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# Soil Characterization and Response of Triticale *(X Triticosecale* WITTMACK) to Nitrogen and Phosphorus Fertilizer Rates at Debretabor Area

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**Low and declining soil fertility are among the major factors responsible for the poor productivity of the small scale rainfed crop farming in most of the Ethiopian highlands. Thus, soil characterization and field experiment was conducted to investigate the effects of applied N and P fertilizer rates on grain yield and yield components for triticale (Triticosecale wittmack L.) production on soils of Wabela, around Debretabor area, Amhara National Regional State (ANRS). The experiment involved factorial combinations of four rates of N (0, 23, 46 and 69 kg ha$^{-1}$) and P (0, 10, 20 and 30 kg ha$^{-1}$) laid down in RCBD with three replications. Soil samples were collected from freshly opened soil profile on genetic horizon bases and from the experimental plot (0-30 cm depth) before planting and after harvest to study selected soil properties. The moist soil color of the profile was very dark brown (7.5YR 3/3), at the surface and dark grayish brown (10YR 3/3) at the bottom, with clay loam to clayey texture. The bulk density values varied with depth of the profile from 1.01 g cm$^{-3}$ at the surface layer to 1.23 g cm$^{-3}$ at the bottom layer. The soil water contents at FC increased with depth except the Bt$_2$ horizon while the soil water contents at PWP increased throughout depth. Soils of the profile indicated that the soil of the site was moderately to slightly acidic in reaction (pH 5.74 to 6.02), high to low in OM (6.46 to 2.24%), high to medium in its total N (0.41 to 0.13%) and high in available P (26.5 to 21.6 mg kg$^{-1}$) from the surface to the subsurface horizons. The soil exchange complex was mainly dominated by Ca and Mg where the order of occurrence was Ca > Mg > K > Na. Similarly, the CEC values were very high ranging from 37.88 to 46.22 cmolc kg$^{-1}$. The available P content of the soil at post harvest increased compared with the pre-sowing status due to residual effects from the highest P rate (30 kg P ha$^{-1}$). The application of different rates of N fertilizer significantly ($P \leq 0.01$) influenced all the tested crop parameters. On the other hand, the main effect of P fertilizer and its interaction with N was found to be non-significant with all the crop characters. The significantly different and highest plant height (89.2 cm), fertile tillers (304.6), spike number (356.3), grain per spike (48.4) and spike length (10.9 cm) were obtained from application of the highest N rate (69 kg N ha$^{-1}$) whereas the minimum records were obtained from the control plot. Similarly, the highest grain yield (2769.7 kg ha$^{-1}$), straw yield (4212.2 kg ha$^{-1}$), total biomass yield (6981.8 kg ha$^{-1}$) and 1000 grains weight (36.9 g) were obtained from application of the highest N rate while showing a decreasing trend with declining N rate. Thus, farmers at the Wabela Peasant Association need tentatively to apply 69 kg N ha$^{-1}$ without P in order to improve the grain yield and yield components of triticale grown on Haplic Luvisols under rain fed conditions.**

**Keywords:** Titicale, Debretabor, Luvisols

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## INTRODUCTION

Ethiopia is the second most populous country in Africa with a population of 73,750,932 (CSA, 2010). Agriculture is the leading sector in the country's economy that accounts for about 45% of the gross domestic product (GDP), employs about 80% of the labor force and generates about 80% of the export earnings (CSA, 2009). The highlands [> 1500 meters above sea level (masl)] cover about half of the total land area of the country and are inhabited by 75% of the livestock population and account for over 95% the regularly cropped area (World Bank, 1996). As is the case with many developing countries, cereals constitute staple food and provide the major portion of energy and protein consumed by the population. In Ethiopia too Cereals are also the most important commodities supplied to local markets, and hence important sources of cash income to millions of farming households.

In the Ethiopian highlands, soil loss due to water erosion is about 1493 million tons per annum as estimated by Hurni (1993). Of this, nearly half is estimated to come from the cultivated fields, which account for only about 13% of the country's total area. These losses will inevitably cause yield decreases unless appropriate measures are taken. Although much of the highlands have high potential for food production because of favorable seasonal precipitation, many of the soils are deficient in plant nutrients. Similarly, soils in the highlands of Ethiopia usually have low levels of essential plant nutrients and organic matter (OM) content, especially low available Nitrogen (N) and Phosphorus (P) has been demonstrated to be major constraint for cereal production and therefore application of fertilizers on these soils play a major role in increasing food production to meet the demands of the growing population (Tekalign *et al*., 1988).

Inorganic fertilizers are a normal requirement for high crop yields. It is estimated that 30-50% of today's crop production in the world comes directly from the use of inorganic fertilizers. Use of the correct type, rate, time and method of application of fertilizers is important for raising production and avoiding damage to the environment. Furthermore, Inorganic fertilizers can quickly replenish lost plant nutrients. However, despite several years of agronomic research on the response of specific food crops to various types of fertilizers, over-generalized and rigid recommendations on their use continue to be made (Gachene and Gathiru, 2003). Such a blanket recommendation does not do justice to the differences in agro-ecology, indigenous soil nutrient supplies and crop specifications (Asefa, 2008).

To alleviate the soil fertility problem in the region the bureau of agriculture and rural development has introduced chemical fertilizers particularly diammonium phosphate (DAP) and urea fertilizers in each district of the zone at a rate of 100 kg DAP (21 kg P and 18 kg N) and 100 kg urea (46 kg N) $ha^{-1}$. The blanket fertilizer recommendation may be in excess of or less than the optimum requirement for crop growth and development. Therefore, the best types and amounts of fertilizer to use for a particular crop in a given area should be decided on the basis of sufficient information obtained through soil and plant-tissue sampling and analysis. Only such studies help to prescribe the best-suited crop for a given soil, and also the appropriate remedies for treating or reclaiming chemically degraded soils.

Triticale is one of the cereal crops which are widely cultivated in the study district (Debretabor). Despite this, there is no considerable work done in the study area to determine the optimum rates of N and P fertilizers needed for triticale production. To meet the food demand and the need of emerging agro-industries in the country, increasing the production and productivity of triticale with appropriate soil management practice is important. The implication is that soil analysis for selected physicochemical properties and plant response studies to applied N and P fertilizers is vital for maximizing the yield of triticale in order to contribute to the efforts to alleviate the current food shortage and improve the living conditions of the poor farmers in the study areas. Accordingly, this study involves field research and laboratory analysis of soils and plant tissues with the goal of characterizing selected soil physicochemical properties and investigating the effects of applied N and P rates on nutrient uptake, and yield and yield components of triticale on the soils of Debretabor areas under rainfed conditions. The specific objectives of the study were to characterize the soils of the study area on the basis of some selected physicochemical properties, and investigate the effects of applying N and P fertilizer rates on grain yield and yield components of triticale production on soils of Debretabor areas

