequent accumulation and higher N content in the straw. The total N uptake (81.2 kg ha^{-1}) was obtained from the application of 150% of the recommended N as USG followed by application of 100% of the recommended N as USG and CU, respectively. The slow releasing and prolonged maintenance of N from USG fertilizer were responsible for the higher total (grain + straw) N uptake. The lowest total N uptake (20.2 kg ha^{-1}) was measured from the control.

Table 12. Effect of USG and CU fertilizers on yield traits, grain yield and N uptake and NUE indices of teff

	GNU	SNU	TNU		PE	AE	NUE	
Treatment		(kg ha^{-1})		RE (%)		(kg kg^{-1})		NHI (%)
Control (No N)	15.0	5.2	20.2	-	-	-	-	74.4
23 kg N (USG) ha^{-1}	31.7	9.7	41.4	92.1	45.9	17.3	50.3	76.7
46 kg N (USG) ha^{-1}	48.3	13.7	62.0	90.8	67.3	26.2	42.7	77.9
69 kg N (USG) ha^{-1}	62.5	18.7	81.2	88.4	77.0	25.8	36.8	76.9
46 kg N (CU) ha^{-1}	46.6	15.0	61.6	89.9	72.0	29.5	46.0	75.7

GNU = Grain N uptake; SNU = Straw N uptake; TNU = Total (Grain + Straw) N uptake; RE = Apparent fertilizer recovery efficiency; PE = Physiological efficiency; AE = Agronomic efficiency; NUE = Nitrogen use efficiency; NHI = Nitrogen harvest index; USG = Urea super granule; CU = Conventional urea

Fertilizer recovery efficiency (RE) and NUE showed a decreasing trend with increasing rates of N fertilizers (Table 12). The maximum RE and NUE were obtained from the application 50% of the recommended N as USG. This might be attributable to the relatively high rise in total crop N uptake relative to the rate of N fertilizer applied and the potential of USG fertilizer to slowly release N so that the plant can take up when it requires and in due course helped attain efficient use of the N applied and reduced unnecessary losses of N to the environment. The lowest RE and NUE were recorded from the application of 150% of the recommended N as USG due to the relatively high rate of N exceeding the rate of increase in total N uptake and grain yield.

The highest PE (77.0 kg kg^{-1}) and AE (29.5 kg kg^{-1}) were recorded from the application of 100% of the recommended N as CU and application of 150% of the recommended N as USG, respectively. Unlike the other N efficiency indices, nitrogen harvest index (NHI) increased with increasing rates of N fertilizer though there were some irregularities.

The highest NHI was obtained from the application 100% of the recommended N as USG followed by application of 150% of the recommended N as USG. This was attributable to the higher N uptake after anthesis due to the prolonged N availability from the slow releasing USG fertilizer and subsequent higher mobilization of N to the grain from the pool of the total N uptake; and application of 100% of the recommended N as USG was more efficient in mobilizing N from the vegetative part to the grain than application of 150% of the recommended N as USG. The lowest NHI was recorded from the control due to the relatively lowest total N uptake and the subsequent little mobilization of N to the grain.

4.6.4. Correlation between Phenological and Agronomic Parameters of Teff

The result from the correlation analysis revealed that there was a significant ($P \leq 0.05$) and positive correlation between phenological parameters, yield related traits and grain yield of teff. As it is elucidated in Table 13, grain yield is significantly and positively correlated with days to heading (r = 0.929), days to flowering (r = 0.899) and days to maturity (r = 0.939), plant height (r = 0.685), straw yield (r = 0.961), biomass yield (r = 0.994). Fufa *et al.* (2000) and Kebebew *et al.* (2002) also reported similar results of positive correlation among grain yield and yield related traits in teff. However, in contrast to the results obtained in this study, Fufa *et al.* (2000) found negative association of yield with days to heading and days to maturity.

Table 13. Correlation coefficients among phenological parameters, yield traits and grain yield of teff

	DH	DF	DM	PH	SY	GY	BW
DH		0.923**	0.906**	0.571*	0.901**	0.882**	0.904**
DF	0.923**		0.875**	0.622*	0.937**	0.891**	0.926**
DM	0.906**	0.875**		0.654**	0.916**	0.905**	0.924**
PH	0.571*	0.622*	0.654**		0.609*	0.685**	0.692**
SY	0.901**	0.937**	0.916**	0.609*		0.961**	0.980**
GY	0.882**	0.891**	0.905**	0.685**	0.961**		0.994**
BW	0.904**	0.926**	0.924**	0.692**	0.980**	0.994**	

DH = Days to heading; DF = Days to flowering; DM = Days to maturity; PH = Plant height (cm); SY = Straw yield (kg ha^{-1}); GY = Grain yield (kg ha^{-1}); BW = Biomass weight (kg ha^{-1}), * and ** indicate significance at $P \leq 0.05$ and $P \leq 0.01$, respectively

5. SUMMARY AND CONCLUSIONS

Soil fertility decline is one of the principal factors contributing to low productivity of crops and food insecurity in Sub-Saharan Africa. Crops are the major agricultural products in Ethiopia which most of the people in the country rely on for their daily food and dietary requirements. Among the cereal crops, wheat and teff are the most important and top priority food crops consumed by the majority of the people.

