Competitive Adsorption of Chloroform and Bromoform Using Commercial Bituminous and Coconut Based Granular Activated Carbons

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Abstract: A study was made to compare efficiency and capacity of two types of granular activated carbon (GAC), Calgon F200 and Norit GCN1240, for removal of Trihalomethanes (THMs) in water and to examine the competition of one adsorbate in the presence of another. Coconut based Norit (GCN1240) and bituminous based Calgon F200 GACs were selected for the study. Multi-component adsorption isotherm models were established for both GACs using same model water containing chloroform (2.54 mg L^{-1}) and bromoform (1 mg L^{-1}). After sample bottles were agitated at the speed of 25 rpm in a mechanical shaker for 15 days, measurements were taken using gas chromatography. The results obtained were checked with Freundlich adsorption isotherm model. This model expresses well adsorption of one THM species in the presence of another with $R^2 > 0.95$. Based on the model, adsorption capacity of Calgon F200 and Norit GCN1240 were found higher for bromoform than chloroform. Calgon F200 showed a higher adsorption capacity compared to Norit GCN1240 for a lower equilibrium concentration (< 3 μg L^{-1}). However, for equilibrium concentrations in the range of 3 - 200 μg L^{-1}, both Calgon F200 and Norit GCN1240 showed similar capacity for competitive adsorption of THMs.

Keywords: Granular Activated Carbon; Adsorption; Bromoform; Chloroform; Trihalomethane

1. Introduction

In 1974, researchers in the Netherlands and the United States demonstrated that trihalomethanes (THMs) were being formed from the interaction of chlorine/bromide with various organic substances in water (Al-Naseri, and Abbas, 2009; USEPA, 1996). These chlorinated organic compounds potentially cause cancer, miscarriages and are mutagenic. Studies also linked these THMs to heart, lung, kidney, liver, and central nervous system damage (Fearing *et al*., 2004; Edward, 2005). Hence, removal of THMs is necessary and it is achieved mostly by applying GAC filtration (Qasim *et al*., 2000; Fearing *et al*., 2004; Edward, 2005). For example, the United States Environmental Protection Agency (USEPA) allows an upper limit of 40 μg L^{-1} THMs in water (USEPA, 1996).

A study was made for adsorption of the most common species of THMs, chloroform and bromoform. Two types of GAC from different manufacturers and base materials, coconut based Norit (GCN1240) and bituminous based Calgon F200, were selected. The selected GACs were recommended by their manufacturers for best adsorption of THMs regardless of the difference in origin of base material. Hence, the study was done to determine the adsorption capacity of the two GACs to determine and compare removal efficiencies. Beside, the competitive adsorption of one THM species in the presence of the other was investigated.

Design of full scale GAC adsorption process involved time consuming and expensive pilot plant studies. Batch adsorption isotherm tests were conducted to predict the breakthrough of THMs removal from water by different types of GAC and to know the result in a short time (15 days) instead of months time pilot study (Crittenden *et al*., 1986; McGuire, 1991). Previous researches have been done for the adsorption capacity determination of GAC for single THM species but not the competitive adsorption of one species in the presence of the other. Thus, this study was initiated with the objectives to (1) establish Freundlich competitive adsorption isotherms for chloroform and bromoform, (2) determine the capacity of each of the two commercially available GACs (Calgon F200 and Norit GCN1240) for competitive adsorption of one THM species in the presence of another, and (3) compare competitive adsorption of THM species on Bituminous and Coconut GACs.

2. Material and Methods

2.1. Experimental Setup and Operational Procedure

2.1.1. Model Water Preparation

For batch adsorption isotherm, model water was prepared batchwise in 10.52 l brown glass bottle from de-ionized water. One mmole of $NaHCO_3$ and the target contaminant chloroform (2.54 mg L^{-1}) and bromoform (1 mg L^{-1}) were added to the bottles. Then, the glass bottle was covered by parafilm to avoid air formation at the top of the bottle and mechanically stirred for one day to achieve complete mixing.

2.1.2. Powdered Granular Activated Carbon (PGAC) Preparation

The grain size of GAC used in batch experiments was 200 x 400 mesh (74 μm x 37 μm). This size was obtained by crushing 12 x 40 mesh (1680 μm x 420 μm) GAC supplied by Calgon (Chemivron carbon, Pittsburg, USA) and Norit (Norit, Amersfoort, The Netherlands). After GAC grains were crushed, the appropriate size for batch was achieved by sieving on 200 x 400 mesh (passing 200 mesh sieve and retained on 400 mesh sieve). The GAC grains that did not pass the upper sieve were returned and crushed again until it passed the sieve. GAC grains of appropriate size were stored in a beaker covered with aluminum foil. Fines produced during crushing and sieving were removed by washing. Then, GAC of appropriate size was stored in a clean beaker filled with

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de-ionized water. The GAC was stirred with a glass rod and allowed to settle. After the GAC particles settled in one to three minutes, the supernatant was poured off and new de-ionized water was added. The stirring and settling was continued using fresh de-ionized water until clear supernatant was achieved. The wet GAC was placed in an oven at 105°C for two days. The dried GAC was stored in a dark amber bottle with teflon lined caps in a decicator (vacuum sealed glass).

2.1.3. Batch Experimental Setup

Batch experiment was conducted to investigate GAC removal capacity of THMs. Model water was prepared using bromoform and chloroform. Powdered granular activated carbon (PGAC 200 x 400 mesh size) was used in batch adsorption experiments to reduce the time necessary to reach equilibrium and to ensure a representative carbon samples.

Glass bottles of 314-318 ml volume were stored in 0.5 M hydrochloric acid (HCl) for two days and cleaned with de-ionized water. Different value of PGAC dosages in the range from 0.02 to 8 g were introduced to 16 batch reactor bottles (seven reactor bottles for Calgon F200 GAC, seven for Norit GCN1240 and two blanks). These bottles (314-318 ml) were subsequently filled with model water followed by pH adjustment of 7.0 ± 0.2 by adding 1.0 and 0.1 M HCl using METROHM-691 pH meter. Once the pH was adjusted, the bottles were covered with double layer parafilm to make air free surface before closing the cap. Then, the bottles were placed on the mechanical shaker and shaken at speed of 25 rpm for 15 days. This contact time was ample to achieve equilibrium in the system for all the THM components studied. After 15 days of adsorption, samples were taken and measured.

2.2. Analytical Methods

2.2.1. Gas Chromatography

Gas chromatography (GC) method use headspace for the determination of volatile halogenated hydrocarbons in the samples. Chloroform was detected by an electron capture detector (ECD). Identification was based on retention time while quantification is based on the intensity of the ECD signal using a five-point calibration.

During sample preparation 5 ml of sample using pipette was added into a 20 mL headspace vial and the vial was closed with a crimp cap with a silicon septum. The sample was heated in a closed headspace vial in order to obtain equilibrium between the concentration of the volatile halogenated hydrocarbons in the headspace above the sample and the concentration in the sample. By purging the headspace with Helium, the volatile hydrocarbons in the headspace were transferred to the GC where they were separated. The components were detected by an ECD and calibration curve and control standards were observed using software (Turbochrom). Identification was based on retention time (5.26 minutes and 11.16 minutes for chloroform and bromoform respectively) while quantification was based on the intensity of the ECD-signal using a five-point calibration. These retention times slightly vary due to aging of the column and were corrected. The quantification of the components was done automatically by the software using linear regression of the second order. Finally results for chloroform < 0.5 µg L^{-1} was reported as < 0.5 µg L^{-1}. When the total THM result was < 2 µg L^{-1}, the sum of the THMs was reported as < 2 µg L^{-1}. But, when the result of one of the components was > 50 µg L^{-1}, the samples were diluted and re-analyzed.

2.3. Data Analysis

Among Freundlich and Langmuir adsorption isotherms, the Langmuir adsorption isotherm is based on the theoretical principle of ideal localized monolayer model where only a single adsorption layer exists. Whereas, the Freundlich adsorption isotherm equations is commonly used for adsorption capacity calculations and this equation is accepted as a standard and is strictly an empirical approach used to describe data for adsorbents such as activated carbon (Roy, 1995; Qasim *et al.*, 2000; Crittenden *et al.*, 2005). Liquid phase isotherms are generally interpreted using the empirical Freundlich equation, which relates the amount of impurity in the solution phase to that in the adsorbed phase. The results were interpreted using Freundlich adsorption isotherm equation. The Freundlich Adsorption Isotherm is expressed as:

$$q_e = KC_e^{\frac{1}{n}}$$

where q_e (mg g^{-1}) represents the amount of THM adsorbed (mg) per unit mass of GAC (g), Ce (mg L^{-1}) is the concentration of residual in contaminated water after the GAC and the contaminated water reach adsorptive equilibrium. K [(mg g^{-1})(L mg^{-1})$^{1/n}$] is Freundlich adsorption capacity parameter and 1/n (unit less) is Freundlich adsorption intensity parameter for each sample tested (Qasim *et al.*, 2000; Crittenden *et al.*, 2005).

For fixed values of Ce and 1/n, the larger the K value the higher is the adsorptive capacity (qe). For fixed values of K and Ce, on the other hand, the smaller the value of 1/n the lesser would be the concentration dependence of adsorption (Ce). Conversely, if the value of 1/n is large, the adsorption bond is weak and the value of qe changes distinctly with small changes in Ce.

3. Results and Discussion

3.1. Batch Isotherm Study

Batch isotherm experiments with PGAC media were carried out with model water containing chloroform and bromoform to examine the effectiveness and adsorption capacity of two GACs (Calgon F200 and Norit GCN1240) produced by two suppliers (Calgon and Norit) for THM removal. In addition, multi-component adsorption isotherms were established to examine the competition of one adsorbate in the presence of another and to compare capacity of bituminous and coconut based GACs.

3.1.1. Competitive Adsorption of Chloroform in the presence of Bromoform

Multi-component adsorption isotherms were established for the two GACs with the same model water containing 2.53 mg chloroform/L and 1.0 mg bromoform/L. Data obtained for chloroform and bromoform fitted well the Freundlich isotherm model and the adsorption is favorable (1/n < 1). The determined Freundlich adsorption isotherm coefficients namely capacity coefficient (K) and strength (1/n) of multi-component isotherm for chloroform in the presence of bromoform is shown in (Table 1). The GACs showed very similar adsorption capacities for chloroform equilibrium concentrations in the ranges from 50 μg L^{-1} to 500 μg L^{-1}. However, for lower equilibrium concentration below 50 μg L^{-1} Calgon F200 showed a higher adsorption capacity in comparison to Norit GCN1240. For higher chloroform equilibrium concentrations (>500 μg L^{-1}), Norit GCN1240 showed a higher adsorption capacity in comparison to Calgon F200 (Figure 1). Conversely, the value of 1/n is large for Norit GCN1240 in comparison to Calgon F200. This implies that Norit GCN1240 has weak adsorption bond toward chloroform and the adsorption capacity (qe) changes distinctly with small changes in equilibrium concentration (Ce) in comparison to Calgon F200.

Table 1. Freundlich isotherm coefficients for competitive adsorption of chloroform and bromoform on Calgon F200 and Norit GCN1240 GAC.

	THM species	Competing species	K $[(mg\ g^{-1})(L\ mg^{-1})^{1/n}]$	1/n
Calgon F200	Bromoform (Co = 1 mg L^{-1})	Chloroform (Co = 2.53 mg L^{-1})	90.87	0.71
Norit GCN1240	Bromoform (Co = 1 mg L^{-1})	Chloroform (Co = 2.53 mg L^{-1})	138.56	0.91
Calgon F200	Chloroform (Co = 2.53 mg L^{-1})	Bromoform (Co = 1 mg L^{-1})	16.72	0.62
Norit GCN1240	Chloroform (Co = 2.53 mg L^{-1})	Bromoform (Co = 1 mg L^{-1})	18.78	0.75

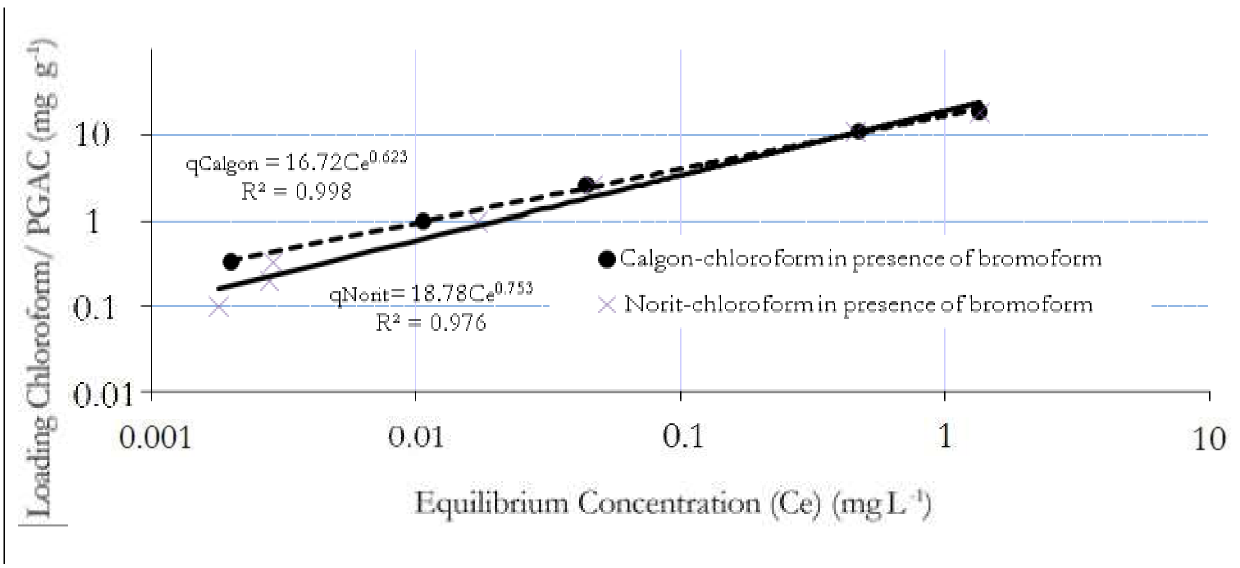

Figure 1. Competitive adsorption isotherm of chloroform in the presence of bromoform. *Calgon F200 and Norit GCN1240, PGAC 200 x 400 mesh; model water: deionized water with initial concentration Co = 2.35 mg L^{-1} of chloroform, and Co = 1.00 mg L^{-1} of bromoform, pH 7.0 ± 0.2, T = 20 ^{O}C.*

3.1.2. Competitive Adsorption of Bromoform in the presence of Chloroform

On the other hand competitive batch adsorption isotherms for bromoform in the presence of chloroform were established for Calgon F200 and Norit GCN1240. The GACs showed very similar adsorption capacities for chloroform equilibrium concentrations more than 2 μg L^{-1}. However, for lower equilibrium concentration below 2 μg L^{-1}, Calgon F200 showed a higher adsorption capacity in comparison to Norit GCN1240. For higher chloroform equilibrium concentrations more than 100 μg L^{-1}, as per the trend line, Norit GCN1240 showed a higher adsorption capacity in comparison to Calgon F200 (Figure 2). Conversely, the value of 1/n is large for Norit GCN1240 in comparison to Calgon F200. This implies that Norit GCN1240 has weak adsorption bond toward chloroform and the adsorption capacity (qe) changes distinctly with small changes in equilibrium concentration (Ce) in comparison to Calgon F200.

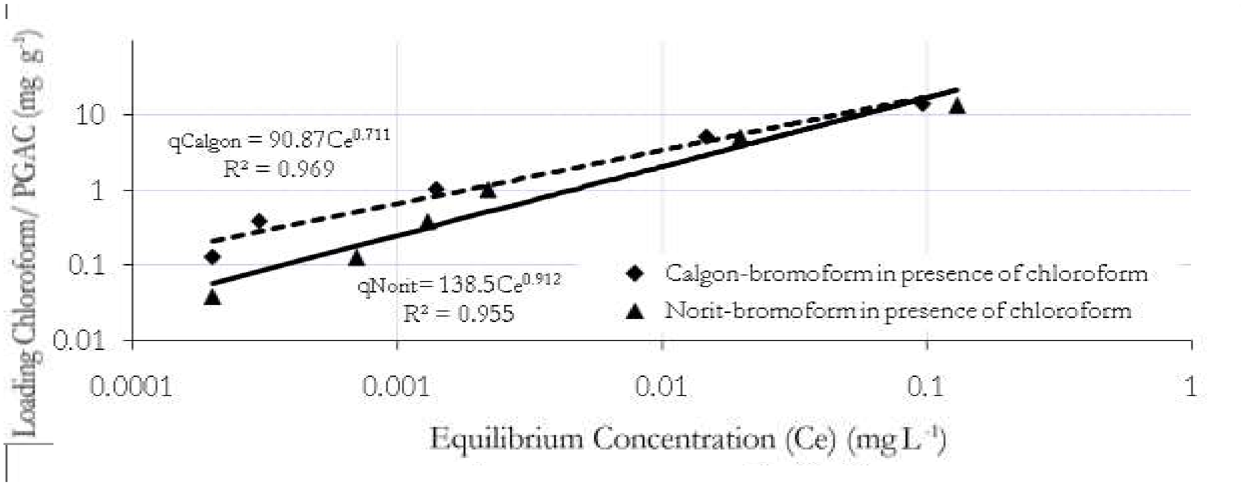

Figure 2. Competitive adsorption isotherm of bromoform in the presence of chloroform. *Calgon F200 and Norit GCN1240, PGAC 200 x 400 mesh; model water: deionized water with initial concentration* C_0 *= 2.35 mg* L^{-1} *of chloroform, and* C_0 *=* *1.00 mg* L^{-1} *of bromoform, pH 7.0 ± 0.2, T = 20* ^{O}C.

3.1.3. Adsorption Comparison of Calgon F200 and Norit GCN1240

In general, the result showed that Calgon F200 has higher capacity for bromoform and chloroform at lower equilibrium concentration (Figure 3). At a higher equilibrium concentration both GACs show more or less same adsorption capacity though the trend line shows slight increase of adsorption capacity for Norit GCN1240. Results compared for chloroform and bromoform adsorption on the two GACs showed that both had higher affinity for bromoform than chloroform as shown in Figure 3 and Table 1. The value of 1/n for bromoform is higher than for chloroform for both Calgon and Norit GACs. This indicates that bromoform has a higher sensitivity towards the equilibrium concentration than chloroform. In general, Norit GCN1240 showed higher 1/n for both competitive adsorption of bromoform and chloroform implying Norit GCN1240's adsorption capacity (amount of solute adsorbed per unit mass of adsorbent) changes more distinctly with small changes in equilibrium concentration than adsorption capacity (q_e) of Calgon F200 (Figure 3).

Even though Norit GCN1240 has high surface area and Iodine number (Table 2), the adsorption capacity of the two GACs showed similar results. This could be attributed to the presence of a narrow porosity which usually is desirable for adsorbent material intended for the removal of organic mater from solution. Micropores provide high surface area to the GAC. Organic matters are adsorbed preferentially in smaller pores where interaction energies are enhanced due to overlapping adsorption potentials of the surrounding pore walls. However, adsorption of organic compounds from solution is significantly reduced when the pore width is less than 1.5 – 2.0 times the diameter of the adsorbate molecule (Li *et al*., 1997; Liu *et al.,* 2007). Chloroform has a hydraulic radius of 51nm (Peesan *et al.,* 2006). This high hydraulic radius might also reduce the adsorption of chloroform in smaller micropores (Liu *et al.,* 2007).

Table 2. Specifications and general characteristics of the granular activated carbons (GACs) used (EOCCC, 2003; NAC, 2004).