## MATERIALS AND METHODS

### Descriptions of the Study Site

The study was conducted in Debretabor District of South Gondar Zone in the Amhara National Regional State. Debretabor, the capital of South Gondar Zone, is located at $11^0$ 49' to $11^0$ 52' North and $37^0$ 58' to $38^0$ 01' East and an average altitude of 2706 meters above sea level (masl) at a road distance of 666 km northwest of Addis Ababa and 100 km northeast of Bahir Dar city. The area is characterized by a unimodal rainfall pattern (May to October) and receives a mean annual rainfall of 1474 mm. The average (2005–2010) annual minimum, maximum and mean temperatures are 9.2, 22.1 and 15.7 $^0$C, respectively. Topographically, 47% of the district is plain, while gentle and steep slope lands account for 45% and 8%, respectively. The rural households are engaged primarily in crop-livestock mixed farming systems. Barley, wheat, teff, sorghum, maize, faba beans, peas and potatoes are the dominant crops while chickpeas and some oil crops are occasionally grown. The yield of cereals is about a ton per ha except for maize that reaches 1.5 t per hectare. The experimental site is located in Wabela Peasant Association (PA) of Debretabor District. It lies at 11$^0$ 53' North and 38$^0$ 01' East with altitude of 2649 masl. The land where this experiment was conducted had been used for grazing before 2005.

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### Experimental Design and Procedures

A 4 x 4 factorial experiment in a randomized complete block design (RCBD) with three replications was used in the study. Four levels of N (0, 23, 46, and 69) and P (0, 10, 20, and 30 P) kg ha$^{-1}$were combined and randomly assigned to experimental units of each block. Gross plot size was 2.4 m x 4 m accommodating 12 rows of triticale spaced at 20 cm of 4 m length. The net plot size was 2.0 m x 3.6 m leaving one outer most row on both sides of each plot and 0.2 m row length at both ends of rows as borders. The experimental plot was plowed and prepared according to farmers' conventional farming practice. Accordingly, the field was plowed three times before planting and the recommendation seed rate (150 kg ha$^{-1}$) was hand drilled in each plot (ARC, 2002). Urea (46% N) and triple super-phosphate [TSP (20% P)] were used as sources of N and P nutrients, respectively. Full dose of P and half dose of N were applied as basal application and the remaining amount of N was top dressed at mid–tillering stage of the crop, after the first weeding. The necessary field management practices were carried out as per the practices followed by the farming community around the area.

### Soil Sampling and Analysis of Soil Physical and Chemical Properties

### Soil Sampling and Sample Preparation

A fresh soil profile pit with 1 m width by 1.5 m length and 2 m depth was opened. The soil profile was described at the field for its morphological properties and sampled on genetic horizon basis for characterization of selected physicochemical properties. The soil properties studied include soil color, particle size distribution (texture), bulk density (BD), soil moisture contents at field capacity (FC) and permanent wilting point (PWP), pH, organic carbon (OC), total N, available P, exchangeable bases (Ca, Mg, K and Na) and cation exchange capacity (CEC). Moreover, three composite surface soil samples (0-30 cm depth) were collected from each replication of the experimental plot before planting to determine the different soil physical and chemical properties listed above. Similarly, surface soil samples were collected from each plot after harvesting the crop and then composited by replication to obtain one representative sample per treatment for the determinations of soil total N and available P contents. Moreover, duplicate undisturbed soil samples were taken using core samplers from the experimental site and each identified horizon of the profile for determinations of bulk density and moisture contents at FC and PWP.

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

### Soil Analysis

Soil color was determined using the Munsell Soil Color Chart (Munsell color company, 1975), Soil texture was determined using Bouyoucos hydrometer method (Day, 1965). Bulk density (BD) was determined from undisturbed (core) soil samples collected using core samplers, weighed at field moisture content and then dried in an oven at 105 $^0$C (Baruah and Barthakur, 1997). The average soil particle density (PD) (2.65 g cm$^{-3}$) was used for estimating total porosity as follows:

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

The moisture contents at FC and PWP were measured at soil water potential -1/3 and -15 bars, respectively, using the pressure plate apparatus, whereas AWHC was obtained by subtracting PWP from FC.

The pH of the soil was measured potentiometrically in the supernatant suspension of a 1:2.5 soil to water ratio using a pH meter as described by Carter and Gregorich

(2008). Organic carbon was determined using the wet oxidation method (Walkley and Black, 1934) where the carbon was oxidized under standard conditions with potassium dichromate in sulfuric acid solution. Finally, the OM content of the soil was calculated by multiplying the percent of OC by 1.724. Total N was determined by the Kjeldahl method (Jackson, 1967) while available P was extracted using the sodium bicarbonate solution following the procedure described by Olsen *et al*. (1954). The exchangeable bases (Ca, Mg, K and Na) in the soil were extracted with 1 molar ammonium acetate ($NH_4OAc$) solution at pH 7.0 (Sahlemeden and Taye, 2000). Exchangeable Ca and Mg in the leachate were determined by atomic absorption spectrophotometer while exchangeable K and Na were determined by flame photometry (Rowell, 1994). The cation exchange capacity (CEC) was measured after leaching the $NH_4OAc$ extracted soil sample with 10% NaCl solution. The amount of ammonium ion in the percolate was determined by the Kjeldahl procedure and reported as CEC (Hesse, 1972). The CEC of the clay fraction was estimated from the difference of the soil CEC and CEC associated with soil OM as follows:

$$\text{CEC (cmol}_c\text{ kg}^{-1}\text{ clay)} = \frac{\text{CEC (cmol}_c\text{ kg}^{-1}\text{ soil)} - (\%\text{OM} \times 200\text{ cmol}_c\text{ kg}^{-1})}{\%\text{clay}}$$

assuming that the CEC of OM is 200 $\text{cmol}_c\ \text{kg}^{-1}$ (Yerima, 1993).

## Agronomic Data Collection

Plant height (cm), days to 50% heading, days to 90% physiological maturity, grain filling period, number of fertile tillers per $m^2$, number of spike per $m^2$ , number of grains per spike, spike length (cm), 1000 grains weight (g), grain yield, straw yield, total above ground biomass yield and harvest index were collected.

Days to 50% heading and 90% physiological maturity were recorded when plants have expressed the respective phenological parameters. Grain filling period was determined by counting the number of days taken from heading to maturity. Plant height was measured from randomly sampled 10 plants per plot at physiological maturity, whereas the number of fertile tillers and the number of spikes per $m^2$ were determined at the late tillering stage and at maturity, respectively. The number of grains per spike and spike length were averaged over 10 spikes taken from the net plot area. Thousand grains weight was determined by taking 1000 grains randomly from each plot harvested and it was adjusted at 12.5% moisture content by using Dicky John hand moisture tester instrument. Grain and straw yields were determined by harvesting the entire net plot of 7.2 $m^2$ and converted into kilogram per hectare. The yields were measured after leaving the harvested plants in open air for about 10 days so that they attained constant weight. Similarly, total above ground biomass yield was determined by weighing after complete sun drying at harvest. Grain yield was measured by threshing the plants at harvest from the net plot area and adjusted to 12.5% seed moisture content and straw yield was determined as the difference between the total above ground biomass (straw plus grain) and the grain yield of the respective treatments. Harvest index was obtained by dividing grain yield by the total biomass weight including the grain yield.