However, depletion of plant nutrients from the soil through intensive soil erosion, removal of nutrients by crop uptake and less return of crop residues, very low addition of manure and organic residues in to the soil, and minimal soil conservation practices threatens the crop production sector. Thus, chemical fertilizers have been considered as one of the primary options to increase crop productivity and eventually satisfy the growing food demand in the country. However, low recovery efficiency of the chemical fertilizers has led to economic loss in the world agriculture and environmental pollution. Hence, the efficient use of chemical fertilizers through different management methods; time and rate of application or selecting enhanced efficiency fertilizer technologies is critical for high economic returns and mitigate environmental pollution.

Thus, an on-farm experiment was conducted to characterize the soil of the study area and evaluate the effectiveness of a slow release N fertilizer-urea super granule (USG), against the conventional urea (CU) fertilizer in improving grain yield and yield related traits of wheat and teff crops. The study area is located in Jamma District, Southern Wollo zone of the Amhara region at coordinates of 10^{o} 27’ N latitude and 39^{o} 15’ E longitude and at an altitude of 2630 masl, receiving a total annual rainfall ranging from 857.5 to 1182 mm and minimum and maximum temperatures of 10.0 and 21.1 ^{o}C, respectively. The study area (Jamma District) is well known by its wide Vertisol coverage and high soil fertility potential to produce cereals mainly wheat and teff, pulses and oil crops.

An improved wheat variety (HAR1685), which was well adopted by the framers in the study area and a local teff variety (*Wajera*), which was the most widely produced variety in the area, were used for the study. Three rates (50, 100 and 150% of the recommended N) as USG were compared with 100% of the recommended N as CU and control (no nitrogen).

Surface soil samples at a depth of 0-20 cm were collected before planting from the experimental sites per replication. Soil pedons were opened in both experimental fields to describe the morphological characteristics and chemical properties of the soil profiles and eventually characterize the soils of the study sites and soil samples were collected from the soil layers at different depths in the soil profiles. Soil samples were also collected at a depth of 0-20 cm from each experimental plot after harvesting for analysis of total N to investigate the residual effect of USG fertilizer.

The soil analyses results of the surface soil samples indicated that the soil of the experimental sites is in a conducive pH ranges for growth of most crops and clayey in texture. The soil organic matter, total nitrogen and available phosphorus content, however, were in the low, low to medium and low ranges, respectively. The percent base saturation of both experimental sites was in the high range and calcium and magnesium were the dominant cations in the surface soils of both experimental fields.

Soil depths were found between 1 and 1.5 m in both soil pedons, beyond which was found light grayish coarse and gravel parent material. Genetic soil horizons could not be identified. However, different soil layers could be identified though clear soil horizon differentiation and boundaries could not be observed.

The field morphological description of soil profiles showed that the soils in most of the soil layers of both profiles had massive block and weak prismatic soil structures with shiny faces of slickensides. The laboratory analyses of the soil samples collected from the soil profiles revealed that soil pH was under the slightly acidic to slightly alkaline ranges and is favorable for most crops and it increased as depth increased. And all the exchangeable bases of the soil profiles were in the high ranges and except K, all the rest showed an increasing trend along with soil depth. Calcium was the dominant cation followed by Mg in the soil cation exchange sites and its concentration increased with depth. Generally, the morphological, physical and chemical properties of the soil profiles and the higher concentration and dominancy of Ca relative to the other basic cations, the increase in the soil pH and the light grayish color of coarse textured parent material underlying the solum indicated that the parent material of the soil profiles was most likely of sedimentary (limestone) origin.

All the necessary agronomic and cultural practices were implemented during the growth period of the test crops and the relevant data were recorded at various growth stages of the test crops (Wheat and Teff) and the growth parameter results and the agronomic data measured were analyzed. After harvest, the plants were partitioned into grain and straw and analyzed for total N content.