Supplier	Unit	Norit	Calgon
GAC name	-	Norit GCN1240	Calgon F200
Iodine number	-	1050	850
Total surface area (B.E.T.)	$m^2 g^{-1}$	1150	850
Apparent density	kg m^{-3}	510	-
Ball-pan hardness	-	99	95
Effective size D10	Mm	0.6-0.7	0.6-0.8
Uniformity coefficient	-	1.9	1.7

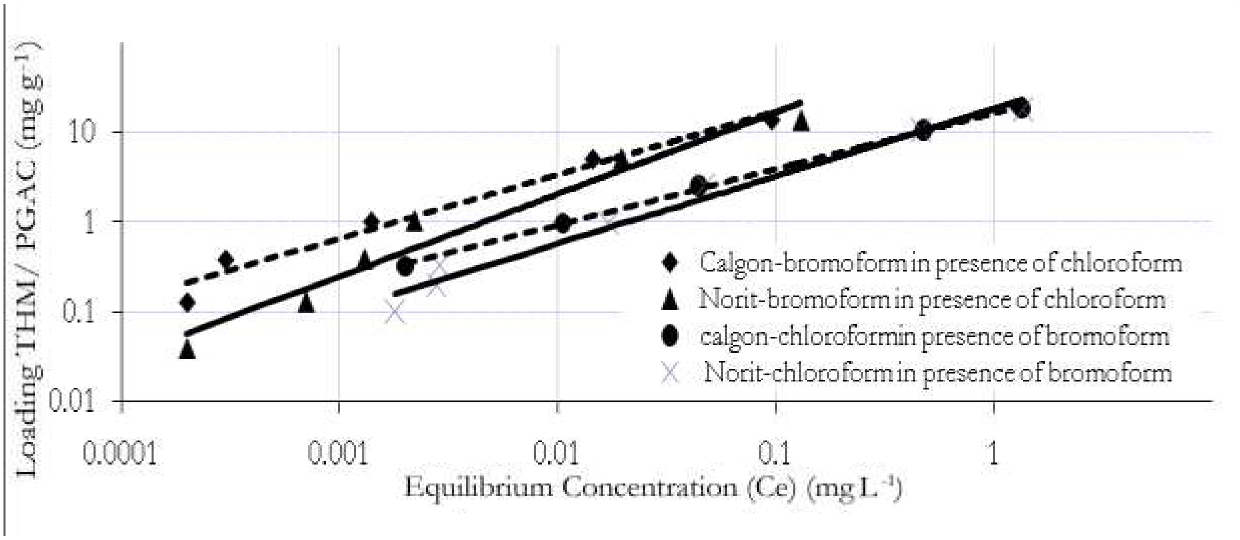

Figure 3. Freundlich adsorption isotherm for bromoform and chloroform adsorption on. Calgone F200 and Norit GCN1240, PGAC 200 x 400 mesh; model water: deionized water with initial concentration C_o = 2.35 mg L^{-1} chloroform, and C_o = 1.00 mg L^{-1} bromoform, pH of 7.0 ± 0.2, T = 20 ^OC.

4. Conclusions

Results from batch adsorption experiment conducted with model water containing bromoform and chloroform using Calgon F200 and Norit GCN1240 GACs fitted well the Freundlich adsorption isotherm. Batch adsorption isotherm model for both Calgon F200 and Norit GCN1240 demonstrated that THMs can be effectively adsorbed and showed much higher capacity for bromoform in comparison to chloroform. Besides, competitive batch adsorption isotherms established for bromoform and chloroform with Calgon F200 and Norit GCN1240 showed very similar adsorption capacities for equilibrium concentrations in the range from 3 μg L^{-1} to 200 μg L^{-1}. However, for lower concentration below 3 μg L^{-1} Calgon F200 showed a higher adsorption capacity in comparison to Norit GCN1240.

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Characterization and Classification of Soils along the Toposequence of Kindo Koye Watershed in Southern Ethiopia

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Abstract: In developing countries, where research funds are limited, the availability of pedogenic information and proper classification of soils will be of great importance. The soils of Kindo Koye watershed were fully characterized along east and west facing toposequences that formed a catena and classified according to the Soil Taxonomy and the WRB Legend to assess the impact of topography on soil development and characteristics. The morphological and physiochemical properties of seven pedons located at the upper, middle and lower slopes of the two toposequences and at the depression were studied. The study revealed the existence of three different soil orders along the toposequences in an area that was previously mapped as Eutric Nitosols. The pedons on the upper and middle slopes of both east and west-facing toposequences and the pedon on the east-facing lower slope were categorized under Ultisols, whereas the pedons on the foot slope west-facing and the depression were categorized under Inceptisols and Entisols, respectively. The Ultisols, Inceptisols and Entisols were further categorized as Acrisols, Cambisols and Fluvisols major groups according to the WRB Legend, respectively. This detail survey and classification of soils shows that topography has a great influence on soil development and characteristics.

Keywords: Catena; Toposequence; Pedon; Soil Taxonomy; WRB Legend

1. Introduction

In developing countries, where research funds are limited, the availability of pedogenic information and proper classification of soils will be of great importance in adopting well tested management technologies and landscape positions without going through the whole process of time consuming and expensive technology selection trials as this will provide the basic information for sustainable agricultural planning (Fikre, 2003). There has not been a comprehensive compilation on soils of Ethiopia, though the felt need for a process-oriented instruction text and as a suitable reference has long been recognized. Even the limited findings are not easily accessible to those who might wish to utilize them (Mesfin, 1998). Consequently, sustainable soil management practices that are based on the understanding of soil systems are not available for most parts of the country (Fikre, 2003).

Landscapes position influences runoff, drainage, soil temperature, soil erosion, soil depth and hence soil formation. Different soil properties encountered along landscapes will affect the patterns of plant production, litter production and decomposition, which will definitely have effects on carbon (C) and nitrogen (N) contents of the soil. Soil properties such as clay content and its distribution with depth, sand content and pH have been shown to be highly correlated with landscape position (Wang *et al.*, 2000) while organic matter has been shown to vary with slope position (Miller *et al.*, 1998).

Soils on steep upper slopes range from moderately deep to shallow. They are well drained with the gravelly and channery silt loam and sandy loam textures commonly associated with rock outcrops. These soils generally have severe erosion potential from exposed or bare soil areas and a greater risk of slope failure. Soils in mid-slope and toe or lower slope positions are usually deep, well-drained, gravelly silt loams, whereas those below prominent sandstone cliffs are usually sandy loams (www.fs.fed.us/r8/boone/resources/soil/index.shtml 03/08/2009). In the lowest landscape positions, water may saturate the regolith to such a degree that drainage and aeration are restricted. Here, the weathering of some minerals and the decomposition of organic matter are retarded, while the loss of iron and manganese is accelerated. In such low-lying topography, special profile features characteristic of wetland soils may develop (Brady and Weil, 2002).

The Ethiopian Mapping Authority (EMA, 1988) characterized the soils of Wolayita areas as Eutric Nitosols. But the Authority used a very small-scale survey that does not specifically tell about the areas considered in this study. Thus, the present study was initiated to fully characterize and classify the soils of the catena following the Soil Taxonomy (Soil Survey Staff, 1999) and the WRB Legend (FAO/WRB, 2006) systems to assess the impact of topography on soil development and characteristics.

2. Materials and Methods

2.1. Description of the Site

The study was conducted at the Kindo Koye watershed, Damot Woyde Woreda, Wolayita Zone, Southern Nations, Nationalities and Peoples' Regional State (SNNPRS). The watershed is located at the coordinates between 6° 52.82' and 6° 53.41' N and 37° 52.42' and 37° 52.63' E with altitude ranging from 1970 to 2061 meters above sea level (masl). The region has a humid climate with an average annual temperature of 20 °C. The monthly mean temperatures range from 17.2 °C in July to 21.9 °C in February. The average annual precipitation is about 1333 mm with monthly minimum and maximum recorded values of 29 mm and 218 mm in the months of January and July, respectively (FAO, 1984). Eighty three percent of the rainfall falls between April and October every year. The major crops and grasses along the selected toposequence

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include maize (*Zea mays*), barley (*Hordem vulgare*), sweet potato (*Ipomoea batatas*), sugarcane (*Saccarum officinarum*), and *teff* (*Eragrotis teff*) and grasses such as *Digitaria diagonalis*. Besides these, plantations dominated by eucalyptus trees (*Eucalyptus camaldulensis*) were present. The soils of the study area are developed on basaltic parent material. According to the WRB Soil Classification System, Eutric Nitosols are the dominant soil units (EMA, 1988).

2.2. Soil Profile Site Selection, Description and Sampling

A catena was selected along east-west facing slopes (toposequences) encompassing landform components spanning from ridge top to valley bottom. The slopes along the toposequences ranged from 0.5 to 25%. The toposequences were divided into three slope categories namely upper slope, middle slope and foot slope, and depression at the center. A total of six pedons with 2 m length, 2 m width and 2 m depth were excavated one each on upper slope west-facing (UWF), middle slope west-facing (MWF), foot slope west-facing (FWF), foot slope east-facing (FEF), middle slope east-facing (MEF) and upper slope east-facing (UEF) and the seventh with 3 m x 3 m and 3 m dimension at the depression (DEP) (Table 1). The soil profiles of all the sampling slopes and aspects were described *in situ* following the guidelines for soil profile description (FAO, 1990) and samples were collected from all identified horizons. Freshly excavated sites were used for sampling and profile description. Core sampler was used to collect undisturbed soil samples from each horizon to determine bulk density. The total area of the study site was 65 ha. The east-facing toposequence is 31 ha and the west-facing one is 34 ha.

Table 1. Description of soil profile site characteristics.

Pedon	Slope (%)	Altitude (masl)	Surrounding landform	Physiographic position	Parent material
UEF	13	2010	Gentle slope	Upper slope	Basaltic
MEF	20	1997	Steep slope	Middle slope	Basaltic
FEF	25	1984	Steep slope	Foot slope	Colluvium/Basaltic
FWF	12	1976	Steep slope	Foot slope	Colluvium/Basaltic
MWF	18	2002	Steep slope	Middle slope	Basaltic
UWF	10	2029	Gentle slope	Upper slope	Basaltic
DEP	0.5	1970	Gentle/flat	Depression	Alluvium/colluvium

UWF = Upper slope west-facing; MWF = Middle slope west-facing; FWF = Foot slope west-facing; DEP = Depression; UEF = Upper slope east-facing; MEF = Middle slope east-facing; FEF = Foot slope east-facing

2.3. Soil Analysis

The soil samples collected from every identified horizon were air-dried and ground to pass through 2 mm sieve. For the determinations of total N and organic carbon (OC), a 0.5 mm sieve was used. Analysis of the physico-chemical properties of the soil samples were carried out following standard laboratory procedures.

Bulk density was determined using the core-sampling method (BSI, 1975). Particle size distribution was analyzed by the hydrometer method (Sahlemedhin and Taye, 2000) using hydrogen peroxide (H_2O_2) to oxidize organic matter and sodium hexameta phosphate ($NaPO_3$) as a dispersing agent. Soil pH was determined in H_2O and 0.1M KCl using 1:2.5 soils to solution ratio using a combined glass electrode pH meter (Chopra and Kanwar, 1976) and change in pH was determined by subtracting soil pH (KCl) from soil pH (H_2O). Cation exchange capacity and exchangeable bases were determined using the 1M-ammonium acetate (pH 7) method followed by repeated washing with ethanol (96%) to remove the excess ammonium ions in the soil solution according to the percolation tube procedure (Van Reeuwijk, 1993) and the base saturation (BS) and exchangeable sodium percentages (ESP) were computed.

Total N was analyzed by the Kjeldahal digestion and distillation procedure (Bremner and Mulvaney, 1982), whereas OC was determined following the wet combustion method of Walkley and Black as outlined by Van Ranst *et al.* (1999). Available phosphorus (P) content of the soils was analyzed using the Olsen method as outlined by Van Reeuwijk (1993). Available micronutrients (Fe, Mn, Zn, and Cu) contents of the soils were extracted by the diethylene triamine pentaacetic acid (DTPA) extraction method (Tan, 1996) all were quantified using atomic absorption spectropotometer .

Finally, analysis of simple correlation coefficient among the different soil physical and chemical properties was carried out using SAS (1997) software to reveal the magnitude and direction of relationships between each other.

3. Results and Discussion

3.1. Soil Morphological Features

Distinct horizons/layers and argillic B-horizons were observed in the pedons, except for the FWF and depression area. Three of the pedons, MEF, FEF and UWF, had Ap and Bt; the UEF had Ap, BA and Bt; the MWF had Ap, AB and Bt; and the FWF had Ap, AB and B, whereas the pedon at the depression had A, AC and C horizon sequences (Table 2).

The depths of the A-horizons decreased with increasing slope (Table 2). Accordingly, the DEP (0.5% slope) and MEF (20% slope) had the deepest and shallowest A-horizons, respectively. The soils at the shoulders tend to be shallower due to erosion, whereas the soils on the foot slope and toe-slope areas tend to be thicker as a result of deposition. Erosion causes stripping of the soil thus preventing the material to stay in place to develop into a soil. The greatest erodibility was associated with the upper slope positions where soils tended to be shallow, coarse in texture and low in organic matter (OM), while lower erodibility was observed at the lower slope positions with deep, organic-rich and leached soils (Lawrence, 1992). Irvin (1996) who related landform elements to soil properties stated that generally, an increase in slope is associated with a reduction in: leaching, OM content, clay translocation, mineral weathering, horizon differentiation, and solum thickness.

Surface soil color (moist) ranged from very dusky red (2.5YR 2/2) to very dark brown (7.5YR 2.5/2) except in the pedon of the depression, whereas the color (moist) of the subsurface horizons varied from dark reddish brown (2.5YR 2.5/3) to very dark brown (7.5YR 2.5/3) (Table 2). The moist soil colors of the horizons in the pedon at the depression, however, varied from reddish brown (5YR 4/4) to very dark brown (7.5YR 2.5/3).

The results showed that soil color is highly influenced by soil OM, where the darkness in the A-horizon decreased with depth. Dark colored surface horizons (values ≤ 3) are often enriched with OM, offering many benefits to the soil (soils.missouri.edu/tutorial/page7.asp 03/08/2009). Soils on slopes that were never saturated with water had reddish and brownish subsoil colors, which are indicatives of well-drained and aerated conditions. Reddish color is due to the presence of iron compounds in various states of oxidation and hydration (Foth, 1990). The horizons in the pedon at the depression varied in color from the others due to reduction reactions caused by water saturation. Pedons that collect water, and are on poorly drained locations where soils are water saturated much of the time, will tend to have grey-colored B-horizons (Foth, 1990). Topography affects the amount of surface runoff, erosion and deposition. If erosion removes soil from the shoulder or back-slope areas of a hill-slope, thinner and light-colored soils remain where the OM content is low. Soils found on foot-slope or toe-slope areas generally show a higher OM content and thicker A- horizon (grunwald.ifas.ufl.edu/Nat_resources/organic_matter/organic.htm 02/08/2009).

The moist consistence of the soils ranged from friable to extremely firm, whereas the wet consistence ranged from slightly sticky/slightly plastic to very sticky/very plastic (Table 2). Despite high clay contents of up to 81% (Table 3), the soil materials were not extremely sticky (Table 2) probably because of the type of clay mineral present. Many red colored tropical soils have clay particles composed mainly of kaolinite and oxides of iron and aluminum, which have little capacity to develop stickiness and to expand and contract on wetting and drying (Foth, 1990). The very friable and friable consistence observed in the surface soils of the pedons (Table 2) could be attributed to the higher OM contents of the layers (Table 5). Although consistence is an inherent soil characteristic, the presence of high OM in the surface horizon changes its consistence (Wakene and Heluf, 2004).

3.2. Soil Physical Properties

3.2.1. Particle Size Distribution

The soil texture varied from clay loam to clay in the surface horizons of all pedons (Table 3) and became finer from the upper to the middle of the toposequences which may be due to removal of fine soil particles from steeper slope positions by erosion. According to Lawrence (1992), of the individual soil properties considered, silt and sand contents were the most highly correlated with erodibility. Moore *et al.* (1993) found that slope was one of the topographic factors which was most highly correlated with soil properties. The investigators have reported that slope was positively correlated with sand content and negatively correlated with silt content, and high OM mainly occurred when slopes were less than 2%. The sediment transport was different for each soil particle size. The transport of coarse-sized particles (sand) was lowest, whereas the transport of fine soil particles (clay) and medium-sized particles (silt) was high. If erosion occurs on a hill-slope, the silt content often is higher in the bottom soils compared to the soils on the hill-slope shoulder (grunwald.ifas.ufl.edu/Nat_resources/soil_forming_factors/formation.htm 02/08/2009).

The subsurface horizons of most pedons were finer in texture than their respective surface horizons, indicating that there was a prominent translocation of clay down the profiles forming argillic horizons. However, the texture of the subsoil horizons of the pedon at the west-facing foot slope was more or less similar to that of its surface horizon, whereas the pedon at the depression possessed coarser (sandy clay loam) texture as compared to the clay texture of its surface horizons (Table 3), which could be attributed to successive deposition of contrasting materials.

Change in clay percentages down the soil profile suggests pedogenic eluviation–illuviation processes, particularly in the upper as well as middle slope profiles. The presence of faint to prominent clay coatings in the subsurface horizons of the five pedons also indicates that clay illuviation/translocation was the main factor for the formation of argillic horizon in the pedons. The *in situ* synthesis of secondary clays, the weathering of primary minerals in the B-horizon, or the residual concentration of clays from the selective dissolution of more soluble minerals in the B-horizon could have also contributed to the accumulation of clays in the subsoil horizons (Rust, 1983; Chadwick and Grahm, 2000; Buol *et al.*, 2003).

Table 2. Morphological features and physical properties of the soils along the toposequences at Kindo Koye watershed.

Horizon	Depth (cm)	Color (moist)	Field texture	Structure*	Consistence Moist	Consistence Wet	Horizon boundary
Upper slope east-facing (UEF) Pedon							
Ap1	0-40	7.5YR 2.5/2	Loam	VW, FI, GR	VFI	SST-SPL	G-S
Ap2	40-64	7.5YR 2.5/2	Clay loam	MO, ME, SB	VFI	ST-PL	C-S
BA	64-90	5YR 3/3	Clay	ST, ME, AB	FI	VST-VPL	C-S
Bt1	90-136	7.5YR 2.5/2	Clay	ST, ME, AB	FI	VS-VP	G-S
Bt2	136+	2.5YR 2.5/4	Clay	ST, ME, AB	VFI	VS-VP	-
Middle slope east-facing (MEF) Pedon							
Ap_1	0-14	2.5YR 2/2	Clay	VW, ME, GR	FR	ST-PL	C-S
Ap_2	14-40	2.5YR 3/3	Clay	VW, FM, AB,	FR	ST-PL	G-S
Bt1	40-53	2.5YR 2.5/4	Clay	MO, FM, AB	EFI	VST-VPL	G-S
Bt2	53-117	2.5YR 3/3	Clay	VS, FM, SB	EFI	VST-VPL	G-S
Bt3	117-165	2.5YR 3/6	Clay	ST, ME, AB	EFI	VST-VPL	G-S
Bt4	165+	2.5YR ¾	Clay	ST, ME, AB	EFI	VST-VPL	-
Foot slope east-facing (FEF) Pedon							
Ap_1	0-18	7.5YR 2/3	Clay loam	VW, ME, GR	FR	SST-SPL	G-S
Ap_2	18-53	5YR 3/2	Clay loam	WE, ME, GR	FR	SST-SPL	G-S
Bt1	53-100	2.5YR 2.5/3	Silty clay	WE, ME, AB	FR	SST-SPL	G-S
Bt2	100-160	2.5YR 2.5/3	Silty clay	MO, ME, AB	FI	SST-SPL	D-S
Bt3	160+	5YR 3/4	Clay	ST, ME, AB	VFI	ST-PL	-
Foot slope west-facing (FWF) Pedon							
Ap1	0-17	7.5YR 2.5/3	Clay	WE, FI, GR	FR	SST-SPL	G-S
Ap2	17-37	7.5YR 3/3	Clay	WE, ME, SB	FR	SST-SPL	G-S
AB	37-54	7.5YR 2.5/3	Clay	MO, FI-ME, AB	FR	SST-SPL	G-S
B1	54-71	7.5YR 2.5/3	Clay	ST, FI-ME, AB	FR	SST-SPL	G-S
B2	71-112	7.5YR 3/3	Clay	ST, FI-ME, AB	FR	SST-SPL	G-S
B3	112-133	7.5YR 3/3	Clay	ST, FI-ME, AB	FR	SST-SPL	G-S
B4	133+	7.5YR 3/3	Clay	ST, FI-ME, AB	FR	SST-SPL	-
Middle slope west-facing (MWF) Pedon							
Ap_1	0-22	2.5YR 3/4	Loam	WE, VF, GR	FR	SST-SPL	C-S
Ap_2	22-43	2.5YR 3/3	Clay	WE, FI, AB	FR	SST-SPL	A-S
AB	43-75	5YR 3/3	Clay	MO, FM, AB	FR	ST-PL	D-S
Bt1	75-95	5YR 3/3	Clay	ST, ME, AB	FR	ST-PL	D-S
Bt2	95-142	2.5YR 3/6	Clay	ST, ME, SB	FR	ST-PL	D-S
Bt3	142+	2.5YR 3/4	Clay	ST, ME, AB	FR	ST-PL	-
Upper slope west-facing (UWF) Pedon							
A1	0-38	7.5YR 2.5/2	Clay loam	WE, FM,GR	VFR	ST-SS	G-D
A2	38-78	7.5YR 2.5/3	Clay loam	VW, FM, GR	VFR	ST-PL	G-S
Bt1	78-102	5YR 3/2	Clay	WE, FM, SB	VFI	VST-VPL	A-S
Bt2	102-171	5YR 3/3	Clay	FI, FM, AB	VFI	VST-VPL	G-S
Bt3	171+	2.5YR 2.5/4	Clay	FI, ME, AB	VFI	VST-VPL	-
Depression (DEP) Pedon							
A1	0-20	5YR 3/3	Clay loam	WE, FM, G	FR	ST-SPL	G-S
A2	20-50	7.5YR 3/3	Clay loam	WE, FM, SB	FR	ST-SPL	G-S
A3	50-70	7.5YR 2.5/3	Sandy loam	WE, M, SB	FR	ST-SPL	G-S
AC1	70-95	7.5YR 3/4	Sandy loam	VW, C, SB	LO	ST-SPL	G-S
AC2	95-120	5YR 3/2	Silty clay	MS	FR	ST-SPL	G-S
C1	120-150	5YR 3/3	SCL	SG	LO	ST-SPL	G-S
C2	150-170	5YR 3/2	SCL	SG	LO	ST-SPL	A-S
C3	170-200	5YR 3/3	Clay loam	MS	FI	ST-PL	A-S
C4	200-209	5YR 3/3	SCL	MS	LO	ST-PL	A-S
C5	209-230	5YR 3/3	Clay loam	MS	FI	ST-SPL	G-S
C6	230-255	5YR 3/3	Sandy loam	MS	LO	ST-PL	A-S
C7	255+	5YR 3/3	Clay	MS	FI	VST-VPL	-

**WE = Week; VW = Very weak; FM = Fine and medium; GR = Granular; AB = Angular blocky; SB = Sub angular blocky; FR = Friable; VFR = Very friable; FI = Firm; VFI = Very firm; EFI = Extremely firm; SST-SPL = Slightly sticky and slightly plastic; ST-PL = Sticky and plastic; VST-VPL = Very sticky and very plastic; G-S = Gradual and smooth; C--S = Clear and smooth; D-S = Diffuse and smooth; A-S = Abrupt and smooth; MO = Moderate; SCL = Sandy clay loam; ME = Medium; LO = Loose*

Table 3. Particle size distribution and bulk density of the soils in Kindo Koye watershed catena.

Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural class	Bulk density (g cm^{3})
Upper slope East-facing (UEF) Pedon						
Ap1	0-40	31	38	31	Clay loam	1.33
Ap2	40-64	23	30	47	Clay	1.26
BA	64-90	21	28	51	Clay	1.46
Bt1	90-136	11	12	77	Clay	1.42
Bt2	136^{+}	9	10	81	Clay	1.33
Middle slope East-facing (MEF) Pedon						
Ap$_1$	0-14	30	32	38	Clay loam	1.36
Ap$_2$	14-40	24	28	48	Clay	1.31
Bt1	40-53	20	20	60	Clay	1.33
Bt2	53-117	18	16	66	Clay	1.34
Bt3	117-165	16	12	72	Clay	1.66
Bt4	165^{+}	20	12	68	Clay	1.35
Foot slope East-facing (FEF) Pedon						
Ap$_1$	0-18	32	30	38	Clay loam	1.34
Ap$_2$	18-53	26	34	40	Clay	1.21
Bt1	53-100	22	20	58	Clay	1.49
Bt2	100-160	18	20	62	Clay	1.42
Bt3	160^{+}	24	16	60	Clay	1.42
Foot slope West-facing (FWF) Pedon						
Ap1	0-17	30	28	42	Clay	1.35
Ap2	17-37	34	26	40	Clay	1.49
AB	37-54	34	24	42	Clay	1.35
B1	54-71	32	26	42	Clay	1.43
B2	71-112	36	30	34	Clay loam	1.27
B3	112-133	30	34	36	Clay loam	1.38
B4	133^{+}	26	34	40	Clay	1.45
Middle slope West-facing (MWF) Pedon						
Ap$_1$	0-22	20	28	52	Clay	1.37
Ap$_2$	22-43	20	24	56	Clay	1.44
A	43-63	20	24	56	Clay	1.41
AB	63-75	22	22	56	Clay	1.41
Bt1	75-95	20	14	66	Clay	1.44
Bt2	95-142	14	10	76	Clay	1.41
Bt3	142^{+}	14	8	78	Clay	1.38
Upper slope West-facing (UWF) Pedon						
A1	0-38	31	34	35	Clay loam	1.25
A2	38-78	31	36	33	Clay loam	1.36
Bt1	78-102	19	22	59	Clay	1.37
Bt2	102-171	19	22	59	Clay	1.26
Bt3	171^{+}	15	20	65	Clay	1.43
Depression (DEP) Pedon						
A1	0-20	23	32	45	Clay	1.28
A2	20-50	17	40	43	Clay	1.28
A3	50-70	31	28	41	Clay	1.37
AC1	70-95	27	30	43	Clay	1.33
AC2	95-120	31	34	35	Clay loam	1.32
C1	120-150	51	20	29	Sandy clay loam	1.45
C2	150-170	47	22	31	Sandy clay loam	1.59
C3	170-200	45	26	29	Sandy clay loam	1.20
C4	200-209	59	16	25	Sandy clay loam	1.34
C5	209-230	27	36	37	Clay loam	1.20
C6	230-255	36	26	38	Clay loam	1.30
C7	255^{+}	20	36	44	Clay	1.43

3.2.2. Bulk Density

Bulk density was highest in the surface horizon of the Pedon in the MEF followed by that in the MEF while the lowest in the UWF followed by the Depression area. The subsoil bulk density was highest (1.66 g cm^{-3}) in the MEF and second (1.59 g cm^{-3}) as well as lowest (1.20 g cm^{-3}) were observed in the Depression area (Table 3). Generally, bulk density increased with depth primarily because of decrease in soil OM content and soil aggregation, as was indicated by the significant negative correlation between the two properties (Table 6). Soils that are loose, porous, or well-aggregated will have lower bulk densities than soils that are compacted or non-aggregated, as pore space (or air) weighs less than the solid space (soil particles) (weather.nmsu.edu/teaching material/soil252/Chapt5.htm 05/12/2007) .

The values of bulk density in the middle slope positions were relatively high, which might be attributed to cultivation. Secondary tillage (cultivation) generally decrease pore space and thus increases bulk density which stands as a reason for the higher bulk densities of the cropped soils than the uncropped soils. The movement of machinery over the field forces solid particles into spaces once occupied by water or air, resulting in less pore space and increased bulk density (weather.nmsu.edu/ teaching material/soil252/ Chapt5.htm 05/12/2007). Bulk density is an indirect measure of pore space and is affected primarily by texture and structure showing that as solid space and clay content increase, bulk density decreases.

3.3. Chemical Properties

3.3.1. Soil pH

The pH (H_2O) of the soil in the surface layers of the pedons was found to be slightly to moderately acidic, as per the rating of Jones (2003), with values ranging from 5.6 to 6.2 (Table 4). In all the soil profiles of the different landscape positions, soil pH measured in water was higher by about 1-2 units than the respective pH values measured in KCl solution. The low soil pH values with KCl determination indicate the presence of substantial quantity of exchangeable hydrogen ion. According to Mekaru and Uehara (1972) and Anon (1993), high soil acidity with KCl solution determination showed the presence of high potential acidity and relatively readily weatherable minerals.

3.3.2. Cation Exchange Capacity and Exchangeable Bases

The cation exchange capacity (CEC) of the soils across the surface and subsurface horizons ranged from 15.4 to 28.8 cmol(+) kg^{-1}. The surface soil CEC was the highest in the UEF pedon followed by the Depression while the lowest was observed in the MEF pedon (Table 4). The CEC values of the five pedons (UWF, MWF, FWF, MEF and FEF) could be considered as medium and that of the remaining two pedons (UEF and DEP) as high in accordance with the rating of Landon (1991). The CEC values of the pedons showed inconsistent relationship with depth (Table 4).

The concentrations of the basic exchangeable cations in the upper slopes were in the order of Ca > Mg > K > Na (Table 4). The exchangeable Ca contents of the upper slope positions were more than quadruple as compared to that of the foot slope positions of the toposequences. The higher Ca content of the soils at the upper slope positions might be due to its strong adsorption to the soil colloids as compared to other cations, particularly Na, because of its higher charge and small hydrated radius (Foth, 1990). However, the order of abundance the basic cations varied markedly along the toposequences which may be due to differences in land use system on the landscape positions. Similar to Ca, the highest Mg contents were obtained in the upper slope positions, although the sub-soil layers of the MWF were rich in Mg. Highest exchangeable K was recorded in the surface horizon of the MWF, and generally the middle and foot slope positions had more K content in surface horizons as compared to the upper slope positions in both east and west-facing sides (Table 4).

Exchangeable Ca and Mg were positively correlated with CEC, whereas the correlations of Na and K with CEC were negative (Table 6). The percent base saturation (52) was found to be highest in the surface horizon of the UEF pedon, whilst the lowest (26) was recorded in the surface horizon of FEF pedon.

Table 4. Cation exchange capacity (CEC), exchangeable bases, ESP, and pH of the soils at the Kindo Koye Watershed.

Depth (cm)	pH (H_2O)	pH (KCl)	Na	K	Ca	Mg	*TEB (cmol(+) kg^{-1})	CEC (cmol(+) kg^{-1})	PBS	ESP
			(cmol(+) kg^{-1})							
Upper slope East-facing (UEF) Pedon										
0-40	6.1	5.2	0.17	0.50	10.98	2.55	14.20	27.40	52	0.62
40-64	5.8	5.3	0.21	0.50	9.18	1.91	12.40	27.60	45	0.76
64-90	6.3	5.2	0.29	0.38	6.99	2.55	10.21	26.60	38	1.09
90-136	6.0	4.8	0.33	0.41	5.49	3.54	9.77	27.60	35	1.19
136$^+$	6.1	4.8	0.37	0.41	5.84	4.03	10.65	28.80	37	1.28
Middle slope East-facing (MEF) Pedon										
0-14	6.2	4.5	0.62	2.03	1.77	0.28	4.70	17.20	27	3.60
14-40	6.1	4.7	0.87	1.55	1.98	0.25	4.65	16.60	28	5.24
40-53	6.1	4.8	0.96	1.97	1.61	0.64	5.18	16.90	31	5.68
53-117	6.6	4.8	0.84	3.69	1.15	0.45	6.13	16.70	37	5.03
117-165	6.7	5.1	0.84	5.11	1.12	0.43	7.50	18.00	42	4.67
165$^+$	6.7	5.1	0.90	5.43	1.18	0.51	8.02	17.20	47	5.23
Foot slope East-facing (FEF) Pedon										
0-18	5.8	4.2	0.73	2.33	1.36	0.69	5.11	19.50	26	3.74
18-53	5.8	4.2	0.96	1.57	1.52	0.38	4.43	16.10	28	5.96
53-100	5.8	4.3	0.97	2.75	1.01	0.41	5.14	18.00	29	5.39
100-160	5.1	4.0	1.75	2.19	0.96	0.43	5.33	17.80	30	9.83
160$^+$	5.5	4.0	1.08	2.68	0.96	0.42	5.14	18.20	28	5.93
Foot slope West-facing (FWF) Pedon										
0-17	5.8	4.4	0.77	3.50	1.04	0.25	5.56	20.60	27	3.74
17-37	5.7	4.3	0.69	2.95	0.81	0.32	4.77	20.20	24	3.41
37-54	5.8	4.3	0.85	2.16	1.01	0.21	4.23	17.60	24	4.83
54-71	5.6	4.2	0.99	1.65	1.19	0.34	4.17	19.50	21	5.08
71-112	5.8	4.3	0.76	1.46	1.17	0.22	3.61	21.00	17	3.62
112-133	5.7	4.3	0.79	1.16	1.28	0.21	3.44	19.50	18	4.05
133$^+$	5.2	4.0	0.87	1.04	1.03	0.30	3.24	19.10	17	4.55
Middle slope West-facing (MWF) Pedon										
0-22	6.1	4.6	0.92	5.93	1.40	0.75	9.00	23.79	38	3.87
22-43	5.8	4.5	0.29	0.26	6.04	2.30	8.89	23.40	38	4.40
43-63	5.7	4.1	0.27	0.21	5.34	3.13	8.94	25.20	35	4.54
63-75	5.7	4.0	0.23	0.16	4.84	2.63	7.87	23.40	34	4.71
75-95	5.8	4.0	0.27	0.17	3.79	3.21	7.45	23.60	32	4.45
95-142	5.9	4.0	0.21	0.16	5.84	3.79	9.99	25.60	39	4.26
142$^+$	6.5	4.1	0.89	3.59	1.16	0.68	6.32	19.50	32	4.56
Upper slope West-facing (UWF) Pedon										
0-38	5.6	4.4	0.15	0.14	6.94	2.47	9.70	23.20	42	0.65
38-78	5.9	4.4	0.20	0.21	7.24	1.88	9.13	24.40	37	0.82
78-102	5.3	4.4	0.44	0.18	6.34	2.88	9.85	26.20	38	1.68
102-171	5.2	4.1	0.52	0.17	3.64	1.23	5.56	25.00	22	2.08
171$^+$	5.6	3.8	0.40	0.17	6.29	1.56	8.42	24.40	35	1.64
Depression (DEP) Pedon										
0-20	6.2	4.4	0.24	0.09	6.64	2.39	9.35	26.60	35	0.90
20-50	5.6	4.3	0.20	0.05	4.14	1.07	5.46	26.00	21	0.77
50-70	6.2	4.2	0.27	0.05	6.89	1.73	8.93	22.00	41	1.23
70-95	6.0	4.3	0.98	1.02	1.51	0.32	3.83	16.40	23	5.98
95-120	5.9	4.4	0.98	1.37	1.60	0.34	4.29	15.40	28	6.36
120-150	6.3	4.4	0.96	1.86	1.22	0.23	4.27	19.50	22	4.92
150-170	6.1	4.4	0.38	0.11	7.49	3.70	11.68	24.60	47	1.54
170-200	6.5	4.4	0.29	0.07	6.09	2.55	9.00	21.20	42	1.37
200-209	6.6	4.5	0.27	0.07	4.69	1.32	6.35	15.60	41	1.73
209-230	6.1	4.4	0.40	0.11	7.98	3.37	11.86	25.40	47	1.57
230-255	6.5	4.6	0.42	0.11	5.49	2.47	8.48	24.40	35	1.72
255$^+$	5.8	4.4	0.38	0.48	8.23	3.70	12.80	28.20	45	1.34

**TEB = Total exchangeable bases; CEC = Cation exchange capacity; PBS = Percent base saturation; ESP = Exchangeable sodium percentage*

3.3.3. Organic Carbon and Total Nitrogen

The organic carbon (OC) and total nitrogen (N) contents of the soils decreased with depth in most pedons, and the surface horizons in the pits on the east-facing slope positions (UEF, MEF and FEF) contained relatively higher OC and total N than their respective west-facing pedons (Table 5). Generally, the pedon at the Depression area has relatively higher OC and total N than the other pedons except for OC in the UEF and MEF and for total N in the FEF. The range of soil OC contents in the surface horizons are considered as very low according to the ratings of Metson (1961), whereas the total N content of the surface horizons ranged from 0.115 (MEF) to 0.217% (FEF) (Table 5) and are considered as low to medium according to Havlin *et al.* (1999).

Organic carbon in the surface layer decreased down slope on east-facing toposequence. The highest organic carbon value of 2.16% was recorded in UEF, the front yard area used for cattle tethering, indicating higher content of organic carbon in uncultivated land as compared to its cultivated counterparts. Wakene and Heluf (2004) have also indicated that intensive cultivation aggravates OM oxidation and hence reduces OC content. Similarly, the organic carbon in surface layer decreased from UWF to MWF. However the FWF had higher organic carbon than MWF, which might be attributed to partial accumulation of the material from the upper and middle slopes. The total nitrogen content of the surface layers along toposequences followed similar trend with that of organic matter, except for the FEF pedon. The difference in OC and total N content among the pedons could be attributed to the effect of variation in the land use systems along the toposequences. In addition, higher OC and total N contents were recorded in the surface as compared to subsurface layers indicating strong correlation between them. However, their contents in the Depression pedon did not follow similar trend due to accumulation of contrasting material that add different materials from top parts through erosion in different years and water-logging, which might have affected decomposition and mineralization (Wang *et al.***,** 2000). Organic carbon and total nitrogen contents were positively correlated with available P and micronutrients, but negatively with clay (Table 6).

3.3.4. Available Phosphorous

Available phosphorus (P) contents of the soils in the surface horizons was highest in the UEF (7.3 mg kg^{-1}) followed by FWF (4.54 mg kg^{-1}) and MEF (4.2 mg kg^{-1}) while the lowest was recorded in the MWF (0.64 mg kg^{-1}) pedon. Available P generally has inconstant relationship with depth in all pedons and irregularities were observed due to contrasting materials (Table 5). There is a general increase in the distribution of available P from top to bottom along the slope both on the east and west-facing toposequences. This is due to the fact that the relationship of slope position to soil properties is, to a great degree, controlled by erosion processes in that it alters the distribution of soil particles and water redistribution over the field. Kravchenko and Bullock (2000) found that in more than half of their study sites, slope was negatively correlated to CEC, organic matter, available P, and exchangeable K.

According to Havlin *et al.* (1999), the available P contents of the soils in the surface horizons are considered to be very low to low**.** The relatively higher available P in the surface horizons of most soil profiles as compared to that of subsurface layers could be attributed to the difference in organic matter contents of the layers. Available P content was positively correlated (r = 0.41) with organic carbon (Table 6). High OM content and a good rate of its mineralization could ensure release of phosphate ions adequate for crop production, though most of the phosphate released in this way will be in the topsoil. If not immediately taken up by the plant or by soil organisms, however, it will be converted to non-labile form. Besides, the phosphate ions are most likely to combine with free iron or aluminum ions in acid soils to form iron III phosphates and aluminum phosphates, which are relatively insoluble (Ahn, 1993).

The decrease in available P content with depth in the pedons, except for the Depression pedon, is attributed to the increment of clay, as available P correlates negatively (r = -0.56) with clay content (Table 6). Iron and aluminum oxides are intimately associated with the kaolinitic clay fraction of the soil or as coatings on the clay, and thereby increase P fixation. Fixation is thus related to soil texture and would be expected to be greater in clayey soils than in light textured ones. This applies particularly when the clay is kaolinitic (Ahn, 1993). Available P had also a very highly significant correlation with Fe, Zn and Cu, and high correlation with Mn (Table 6).

3.2.5. Available Micronutrients (Fe, Mn, Zn and Cu)

The micronutrients contents in all pedons decreased with increasing soil depth (Table 5). The order of micronutrients concentration in the pedons was Mn > Zn > Fe > Cu, except for east-facing foot slope where Zn > Mn > Fe > Cu was recorded.

The concentrations of Cu and Fe are very low and that of Mn and Zn fall in low to high ranges as compared with the normal ranges of these nutrients in soil (Havlin *et al.*, 1999). The trend of Mn concentration under different slope positions was similar to that of Fe distribution (Table 5) indicating that these two elements have similar chemical behavior in tropical soils (Kravskoof, 1972).

The distribution of CU was consistently decreased from the surface to the subsurface horizons, which might be attributed to the strong association of Cu with soil organic matter. There was also a positive correlation between copper and organic matter showing that copper is strongly complexed with organic matter as was also described earlier by Wakene and Heluf (2004). Moreover, the Fe and Mn contents were also decreased consistently with depth in the profiles of every landscape positions.

Table 5. Total nitrogen, organic carbon (OC) and available phosphorus and micronutrients contents of the soils at the Kindo Koye Watershed.