## Statistical Analysis

The agronomic data were subjected to analysis of variance (ANOVA) using SAS software program (SAS Institute, version 9). The results of soil and tissue samples were interpreted using descriptive statistics. Mean separation was carried out using the least significant difference (LSD) (Gomez and Gomez, 1984).

## RESULTS AND DISCUSSIONS

### Characterization of the Soil of the Study Area

The soil morphological features of the experimental field were described on a freshly opened soil profile based on the FAO (2006) guidelines. Besides, the physical and chemical properties of the soil profile samples were analyzed in the laboratory following standard laboratory procedures. The results obtained are presented and discussed in the following sections.

### Soil Morphological Features

The soil profile opened was very deep (> 200 cm) and the moist soil color at the surface horizon was dark brown (7.5YR 3/3), whereas changed to dark grayish brown (10YR 3/3) at the $Bt_3$ horizon (Appendix Table 4). The observed color change may be due to drainage problem at the $Bt_3$ horizon.

The structure of the soil was weak, fine to medium granular in the surface horizon. The subsurface horizons changed from moderate, medium sub-angular blocky structure to strong coarse angular blocky in the middle and lower horizons (Appendix Table 4). Strong angular and sub-angular blocky structures might possibly reflect the low contents of OM, the existence of high clay

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

| Depth (cm) | Horizon | Particle size (%) | | | Textural class | BD (g cm$^{-3}$) * | TP (%) | Water content | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Sand | Silt | Clay | | | | FC (%) | PWP (%) | AWHC (%) |
| 0-23 | Ap | 16 | 48 | 36 | Clay loam | 1.01 | 61.89 | 33.43 | 21.87 | 11.56 |
| 23-65 | AB | 15 | 29 | 56 | Clay | 1.08 | 59.25 | 33.81 | 24.09 | 9.72 |
| 65-95 | Bt$_1$ | 15 | 31 | 54 | Clay | 1.13 | 57.36 | 35.57 | 24.48 | 11.09 |
| 95-138 | Bt$_2$ | 14 | 28 | 58 | Clay | 1.21 | 54.34 | 34.68 | 24.59 | 10.09 |
| 138-200$^+$ | Bt$_3$ | 9 | 17 | 74 | Clay | 1.23 | 53.58 | 36.43 | 25.84 | 10.59 |
| Composite surface (0-30 cm) soil samples before planting | | | | | | | | | | |
| Block 1 | - | 19 | 45 | 36 | Clay loam | 1.02 | 61.51 | ND | ND | ND |
| Block 2 | - | 22 | 43 | 35 | Clay loam | 1.05 | 60.38 | ND | ND | ND |
| Block 3 | - | 22 | 44 | 34 | Clay loam | 1.03 | 61.13 | ND | ND | ND |
| Mean | - | 21.7 | 44 | 35 | | 1.03 | 61.01 | ND | ND | ND |

*BD = Bulk density; TP = Total porosity; FC = Field capacity; PWP = Permanent wilting point; AWHC = Available water holding capacity; ND = Not determined

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

| Depth (cm) | Horizon | pH ($H_2O$) | *OM (%) | TN (%) | C:N | AP (mg kg$^{-1}$) | Exchangeable bases (cmol$_c$ kg$^{-1}$) | | | | CEC (cmol$_c$ kg$^{-1}$) | | PBS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Ca | Mg | K | Na | Soil | Clay | |
| 0-23 | Ap | 5.74 | 6.46 | 0.41 | 9.14 | 26.5 | 11.56 | 7.49 | 1.37 | 0.06 | 37.88 | 69.33 | 54.1 |
| 23-65 | AB | 5.82 | 3.21 | 0.22 | 8.46 | 25.8 | 14.98 | 3.64 | 1.18 | 0.08 | 41.73 | 63.05 | 47.6 |
| 65-95 | Bt$_1$ | 5.95 | 2.85 | 0.19 | 8.70 | 24.3 | 20.65 | 3.01 | 1.16 | 0.09 | 42.59 | 68.31 | 58.5 |
| 95-138 | Bt$_2$ | 6.15 | 2.75 | 0.15 | 10.63 | 22.4 | 23.54 | 3.53 | 1.23 | 0.19 | 43.44 | 65.41 | 65.6 |
| 138-200$^+$ | Bt$_3$ | 6.02 | 2.24 | 0.13 | 9.99 | 21.6 | 32.10 | 2.78 | 1.27 | 0.17 | 46.22 | 56.41 | 78.6 |
| Composite surface (0-30 cm) soil samples before planting | | | | | | | | | | | | | |
| Block 1 | - | 5.76 | 6.49 | 0.39 | 9.65 | 25.7 | 10.70 | 11.98 | 1.11 | 0.06 | 38.73 | 71.53 | 61.6 |
| Block 2 | - | 5.66 | 6.54 | 0.41 | 9.25 | 26.1 | 11.50 | 10.80 | 1.21 | 0.07 | 39.21 | 74.66 | 60.1 |
| Block 3 | - | 5.62 | 6.72 | 0.38 | 10.26 | 26.7 | 11.12 | 8.70 | 1.19 | 0.06 | 41.25 | 81.79 | 51.1 |
| Mean | - | 5.68 | 6.58 | 0.39 | 9.78 | 26.2 | 11.10 | 10.49 | 1.17 | 0.06 | 39.73 | 76.00 | 57.6 |

*OM = Organic matter; TN = Total nitrogen; C: N = Carbon to nitrogen ratio; AP = Available (Olsen) phosphorus; CEC = Cation exchange capacity; PBS = Percent base saturation

**Table 3**. Effects of different levels of applied N and P fertilizers on total N and available P of the soil after crop harvest

| Applied N (kg ha$^{-1}$) | Applied P (kg ha$^{-1}$) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 10 | 20 | 30 | Mean | 0 | 10 | 20 | 30 | Mean |
| | Total N (%) | | | | | Available P (mg kg$^{-1}$) | | | | |
| 0 | 0.31 | 0.28 | 0.34 | 0.32 | 0.31 | 22.79 | 23.84 | 23.52 | 25.51 | 23.91 |
| 23 | 0.34 | 0.32 | 0.33 | 0.38 | 0.34 | 22.49 | 24.43 | 23.39 | 25.78 | 24.02 |
| 46 | 0.40 | 0.33 | 0.34 | 0.34 | 0.35 | 22.25 | 24.07 | 25.67 | 26.09 | 24.52 |
| 69 | 0.34 | 0.37 | 0.34 | 0.36 | 0.35 | 23.77 | 25.21 | 26.88 | 27.34 | 25.80 |
| Mean | 0.34 | 0.31 | 0.33 | 0.34 | | 22.82 | 24.39 | 25.62 | 26.18 | |