The results obtained from this study showed that application of 100% of the recommended N as CU gave higher yields in both test crops, though with statistically insignificant difference ($P > 0.05$), than application of USG at the same application rate of N. In this study, wheat and teff yields increased with increasing rates of USG and the highest rate of USG (150% of the recommended N) gave the highest and promising yield increments which signaled higher rates of N fertilizers than the existing recommendation rate should be evaluated if they could give economically beneficial and higher yields. The N fertilizer recovery efficiency of the test crops could, however, be improved with USG fertilizers over the CU.

Therefore, considering the output from this study that the grain and total biomass yields obtained from the application of 100% of the recommended N as CU outweighed the yields obtained from the application N as USG with the same rate, and inaccessibility and difficulty in mode of application (labor-intensive practice) of USG fertilizer, particularly for small grain cereals, it can be concluded that at the existing full recommendation rate of N for teff and wheat crops, the conventional urea fertilizer is preferred to USG fertilizer for better and economic yield returns.

The following recommendations can be drawn from the observations and output of this study;

- ✓ The highest rate (150% of the recommended N) as USG tested in this study gave promisingly highest grain yield and total biomass yields. Thus, CU and USG fertilizers should be evaluated at higher rates of N than the full recommendation rate used in this study. Socio-economic studies should be incorporated in the USG and CU fertilizer evaluation studies since their method, mode, and frequency of application is different and is a function of soil condition, labor, time and money.

- ✓ The existing full recommendation rates of N for teff and wheat crops being used in most of the country is presumably outdated and consequently has led to under utilization of fertilizers and the consequent low economic returns and low crop productivity far less than the genetic potential of the crops. Hence, the existing N fertilizer recommendations for teff and wheat should be renewed accordingly and location and crop specific, and soil test based fertilizer rate determination studies should be conducted. (I think you will be challenged here since you are making a conclusion without supporting economic analysis. The higher rate N may give slightly higher yields but the difference may not be economically better.)

- ✓ Different studies indicated that USG fertilizers are most suited and responsive for crops produced in lowland soils which have adequate soil water content to dissolve the USG pellets early after application (Rice and rice farm lands could be an example most suited for USG fertilizers). Accordingly, the urea super granule fertilizers should be extensively evaluated and disseminated to the farmers in the potential rice growing areas of the country. You did not include rice in your study. Hence, please do not add perosnal opinion in your conclusions abnd recommendations. Stick to the wheat and tef work.

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7. APPENDIX

Appendix Table 1. Monthly and yearly total rainfall (mm) at Wereillu area (2002-2011)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
2002	63.4	12.7	51.5	28.8	0.0	43.4	242.1	324.4	32.4	5.7	0.0	15.6	820.0
2003	22.7	19.8	43.4	56.6	3.2	56.5	306.5	252.4	74.4	0.0	2.2	38.0	875.7
2004	13.3	15.9	46.9	50.8	2.9	42.3	229.0	246.9	50.4	4.0	7.9	0.0	710.3
2005	38.6	0.0	79.9	41.1	93.2	38.5	340.4	294.1	35.7	0.0	0.0	0.0	961.5
2006	26.3	3.9	83.6	73.5	11.6	18.3	262.2	397.1	73.8	9.9	6.7	1.5	968.4
2007	11.8	32.3	12.6	32.0	2.4	80.5	319.9	315.8	99.2	0.0	0.0	xx	906.5
2008	0.0	0.0	0.0	0.0	7.7	37.5	339.1	243.7	82.0	9.2	74.8	0.0	794.0
2009	14.4	0.0	22.0	0.1	6.1	32.9	349.3	234.7	41.7	8.1	xx	25.4	734.7
2010	9.8	23.9	42.1	44.1	46.7	15.5	357.3	473.3	33.6	0.0	10.8	13.1	1070.2
2011	9.7	0.0	73.7	36.8	xx	35.5	268.3	336.6	76.1	2.5	1.5	0.0	840.7
Mean	21.0	10.9	45.6	36.4	19.3	40.1	301.4	311.9	59.9	3.9	11.5	10.4	868.2