Depth (cm)	Total N (%)	OC (%)	C/N ratio	Available P (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})
Upper slope East-facing (UEF) Pedon								
0-40	0.178	2.163	12	7.30	1.39	4.51	10.23	0.18
40-64	0.140	1.344	10	1.40	0.59	0.53	3.94	0.11
64-90	0.113	0.789	7	0.92	1.06	0.40	3.41	0.31
90-136	0.070	0.481	7	0.92	0.59	0.95	0.79	0.18
136^{+}	0.090	0.585	7	1.66	0.37	0.44	0.48	0.15
Middle slope East-facing (MEF) Pedon								
0-14	0.115	1.948	17	4.20	1.19	3.83	6.09	0.18
14-40	0.185	1.318	7	1.34	0.79	4.80	2.49	0.24
40-53	0.132	1.127	9	1.34	0.37	0.88	1.91	0.18
53-117	0.110	0.879	8	1.34	0.66	0.84	1.17	0.07
117-165	0.123	0.813	7	2.34	0.37	0.29	0.40	0.13
165^{+}	0.070	0.530	8	2.20	0.55	0.20	0.66	0.13
Foot slope East-facing (FEF Pedon								
0-18	0.217	1.743	8	2.30	1.03	8.78	7.96	0.20
18-53	0.153	1.743	11	1.30	2.57	7.55	7.52	0.24
53-100	0.137	0.905	7	0.34	0.66	0.81	1.76	0.15
100-160	0.112	0.813	7	0.30	0.51	0.33	0.62	0.18
160^{+}	0.098	0.720	7	0.30	0.18	0.15	0.70	0.07
Foot slope West-facing (FWF) Pedon								
0-17	0.127	1.555	12	4.54	2.20	7.22	6.40	0.20
17-37	0.108	1.113	10	2.48	1.36	7.11	5.30	0.15
37-54	0.148	0.966	7	1.98	1.30	5.30	4.36	0.13
54-71	0.141	1.325	9	1.98	1.72	4.60	4.29	0.15
71-112	0.160	1.452	9	1.90	1.85	11.97	7.15	0.29
112-133	0.140	1.662	12	2.56	ND	6.27	8.07	0.24
133^{+}	0.143	1.489	10	2.56	3.48	9.77	8.36	0.22
Middle slope West-facing (MWF) Pedon								
0-22	0.116	1.069	9	0.64	0.70	0.59	3.85	0.07
22-43	0.109	1.051	10	0.46	0.73	0.20	3.15	0.13
43-63	0.092	0.879	10	1.18	0.66	0.33	2.64	0.13
63-75	0.095	0.668	7	1.12	0.66	0.81	2.53	0.11
75-95	0.070	0.554	8	1.00	0.37	0.62	2.02	0.07
95-142	0.049	0.513	10	1.00	0.29	0.24	1.14	0.13
142^{+}	0.028	0.358	13	1.00	0.31	0.24	0.51	0.04
Upper slope West-facing (UWF) Pedon								
0-38	0.146	1.572	11	1.38	2.22	8.16	8.58	0.22
38-78	0.115	1.407	12	1.20	2.09	3.21	8.07	0.24
78-102	0.085	0.880	10	0.56	0.57	0.92	2.73	0.13
102-171	0.092	0.657	7	0.56	0.44	0.37	2.24	0.13
171^{+}	0.070	0.491	7	0.28	0.33	0.68	1.23	0.18
Depression (DEP) Pedon								
0-20	0.189	1.890	10	1.50	1.43	9.79	6.62	0.31
20-50	0.185	1.638	9	1.50	1.45	6.89	6.25	0.22
50-70	0.168	1.134	7	1.24	1. 63	6.93	7.04	0.11
70-95	0.143	1.239	9	1.80	1.19	5.43	5.48	0.31
95-120	0.169	1.155	7	2.42	1.52	4.93	4.84	0.31
120-150	0.112	0.819	7	3.60	1.87	7.85	5.90	0.29
150-170	0.126	0.945	8	4.30	1.32	6.23	5.52	0.29
170-200	0.115	1.176	10	4.18	1.83	6.18	6.09	0.24
200-209	0.147	0.990	7	3.70	2.42	12.56	5.52	0.33
209-230	0.112	1.197	11	5.20	1.01	2.79	4.51	0.24
230-255	0.113	0.882	8	4.60	1.08	1.36	3.98	0.22
255^{+}	0.147	1.113	8	6.36	4.93	2.95	5.30	0.40

3.4. Classification of the Soils

The dominant soils of the area were previously mapped as Eutric Nitosols (EMA, 1988). The soil profiles, except that of the depression, had thick (37 to 78) surface horizons, having moist color of 7.5YR 5/2 and dark and very weak to weak structure. The organic carbon content of the surface horizons of the pedons ranged from 1.05 to 1.95% with percent base saturation values of less than 50 using 1M NH_4OAc at pH 7. Thus, the six pedons possessed umbric epipedons, whereas the pedon on the depression failed to meet criteria for any other epipedons except Ochric.

In the subsurface horizons of all, but FWF pedon, thick horizons (133 to 171 cm) with clay contents ranging from 51 to 81% were observed. The clay contents of the subsurface horizons were found to be more than 1.2 times greater than their respective surface layers, the subsurface horizons contained 8% more clay than the horizon above where the horizon above had more than 40% clay and these clay increments were found within distances less than 15 cm (Table 4). The apparent cation exchange capacities of the horizons ranged between 25 and 88 cmol(+) kg^{-1}. Besides, faint and prominent pedfaces, argillians, were observed in the horizons. These properties would therefore qualify the horizons of the five pedons as argillic subsurface diagnostic horizons as described by Buol *et al.* (2003). Considering these features, the five pedons were grouped under Ultisols. The subsurface layers of the FWF pedon did not show clay increment, although there was evidence of color alteration indicating that it possesses cambic horizons. In addition, it has base saturation less than 50% using 1M NH_4OAc at pH 7 between the umbric epipedon and a depth of 180 cm. Thus, it was classified as Inceptisols, whereas the pedon at the Depression without any diagnostic horizon was classified as Entisols.

The region is characterized by isothermic temperature and ustic moisture regimes based on the estimates made using the mean annual and monthly temperature and moisture distributions of the region, respectively (Van Wambeke, 2003). Thus, the five pedons were classified as Ustults on the bases of soil moisture regime at the suborder level. Further, the pedons did not have a densic, lithic, paralithic or petroferric contact within 150 cm; and did not have a clay decrease of 20% or more from the maximum clay content. Hence, they were classified as Paleustults and Typic Paleustults at great groups and subgroups, respectively (Table 7).

Considering the ustic soil moisture regime, absence of free carbonates within 200 cm of the mineral soil surface and base saturation (1M NH_4OAc) of less than 60% in all horizons at a depth between 25 and 75 cm from the mineral soil surface and the presence of umbric epipedon, the the FWF pedon was further classified as Ustepts, Dystrustepts and Humic Dystrustepts at suborder, great groups and subgroup levels, respectively (Table 7).

The pedon at the Depression was classified as Fluvents based on the features such as < 25% slope, 0.2% or more OC and irregular decrease in OC content from a depth of 25 cm to 125 cm. This Depression area pedon was further classified as Aquic Usticfluvents due to ustic soil moisture regime with seasonal aquic conditions.

The classification of the soils of the five pedons as Ultisols, and that of FWF and DEP as Inceptisols and Entisols, respectively, was a major deviation from the previous soil map (EMA, 1988). The position of the FWF and DEP pedons on the catena makes these orders different from the rest of the pedons in the area and showing the influence of topography on soil development.

The five pedons, which were grouped under Ultisols following Soil Taxonomy, were classified as Acrisols due to the presence of an argillic B horizon; having a base saturation which is less than 50% in, at least, some part of the B horizon within 125 cm of the surface. They were further grouped under Ferric Acrisols at the unit level because of their ferric properties (Table 7)

The FWF pedon was categorized as Dystric Cambisols due to the presence of an umbric A horizon, which is more than 25 cm thick a base saturation of less than 50% in at least some part of the B horizon. The pedon at the depression was categorized under Dystric Fluvisols as it developed from recent alluvial deposits, and had no diagnostic horizons other than an ochric A and base saturation of less than 50%, at least in some part of the soil between 20 and 50 cm from the surface (Table 7).

Contrary to the report of the EMA (1988), the present study revealed the existence of three soil orders or mapping units within the catena. This is a result of detail survey and classification of soils and shows that topography has a great influence on soil development.

4. Conclusions

The soils of a catena could differ as a result of erosion, transport and deposition of surface materials as well as leaching, translocation and deposition of chemicals and particulate constituents in the soil. Topography plays a major role in these processes and thereby influences the development and characteristics of the soils along the toposequences. Most of the important soil quality indicators such as bulk density, structure, OC, soil pH, CEC, total N, available P, exchangeable bases, and available micronutrients were influenced by the different landscape positions, particularly at the surface horizon. Continuous intensive cultivation without appropriate soil management practices has contributed to the degradation of the important soil quality indicators. Therefore, reducing intensive cultivation, and integrated use of inorganic and organic fertilizers could replenish the degraded soil quality parameters for sustainable productivity. However, further study of the areas is recommended especially with respect to soil landscape - land management relationships so as to give sound conclusion for the sustainable use of the land.

Table 6. Correlation between properties of the soils in Kindo Koye watershed catena.

	BD	Na	K	Ca	Mg	CEC	Total N	OC	Av. P	Fe	Mn	Zn	Cu
Clay	0.296	0.107	0.263	-0.123	0.184	0.151	-0.660**	-0.693**	-0.564**	-0.586**	-0.753**	-0.862**	-0.618**
BD		0.157	0.263	-0.165	0.000	-0.044	-0.269	-0.387	-0.095	-0.121	-0.259	-0.323	-0.152
Na			0.664**	-0.826**	-0.756**	-0.731**	0.049	-0.062	-0.182	-0.093	-0.028	-0.228	-0.092
K				-0.696**	-0.633**	-0.529*	-0.097	-0.102	-0.097	-0.176	-0.165	-0.277	-0.377
Ca					0.828**	0.797**	-0.009	0.069	0.284	0.122	-0.115	0.191	0.193
Mg						0.815**	-0.300	-0.252	0.158	0.005	-0.282	-0.108	0.070
CEC							-0.188	-0.083	0.088	-0.004	-0.260	0.015	0.004
TN								0.782**	0.283	0.416*	0.662**	0.673**	0.497*
OC									0.414*	0.428*	0.627**	0.840**	0.390
Av. P										0.526*	0.352	0.501**	0.478*
Fe											0.588**	0.606**	0.646*
Mn												0.782**	0.585**
Zn													0.517*

***. = Correlation is significant at $P \leq 0.0$; *.= Correlation is significant at $P \leq 0.05$; BD = Bulk density; CEC = Cation exchange capacity; OC = Organic carbon; Av. P = Available phosphorus*

Table 7. Classification of the soils of Kindo Koye watershed catena following Soil Taxonomy and the WRB Systems.

	Soil Taxonomy				The WRB legend	
Pedon*	Order	Suborder	Great group	Subgroup	Major Groups	Units
UEF	Ultisols	Ustults	Paleustults	Typic Paleustults	Acrisols	Ferric Acrisols
MEF	Ultisols	Ustults	Paleustults	Typic Paleustults	Acrisols	Ferric Acrisols
FEF	Ultisols	Ustults	Paleustults	Typic Paleustults	Acrisols	Ferric Acrisols
DEP	Entisols	Fluvents	Usticfluvents	Aquic Ustivfluvents	Fluvisols	Dystric Fluvisols
FWF	Inceptisols	Ustepts	Dystrustepts	Humic Dystrustepts	Cambisols	Dystric Cambisols
MWF	Ultisols	Ustults	Paleustults	Typic Paleustults	Acrisols	Ferric Acrisols
UWF	Ultisols	Ustults	Paleustults	Typic Paleustults	Acrisols	Ferric Acrisols

**UWF = Upper slope west-facing; MWF = Middle slope west-facing; FEF = Foot slope east-facing; DEP = Depression; FWF = Foot slope west-facing; MEF = Middle slope east-facing; UEF = Upper slope east-facing*

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Advances in Improving *Ukiriguru* Composite B Maize (*Zea mays* L.) Variety through S_1 Recurrent Selection

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Abstract: S_1 recurrent selection was carried out to improve grain yield, plant height, ear placement, resistance to lodging and other desirable agronomic traits in *Ukiriguru* composite B (UCB) maize variety. This paper presents the genetic gain and progress made in improving these traits through two cycles of selection. Three hundred and sixty, and 254 S_1 families were evaluated in three environments and 36 and 25 families were selected following 10% selection intensity during the first (C_1) and the second (C_2) cycles, respectively. The selected families were recombined in isolated half-sib recombination blocks using remnant seeds. The progress made through selection was determined by evaluating the parent population (UCB C_0), the first (UCB S_1 C_1) and the second (UCB S_1 C_2) selection cycles in six environments in a randomized complete block design in four replications. Commercial open-pollinated and hybrid varieties were included as checks. UCB S_1 C_2 produced mean grain yield of 8.7 t ha^{-1} and had a significant ($P < 0.01$) genetic gain of 30% (2.0 t ha^{-1}) with mean gain of 15.0% (1.0 t ha^{-1}) cycle^{-1}. The selection also resulted in short plant height and low ear placement with significant ($P < 0.01$) genetic gain of 9.6% (30.8 cm) and 19.6% (39.6 cm), respectively, and superiority in tolerance to diseases and resistance to lodging. Still selection had significant ($P < 0.01$) grain yield benefit of 35.0% (3.1 t ha^{-1}) and 29.3% (2.6 t ha^{-1}) relative to Gibe Composite 1 and Kuleni, respectively, and showed comparable yield potential with commercial hybrids, BH660 and BH670. It was concluded that two cycles of S_1 recurrent selection have brought significant genetic improvement in grain yield and major agronomic traits in UCB. Hence UCB S_1 C_2 was fully released and recommended for commercial production in the mid-altitude (1600-1800 masl) agro-ecologies of Jimma and Illu Ababora Zones, and similar areas in the south-western areas of Ethiopia. After release, it was named as 'Morka' meaning 'competent', to express its yield potential which is comparable to the yield potential of popular hybrid varieties in the zones.

Keywords: Genetic Gain; *Morka*; Recurrent Selection; Response to Selection; *Ukiriguru* Composite B

1. Introduction

The late maturing maize composites of east African origin are well adapted to the potential maize environment in Ethiopia. Originally introduced from Tanzania, Ukiriguru composite B (UCB) used to be the most adapted and well preferred variety in Jimma and Illu Ababra zones in the southwestern part of the country since its release in 1975. The variety was reported to possess adequate level of resistance to the major leaf diseases, such as turcicum leaf blight (TLB) (*Helminthosporium turcicum*), common rust (CR) (*Puccinia sorghi*) (Assefa, 1995) and also to gray leaf spot (GLS) (*Cercospora zeae-maydis*) reportedly introduced to Ethiopia in 1998/99 (Dagne *et al*., 2001) and storage pests (Demissew *et al*., 2004).

It, however, grows tall and reaches a height of 350 cm with heavy cobs placed at 250 cm almost three quarters up the plant. As a result it is susceptible to lodging and gives high yield only when there is no heavy wind accompanying rain storm. Therefore a considerable amount of grain yield is lost, especially in a hot and humid climate where germination and rotting are easily initiated. Other than this, leafiness and inefficient transfer of assimilates to ear sink are also considered to be important limitations to grain yield in most of locally adapted east African composites and in UCB in particular (Benti, 1986 and Benti *et al*., 1988). Accumulation of undesirable traits through cross pollination with pollen from nearby maize fields has worsen the situation by accelerating genetic deterioration of the variety leading to low yield potential. Despite its resistance to biotic constraints, it was, therefore, no more attractive to grow the variety with all the limitations. Farmers have, therefore, withdrawn from growing the variety and seed production was stopped in 1995. To solve this problem, the maize breeding team based at Jimma Agricultural Research Center (JARC) has been working on improving the variety through S_1 recurrent selection since 1998.

In maize several studies indicated that the inheritance of ear height is controlled by additive genes (Robinson *et al*., 1949, Giesbrecht, 1961 and Harville *et al*., 1978). Similar studies carried out in Ethiopia in locally adapted maize composites of east African origin have also confirmed that the inheritance of grain yield and, ear and plant height is mainly controlled by additive gene effects (Leta and Ramachandrappa, 1998; Jemal, 1999) implying that selection programs that utilize additive gene effects can be useful in improving these quantitative characters.

Initially tested by East and Jones (1918) and Hayes and Garber (1919) to improve quantitative traits in allogamous crops, recurrent selection is extensively used in maize breeding (Hallauer, 1985). Recurrent selection methods for intra population improvement of quantitative characters in maize have been based on individual or family performance for improvement of the population *per se* or hybrid-testcross family or for improvement of combining ability of the population (Hallauer and Miranda, 1981). Among those selection methods, S_1 recurrent selection has been effective in improving grain yield and other traits in cross pollinated crops. In maize it is considered to be more efficient than other selection schemes in improving a broad based population. Burton *et al.* (1971) realized gains of 4.2% cycle^{-} over four cycles of selection for grain yield in Krug. Genter (1973) found that S_1 recurrent selection was more effective than top-cross selection for improving population per se performance and was equal to test cross selection for improving combining ability. Besides its effectiveness in improving performance in terms of productivity, it has been

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useful in improving resistance to biotic stresses such as European corn borer (Penny *et al.*, 1967), stalk rote (Jinahyon and Russell, 1969) and downy mildew (De Leon *et al.*, 1993). In Ethiopia, various forms of intra and inter population recurrent selection schemes have been practiced to improve different populations. Full sib family and mass selection have resulted in improving varieties for higher grain yield, and lodging and disease resistance (Benti *et al.*, 1993). The improved versions were either used as sources of inbred lines in hybrid development program or released as improved varieties for commercial production. In this improvement program, S_1 recurrent selection has been carried out in UCB to improve grain yield, plant height and ear placement, resistance to lodging and other desirable agronomic traits. This paper presents the genetic gain and progress made in improving these traits through two cycles of selection.

2. Materials and Methods

Two cycles of S_1 recurrent selection have been carried out in UCB. Each cycle involved family generation, evaluation and recombination. After two cycles of selection, the selection cycles were evaluated in multilocation field experiments to find out genetic gains and progress achieved through the improvement program. The details of the protocols are elaborated below.

2.1. Family Generation

To generate S_1 families in both the first and the second cycles, the parent population, UCB C_0 , and the half sib recombined generation of the first cycle, UCB S_1 C_1 F_1, were planted in a uniform and large plot at JARC. In both cases, recommended management practices and fertilizer levels were applied except row and plant spacing which were set at 80 and 50 cm, respectively, to enable plants sufficiently express their genetic potential for better success in selecting ideal types. The first cycle was initiated by selfing 500 plants selected based on plant and ear height and resistance to diseases. Ears of the selected plants were covered by polythene plastics before silk emergence and kept under close supervision until pollination. All the candidate plants were regularly visited for silk emergence and pollen shading. Depending on the synchrony of silk emergence and pollen shading, the tassels of the selected plants were covered by pollen bag a day before pollination. Then pollen was collected on subsequent days and all the covered silks were self pollinated. Ears suspected to have been open-pollinated were rejected. The pollen bags were kept on the pollinated ears until harvest. Selfed plants observed to be severely attacked by leaf diseases and/or root or stalk lodged at advanced development stages were eliminated. Selfed ears were harvested individually and further selection was finally exercised based on ear characters and rotting. The second cycle was initiated by selfing 350 selected plants in the first half sib recombined generation, UCB S_1 C_1 F_1, of the first cycle of selection. Plants were selected and self pollinated and then best ears selected following the same procedures mentioned above. Finally 360 and 254 selfed ears were shelled individually as S_1 families and put in family evaluation in the first and second cycles, respectively.

2.2. Family Evaluation

In order to select families which have desirable traits, the 360 and 254 families generated in the first and second cycle were evaluated in a 19 x 19 and 16 x 16 (0, 1) alpha lattice design with two replications in the main season of the year 2000 and 2002, respectively, at JARC, Hurumu Testing Site (HTS) and Bako Agricultural Research Center (BARC) in the western and southwestern part of Ethiopia. Two rows each of 5.1 meter length were grown per plot with spacing of 75 and 30 cm between the rows and plants, respectively. Two seeds were planted per hill and then thinned to one plant per hill to adjust the plant density to 44, 444 plants hectare^{-1}. UCB C_0, and UCB C_0 and UCB S_1 C_1 F_1 were included in the first and second experiments, respectively, as reference entries in selecting the best families. The number of families evaluated in the first cycle was reasonably high to increase the chances of capturing families with low ear placement and short plant height. In both cycles, selection intensity of 10% was followed to select the best families based on the mean data combined across the three locations and visual selection in the field. Accordingly, 36 and 25 best families were selected for recombination to compose the first and the second selection cycles, respectively.