**Table 4.** Mean square estimates for triticale agronomic parameters, yield and yield components as affected by applications of N and P fertilizers

| Parameters considered | Mean squares for source of variation | | | |
|---|---|---|---|---|
| | N (3) | P (3) | N x P (9) | Error (30) |
| Plant height (cm) | 118.1796$^{**}$ | 1.8507$^{ns}$ | 1.2992$^{ns}$ | 2.5153 |
| Days to heading | 21.7430$^{**}$ | 1.0763$^{ns}$ | 0.2430$^{ns}$ | 1.4500 |
| Days to maturity | 17.2430$^{**}$ | 0.9097$^{ns}$ | 0.2430$^{ns}$ | 1.6569 |
| Grain filling period | 23.7222$^{**}$ | 1.0555$^{ns}$ | 0.0833$^{ns}$ | 3.2708 |
| Number of fertile tillers | 2572.9097$^{**}$ | 12.6875$^{ns}$ | 1.0949$^{ns}$ | 249.943 |
| Number of spikes m$^{-2}$ | 8452.7431$^{**}$ | 66.1319$^{ns}$ | 16.9838$^{ns}$ | 118.435 |
| Spike length (cm) | 9.8157$^{**}$ | 0.0407$^{*}$ | 0.0029$^{ns}$ | 0.1873 |
| Grain per spike | 11.2646$^{**}$ | 2.755$^{ns}$ | 0.5315$^{ns}$ | 1.2970 |
| Thousand grain weight (g) | 16.0735$^{**}$ | 0.2633$^{ns}$ | 0.1363$^{ns}$ | 0.0968 |
| Grain yield (kg ha$^{-1}$) | 3992052.20$^{**}$ | 21191.00$^{ns}$ | 20033.60$^{ns}$ | 6047.19 |
| Straw yield (kg ha$^{-1}$) | 7238857.43$^{**}$ | 232295.86$^{ns}$ | 165772.41$^{ns}$ | 185645.77 |
| Total biomass yield (kg ha$^{-1}$) | 21797254.74$^{**}$ | 333017.59$^{ns}$ | 1724055.38$^{ns}$ | 204206.11 |
| Harvest index (%) | 0.137927$^{*}$ | 2.6313$^{ns}$ | 1.5827$^{ns}$ | 0.00090 |

Figures in parentheses are values for degrees of freedom for respective source of variation; ** = Significant at $P \leq 0.01$; * = Significant at $P \leq 0.05$; ns = Non-significant at $P > 0.05$

content and probably the presence of expandable clay minerals such as montmorillonite (Mohammed *et al.,* 2005) which is in line with the current finding (Tables 1 and 2).

The surface soil and the adjacent subsurface horizons of the profile had slightly hard (dry), friable (moist) and, slightly sticky and slightly plastic (wet) consistence. However, the subsurface horizons were hard, firm and sticky and plastic consistence in the middle and to very hard, firm, and very sticky and very plastic in the lower subsoil horizons (Appendix Table 4). This change may be due to differences in the clay and OM contents. The horizon boundary varied from clear and smooth to gradual and smooth in the second layer and to clear and wavy in the third layer. The $Bt_2$ horizon had clear and smooth boundary.

## Physical Properties of the Soil

### Texture, Bulk Density and Total Porosity

The results of the laboratory analysis for physical properties of the soil profile and the composite soil samples presented in Table 1 revealed that the texture of the surface layer and the composite soil samples were clay loam at which silt was the dominant soil separate whereas the subsurface soil was clay in texture throughout the profile. The clay content of the soil within the profile increased with depth from 36% in the surface layer to 74% at the bottom (138-200$^{+}$ cm) depth of the profile whereas the sand content decreased with depth from 16% in the surface layer to 9% at the bottom layer of the profile. This differentiation in texture is attributed to illuviation of finer materials from the upper to the lower soil layers suggesting the presence of argic horizon (FAO-WRB, 2006).

The bulk density of the soils increased with depth, whereas total porosity decreased with depth of the soil profile (Table 1). The Ap horizon had high OM (6.46%) with lowest (1.01 g cm$^{-3}$) bulk density and highest (61.89%) total porosity of the soil horizons. However, the fine textured $Bt_3$ horizon had low OM (2.24%) with the highest (1.23 g cm$^{-3}$) bulk density and tended to have less (53.58%) total porosity (Tables 1 and 2). The mean bulk density value of the surface soil (1.03 g cm$^{-3}$) was closer to the average bulk density of cultivated loam soils (1.1-1.4 g cm$^{-3}$) (Miller and Donahue, 1997). The same authors also suggested that for good plant growth, bulk densities should be below 1.4 g cm$^{-3}$ for clay soils. Therefore, the bulk density values observed in these soils approached to the normal range for mineral soils. Total porosity values of soils range as low as 25% in compacted subsoils to more than 60% in well aggregated, high OM surface soils (Brady and Weil, 2008). Sands with a total porosity of less than about 40% and clay soils with less than 50% are liable to restrict root growth due to excessive strength (Landon, 1991).

## Soil Water Characteristics

The soil water contents at FC increased with depth for in the profile except the fourth layer while the PWP increased consistently throughout the profile (Table 1). The highest (36.43%) and lowest (33.43%) soil water contents at FC were observed in the deepest subsoil and the surface soil (0-23 cm) horizons, respectively. Likewise, the highest (25.84%) and lowest (21.87%) soil water contents at PWP were recorded for the same layers as the field capacity (Table 1). Similarly, 33.51 and 38.44% water content at FC were observed at the surface (0-20 cm) and subsurface (120-200$^{+}$cm) soil horizons, respectively. Moreover, on the same soil horizons, 23.84 and 30.10% values of water content at PWP were recorded, respectively, for Alfisols of Bako areas under cultivated land (Wakene and Heluf, 2004). This may be due to the increasing values of clay contents with profile depth. The available water holding capacity (AWHC) of the soil did not show a clear pattern with depth (Table 1). However, the highest AWHC value (11.56%) was observed at the surface (Ap) and the lowest (9.72%) at the subsurface (AB) horizons.

## Chemical Properties of the Soil

### Soil Reaction (pH)

Except for the extreme bottom layer ($Bt_3$ horizon), the pH of the profile increased consistently with depth (Table 2). This increase in pH may be due to increase in exchangeable Ca with depth (Table 2). The increase in concentrations of these cations with depth, in turn, may suggest the existence of downward movement of these constituents within the profile. According to the classification suggested by Brady and Weil (2008), the soil reaction based on the pH ($H_2O$) values recorded in the soil profile studied qualify for moderately acidic in the upper 0-95 cm to slightly acidic reaction for the lower subsurface (95-200$^{+}$ cm) horizons. In a similar rating, the mean pH of the composite surface soil samples was grouped under moderately acidic reaction (Table 2). The pH observed on the surface soil will provide some range of choice for cereal production.

### Organic Matter and Total Nitrogen

The organic matter content of the soil decreased consistently with depth (Table 2). According to the OM content rating criteria established by Berhanu (1980), soils having less than 0.8%, between 0.80 and 2.60%, between 2.60 and 5.20% and greater than 5.20% are rated as very low, low, medium and high, respectively. In accordance with this rating, the surface layer of the soil profile and the composite surface soil samples had high OM while the subsurface horizons from AB to $Bt_2$ had medium OM content. Low OM content was observed at the $Bt_3$ horizon. The OM content of the Ap horizon exceeded that of the $Bt_3$ horizon by 188%. The high OM content in the surface horizon and surface soil samples could be ascribed to presence of sufficient biomass production for decomposition and recent land use change from controlled grazing to cultivation. On the other hand, its regular decrease with depth of the profile is due to decreasing root biomass with depth. This relationship of the soil constituents clearly indicated that the surface soil horizons were the most biologically active part of the soil systems.