Source: Sirinka Agricultural Research Center; xx = indicates data not available

Appendix Table 2. Mean monthly and annual minimum temperature (^{o}C) at Wereillu area (2002-2011)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
2002	8.9	9.7	10.7	10.7	xx	11.8	11.3	10.4	10.7	6.5	8.7	9.7	9.9
2003	8.9	10.1	10.8	11.4	12.8	11.7	10.3	10.3	10.2	9.1	7.9	7.6	10.1
2004	9.6	9.2	10.0	10.6	12.6	11.6	10.2	10.0	10.3	8.8	8.5	8.8	10.0
2005	8.5	9.9	10.5	11.3	10.9	11.2	9.9	10.4	10.4	9.2	8.5	6.8	9.8
2006	8.4	9.7	10.1	10.4	11.9	11.6	10.7	10.2	10.4	10.2	8.7	9.1	10.1
2007	8.8	10.3	10.5	11.4	12.3	11.5	10.3	10.5	10.2	9.0	8.6	5.7	9.9
2008	6.2	7.6	9.2	11.7	12.5	11.4	10.1	10.5	10.3	9.0	7.2	7.1	9.4
2009	8.4	9.4	10.1	11.0	12.1	12.8	10.3	10.4	11.0	10.0	xx	9.7	10.5
2010	8.6	10.8	9.9	11.6	12.7	12.5	10.6	10.5	10.5	9.6	8.3	8.8	10.4
2011	8.8	9.0	9.8	11.6	xx	11.8	10.5	10.6	10.6	9.4	9.4	7.7	9.9
Mean	8.5	9.6	10.2	11.2	12.2	11.8	10.4	10.4	10.5	9.1	8.4	8.1	10.0

Source: Sirinka Agricultural Research Center. xx = indicates data not available

Appendix Table 3. Mean monthly and annual maximum temperature (^{o}C) at Wereillu area (2002-2011)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
2002	20.6	22.9	22.4	22.9	xx	24.5	22.4	19.7	20.3	20.8	21.2	21.2	21.7
2003	21.6	22.8	22.7	22.6	24.2	24.1	19.5	19.6	20.1	20.5	20.7	20.5	21.6
2004	23.1	22.5	22.9	22.5	24.6	22.6	20.4	20.2	20.3	20.3	20.9	21.5	21.8
2005	21.9	24.0	23.6	23.4	22.9	23.3	21.2	19.6	19.9	19.9	20.0	20.5	21.7
2006	22.0	23.0	22.8	21.3	23.3	23.9	20.0	19.0	19.4	20.7	20.4	20.9	21.4
2007	21.9	22.3	23.7	23.1	24.1	22.3	20.2	19.4	20.3	20.1	19.8	20.6	21.5
2008	22.3	22.7	24.0	23.0	23.9	24.3	20.5	19.5	20.3	20.6	xx	xx	22.1
2009	21.6	22.5	23.9	24.1	24.4	25.4	19.8	20.1	21.0	21.1	xx	20.9	22.3
2010	21.6	22.6	22.2	22.7	23.4	24.7	20.0	19.3	20.4	21.3	21.0	20.9	21.7
2011	22.0	22.9	21.5	24.0	xx	24.5	21.1	19.1	20.7	20.2	21.2	20.9	21.6
Mean	21.9	22.8	23.0	23.0	23.9	24.0	20.5	19.6	20.3	20.6	20.7	20.9	21.7

Source: Sirinka Agricultural Research Center. xx = indicates data not available

Appendix Table 4. Mean squares and standard errors of the means (SEM) of crop phenology, growth, yield traits and yield of wheat and teff as affected by urea super granule and conventional urea fertilizers

Plant parameter	Means squares of sources of variation: Treatment (4)	Error (8)	CV (%)	SEM
		Wheat		
Days to heading	82.8333333**	1.9333333	1.80	0.80
Days to flowering	70.6000000**	2.1000000	1.72	0.84
Days to maturity	83.6000000**	2.8500000	1.43	0.97
Plant height (cm)	161.5310**	8.8665	3.84	1.72
Spike length (cm)	6.41246823**	0.14483833	4.64	0.22
Spike numbers per plant	7.0975**	0.9954	12.63	0.58
Number of kernels per spike	134.4953**	16.0168	15.86	2.31
1000 kernels weight (g)	16.4649**	1.3763	3.06	0.68
Straw yield (kg ha^{-1})	2941130.09**	33172.75	4.80	105.10
Grain yield (kg ha^{-1})	1681128.576**	22671.987	6.59	86.90
Biomass weight (kg ha^{-1})	9932807.65**	110139.03	5.30	191.60
Harvest index	0.00156878**	0.00005967	2.08	0.01
		Teff		
Days to heading	60.4000000**	3.1000000	2.37	1.02
Days to flowering	71.7333333**	2.1333333	1.75	0.84
Days to maturity	51.6000000**	2.0000000	0.98	0.82
Plant height (cm)	371.669000**	10.285500	4.83	1.85
Straw yield (kg ha^{-1})	3766195.87**	46566.23	7.76	124.60
Grain yield (kg ha^{-1})	1594614.537**	87927.183	6.14	60.50
Biomass weight (kg ha^{-1})	10534241.87**	54450.76	4.99	134.70
Harvest index	0.00185038*	0.00029783	4.58	0.02

Figures in parenthesis = Degrees of freedom; * = Significant at $P \leq 0.05$; ** = Significant at $P \leq 0.01$; CV = Coefficient of variation