2.3. Family Recombination

The selected families were recombined in isolated half-sib recombination block using remnant seeds. The families were planted in separate rows and served as female rows by detasseling before pollen shading. A balanced composite of seed was mixed from all the selected families and planted as male rows in between the female rows. The seed harvested from the female rows were mixed and planted in isolation for further recombination. The first and the second cycles were further recombined in isolation up to the third and the second generation, respectively, before promoting to multilocation field experiments.

2.4. Evaluation for Progress through Selection

To determine the progress made through selection, the parent population (UCB C_0), and the first (UCB S_1 C_1) and the second (UCB S_1 C_2) selection cycles were evaluated in field experiments at JARC, BARC and HTS in 2005, at BARC and HTS in 2006 and at BARC in 2007, totally in a six year-location environments. Entries were arranged in a randomized complete block design with four replications at each environment. Four rows each of 5.1 meter length were grown in a plot with spacing of 75 and 30 cm between the rows and plants, respectively. Two seeds were planted hill^{-1} and then thinned to one plant hill^{-1} to adjust the plant density to 44,444 plants per hectare (ha). All management practices and fertilizer levels were applied following specific research recommendations for each location. Commercial open-pollinated (OPVs) and hybrid varieties were included as checks. Data on grain yield and all agronomic characters were recorded on the two middle rows. Plant and ear height were measured on ten randomly selected plants and the mean was recorded for the plot. Ear position was calculated as the ratio of ear height to plant height. All plots were hand harvested and field weight of the harvested cobs was measured. Grain yield was then computed considering 80% shelling percent and adjusted at 12.5% moisture. Data on disease severity were recorded in a 1-5 scale, where 1 indicates clean or no infection and 5 severely diseased, and then log transformed before analysis. Analysis of variance was done separately for each environment and then combined across environments using MSTAT-C software. The data from the experiment conducted at Bako in 2005 was excluded from the combined analysis because of high error variance for all variables. Genetic gains cycle^{-1} were calculated as $[(C_n - C_{n-1})/C_{n-1}]$ 100, where n is the number of cycle (Falconer, 1989). The overall response to selection (R) as a change in population mean was calculated by subtracting the average of the second cycle from the average of the whole population before selection. As a measure of the selection applied, selection differential (S), was estimated as a deviation of the mean phenotypic value of the individual families selected as parents for recombination from the mean phenotypic value of the parental population before selection (UCB C_0 in the first cycle and UCB C_2 F_2 in the second cycle). In order to show how the response is related to the selection differential, realized heritability (h^2r) was estimated as $h^2r = R/S$, as indicated by Falconer (1989).

3. Results and Discussions

Combined analysis of variance for grain yield, days to 50% silking, ear and plant height, ear position, and severity of GLS, TLB and CR indicated highly significant differences among the varieties (Table 1). Mean squares due to genotype x environment (G x E) interaction was also significant for all characters except plant height and ear position. No significant differences were observed among varieties for lodging percent. Therefore response to selection was not measured for lodging percent. Mean grain yield combined across five environments varied from 5.7 to 8.7 tons (t) ha^{-1} (Table 2). The second selection cycle (UCB S_1 C_2) produced the highest mean grain yield and had a significant ($P < 0.01$) genetic gain of 30% (2.0 t ha^{-1}) (Table 3). Cycle wise, the gains were 0.8 t ha^{-1} (11.0%) and 1.2 t ha^{-1} (16.4%) in the first and second cycles, respectively, indicating progressive increases in productivity with cycles of selection. More recently, Ruiz de Galarreta and Alvarez (2007) also reported linear increases in grain yield with cycles of selection in six cycles of S_1 recurrent selection in two Spanish maize synthetics. The mean genetic gain for grain yield cycle^{-1} was 15.0% (1.0 t ha^{-1}). This is immense compared with 44% yield increase reported by Janet and West (1993) after four cycles of S_1 selection exercised in a population that has undergone 10 cycles of mass selection for low ear height.

UCB S_1 C_2 was also improved for short plant height, low ear placement and ear position. Plant height was reduced significantly ($P < 0.01$) with genetic gain of 9.6% (30.8 cm). The regresses with cycles were 4.1% (13.3 cm) in the first and 5.6% (17.5 cm) in the second cycle with mean reduction of 4.92% (15.4 cm) cycle^{-1}. Ear height was also reduced significantly and followed similar trend with plant height but with more magnitude. It decreased by 20% (39.7 cm) from 201.7 cm in the parent population to 162 cm in the second cycle. The mean reduction cycle^{-1} was 10.4% (19.8 cm) with statistically significant ($P < 0.01$) drops of 9.5% (19.2 cm) and 11.2% (20.4 cm) in the first and second cycle, respectively. Both traits diminished progressively with cycles of selection.

To more clearly demonstrate changes of those traits with cycles of selection, linear regression lines were fitted to the mean values of grain yield and other agronomic traits (Figures 1a and b), in the parent population and the two selection cycles plotted against cycles of selection. It is very clear to see the slopes of the regression equations indicating the average realized gains in selection for those traits cycle^{-1} of selection. If we take the slopes of these equations and express them as percent of the mean values recorded in the parent population for a particular trait they give the average gains cycle^{-1} in percent which is the same as the gains cycle^{-1} computed using the previous formulae. For instance, expressing the slope of the regression line fitted to grain yield which is unity as a percent of the mean grain yield of the parent population gives us 14.6% as mean gain in grain yield cycle^{-1}. Contrary to grain yield, the slopes of the regression lines fitted to ear and plant height are negative substantiating reduction of these traits with cycles of selection. Expressing these values as percent of the mean ear and plant height of the parent population, yields mean responses of -10.3 and -5.0 percent cycle^{-1}.

Considering positive genetic correlation of grain yield with ear and plant height in maize (Hallauer and Miranda, 1981), the negative response observed in ear and plant height in association with positive response in grain yield was quite interesting. This might have happened since low ear placement and short plant height, and better grain yield were set as selection criteria in this improvement program. Other selection experiments in which grain yield was the only selection criterion have produced variable effects on ear height as a correlated response. Harris *et al.* (1972) and Moll *et al.* (1975) reported increases in ear height when grain yield was the only selection criterion. On the other hand, Walejko and Russell (1977) and Crosbie and Mock (1979) reported no significant changes in ear height following selection for grain yield.

In addition to responses to selection, it was also important to measure selection differential since it is the relationship between the two, and not the responses alone, that is of interest from the genetic point of view (Falconer, 1989). Selection differential was computed as the deviation of the mean of the families selected for recombination in each cycle from the mean of the respective parent populations with the assumption that all the selected families were equally fertile in setting seeds and shading fertile pollen and have equally contributed to the subsequent selection cycles. As a quotient of the two parameters, realized heritability is an index used to quantify the degree to which a trait in the population can be changed through selection. Higher values indicate better position of the selection cycle than the original population, hence indicating the rate at which the population is changing in a particular trait.

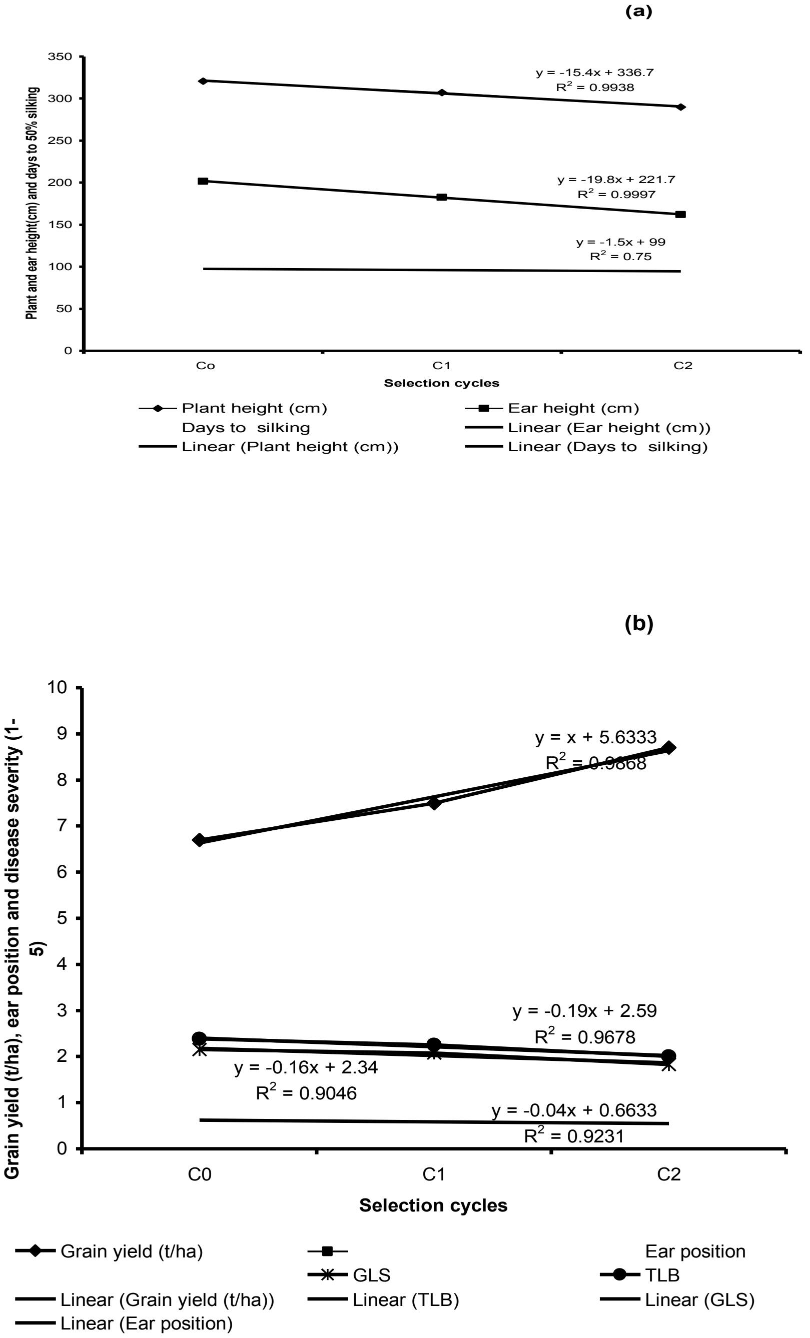

Figure 1. Trends of important agronomic traits (a) and grain yield (b) with cycles of selection

Table 1. Combined analysis of variance for grain yield and other traits of maize evaluated across five environments.

Source of variation	DF	Mean square						Diseases (1-5 scale)		
		Grain yield	Days to 50% silking	Plant height	Ear height	Ear position	Lodging (%)	GLS	TLB	CR
Environments (E)	4	10674.1**	4348.5**	15761.1**	12113.7**	0.034**	847.8*	0.015	0.104**	0.125**
Error	15	92.84	6.47	407.6	354.6	0.003	217.4	0.021	0.005	0.008
Replication	12	9043.6*	43.84	143.84	576.11**	0.004	144.0	0.124	0.171	0.096**
Genotypes (G)	7	1956.4**	94.4**	7574.8**	9767.7**	0.03**	102.2	0.124**	0.063**	0.061**
G X E	28	218.3**	31.0**	560.6	565.8**	0.005	155.8*	0.016**	0.010**	0.013**
Error	105	98.3	2.9	456.4	289.8	0.003	97.9	0.007	0.005	0.005
CV (%)		13.8	1.81	7.34	10.2	10.10	38.7	6.41	5.11	6.26

** and ** = Significant at $P \leq 0.05$ and 0.01 levels, respectively; CR = Common rust; CV = Coefficient of variation; DF = Degrees of freedom; GLS = Gray leaf spot; TLB = Turcicum leaf blight*

Table 2. Mean grain yield and major agronomic traits of different selection cycles and the standard checks of maize combined across five environments.

Entry	Grain yield (t ha^{-1})	Plant height (cm)	Ear height (cm)	Ear position	Days to 50% silking	Diseases (1-5 scale)			Lodging (%)
						GLS	TLB	CR	
UCB C_o	7.6bcd	320.6a	201.7a	0.63a	97a	2.15(1.33)b	2.38(1.37)bc	1.23(1.07)bc	17.36(22.8)
UCB $\mathbf{S_1}$ C_1F_2	7.2abc	304.1ab	179.0b	0.55b	94a	2.07 (1.30)bc	2.23(1.32)d	1.15(1.05)c	15.0(21.2)
UCB $\mathbf{S_1}$ C_1F_2	7.5abc	307.3ab	182.5b	0.57b	97a	2.08(1.30)bc	2.25(1.35)d	1.20(1.07)c	20.61(25.5)
UCB S_1 C_2	8.7a	289.8bc	162.1c	0.55bc	94bc	1.83(1.25)c	2.00(1.30)d	1.15(1.05)c	14.99(21.4)
BH660	7.9ab	302.2bc	179.7b	0.60ab	95b	2.08(1.31)bc	2.10(1.32)d	1.25(1.09)bc	22.47(27.4)
BH670	7.7ab	292.4bc	168.4bc	0.53cd	96ab	2.08(1.31)b	2.15(1.33)b	1.10(1.04)b	12.65(27.0)
Kuleni	6.2cd	263.3d	138.4d	0.58b	91d	2.25(1.34)bc	2.40(1.38)bcd	1.33(1.11)c	23.04(27.4)
Gibe composite-1	5.7d	266.7d	135.9d	0.52d	93c	2.33(1.51)a	3.05(1.47)a	1.68(1.21)a	20.27(27.2)
Mean	7.2	291.0	166.8	0.57	95b	(1.30)	(1.35)	(1.09)	(25.5)
F-test	**	**	**	**	**	**	**	**	ns
LSD (0.01)	1.40	17.70	14.10	0.045	1.43	0.069	0.010	0.058	-
CV (%)	13.91	7.34	10.21	10.10	1.80	6.81	5.11	6.26	38.69

*Means within a column followed by the same letter(s) are not significantly different at $P \leq 0.01$. ** Significant at $P \leq 0.01$; ns = Not significant at $P > 0.01$; LSD = Least significant diffirence; CV = Coefficient of variation; GLS = Gray leaf spot; TLB = Turcicum leaf blight; CR = Common rust; Values in parenthesis indicate transformed data*

In this study realized heritability was found to increase progressively with the selection cycles for the major agronomic traits indicating better response of the population to selection (Table 4). For grain yield realized heritability was 0.44 and 0.84 in the first and second cycles, respectively, indicating possibility in improving grain yield with further cycle of selection. Besides grain yield, plant and ear heights were the major traits for which improvement was sought in this population improvement program. Plant height has, however, showed less realized heritability than ear height indicating no sign of progress even with further cycles of selection. This was expected because in UCB there is very high correlation between grain yield and plant height. Hence, tall plants with reasonably lower ear placement and better cob size were selected for, not to sacrifice grain yield while selecting for short plant height.

Table 3. Genetic gains (%) achieved in grain yield and other agronomic traits with two cycles of S_1 recurrent selection in *Ukiriguru* composite B maize.

Trait	Cycle 1	Cycle 2	Overall gain	Average
Grain yield	11.1	16.4	29.3**	14.0
Ear height	-9.5**	-11.2**	-19.6**	-10.3**
Plant height	-4.14	-5.7	-9.6**	-5.0
Ear position	-9.5**	-3.5	-12.6**	-6.3
Days to 50 % silking	0.0	-3.1**	-3.1**	-1.55
Disease severity				
Gray leaf spot	-3.3**	-12.0	-14.9**	-7.5
Turcicum leaf blight	-5.5**	-11.1**	-16.8**	-8.4
Common rust	-2.4	-4.2	-6.5	-3.3

*** Gains are statistically significant at P $\leq$ 0.01*

Table 4. Selection differential (S), responses to selection (R) and realized heritability (h^2r) achieved in different traits in two cycles of S_1 recurrent selection in *Ukiriguru* composite B maize variety.

Cycle	Days to 50% silking	Ear height (cm)	Plant height (cm)	Diseases (1-5 scale)* GLS	TLB	CR	Grain yield (t ha^{-1})
Cycle 1							
C_0 ($\bar{X}_0$)	97	201	320	2.15	2.38	1.23	6.7
$\bar{X}_{se}$	90	151	256	1.8	1.6	1.4	5.0
$\bar{X}_1$	97	182.5	307.3	2.08	2.25	1.2	7.5
$S = \bar{X}_{se} - \bar{X}_0$	7	50	64	0.35	0.78	0.17	1.72
$R = \bar{X}_1 - \bar{X}_0$	0	18.5	12.7	0.07	0.13	0.03	0.75
$h^2r = R/S$	0	0.37	0.19	0.2	0.17	0.17	0.44
Cycle 2							
C_1 ($\bar{X}$ 1)	97	182.5	307.3	2.08	2.25	1.2	7.5
$\bar{X}_{se}$	91	134	237	1.5	1.5	1.0	6.0
$\bar{X}_2$	94	162.1	289.8	1.83	2.0	1.15	8.7
$S = \bar{X}_{se} - \bar{X}$ 1	6	48.5	70.3	0.58	0.75	0.20	1.47
$R = \bar{X}_2 - \bar{X}$ 1	3	38.9	17.5	0.25	0.25	0.05	1.23
$h^2r = R/S$	0.5	0.42	0.24	0.43	0.33	0.25	0.84

*GLS = Gray leaf spot; TLB = Turcicum leaf blight; CR = Common rust; *1 indicates clean or no infection and 5 severely diseased; $\bar{X}_0$ = Mean of the parent population; $\bar{X}_1$ = Mean of cycle one; $\bar{X}_2$ = Mean of cycle two; $\bar{X}_{se}$ = Mean of families selected as parents of the respective selection cycles*

The remarkable reduction in ear height has contributed positively to improve resistance to lodging as a correlated response to selection. It was observed that high ear placement was the main character causing lodging in UCB more than tall plant height since with no much reduction in plant height resistance to lodging, though not statistically significant, improved together with 20% reduction in ear height. Similar to resistance to lodging disease resistance also improved as a positive and correlated response to selection. Severity of GLS reduced significantly from 2.2 in UCB C_0 to 1.8 in UCB S_1 C_2. In maize inheritance of resistance to GLS is governed by recessive genes of quantitative and additive nature (Ulrich *et al.*, 1990). Hence selfing followed by selection might have increased the frequency of homozygous recessive genotypes.

In addition to improvement over the parent population, UCB S_1 C_2 had significant ($P < 0.01$) grain yield benefits of 35.0% (3.0 t ha^{-1}) and 29.3% (2.6 t ha^{-1}) relative to Gibe composite 1 and Kuleni, respectively. This has clearly indicated that UCB S_1 C_2 can be used in place of these commercial open-pollinated varieties at least in the mid-altitude (1600-1800 masl) agro ecologies in the southwestern part of Ethiopia. The improvement made has also put UCB S_1 C_2 in a position to compete with the commercial hybrids, BH660 and BH670. The parent population was yielding lower than both hybrids with no statistically significant yield difference. After two cycles of selection, however, gain of 2.0 t ha^{-1} has put UCB S_1 C_2 in a position to yield higher than the two hybrids even though the yield difference was still not statistically significant. In the Ethiopian national maize breeding program it has not been a common experience to see open-pollinated varieties yielding higher than hybrid varieties. Higher yield of UCB S_1 C_2 observed in this study can be ascribed to certain phenotypic characters that have been improved to the extent that the resemblance between UCB S_1 C_2 and the two hybrids has been improved. The improvement program has removed extremely tall phenotypes with high ear placement and this has brought down the ear placement and plant height which have in turn improved resistance to lodging. In addition, being late maturing types both were competent enough in equally exploiting the longer growing period. Above all it is the efficient and comparable sink-source relationship that has empowered the improved version to be competent with the hybrids in productivity.