In line with OM content of the profile, the contents of the total N also decreased consistently with depth suggesting the strong correlation between the two soil parameters (Table 2). Based on the rating of total N set by Tekalign (1991), total N contents of soils less than 0.05 are rated as very low; between 0.05 and 0.12 as low; between 0.12 and 0.25 as medium and greater than 0.25 as high. Based on this classification, the total N contents of the surface layer of the profile and the mean total N contents of the composite surface soil samples of the study area are normally rated as high while the total N contents of the subsurface horizons are generally rated as medium. The high total N contents in the surface layer indicate that the soils of the study area have potential in N to support proper growth and development of crops.

However, the site must be fertilized with external N inputs for sustainable production as N is dynamic is liable for leaching and volatilization loses.

According to Brady and Weil (2008), the C:N ratio in the OM of arable surface (Ap) horizon commonly ranges from 8:1 to 15:1, the median being near 12:1. Thus the C:N ratio of the surface horizon and surface soil samples may be considered within this range.

## Available Soil Phosphorus

The available P extracted by the Olsen method displayed a decreasing pattern from 26.5 mg $kg^{-1}$ at the surface layer to 21.6 mg $kg^{-1}$ at the fifth layer (Table 2). Available P at the bottom horizon is lower than the surface layer by 23%. Olsen *et al.* (1954) have indicated that extractable P below 5 mg $kg^{-1}$ is considered as low; between 5 to 10 mg $kg^{-1}$ as medium and greater than 10 mg $kg^{-1}$ as high. Thus, the available P contents of all horizons in the profile are rated as high based on the rating of Olsen *et al.* (1954). According to same, the average available P contents of the composite surface soil samples (26.2 mg $kg^{1}$) was also rated as high where response of crops to P fertilization at such P level may not be very high.

The high P level could be due to the high organic matter content or high inherent P content of the parent material. Furthermore, the history of the land indicated that the land use had been used for grazing before some years ago and hence a high accumulation of OM was obtained. The decrease in available P with depth is attributed to the increment of clay content and which were found to increase with depth and clay type which can cause fixation of P. This is in agreement with the findings of Tekalign *et al.* (1988) who reported that topsoil P is usually greater than that in subsoil due to sorption of the added P, greater biological activity and accumulation of organic material on the surface. In Habro highlands of Hararghe area, higher available P values (63.0-56.0 mg $kg^{1}$) were observed on Nitisols in the middle horizons (24-87 cm) of the soil profile (Yohannes, 1999).

## Exchangeable Bases

Exchangeable Ca followed by Mg was the predominant cation in the exchange sites of both the profile and the composite surface soil colloidal materials (Table 2). Exchangeable Ca and Mg together consisted of 50 to 75% of the exchange complex in the surface to the subsurface horizons ($138\text{-}200^{+}$cm) of the profile, respectively. The exchangeable Ca exclusively occupied 31 and 69% of the exchange sites of the Ap and the $Bt_3$ horizons, respectively. According to the rating set by Landon (1991), soils having exchangeable Ca less than 4.0, between 4.0 and 10.0 and greater than 10.0 $cmol_c$ $kg^{-1}$ are considered as low, medium and high, respectively. Thus, the soils of the profile and surface soil samples were rated as high in their exchangeable Ca contents.

Exchangeable Mg decreased with soil depth of the profile except in the depth of 95-138 cm (Table 2). Based on the classification set by Landon (1991), soils containing Exchangeable Mg greater than 4.0, between 0.5 and 4.0 and less than 0.5 $cmol_c$ $kg^{-1}$ are considered as high, medium and low, respectively. Therefore, soils of the surface layer as well as the surface soil samples are high in exchangeable Mg while the subsurface soils are generally rated as medium in their exchangeable Mg contents. Exchangeable K did not show consistent relationship with profile depth (Table 2). However, the highest (1.37 $cmol_c$ $kg^{-1}$) was obtained at the surface horizon. Soils containing exchangeable K less than 0.15, between 0.15 and 0.30, between 0.30 and 0.50, and greater than 0.50 $cmol_c$ $kg^{-1}$ are regarded as deficient, marginal, adequate and rich, respectively, in this specific nutrient (Landon, 1991). Consequently, the soils of the study site were rich in exchangeable K content.

The content of exchangeable Na increased with soil depth from the surface to the subsurface (95-138 cm) layer of the soil profile. The exchangeable Na contents of the profile and composite sample soils were generally very low as compared to the critical level that causes deterioration of soil structure and Na toxicity when the exchangeable Na percentage (ESP) is greater than 15% (Miller and Donahue, 1997).

## Cation Exchange Capacity and Percent Base Saturation

Cation exchange capacity of the soils consistently increased with profile depth (Table 2). The CEC value of the $Bt_3$ horizon increased by 22 and 11% over the Ap and AB horizons, respectively. As per the rating of soil characteristics, by Landon (1991), CEC value greater than 40 $cmol_c$ $kg^{-1}$ is rated as very high; between 25 and 40 $cmol_c$ $kg^{-1}$ as high; between 15 and 25 $cmol_c$ $kg^{-1}$ as medium; between 5 and 15 $cmol_c$ $kg^{-1}$ as low and less than 5 $cmol_c$ $kg^{-1}$ as very low. Therefore, the CEC of the surface and subsurface horizons of the soil profile were rated as high to very high, respectively. Generally, the high to very high values of CEC in this soil profile indicated the presence of high nutrient reserves.

Computed values of CEC in relation to clay showed unsystematic variation with depth of the profile (Table 2). In general, the values of CEC of clay of the soils of the profile ranged between 56.41 $cmol_c$ $kg^{-1}$ clay at the depth of 138-200$^+$ cm to 69.33 cmol$_c$ kg$^{-1}$ clay at the surface layer. This may indicate the variability of the type of clay mineral found in the soil profile.

The percent base saturation (PBS) values of the horizons increased persistently with depth and were greater than 50% throughout the profiles except the 23-65 cm depth (Table 2). Soils having greater than 50% base saturation are considered as high while soils having less than 50% base saturation are considered as low based on the concept indicated by (FAO-WRB, 2006). Accordingly, the soils of the study area had high base saturation in most part of the profile and regarded as fertile soils.

## Classification of the Field Soil

On the basis of profile description (Appendix Table 4) and the results of analysis of soil samples collected from each horizon (Tables 1 and 2), the soil along the profile was characterized by textural differentiation with a lower clay content in the topsoil than in the subsoil. The subsurface (Bt$_1$ to Bt$_3$) horizons had maximum accumulation of clay which was 50 to 106% more than the surface (Ap) horizon, respectively. The CEC value of clay ranged from 69.33 cmol$_c$ kg$^{-1}$ in the surface to 56.41 cmol$_c$ kg$^{-1}$ in the bottom horizons and the percent base saturation of Bt$_1$, Bt$_2$ and Bt$_3$ horizons are 58.5, 65.6 and 78.6, respectively. According to FAO-WRB (2006), soils having marked textural differentiation within the soil profile with accumulation of clay in the subsurface 'argic' horizon qualify for Luvisols. Moreover, it is indicated that soils having argic horizon that has a CEC of 24 cmol$_c$ kg$^{-1}$ clay or more within 200 cm of the soil surface and a base saturation (by 1M NH$_4$OAc) of 50% or more in the major part between 50 and 100 cm from the soil surface satisfy for Luvic soil unit. Therefore the profile qualifies to recognize it as Luvisols under the level of reference group. As there are no other qualifying characteristics, haplic as defined by FAO-WRB (2006) is prefixed to qualify the soil as Haplic Luvisols.

Mesfin (1998) reported that in Ethiopia, Alfisols (Luvisols) occur in the northern highlands in association with Vertic Cambisols on the flat land derived from colluvium materials. The same author also stated that in general, these soils have good potential for agriculture. Physically they are porous hence well drained and have a high water storage capacity, a well developed stable structure and a water-and air-permeable rooting zone. Chemically, the exchange complex remains with a high degree of base saturation.

## Effects of Applied N and P on Total N and Available P of the Soil

Addition of nutrients will result in certain portion of these nutrients being left in the soil after harvesting the crops. The amount remaining depends on the amount added, the yield level, the portion of crop harvested and the soil type. Accordingly, in the present study, application of increasing levels of N fertilizer displayed a linear increase in the total N contents of the soils after harvest (Table 3). However, the total N contents of the sample from the control plot after harvest (0.31%) was reduced as compared to the total N of the soil before planting (0.39%). This might be due to the utilization of N by triticale crop as well as N losses through different mechanisms such as leaching and denitrification. Fertilization of N at the highest rate raised the available P contents of the soil after harvest (Table 3). This may be attributed to the effect of N in improving the solubility and availability of P.

Increasing P fertilizer rates from 10 to 20 and 30 kg ha$^{-1}$ increased total N contents from 0.31 to 0.33 and 0.34%, respectively. Likewise, application of P fertilizer increased the available P contents of the soil after harvest (Table 3). Application of 30 kg P ha$^{-1}$ gave the highest available P content (26.18 mg kg$^{-1}$) that is 15% increment as compared to that of the control plot (22.82 mg kg$^{-1}$). This may be due to the residual effect of applied P fertilizer. Mekonnen (2005) pointed out that the available P and total N in post harvest soil treated with 69 kg N and 20 kg P ha$^{-1}$ were higher compared to pre-sowing soil after harvest.

## Response of Triticale to Applied N and P Fertilizers

Analysis of variance for crop agronomic parameters and yield and yield components demonstrated that application of different rates of N fertilizer significantly ($P \leq 0.01$) influenced all of the tested crop parameters except harvest index which was significant at $P \leq 0.05$ (Table 4). In contrast, the main effect of P fertilizer and interaction with N did not significantly affect all agronomic parameters considered. Despite high total N obtained in the soil, the crop showed response to N fertilizer application. This may indicate that the N found in the soil was not in the inorganic form (the form that plants actually absorb) to boost the growth of plants. According to Brady and Weil (2008), the quantity of N in the readily available $NO_3^-$ and $NH_4^+$ is seldom more than 1-2% of the total soil N. Even if native OM has high concentration of N (low C:N ratio), only a small percentage of it could be considered as potentially available N (Dalias *et al*., 2002).

## Effects of N and P Fertilization on Crop Phenology

Significant variation in number of days to heading was observed due to different rates of N application (Table 4). Addition of N fertilizer at higher dose (69 kg N $ha^{-1}$) hastened the heading significantly as compared to the plots receiving 0, 23 and 46 kg N $ha^{-1}$ while the mean days to heading of 23 and 46 kg N $ha^{-1}$ was statistically at par (Table 5).

In line with the results of this study, Cock and Ellis (1992) indicated that sufficient N results in rapid growth and heading. According to same, too little N resulted in slow growth rate and delayed heading and growth, whereas excessive N kept vegetative growth active and finally resulted in delayed heading and flowering. In contrast to this the application of 23 to 92 kg N $ha^{-1}$ significantly delayed heading of triticale (Getenet 2007). On the other hand, neither the main effects of P fertilizer nor interaction with N fertilizer rates was significantly in influenced the heading of triticale However, application of 30 kg P $ha^{-1}$ reduced days to heading compared with the control (Table 5).

The number of days to 90% physiological maturity displayed significant differences due to N treatments (Table 4). Physiological maturity was delayed at 0 and hastened at 69 kg N $ha^{-1}$, respectively (Tables 5). Application of 69 kg N $ha^{-1}$ decreased days to maturity by 6.33 days over the control. On the other hand, P fertilization at different rates and interaction with N did not affect days to maturity and grain filling significantly (Tables 4). However, higher rates of P application fastened plant maturity (Endalkachew, 2006). Although the main effect of N fertilizer application significantly affected grain filling of the crop, there was no statistical difference in grain filling period between fertilization of 23 and 46 kg N $ha^{-1}$ (Tables 4). Plants receiving the highest N fertilizer rate filled grain by 1.5 days earlier compared to the control treatment.

## Effects of N and P Fertilization on Triticale Growth Parameters

Statistical analysis of data showed highly significant ($P \leq 0.01$) differences in plant height due to the main effect of N fertilizer rates (Table 4). Furthermore, plants supplied with 69 kg N $ha^{-1}$ were significantly taller than those at lower N rates while plants with no N fertilizer were the shortest (Table 6 and Appendix Table 5). Various studies conducted in Ethiopia indicated that plant height of triticale increased as the amount of applied N increased (Minale *et al.,* 2006; Getenet, 2007). However, neither the main effects of P nor its interaction with N fertilizer rates had significant effect on plant height although the minimum plant height (84.7 cm) was obtained from the treatment without P application and the maximum (85.2 cm) from 20 kg P $ha^{-1}$ (Table 6).

The effect of applied N on the number of productive tillers was statistically ($P \leq 0.01$) significant (Table 4). The differences in mean number of tillers obtained due to the increasing rates of applied N were significant between each other. Application of 69 and 46 kg N $ha^{-1}$ increased the number of fertile tillers $m^{-2}$ by 57 and 40%, respectively over the control (Table 6). Graham *et al*. (2007) revealed that tillering was enhanced with increasing N rates. Moreover, fertile tillers of triticale ranging from 396 to 470 $m^{-2}$ with increasing N rate from 0 to 70 kg $ha^{-1}$ on a clay soil in Iran (Ghobadi, 2010). The highest N (150 kg $ha^{-1}$) treatment resulted in increased number of productive tillers (295) $m^{-2}$ in Pakistan (Bakht, 2010).