Considering the improved yield potential and other desirable traits UCB S_1 C_2 was proposed for release. Hence, UCB S_1 C_2 was promoted to verification trials and presented to the National Variety Releasing Committee (NVRC) evaluation for release as an open-pollinated variety. Mean data on major agronomic characters and grain yield measured in two on station and four on farm verification sites is indicated in Table 5. These data have clearly substantiated the improvement that has been observed in on station research plots. UCB S_1 C_2 has maintained its superior performance relative to the parent population and the two commercial open-pollinated varieties, Gibe Composite 1 and Kuleni. Earliness, moderate ear placement and plant height, and resistance to lodging and diseases, and attractive ear characters were found to be the desirable traits that confirmed its superior performance. Contrary to on station results mean plant and ear heights measured in verification trials showed much more improvement. Both traits showed corresponding reduction of 24.8% (87 cm) and 14.2% (32 cm) from 350 and 226 in UCB C_0 to 263 and 194 cm in UCB S_1 C_2 indicating the suitability of UCB S_1 C_2 to the real farmers' field condition. In line with this, significant improvement in resistance to lodging has been noticed. It was more interesting to see the genetic gain of 2.0 t ha^{-1} in research plot to be repeatedly measured in larger plots. This clearly indicated that genetic improvement has played significant role in improving productivity by 2.0 tons as both the parent population and UCB S_1 C_2 were evaluated under similar management and environment both in research center and farmers' field. This yield benefit is, however, limited to the mid-altitude (1600-1800 masl) agro ecologies of Jimma and Illu Ababora zones and similar areas in the southwestern part of Ethiopia. Moving this variety out of this altitudinal range in either direction may cause yield reduction. In higher altitude TLB was observed to be the limiting factor. In lower altitude the variety may grow tall and lodge because of heavy winds combined with rainfall. This recommendation has been approved by the NVRC during its meeting when the variety was officially approved for full release in February 2008. The variety was named as "*Morka*" meaning competent, to express its yield potential which is comparable with the yield potential of popular hybrid varieties in the regions.

Table 5. Mean data combined across two on station and four on farm sites in *Morka* maize variety verification trial.

No	Entry	Days to 50% ssilking	Plant height (cm)	Ear height (cm)	Diseases (1-5)* GLS	TLB	CR	Lodging (%)	Plant aspect (1-5)**	Ear aspect (1-5)**	Diseased ears (N0)	Bare tips (No.)	Grain yield (t ha^{-1})
1	Kuleni	74	270	149	2.2	2.2	1.0	9.4	3.0	2.5	15	8	5.1
2	Gibe Composite 1	76	266	123	3.2	2.6	1.5	7.5	3.0	2.6	31	10	3.8
3	UCB C_O	91	350	226	2.0	2.0	1.0	34.3	3.0	2.2	6	0	4.2
4	Morka	79	263	194	1.5	1.5	1.0	2.6	1.4	1.4	3	0	6.2

*GLS = Gray leaf spot; TLB = Turcicum leaf blight; CR = Common rust; *1 indicates clean or no infection and 5 severely diseased; ** 1 is good and 5 is poor*

4. Conclusions

It can be concluded that two cycles of S_1 recurrent selection have brought significant genetic improvement in the major agronomic characters and grain yield in UCB. The improved version was released and recommended for production with two cycles of improvement before reaching the yield plateau. This was mainly due to two reasons. First there is urgent need to have open-pollinated variety in place as an option to BH660 which is the popular hybrid in Jimma and Illu Ababora zones and the southwestern part of the country as a whole. Second it was felt important to reserve some level of variability in the population to overcome some production challenges that may come up in the future. The selection scheme used is known for improving resistance to inbreeding depression and inbred lines developed from the improved population may have better seed production potential. Hence UCB S_1 C_2 can be used as source of inbred lines in hybrid development program. However, the genetic purity of the variety has to be maintained following standard method of maintaining open-pollinated variety. The seed can be formally or informally produced on farmers' field with sufficient isolation from other maize fields. A link has already been established with the formal seed system to multiply and avail seed to users. The Ethiopian Seed Enterprise (ESE) multiplied seed on 60 ha in the main season of 2008 in Jimma and Illu Ababora zones in collaboration with the Ministry of Agriculture and Rural Development offices of the two zones. *Morka* is, therefore, distributed to farmers as of the main season of 2009 as an option to hybrid varieties.

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Coffee Leaf Rust Epidemics (*Hemileia vastatrix*) in Montane Coffee (*Coffea arabica* L.) Forests in Southwestern Ethiopia

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Abstract: Coffee *(Coffea arabica* L.) is native to southwestern Ethiopia growing as understory of the rainforests that harbor huge floral and faunal diversities. Besides drastic reduction in the forest cover and low average yield, the crop is attacked by several diseases among which coffee berry disease, coffee wilt disease and coffee leaf rust caused by *Colletotrichum kahawae, Gibberella xylarioides* and *Hemileia vastatrix*, respectively, are the major fungal diseases contributing to reduced yield in the country. The epidemics of coffee leaf rust (CLR) was monitored between July 2007 and April 2008 in Bonga, Berhane-Kontir and Yayu montane coffee forest populations of southwest Ethiopia to determine the incidence and severity of CLR and its seasonal variation in the forest coffee populations and their reaction to leaf rust in the natural habitat. Thirty coffee trees were selected from each forest (three sites within a forest) coffee population to record incidence (percent rusted leaves), severity (percent leaf area damaged) and sporulated lesion density (number of lesion per leaf, SLD) from selected six branches per tree. An average of 10-12 leaves per branch was considered to determine each disease parameter. The data were analyzed using nested design (tree under location) using SAS statistical package. The occurrence of CLR significantly varied with locations and seasons. Overall mean incidence of 31.1, 21.4 and 7.9 and SLD of 2.7, 1.8 and 0.86 occurred in Yayu, Berhane-Kontir and Bonga montane coffee forest populations, respectively. Leaf rust was low (13.9%) in July 2007 and high (29.6%) in January 2008. Significant variation observed among each coffee tree within a location and season significantly interacted with both location and coffee trees within a location. The mean rust incidence varied from 0.36 to 18.5% in Bonga, 1.8 to 49% in Berhane-Kontir, and 11.8 to 62.6% in Yayu forest coffee populations. The corresponding severity ranged from 0.08 - 1.2%, 0.24 - 1.7% and 0.91 - 3.3% whereas the SLD varied from 0.08 - 1.9, 0.33 - 3.65 and 1.5 - 5.9% in that order. The observed heterogeneity of forest coffee populations to leaf rust in the field under native agro-ecology provides an opportunity to develop resistant varieties among the enormous forest coffee genetic resources and at the same time calls for strategic multi-site in situ conservation to rescue and maintain the present genetic variation and enhance co-evolutionary processes. The selected forest coffee trees that showed promising results should be further investigated for their possible value for future utilization. The location-season and coffee tree-season interaction effects necessitate characterization of *Hemileia vastatrix* races prevalent at each location and insist strategic variety development for contrasting environments.

Keywords: Coffee Leaf Rust; Ethiopian Coffee; Epidemics; *Hemileia Vastatrix*; Incidence; Seasonal Variation; Severity

1. Introduction

Coffee (*C. arabica* L.) is the only tetraploid species representing the genus *Coffea* and native to semi-humid highland forests of southwest Ethiopia (Sylvain, 1958; Melaku, 1982; Wintgens, 2004). This crop is dominantly grown traditionally under rainfed in Afro-montane rainforest coffee belt generally categorized into sub humid hot to warm low to mid highland mountains/SH_{1-7}; sub humid tepid to cool mountains/SH_{2-7}; humid-hot to warm low to mid highland mountains/H_{1-7}; and humid tepid to cool highland mountains/H_{2-7} (Paulos and Tesfaye, 2000).

The crop is produced under forest, semi-forest, garden and plantation production systems which account for about 10, 35, 50 and 6% of the total production in the country (Workafes and Kassu, 2000; Alemayehu *et al.*, 2008; MoARD, 2008). Recent report indicated that Ethiopia is the fifth largest coffee producer in the world after Brazil, Vietnam, Indonesia and Colombia (Sette, 2011). It remains as a backbone of Ethiopian economy contributing 41% of foreign exchange, sustaining more than 1 million farming household, absorbing 25% employment opportunity and 10% of government revenue (Petit, 2007; MoARD, 2008). Moreover, its genetic resources contained in the rainforests were valued to around 1458 and 420 million USD at 5 and 10% discount rate, respectively (Hein and Gatzweiler, 2005).

The crop is vulnerable to several diseases among which coffee berry disease caused by *Colletotrichum kahawae* Waller and Bridge, coffee wilt disease caused by *Gibberella xylarioides* Heim and Saccas and coffee leaf rust caused by *Hemileia vastatrix* Berk. and Br., are the major fungal diseases in Ethiopia. Coffee leaf rust (CLR) is one of the most important diseases of *C. arabica* in the world (Kushalappa and Eskes, 1989). It belongs to the family of Pucciniaceae in the order of Uredinales of the class Basidiomycetes. The genus has unknown pycnidial and aecidial stages and only the dikaryotic uredospores are responsible for the disease development (Kushalappa and Eskes, 1989). The pathogen exists in different physiologic groups and over 40 different races have been identified all over the world so far (Muller *et al.,* 2004). Among these, five physiologic races were reported to exist in Ethiopia (Meseret *et al.*, 1987).

The uredospores germinate in 2-4 hours under optimum conditions (22 ^{0}C and 100% RH) and complete the penetration process within 24-48 hours. Since the spores germinate only in the presence of free water, epidemics are prevalent during the wet season. Wind is responsible for the long distance dispersal while rain is

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important for dissemination of the disease within the coffee canopy (King'ori and Masaba, 1994). The pathogen survives primarily as a mycelium in the living tissues of infected leaves.

The disease has existed in Ethiopia for long time without ravaging *C. arabica* plantations as in other countries. The long-term coexistence of coffee and rust (Eskes, 1989), high genetic diversity and high level of resistance (Van der Graaff, 1981), low average productivity associated with shade and existence of antagonistic biological agents might have maintained rust at low level. Meseret (1996) evaluated large number of coffee accessions including coffee berry disease (CBD) resistant selections and reported existence of partial resistance to CLR. Similarly, Girma and Chala (2009) tested large number of Arabica coffee collections for resistance to CLR and reported existence of significant differences among the collections. Despite the availability of effective fungicides and resistant varieties for the control coffee leaf rust, it may still cause losses varying between 10 and 40% in different countries (Silva *et al.,* 2006).

Although the Ethiopian montane rain forests are hosting large gene pool of *C. Arabica,* they are under severe threat of extinction. According to recent reports, the forests are disappearing at an alarming rate of 100,000-120,000 hectare (ha) per annum (Simayehu *et al.*, 2008). Such overwhelming Arabica forest coffee destruction, and its narrow genetic basis outside Ethiopia, has initiated an *in situ* coffee conservation accompanied with its characterization for agronomic, breeding, and disease and insect pests resistance traits. Subsequently, the reaction of forest coffees to coffee berry and wilt diseases (Arega, *et al.*, 2008), the insect pest dynamics and their natural enemies in the forest (Chemeda, 2007) and ecophysiological aspect (Taye and Burkhardt, 2008) of forest coffee populations were evaluated. However, the forest coffee has not been studied in detail for its reaction to leaf rust to develop resistant varieties as well as to focus on conservation of wide genetic base of the forest areas. Moreover, knowledge of seasonal occurrence of CLR is essential for developing effective disease management tactics, establishing selection strategy, and identifying an optimum time of assessment for genotype screening under field conditions. Data based on epidemiological studies are useful to develop effective management strategies. However, only limited work has been done so far in the forest coffee-rust pathosystem. Taking these recurring situations into consideration, the specific objectives of this study were to determine the incidence and severity of CLR in the forest coffee and to describe the seasonal variation of CLR in the forest coffee populations.

2. Materials and Methods

2.1. Study Area Description

Studies on coffee leaf rust (CLR) were conducted in Berhane-Kontir (Sheko District), Bonga (Gimbo District), and Yayu (Yayu District) montane forest coffee populations found in southwest Ethiopia. Both the Berhane-Kontir and Bonga forests are found in the Southern Nations, Nationalities and Peoples' Region (SNNPR) in Bench-Maji and Kaffa Zones, respectively, while the Yayu forest is found in Illubabor Zone of the Oromia Regional State (Table 1; Figure 1). The forests form part of national coffee forest protection priority areas among which about 20,000 ha of Berhane-Kontir, 18,600 ha of Yayu and 5,500 ha of Bonga forest were identified for biodiversity and forest coffee conservation in the country (Paulos and Demel, 2000). The forest soil is clay loam in texture. These rainforests are situated at an altitude range between 1100 and 1870 meters above sea level (masl) with an average annual temperature varying from 19.1 to 22 ^{0}C and annual rainfall from 1472-1599 mm (EMSA, 2007) (Table 1).

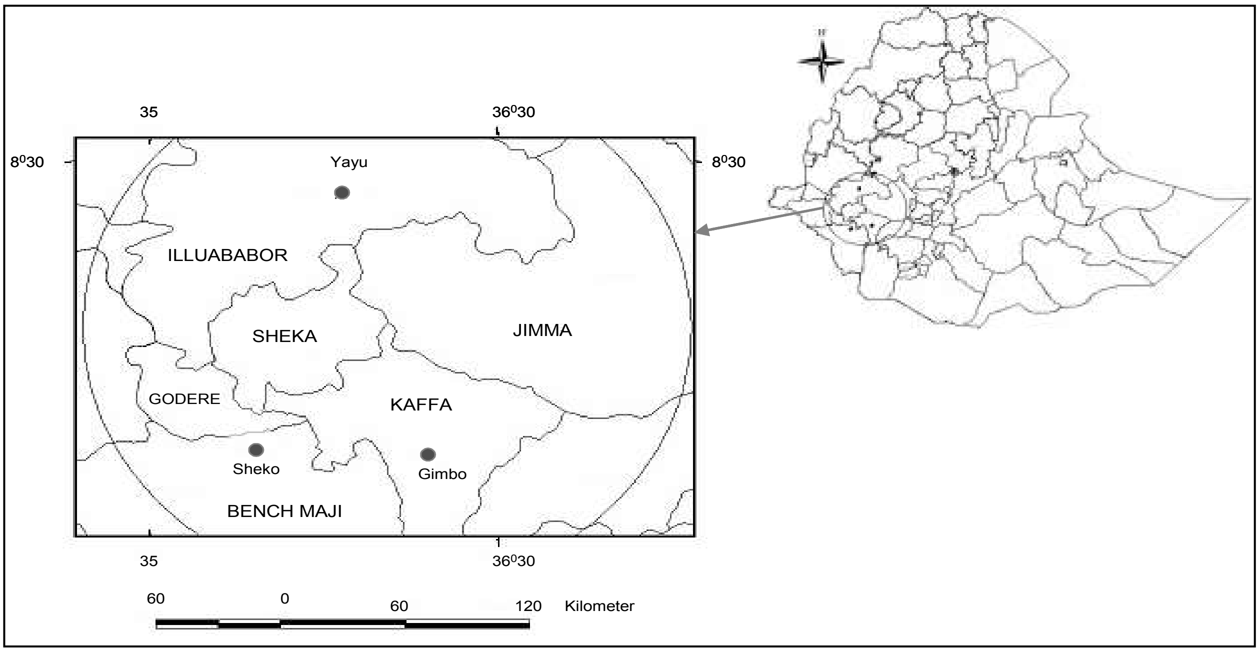

Figure 1. Map of Ethiopia showing coffee leaf rust study sites (●) in 2007 and 2008 in southwestern Ethiopia.

Table 1. Description of coffee leaf rust disease study sites in the montane coffee forest populations of southwestern Ethiopia.

Study area	Bonga[a]	Berhane-Kontir[a]	Yayu
Region	SNNPR	SNNPR	Oromia
Zone	Kaffa	Benchi-Maji	Illuababor
District	Gimbo	Sheko	Yayu
Coordinate (N)	7° 17´-7° 20´	7° 04´-7° 07´	8° 23´
(E)	36° 03´-36° 13´	35° 25´-35° 26´	35° 47´
Altitude (masl)	1620-1870	1110 -1180	1490-1497
Annual rainfall (mm)	1560.7	1535.4	1599
Mean temperature (^{0}C)	19.2	22.0	20.6

Note: a = Southern Nations, Nationalities and Peoples' Region

2.2. Assessment of Coffee Leaf Rust in Forest Coffee Populations

Survey of CLR disease was conducted in July 2007 (beginning of the rainy season, *Kiremt*), October 2007 (beginning of the dry season, *Tseday)*, January 2008 (middle of the dry season, *Bega*) and April 2008 (beginning of the short rainy season, *Belg)* to determine the seasonal variation of leaf rust in the Berhane-Kontir, Bonga and Yayu montane forest coffee populations. Three specific fields of about 50 m x 50 m which were assumed to represent each forest coffee populations were selected from each of these montane forest coffee populations based on accessibility, coffee tree uniformity and information on previous work on CBD and coffee wilt disease (CWD). A sample size of 10 trees with relatively uniform age were systematically selected at a distance of about 6-8 m interval within the sampling plot from each forest coffee site yielding a total of 30 coffee trees from each location. A sample size consisting of all the leaves in four simple branches of 4-6 plants was reported to have the least coefficient of variation (CV, %) in a plot of 100 plants (Kushalappa, 1989) and similarly, Meseret (1996) used five trees per site as determined with low coefficient of variation. Based on these facts, three pairs of branches each pair representing upper, middle and lower canopy layers of the coffee plant were selected and marked with label to assess CLR incidence, severity and sporulating lesions per leaf on a total of 270 pairs of branches in the three locations.

Rust incidence expressed in percentage was determined as the number of diseased leaves per branch. Similarly, rust severity as proportion of leaf area rusted was estimated on all leaves of sampled branch using diagrammatic scale developed by Kushalappa and Chaves (1980). In the diagrammatic scale, 1, 3, 5, 7 and 10 indicates 1, 3, 5, 7 and 10% of leaf area rusted, respectively. Any rust severity on the leaves was estimated by making a cumulative count of each sporulating lesion area per leaf (Figure 2) following the scale of Kushalappa and Chaves (1980). The sporulating lesion density (SLD) was determined as the number of sporulated lesions per infected leaves.

The data were summarized on excel spreadsheet software and the mean rust incidence, severity and SLD were analyzed for each forest coffee tree. Analysis of variance (ANOVA) was performed using single stage nested design (tree was nested under location) and time of rust assessment made (season) was considered as cross effect over the locations. Multiple range comparison tests were applied wherever appropriate using the Fisher protected significant difference test (LSD) at a probability level of 5%. The statistical analysis was performed using SAS statistical package (SAS, 2001).

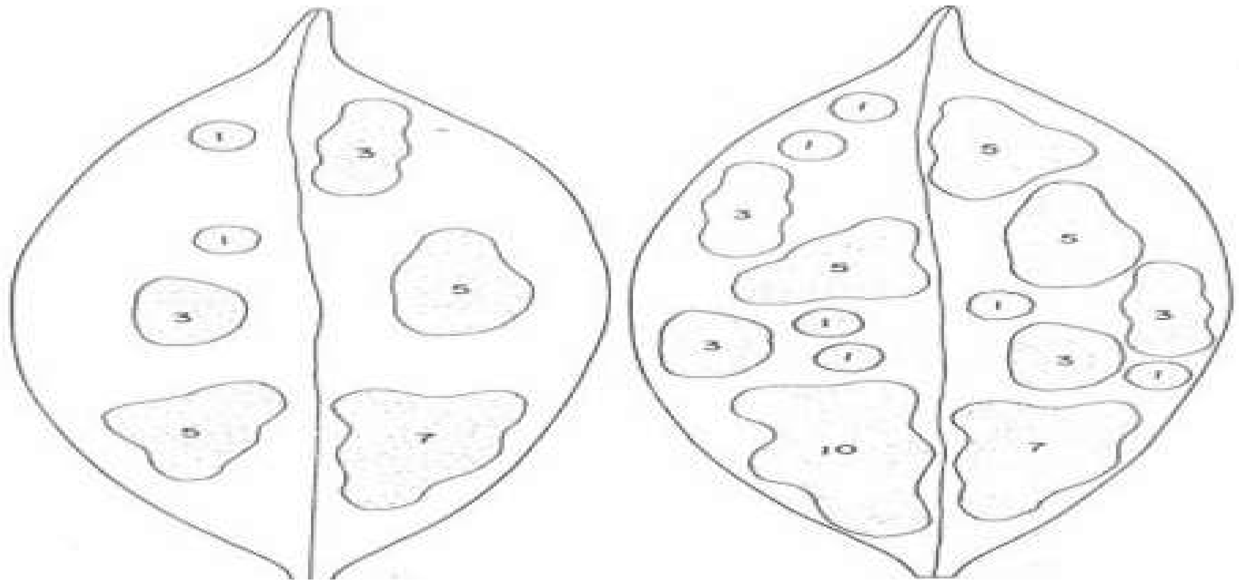

Figure 2. Assessment key for percent coffee leaf area rusted due to *Hemilei vastatrix* (Adopted from Kushalappa and Chaves, 1980).