The effects of P application rates and the interaction between N and rates of applied P on number of productive tillers were not significantly ($P > 0.05$) different (Table 4). However, the number of tillers of triticale produced by P fertilizer applied at the rate of 30 kg P $ha^{-1}$ exceeded that of all P rates while the lowest was obtained without P application (Table 6 and Appendix Table 5). The non-significant difference of number of tillers observed in this experiment for the effect of P was in agreement with the finding documented by Salilew (2007) on triticale.

## Effects of N and P fertilizers on Triticale Yield and Yield Components

### Number of Spikes, Grain per Spike and Spike Length

Analysis of variance indicated that the main effects of applied N fertilizer rates had significant effect ($P \leq 0.01$) on the number of spike $m^{-2}$ (Table 4). As indicated in Table 7, the application of highest N rate (69 kg N $ha^{-1}$) resulted in the highest number of productive spikes (356.3) $m^{-2}$ whereas the lowest number of spikes was obtained from the control. Additionally, spikes of 396 and 496 $m^{-2}$ at 0 and 105 kg N $ha^{-1}$ were observed, respectively (Ghobadi *et al.,* 2010). Similarly, Getnet (2007) recorded 340 and 240 spikes $m^{-2}$ with 69 and 0 kg N $ha^{-1}$ application. Generally, the consecutive increment in the rate of applied N fertilizer resulted in highly significantly differing numbers of productive spikes. This agreed with the finding of several other researchers (Minale *et al*., 2006; Salilew, 2007)

Number of spikes $m^{-2}$ was not significantly ($P > 0.05$) affected by the main and interaction effect of P fertilizer application (Table 4). However, the highest number of spikes (324.9) $m^{-2}$ was obtained with application of 30 kg $ha^{-1}$ P (Table 7). In line with the result obtained from this study, Endalkachew (2006) also reported non-significantly differing number of spikes of wheat ranging

**Table 5.** Main effects of N and P fertilization on triticale phenology

| N or P rates | Days to 50% heading | Days to 90% maturity | Grain filling (days) |
|---|---|---|---|
| N (kg ha$^{-1}$) | | Effects of N fertilizer | |
| 0 | 76.33a | 146.16a | 69.83a |
| 23 | 74.50b | 143.33b | 68.83ab |
| 46 | 73.91b | 141.50c | 67.59ab |
| 69 | 71.50c | 139.83d | 68.33b |
| LSD (0.05) | 1.004 | 1.0732 | 1.5079 |
| SE (±) | 0.897 | 0.793 | 0.512 |
| P (kg ha$^{-1}$) | | Effects of P fertilizer | |
| 0 | 74.41 | 142.25 | 67.84 |
| 10 | 74.00 | 142.91 | 68.91 |
| 20 | 74.16 | 142.66 | 68.50 |
| 30 | 73.66 | 143.00 | 69.40 |
| LSD (0.05) | ns | ns | ns |
| SE (±) | 1.032 | 1.063 | 0.5337 |
| CV (%) | 1.625 | 0.901 | 2.634 |

*Means within a column sharing common letter(s) are not significantly different at $P \leq 0.01$; ns = Non-significant at $P > 0.05$; CV values of the respective parameters are common for both main effects; CV = Coefficient of variation; LSD = Least significant difference; SE = Standard error of mean

**Table 6.** Main effects of N and P fertilization on triticale growth parameters

| N or P rates | Plant height (cm) | Fertile tillers m$^{-2}$ |
|---|---|---|
| N (kg ha$^{-1}$) | Effects of N fertilizer | |
| 0 | 81.6a | 194.3a |
| 23 | 84.4b | 245.0b |
| 46 | 85.7b | 271.7c |
| 69 | 89.2c | 304.6d |
| LSD (0.05) | 1.322 | 13.181 |
| SE (±) | 0.598 | 10.533 |
| P (kg ha$^{-1}$) | Effects of P fertilizer | |
| 0 | 84.7 | 253.4 |
| 10 | 85.4 | 254.6 |
| 20 | 85.6 | 250.5 |
| 30 | 85.2 | 257.0 |
| LSD (0.05) | ns | ns |
| SE (±) | 1.038 | 16.025 |
| CV (%) | 1.861 | 6.226 |

*Means within a column sharing common letter(s) are not significantly different at $P \leq 0.01$; ns = Non-significant at $P > 0.05$; CV values of the respective parameters are common for both main effects; CV = Coefficient of variation; LSD = Least significant difference; SE = Standard error of mean

from 373.1 to 393.2 m$^{-2}$ due to P rates from 0 to 30 kg ha$^{-1}$. Grains per spike and spike length were significantly ($P \leq 0.01$) affected by the application of different rates of N fertilizer (Table 4). For both yield components, the maximum and the minimum records were obtained at the highest and the lowest N rates, respectively. Moreover,

**Table 7**. The main effects of N and P fertilizers on triticale yield components

| N or P rates | Spikes $m^{-2}$ | Spike length (cm) | Grains per spike |
|---|---|---|---|
| N (kg ha$^{-1}$) | | Effects of N fertilizer | |
| 0 | 294.4a | 8.2a | 46.3b |
| 23 | 305.1b | 9.2b | 46.8b |
| 46 | 326.2c | 10.3c | 48.3a |
| 69 | 356.3d | 10.9d | 48.4a |
| LSD (0.05) | 9.073 | 0.360 | 0.949 |
| SE (±) | 6.626 | 0.336 | 0.906 |
| P (kg ha$^{-1}$) | | Effects of P fertilizer | |
| 0 | 315.4 | 9.7 | 47.1 |
| 10 | 319.2 | 9.7 | 47.5 |
| 20 | 322.3 | 9.5 | 48.2 |
| 30 | 324.9 | 9.7 | 47.5 |
| LSD (0.05) | ns | ns | ns |
| SE (±) | 9.676 | 0.225 | 0.933 |
| CV (%) | 3.395 | 4.487 | 2.39 |

*Means within a column sharing common letter(s) are not significantly different at $P \leq 0.01$; ns = Non- significant at $P > 0.05$; CV values of the respective parameters are common for both main effects; CV = Coefficient of variation; LSD = Least significant difference; SE = Standard error of mean

**Table 8**. Effects of N and P fertilization on yield and harvest index of triticale

| N or P rates | Thousand grains weight (g) | Grain yield (kg ha$^{-1}$) | Straw yield (kg ha$^{-1}$) | Total biomass yield (kg ha$^{-1}$) | Harvest index (%) |
|---|---|---|---|---|---|
| N (kg ha$^{-1}$) | | | Effects of N fertilizer | | |
| 0 | 34.6d | 1488.4a | 2445.8d | 3934.2d | 38.7b |
| 23 | 35.5c | 1839.1b | 3100.7c | 4939.8c | 37.4b |
| 46 | 36.1b | 2410.9c | 3788.1b | 6198.9b | 39.1a |
| 69 | 36.9a | 2769.7d | 4212.2a | 6981.8a | 40.0a |
| LSD (0.05) | 0.271 | 64.836 | 359.24 | 376.77 | 0.531 |
| SE (±) | 0.718 | 29.50 | 171.395 | 188.89 | 0.011 |
| P (kg ha$^{-1}$) | | | Effects of P fertilizer | | |
| 0 | 35.6 | 2094.9 | 3248.4 | 5343.3 | 39.5 |
| 10 | 35.7 | 2111.1 | 3370.5 | 5481.6 | 38.8 |
| 20 | 35.9 | 2138.9 | 3348.4 | 5487.2 | 39.0 |
| 30 | 35.9 | 2163.2 | 3579.6 | 5742.7 | 37.5 |
| LSD (0.05) | ns | ns | ns | ns | ns |
| SE (±) | 0.7791 | 152.223 | 264.31 | 397.885 | 0.011 |
| CV (%) | 0.910 | 3.655 | 12.722 | 8.195 | 7.751 |

*Means within a column sharing common letter(s) are not significantly different at $P \leq 0.01$; ns = Non- significant at $P > 0.05$; CV values of the respective parameters are common for both main effects; CV = Coefficient of variation; LSD = Least significant difference; SE = Standard error of mean

grains per spike of triticale increased from 47.6 to 55.9 as N rate increased from 0 to 100 kg ha$^{-1}$ (Biberdzic *et al.,* 2010)

Application of P fertilizer on the other hand, had no significant effect on spike length and grains per spike where it was also verified from the weak coefficient of correlation observed. Similarly, the interaction of the fertilizers N and P had no significant effect on either of the yield components that is spike length or number of grains per spike (Table 4).

## Thousand Grains Weight

The thousand grains weight was significantly affected by the main effect of N fertilizer application. On the other hand, the main effect of P rates and the interaction effects between N and P rates were not significantly ($P > 0.05$) different (Table 4). The lowest (34.6 g) and the highest (36.9 g) thousand grains weight were obtained with no N and 69 kg N $ha^{-1}$ application, respectively (Table 8). Generally, the weight of thousand grains of triticale increased linearly as the rates of applied N increased from the lowest to highest N rate. Furthermore, the progressively increasing weight of thousand grains observed in the present study was in agreement with the maximum weight of 1000 grains due to the application of the highest rate of N fertilizer (Biberdzic *et al.,* 2010).

## Grain Yield

The triticale grain yield was responded significantly ($P \leq 0.01$) to the application of N fertilizer rates (Table 4). The highest mean grain yield (2769.7 kg $ha^{-1}$) was obtained from the maximum N rate (69 kg N $ha^{-1}$) with an increment of 15% and 86% yield advantage over the next higher N rate (46 kg N $ha^{-1}$) and the control plot, respectively (Table 8 and Appendix Table 7). Generally, grain yield exhibited a linear increase with increasing rates of N fertilizer. Several other studies also indicated positive and linear responses of grain yield to increasing levels of N fertilizer (Ghobadi *et al.,* 2010; Gulmezoglu and Aytac, 2010). Similarly application of 80 and 120 kg N $ha^{-1}$ showed yield advantage of 29 and 38% over the control (Biberdzic *et al.,* 2010). The yield of wheat and triticale cultivars also increased in response to incremental additions of fertilizer N (Sayre *et al.,* 1996). The increase in grain yield might be due to effect of N which expands the plant to produce taller plants, longer spikes, more grain per spike and therefore more grain yield.

On the contrary, grain yield was not significantly affected by the main and interaction effect P fertilization with N rates (Table 4). However, grain yield of triticale showed an increasing trend with increasing the rates of P. The maximum grain yield (2163.2 kg $ha^{-1}$) was obtained from application of 30 kg P $ha^{-1}$ followed by 2138.9 kg $ha^{-1}$ which received 20 kg P $ha^{-1}$ (Table 8).

## Straw and Total Biomass Yields

Analysis of variance exhibited significant differences in straw yields due to the main effect of N fertilizer. However, main effect of P and the interaction with N fertilizer did not significantly affect straw yield (Table 4). As indicated in Table 8, N applied at the rate of 69 kg N $ha^{-1}$ revealed the highest mean straw yield (4212.2 kg $ha^{-1}$) followed by 46 kg N $ha^{-1}$ (3788.1 kg $ha^{-1}$). The increments in straw yield obtained with 46 and 69 kg N $ha^{-1}$ rates over the control were 55 and 72%, respectively. This increase in straw yield to applied N might have resulted due to increased vegetative growth as was reflected in case of plant height and biomass yield. In line with the current finding, Ghobadi *et al.* (2010) suggested N rates had significant influence on straw yield of triticale.

In line with the grain and straw yields, total biomass yield was also significantly ($P \leq 0.01$) affected by application of N fertilizer (Table 4). Accordingly, the highest total biomass yield (6981.8 kg $ha^{-1}$) was obtained with the highest N rate (69 kg $ha^{-1}$) followed by 46 kg N $ha^{-1}$ with an increment of 3047.6 kg $ha^{-1}$ or 77% total biomass yield advantage over the control. The next higher mean biomass yield was obtained with 58% yield advantage over the control (Table 8).

As indicated in Table 8, application of P fertilizer did not show significant effect on total biomass yield production of triticale. However, maximum total biomass yield was observed in plots treated with highest P and minimum total biomass yield was resulted from the control. Similarly, the interaction effects of N with P fertilizer were found non-significant for total biomass (Table 4).

## Harvest Index

Application of N marked significant ($P \leq 0.05$) effect on triticale harvest index (HI) while application of P and interaction with N rates had no significant effect on HI (Table 4). The mean HI values varied from 38.7 to 40.0% where HI with the N application at the rates of 46 and 69 on one hand were significantly different from the 0 and 23 kg $ha^{-1}$ (Table 9). The mean harvest indices of the control and 23 kg N rates were comparable and low. Since harvest index is the ratio of grain yield to total above ground biomass, the highest harvest indices recorded for 46 and 69 N rates were due to higher grain yield (Table 8).

## SUMMARY AND CONCLUSIONS

The field description of soil morphology and the results of analysis of the samples taken from the horizons of the profile revealed that the experimental field soil qualifies for Haplic Luvisols according to the FAO-WRB (2006) classification. Application of increasing levels of N fertilizer displayed a linear increase in the total N and available P contents of the soils after harvest. Likewise, increasing P fertilizer rates from 10 to 20 and 30 kg ha$^{-1}$ increased both total N and available P contents of the soil after harvest.

Application of N fertilizer rates significantly ($P \leq 0.01$) influenced all the crop parameters tested except harvest index which was significant at $P \leq 0.05$. In contrast, the main effect of P fertilizer and its interaction with N was found to be non-significant for all crop parameters considered. The highest mean grain yield (2769.7 kg ha$^{-1}$) was obtained from the maximum N rate (69 kg N ha$^{-1}$) with an increment of 15% and 86% yield advantage over the next higher N rate (46 kg N ha$^{-1}$) and the control plot, respectively.

Thus, farmers at the Wabela Peasant Association need tentatively to apply 69 kg N ha$^{-1}$ without P in order to improve the grain yield and yield components of triticale grown on Haplic Luvisols under rain fed conditions.

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