3. Results

Coffee leaf rust assessment made in three southwestern Ethiopian montane coffee forest populations revealed its presence in all fields assessed differing in magnitude with time (season) and location of the forest coffees. A significantly ($P < 0.001$) high (31.1%) rust incidence was recorded in Yayu followed by Berhane-Kontir (21.4%) and Bonga (7.9%) forest coffee populations. The mean rust incidence varied from 18.2-46.2 in Yayu, 7.3-36.6 in Berhane-Kontir and 5.9-9.1% in Bonga between July 2007 and April 2008 (Figure 3). The overall incidence was high (29.6%) in January and April (22.7%) in Yayu and Berhane-Kontir, respectively, while it was low in July (13.9%) in Berhane-Kontir and October (14.3%) in Yayu. Rust incidence was consistently higher in Yayu and Brerhane-Kontir and lower in Bonga forest during all the four months (Figure 4).

The reaction of coffee trees to CLR infection within a location was significantly different ($P < 0.001$). The mean rust incidence varied from 0.36-18.5% in Bonga, 1.8-49% in Berhane-Kontir, and 11.8-62.6% in Yayu forest coffee populations (Table 2). There was no coffee tree that showed greater than 20% rust incidence in Bonga. On the other hand, there were only three coffee trees (Y2, Y14, and Y27) that had less than 19% rust infection among the evaluated Yayu forest coffee populations (Table 2). Coffee tree infection by CLR varied from among months and some forest coffee trees had as high as 69% rust incidence in January 2008 but less than 3% incidence in July 2007. Similarly, some coffee trees had high incidence (40%) in October 2007 and low rust (10%) in July 2007 (data not shown). This subsequently resulted in significant interaction and variation with both coffee tree and forest locality.

Significant difference ($P < 0.001$) was observed in the level of SLD across forest coffee populations as well as selected months. A mean SLD value of 2.66, 1.79 and 0.86 were calculated for Yayu, Berhane-Kontir and Bonga, respectively (Table 2) but it ranged from 2.2-3.5 in Yayu, 1.4-2.4 in Berhane-Kontir and 0.45-1.1 in Bonga forest coffee populations between July 2007 and April 2008. The SLD was consistently higher in Yayu and Brerhane-Kontir and lower in Bonga forest during all the four selected months (Figure 4). Each individual tree also varied with amount of SLD accommodated per tree per leaf and ranged from 0.08-1.90, 0.33-3.65 and 1.50-5.90% in Bonga, Berhane-Kontir and Yayu forest coffee populations, respectively (Table 2).

The pattern of CLR severity in the forest coffee population essentially followed SLD as only the visible sporulating lesions were accounted in the severity estimation. The mean rust severity varied from 0.08-1.20% in Bonga, 0.24-1.70% in Berhane-Kontir and 0.91-3.30% in Yayu forest coffee populations (Table 2) while an overall rust severity of 0.55%, 0.99 and 1.40 were calculated for the respective forests coffee populations (Table 2 and Figure 3).

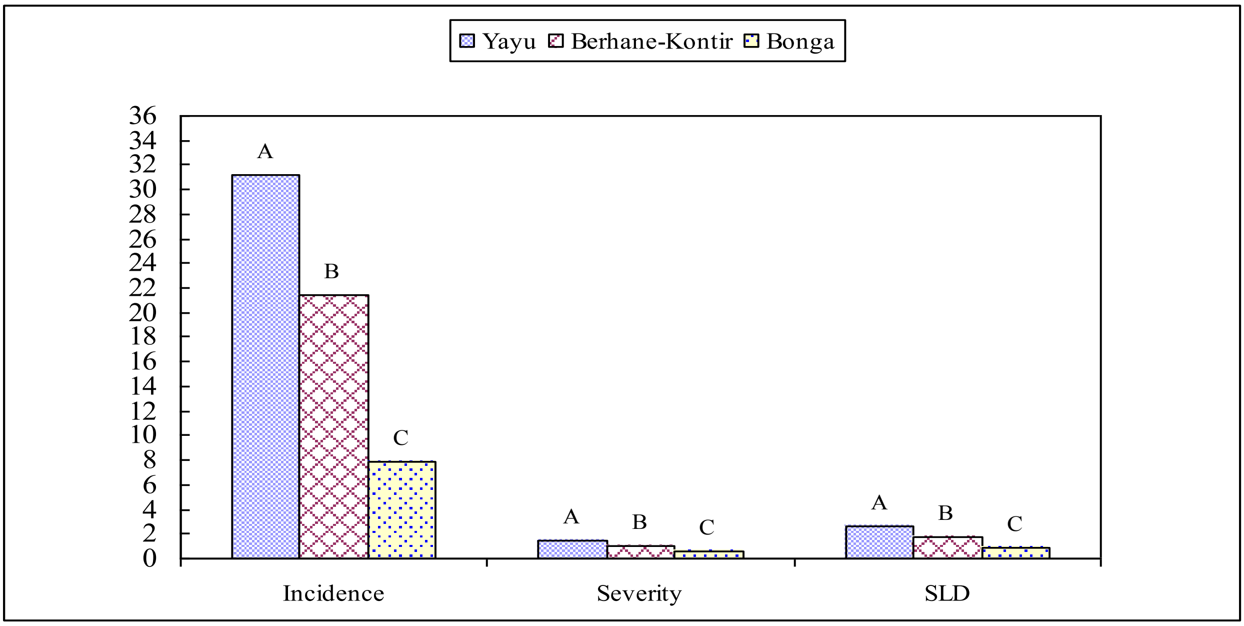

Figure 3. Coffee leaf rust incidence (%), severity (%) and sporulation lesion density (SLD) in three montane forest coffee populations of southwestern Ethiopia (July 2007-April 2008). Values were mean of four assessments (July 2007, October 2007, January 2008 and April 2008) for each disease parameter at each location. Bars with the same letters within each disease parameter are not significantly different according to LSD at $P = 0.05$.

Table 2. Coffee leaf rust incidence (I), severity (S) and sporulated lesion density (SLD) in three montane coffee forest populations (B, BK and Y) of southwestern Ethiopia from 2007 - 2008.

	Bonga (B)				Berhane-Kontir (BK)				Yayu (Y)		
Tree	I	S	SLD	Tree	I	S	SLD	Tree	I	S	SLD
B1	6.65	0.48	0.58	BK1	13.49	0.71	1.15	Y1	62.55	3.34	5.93
B2	18.52	0.99	1.35	BK2	23.11	0.71	1.23	Y2	18.51	1.59	3.60
B3	6.77	0.59	0.89	BK3	32.07	1.30	2.27	Y3	21.71	1.12	1.87
B4	5.60	0.45	0.58	BK4	20.31	1.27	1.74	Y4	30.87	1.36	2.58
B5	4.74	0.34	0.48	BK5	6.38	0.40	0.55	Y5	28.14	1.19	2.47
B6	10.70	0.59	0.88	BK6	12.38	0.90	1.25	Y6	38.16	1.30	2.60
B7	7.76	0.40	0.70	BK7	11.06	0.67	1.09	Y7	29.14	1.25	2.11
B8	8.00	0.89	1.41	BK8	24.67	0.88	1.34	Y8	62.61	2.08	4.14
B9	11.27	0.66	1.00	BK9	25.68	1.02	2.00	Y9	19.79	1.96	3.23
B10	6.20	0.45	0.82	BK10	1.80	0.24	0.33	Y10	27.18	0.96	1.76
B11	8.45	0.77	1.19	BK11	16.73	0.87	1.35	Y11	30.01	1.34	2.17
B12	8.70	0.46	0.74	BK12	17.58	0.90	1.51	Y12	26.86	0.92	2.06
B13	14.29	0.73	1.09	BK13	19.39	0.95	1.44	Y13	35.98	1.45	3.12
B14	7.03	0.59	0.93	BK14	16.46	0.96	1.45	Y14	17.04	1.31	1.96
B15	13.54	0.81	1.32	BK15	3.36	0.24	0.34	Y15	25.38	1.61	2.79
B16	7.15	1.15	1.90	BK16	29.72	0.92	1.64	Y16	34.74	1.30	2.71
B17	10.25	0.52	0.98	BK17	7.78	1.06	1.70	Y17	33.61	0.91	1.70
B18	9.28	0.44	0.65	BK18	19.98	0.88	1.36	Y18	24.99	0.83	1.50
B19	7.88	0.50	0.88	BK19	7.27	0.68	1.13	Y19	35.21	1.19	3.15
B20	16.54	0.97	1.68	BK20	13.14	0.67	1.05	Y20	22.86	1.06	2.19
B21	4.30	0.66	1.08	BK21	16.12	1.10	1.88	Y21	27.52	1.06	1.96
B22	1.12	0.20	0.31	BK22	28.86	1.23	2.42	Y22	50.38	1.76	3.59
B23	3.19	0.38	0.56	BK23	45.90	1.52	3.36	Y23	35.99	2.05	3.18
B24	1.27	0.18	0.24	BK24	48.34	1.73	3.81	Y24	33.69	2.02	3.97
B25	10.70	0.47	0.72	BK25	47.99	1.49	2.89	Y25	34.05	1.36	2.33
B26	1.14	0.18	0.23	BK26	15.04	1.28	2.98	Y26	27.21	1.04	1.86
B27	8.37	0.45	0.63	BK27	27.50	1.41	2.96	Y27	11.87	0.91	2.04
B28	0.36	0.08	0.08	BK28	20.33	1.23	2.30	Y28	26.70	1.09	2.14
B29	3.25	0.39	0.52	BK29	20.60	0.89	1.48	Y29	23.01	1.13	2.29
B30	14.34	0.73	1.49	BK30	49.07	1.67	3.65	Y30	38.00	1.37	2.75
Range	0.36-18.5	0.08-1.2	0.08-1.9		1.8-49	0.21 - 1.7	0.33-3.65		11.8-62.6	0.91- 3.3	1.15-5.9
Mean	7.91	0.55	0.86		21.40	0.99	1.79		31.12	1.40	2.66
LSD(0.05)	11.65	0.697	1.28		11.65	0.697	1.28		11.65	0.697	1.28

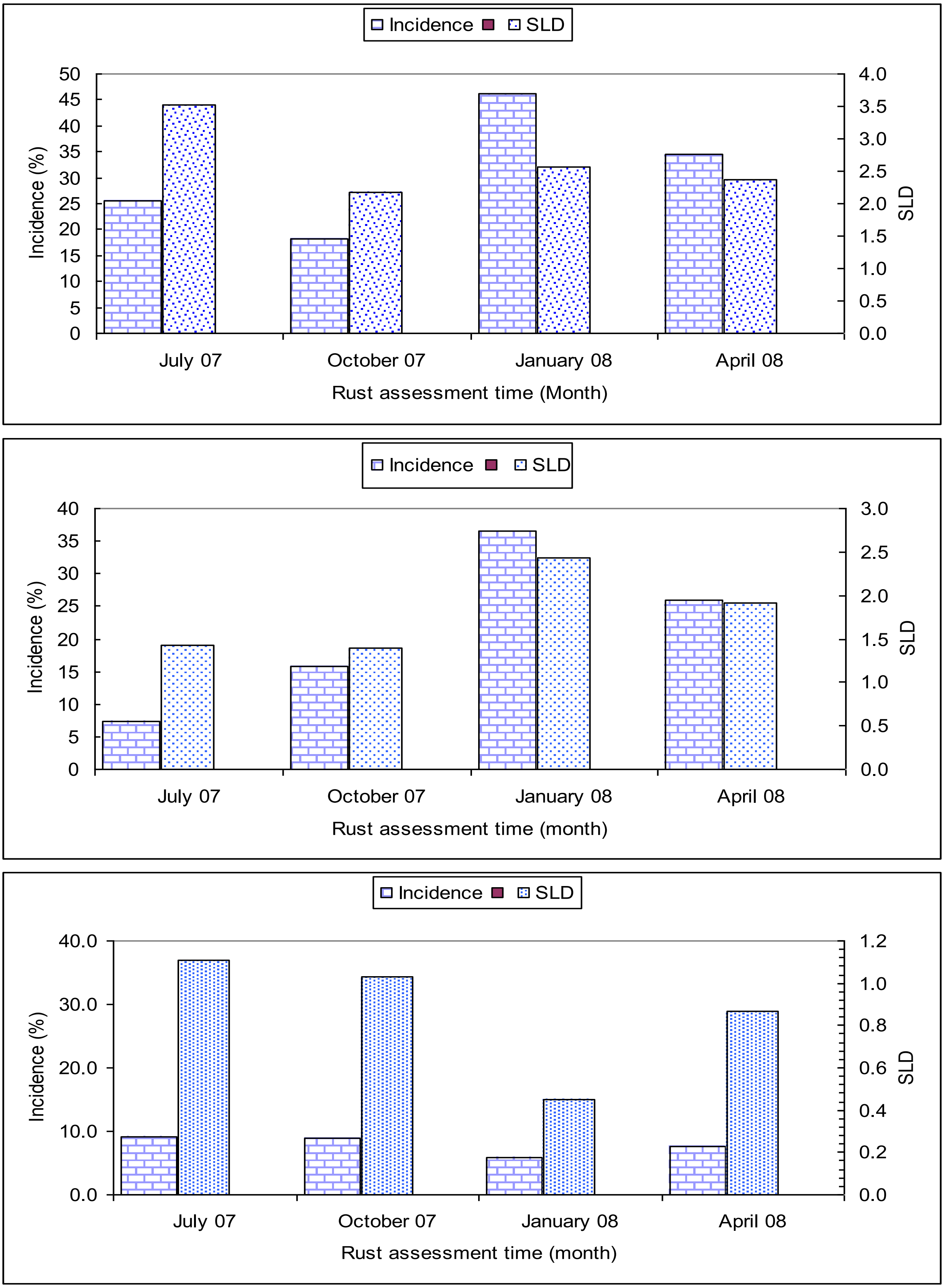

Figure 4. Coffee leaf rust incidence (I) and sporulated lesion density (SLD) in Yayu (a), Berhane-Kontir (B) and Bonga (c) over four selected months during 2007 and 2008.

4. Discussion

4.1. Coffee Leaf Rust in the Forest Coffee Populations

The occurrence of CLR varied from location to location and its incidence was high in Yayu followed by Berhane-Kontir and Bonga forest coffee population. Arega *et al.* (2008) also reported higher rust incidence in Yayu than in Bonga forest coffee population. These variations across forests were attributed to human activities, altitude and environmental gradients across the location. Inadvertent human activities such as transformation of the intact natural forest to semi-forest production system for improving productivity and coffee farmland expansion, exclusive thinning of over story trees, slashing of weeds and shrubs (at least twice a year in Berhane-Kontir), adjusting coffee tree population using self-regenerated coffee trees and seedlings might have increased the transmission and contact of the rust pathogen within the forest coffee trees. Soto-Pinto *et al.* (2002) reported significantly higher rust incidence in plots where paths were present than plots without paths in the forest. Higher rust incidence predominantly occur in plantation and garden than in forest coffee (Meseret, 1996; Eshetu *et al.,* 2000) and intensive production system (Avelino*,* 2006) implying variation in rust intensity with coffee management practices.

The low SLD in the Bonga montane forest coffee population is mainly due to poor light penetration into the dense canopy cover of forest trees and minimal disturbance of the intact forests. This resulted in lower infection frequency and lesion expansion on the leaves that subsequently resulted in low SLD and subsequent rust severity. Thus, management practices and variable crop bearing potential from location to location and tree canopy stature might have influenced leaf rust. It is assumed that higher yields and high light intensity predispose coffee plants to rust infection (Eskes, 1989). According to Avelino *et al.* (2004) and Avelino (2006), both rust and yields did not reach high level under dense shade indicating that shades reduce leaf rust through keeping yields at low levels.

The differences in rust incidence, severity and SLD across the forest coffee populations were also related to variation in altitude. Studied fields in Yayu and Berhane-Kontir forest coffee populations were situated at an altitude less than 1200 masl, whereas the Bonga forest fields were found between 1620 and 1870 masl. Simple linear correlation analysis based on data set in this report revealed inverse relationship between rust incidence and altitude but not significant. Nevertheless, the effect of altitude on the development of CLR was reported by several researchers (Kushalappa, 1989; King'ori and Masaba, 1994; Brown *et al.,* 1995; Meseret, 1996). Rust incidence decreased with increase in altitude and, at higher altitudes, the low night temperatures followed by still low day temperatures resulted in a longer latent period and slower epidemic, while it hasten rust development in low altitude belts.

The observed high location and seasonal variation and interaction realistically discerned the difference of each coffee tree from location to location grown under diverse environment. It also indicates existence of variation in susceptibility of coffee trees to leaf rust over months, which may be due to variation in conduciveness of environmental factors that directly or indirectly influence leaf rust development, effect of leaf age, and variation in expression of susceptibility to leaf rust.

4.2. Seasonal Variation of Coffee Leaf Rust

The seasonal variation of rust in the forest could be categorized into two major distinct seasons based on crop phenology and pattern of rainfall prevailed in the forest coffee populations as there are only two main distinct (dry and wet) seasons in Ethiopia, namely winter and summer which are dry and wet seasons, respectively. The spring (onset of short rains) and the autumn (onset of dry period) are indistinctively linked to the formers as a transition periods. Rust was initiated during the onset of rain and further amplified in subsequent rainy season and attained highest values at later stage corresponded to the onset of dry season in the forests.

The occurrence of mean monthly temperature varying from 17.7-18.4 ^{0}C in Yayu and 20.1-20.7 ^{0}C in Berhane-Kontir and relative humidity of 79.9-82.7% in Yayu and 79.7-88.7% in Berhane-Kontir that prevailed within the forest coffee canopy during November 2007 to January 2008 might have favored CLR development in both locations (Table 3). It has been reported that rapid development of rust pustules and heavy sporulations are intensified by sunny warm weather conditions accompanied by intermittent rains (Muthappa *et al.*, 1989). The seasonal fluctuation of rust severity observed in the study areas is in agreement with previous reports where maximum leaf rust occurred in November to December corresponding to the onset of dry season and harvesting time (Meseret, 1996; Eshetu *et al.,* 2000). Moreover, low rust incidence has been reported for the period from June to September that increased to high level during November to March in the forest coffee populations (Arega *et al.*, 2008).

Furthermore, abscission of senescent leaves, sustaining of infected leaves over an extended period serving as source of uredospores, and insignificant leaf formation in dry season might have drastically elevated rust in the relatively dry period. It is reported that both older and newly formed young leaves are resistant to rust infection, whereas young leaves of an intermediate age are susceptible to rust (Eskes, 1983; 1989; Meseret, 1996). Younger leaves are found to be immune to infection due to absence of well-developed stomata (McCain and Hennen, 1984). On such leaves, the fungus fails to recognize stomata for infection to take place (Coutinho *et al.*, 1994). Besides, the hydrophobic nature of young leaf surface may hinder uredospore germination and penetration processes.

Coutinho *et al.* *(*1994) observed no spore production on older leaves. Similarly, the inhibition of *H. vastatrix* uredospore germination has been reported to take place due to host metabolites induced by non-pathogenic fungi (Martins *et al.,* 1986) and endophytic bacteria (Shiomi *et al.*, 1998) as well as hyperparasitization by *Verticillium* spp. (Meseret, 1983; Eskes, 1989; King'ori and Masaba, 1994). The longer lifespan of forest coffee leaves grown under shade in undisturbed forests are privileged to accommodate large populations of such resident micro-organisms that either antagonize or create antifungal environment unconducive in the phyllosphere.

Generally, coffee trees were rarely free from rust infection; rather both sporulating and non-sporulating lesions were observed with low sporulation intensity and SLD. Eskes (1983) indicated that many coffee plants in Ethiopia do not have any recognizable major resistance gene and the resistance of C. arabica to rust may be due to minor genes. These minor genes are sensitive to environmental factors, such as light intensity and temperature. In *C. canephora*, leaves grown under shade and exposed to sun showed resistant and susceptible reactions, respectively (Eskes, 1983). Significant variation in reaction to leaf rust across season in both Arabica and Robusta coffee were also reported (Eskes, 1983; Dakwa, 1987).

Table 3. Temperature and relative humidity measured within the forest coffee tree canopy at Yayu and Berhane-Kontir forest coffee populations.

	Yayu		Berhane-Kontir	
Month and year	Temperature (^{0}C)	Relative humidity (%)	Temperature (^{0}C)	Relative humidity (%)
June 2007	18.81	52.58	20.95	74.75
July 2007	18.15	73.54	20.26	77.05
August 2007	18.14	69.12	19.85	65.24
September 2007	18.43	70.42	19.92	88.37
October 2007	18.00	79.87	20.11	82.39
November 2007	18.38	82.74	20.65	79.73
December 2007	17.70	81.45	20.24	88.66
January 2008	18.84	76.76	21.01	78.18
February 2008	20.03	70.37	21.48	67.10
March 2008	20.99	68.66	21.85	73.04
April 2008	20.28	80.80	21.31	67.93
Mean	18.89	73.30	20.69	76.59

In summary, coffee leaf rust was present in all assessed forest coffee populations, but significantly varied from location to location and among months as well. The level of coffee tree infection by CLR was also significantly varied among each other indicating variability of each coffee tree from location to location and within a location in response to rust infection. The observed significant coffee tree by month interaction implied variation in conduciveness of environment for rust development over time (month). This may also emanate from the existence of quantitative variations in both host and pathogen in different environmental combinations.

The significant variation of indigenous forest coffee trees in reaction to CLR, its responsiveness to environmental instability and variation in leaf age might have synergistically induced significant forest coffee tree-environment-interaction which is little understood under natural pathosystem. In these recurring natural rust forest coffee system, coherent investigations with introduction of modifications into the natural system is suggested. The interaction effects also necessitate characterization of *Hemileia vastatrix* races prevalent at each location to persevere strategic variety development for contrasting environments. The existence of heterogeneous montane coffee forests to rust in the field under native agro-ecology is an asset to develop resistant varieties among the enormous forest coffee genetic resources and calls for strategic *in situ* conservation to rescue and maintain the present variation and encourage co-evolutionary processes.

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Relationships between Plant Biomass and Species Richness under Different Farming Systems and Grazing Land Management in Montane Grasslands of Kokosa District, Southern Ethiopia

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Abstract: The study was conducted in a montane grassland of Kokosa District, West Arsi Zone of Oromia Region, southern Ethiopia. The objective of the study was to investigate the relationships between aboveground plant biomass and species richness in three farming systems and four grazing management systems. A total of 180 quadrats (each 1 m x 1 m) were sampled in the three farming systems (dominant livestock-*enset*, *enset*-livestock and *enset*-livestock-cereal) and four grazing management systems (communal, enclosure, stream bank and benchmark). All the farming system and grazing management have different management practices. Plant species composition and aboveground plant biomass at different sites were quantified. Altogether 50 plant species (34 grasses, 4 legumes, 3 sedges and 9 forbs) were recorded in the montane grassland of Kokosa District. Even though the majority of the plant species share the different farming systems and grazing management practices, the highest number of species (39) was recorded in the *enset*-livestock farming system, whereas the lowest (33) species were recorded in the *enset*- livestock-cereal farming system when all the grazing management and farming systems were combined. Significantly, the highest species richness (4.9 species m^{-2}) was recorded in the enclosure grazing management site whereas the lowest (3.4 species m^{-2}) was recorded in the benchmark grazing site when all grazing sites and farming systems were combined. The relationship between species richness and biomass was detected in the montane grassland. There was significant difference ($P \leq 0.05$) in species richness for a combination analysis of farming system by grazing management system of the montane grassland. The highest biomass was recorded in the benchmark grazing management sites while the lowest was recorded in the communal grazing sites. On the contrary, maximum species richness was found in the enclosure grazing management sites which had intermediate biomass yield and the lowest species richness was recorded in the benchmark grazing areas with the maximum biomass records. Thus, species richness was observed first to ascend along with biomass increment up to 1932 kg ha^{-1} and then declined at constant increase of biomass. An increase in biomass in the benchmark grazing sites was not accompanied by an increase in species richness suggesting the dominance of few species in these sites. The rationale behind this might be due to the competitive exclusion of the less competent species from the community at peak biomass production.

Keywords: Biomass; Farming System; Grazing Management; Montane Grassland; Species Richness

1. Introduction

Species richness is the most commonly reported diversity measurement within the community (Sanderson *et al*., 2004). Variation in the patterns of species richness across geographical and environmental gradients has long attracted the interest of ecologists. As a result, several theories of species diversity have so far been advanced (Tilman, 1982; Huston, 1994; Rosenzweig, 1995; Gaston, 2000).

Investigation on the relationships between species richness and biomass or productivity has been a central focus in the community ecology (Mittlebach *et al.,* 2000; Cornwell and Grubb, 2003; Fox, 2003; Venterink *et al.,* 2003). This relationship has been investigated since the mid-1960s, but the causal mechanisms have been in dispute for long period (Oksanen, 1996; Brocque and Buckney, 2003). The relationship between herbaceous biomass and richness often has a hump-shape with a peak in species richness at a low to intermediate level of biomass (Grime, 1997). At a very low level of biomass, richness is primarily limited by the inability of a species to survive the abiotic conditions. In this range, an increase in biomass reflects a decrease in the harshness of the environment. Above some point roughly corresponding to the peak species richness, the abiotic environment is presumably amenable to most species.

At higher levels of biomass, the decline in species richness is believed to be due to competitive exclusion (Grime, 1973; Huston, 1994). Rosenzweig (1995) emphasized that it is the decline in species richness at high biomass level that is the unsolved puzzle, whereas the positive correlation between richness and biomass is inevitable and some authors report as more biomass, more individuals, and higher probability for more species (May, 1975; Oba *et al*., 2001). Accordingly, the decline of species richness at high biomass production levels is the crucial question for its application in conservation and management of grassland (Van der Maarel, 1997; Oba *et al*., 2001).

Several studies have indicated that the relationship may differ when a range of different habitats are analyzed together (Gross *et al*., 2000; Virtanen *et al*., 2000; Oba *et al*., 2001). Thus, regional differences in species richness for a community type should be observed at all spatial scales. Species richness is correlated with productivity in most situations (Huston, 1994; Rosenzweig, 1995). In this

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regard, most of the studies, where biomass has been related to species richness, have been done in temperate grasslands (Waide *et al.*, 1999; Rydin and Barber, 2001) and wetlands (Grace and Jutila, 1999). Moreover, the relationship may differ depending on the geographical or taxonomical contexts the mechanisms underlying it being still unclear (Rosenzweig and Abramsky, 1993; Gaston, 2000). Cornwell and Grubb (2003) concluded that as ecology is a science of 'contingent generalizations', studies in varied biomes must continue to refine knowledge about where, at what scale and for which taxa the relationship of species richness and biomass is unimodal. However, no study has, to the best of our knowledge, evaluated the relationship between biomass and species richness in montane grasslands in Ethiopia. Therefore, the current study was designed to investigate the relationships between biomass and species richness in the montane grasslands of the Kokosa District under varied grazing management and farming systems.

2. Materials and Methods

2.1. Description of the Study Area

2.1.1. Geographical Location and Climate

The study was conducted in the Kokosa District in West Arsi Zone of Oromia Region, Southern Ethiopia (Figure 1). The mean altitude of the District is 2650 meters above sea level (masl) with a mean annual rainfall of 1600 mm and mean annual temperature of 16 ºC. The District is characterized by a bimodal rainfall (two **t**imes showers within a year) with a total rainy season lasting over eight months in a year. The main rainy season is from late March to September. The short rainy season occurs from October to November. The typical dry season is from December to February.

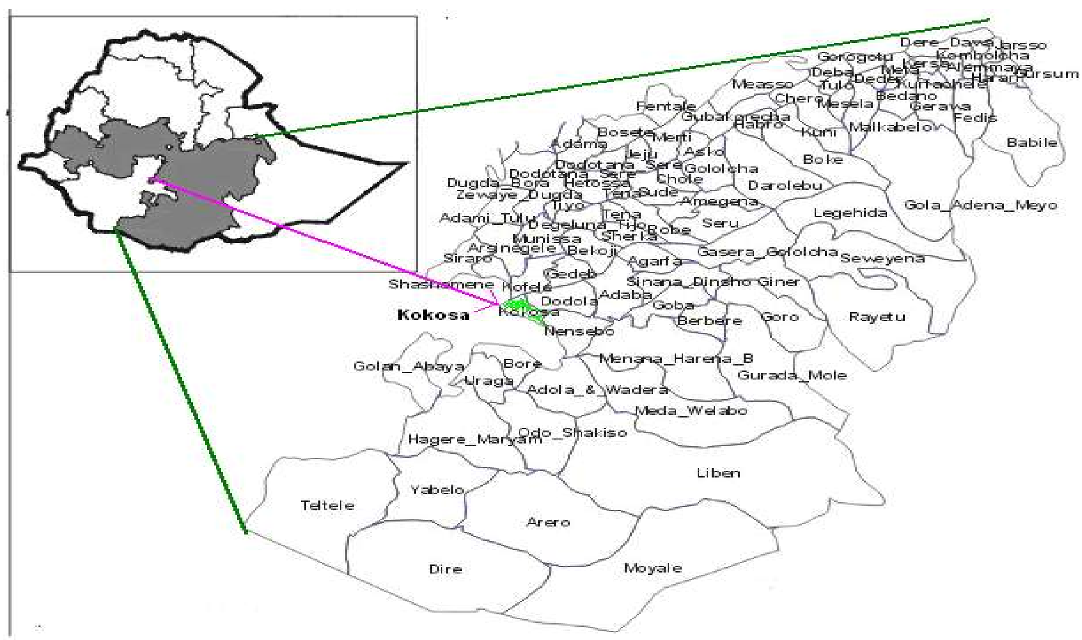

Figure 1. Location map of the study area.

2.1.2. Topography and Vegetation

The topography of the District consists of complex features of landscape comprising of medium steep to gentle slope, hilly, mountainous and undulating features. Seasonally waterlogged grounds, which are less favorable for cereal crop cultivation, are common. The vegetation of the District is predominantly natural grassland with few patches of scattered trees. The forests occurring in limited areas are characterized by species such as *Juniperus procera*, *Podocarpus fulcatus*, *Hagenia abyssinica,* etc.

2.1.3. Farming System and Land Cover

In the Kokosa District, highland pastoralism has been the predominant farming system type for the last four to five decades (ABRDP, 1999; Daniel, 1999) where livestock production is the main source of livelihood and crop cultivation is a recently introduced component. At present, livestock production and *enset* cultivation are the major sources of livelihood. Barley, wheat and maize are among the few crops grown in the area mixed with *enset* cultivation. Cereal crop cultivation is less suitable in most areas of the District due to periodic frost attack and seasonally waterlogged grounds. The major grazing types in the District are enclosures, communal grazing lands, stream sides and bottom lands.

2.1.4. Human and Livestock Population

Kokosa District is one among the densely populated areas in the country. There are 169 persons per square kilometer (Zerihun, 2002). Human population of the District is about 117,401. Similarly, the livestock population constitutes 304,000 cattle, 80,154 small ruminants and 40,162 equines (MoARD, 2006).

2.2. Sampling Methods

The study was conducted from August to October, 2006 when most of the plant species are expected to be at peak flowering stages. Stratified random sampling method was used to determine the biomass and species richness at the study sites (Sokal and Rolf, 1981; Bowen and Starr, 1982). The study District was stratified into different farming systems (dominant livestock-*enset*, *enset*-livestock and *enset*-livestock-cereal) based on secondary information; site observations; and discussions with experts of respective agricultural development offices, community members and elders of the area. Each farming system was further stratified into communal, enclosure, stream bank grazing areas and benchmark sites.

The dominant livestock-*enset* lands are areas which have large number of livestock rearing and less *enset* cultivation. *Enset*-livestock lands are areas where *enset* cultivation is dominant and livestock production is a secondary activity. The *enset*-livestock-cereal lands are areas where integrated *enset*, livestock and cereal crop production is practiced. These areas are characterized with intensive grazing pressure due to cereal crops and *enset* encroachment.

The benchmark sites represent areas, which were protected from livestock grazing for about 5-10 years and had a relatively low grazing intensity and used for comparison purpose. School, church or mosque compounds were identified and used as benchmark sites in each farming system. The communal grazing areas are areas which are exposed to continuous defoliation, whereas the enclosure grazing areas are areas which were enclosed for one season to one year and intermediately grazed. The stream bank sites are grazing areas which are found at the periphery of water bodies and intensively grazed.

As the area coverage of each grazing type under the three land use systems were proportionally comparable, equal number of grazing sites were considered in each grazing type. Thus, a total of 12 sites (4 sites each) were considered in all the three farming systems. In each grazing site, a sampling block of 1000 m x 50 m was demarcated in continuous or in a separated form. The demarcated area was again further sub-divided into three plots of 250 m x 50 m. In each of the sub-divided plot, a belt transect of 20 m x 10 m was randomly laid out across the plots (Abule, 2003) towards north-south direction. Finally, five quadrats in each of the communal, enclosure, stream bank and benchmark areas each measuring 1 m x 1 m were randomly established at each corner and center of the belt transects. Accordingly, a total of 180 quadrats (each 1 m x 1 m) were sampled to estimate aboveground biomass (Brand and Goetz, 1986; Mannetje, 2000; Whaley and Hardy, 2000). In the entire quadrat, the herbaceous vegetations (grasses, legumes and forbs) were clipped at ground level using hand shears. The clipped herbaceous species were then sorted according to their species (grasses, legumes and forbs) and packed in labeled paper bags. Then the fresh herbages of each plant class were first air dried and finally oven dried at 70 ºC for 48 hours and weighed (Brand and Goetz, 1986; Roberts *et al.*, 1993; Whaley and Hardy, 2000) using sensitive balance for oven dry matter weight determination. All the vascular plants rooted inside the 1 m^2 plots of the 180 quadrats were recorded. The altitude, longitude and latitude readings of the sampled grazing management sites within the farming system types were measured and recorded using GPS (Table 1).

Table 1. Altitude, longitude and latitude readings of the sampling (grazing) sites within a farming system.

Farming system	Altitude (masl)	Longitude (E)	Latitude (N)
Dominant livestock-*enset*	2594	38^0 48'	6^0 27.84'
	2580	38^0 50'	6^0 27.78'
	2575	38^0 47'	6^0 27.12'
Enset-livestock	2600	38^0 47'	6^0 25.80'
	2629	38^0 47'	6^0 26.40'
	2636	38^0 47'	6^0 26.40'
Enset-livestock-cereal	2740	38^0 09'	6^0 28.92'
	2720	38^0 41'	6^0 28.32'
	2710	38^0 47'	6^0 26.52'

2.3. Statistical Analysis

The sampling quadrats of 1 m^2 from a belt transect of 20 m x 10 m were considered for biomass and species richness data analysis. This was done by sorting the data into separate farming system and the grazing types as well as for their combination to elucidate the relationship between species richness and biomass. Furthermore, logarithmic data transformation of biomass was made for the biomass data that did not fulfill the assumption of the analysis of variance. A two-way analysis of variance was computed to investigate the effects of farming system and the grazing type on aboveground biomass and richness of plant species following the Generalized Linear Model (GLM) procedure of SAS Version 8.1 (SAS Institute Inc., 1999). The least significant difference (LSD) test was employed for mean comparison.

3. Results and Discussion

3.1. Biomass Production

3.1.1. Dry Matter Biomass Production in Dominant Livestock-*Enset* Farming System

Table 2 depicts that the total dry matter biomass was highest in the benchmark sites followed by the enclosures while the least was recorded in the communal grazing areas. However, there were no significant variations in legume and grass dry matter biomass between benchmark and enclosure on the one hand and between communal and stream bank grazing areas on the other. The dry matter biomass contribution of grasses was very high while the contribution of legumes to the dry matter was the least. The dry matter biomass contribution of grasses, forbs and legumes in the predominantly livestock-*enset* farming system were about 81, 15 and 4%, respectively. The variation in dry matter yield among the grazing management systems might be due to the differences in the conditions of the grazing sites. There were fair condition in the communal grazing areas and along the stream banks and good to excellent condition class in the enclosure and benchmark grazing sites (Bekele, 2007). This result was in line with the earlier findings of Zerihun (1986), Gemedo (2004) and Manske (2004) who reported dominance of poor to fair range conditions of grazing areas exposed to continuous defoliation both in lowland and highland grazing areas.

Table 2. Mean (± SE) dry matter biomass production (kg ha^{-1}) by species of the different grazing types in the predominantly livestock-*enset* farming system.

Plant species*	Grazing management types				Coefficient of variation (%)
	Communal	Enclosure	Stream bank	Benchmark	
Grasses	286±53.7b	2234.0±163.8a	335.13±33.3b	2366.67±105.5a	13.5
Legumes	2.67±1.7b	190.67±38.4a	14.43±6.2b	116.17±39.9a	59.5
Forbs	46.67±37.7c	258.67±52.6b	69.30±10.6bc	633.11±97.9a	40.4
Total biomass	335.33±37.3c	2683± 167.9b	418.87±18.5c	3116±183.8a	11.9

**Means within a row followed by the same letter are not significantly different at P ≤ 0.05. SE = Standard error*

3.1.2. Dry Matter Biomass Production in *Enset*-Livestock Farming System

The study showed that the dry matter production of the grasses, legumes and forbs in the benchmark sites in the predominantly *enset*-livestock farming systems were significantly (P ≤ 0.05) higher than in the other grazing types (Table 3). On the other hand, the dry biomass yield of legumes showed an increasing trend when the grazing intensity changed from the heavily grazed communal and stream bank areas to the moderately grazed enclosure and benchmark grazing areas. The lower contribution of the overall legume dry biomass in the communal and stream bank grazing areas might be attributed to the higher trampling pressure and the inability of legumes to withstand heavy grazing pressure. The low legume dry matter biomass on the other hand might indicate the poor forage quality of the natural pasture in the District (Kidane, 1993; Tsige-yohannes, 1999). In line with this, van Soest (1982) and Sleugh *et al.* (2000) also confirmed that legumes increase the quality and quantity of pastures through atmospheric N-fixation.

3.1.3. Dry Matter Biomass Production in *Enset*-Livestock-Cereal Farming System

Table 4 below depicts the dry matter biomass in the *enset*-livestock-cereal farming system. The Table reveals that the benchmark grazing areas had a significantly (P ≤ 0.05) higher grass and legume biomass than the other grazing types. The study indicated that the total dry matter biomass of the herbaceous plants in the grasslands changed from 609 kg ha^{-1} in the heavily grazed communal grazing areas to 4166 kg ha^{-1} in the benchmark sites in the *enset*-livestock-cereal based farming system of the study area (Table 4).

Table 3. Mean (± SE) dry matter biomass production (kg ha^{-1}) by species of the different grazing types in the predominantly *enset*-livestock farming system.

Plant species*	Grazing management types				Coefficient of variation (%)
	Communal	Enclosure	Stream bank	Benchmark	
Grasses	323.33±22.0d	2398.00±65.0b	582.23±65.0c	2798.33±105.0a	6.32
Legumes	0.433±0.4c	227.10±67.0b	2.67±2.3c	355.10±30.9a	43.74
Forbs	21.23±10.0c	369.10±109.0b	24.43±8.7c	732.40±39.6a	35.33
Total biomass	345.00±23.0c	2889.00±144.0b	609.33±69.0c	3885.00±7.7a	11.07

**Means within a row followed by the same letter are not significantly different at P ≤ 0.05. SE = Standard error*

Table 4. Mean (± SE) dry matter biomass production (kg ha^{-1}) by species of the different grazing types in the predominantly *enset*-livestock-cereal farming system.

Plant species*	Grazing management types				Coefficient of variation (%)
	Communal	Enclosure	Stream bank	Benchmark	
Grasses	595.53±62.0c	2818.20±91.0b	560.93±56.0c	3238.53±80.0a	7.1
Legumes	4.23±3.0c	96.36±47.0b	2.33±0.0c	226.53±0.0a	49.9
Forbs	9.23±3.0b	315.13±55.0a	26.47±14.0b	455.64±91.0a	46.2
Total biomass	609.00±57.0c	3193.00±113.0b	589.73±67.0c	4166.00±138.0a	6.8

**Means within a row followed by the same letter are not significantly different at $P \leq 0.05$. SE = Standard error*

3.1.4. Interaction Effects of Farming System and Grazing Management on Dry Biomass Production

The variation in mean biomass was highly significant ($P \leq 0.001$) due to farming systems and grazing management types (Table 5). The change in biomass yield may be due to the overriding influences of grazing intensity, size of pasture land and length of grazing periods. This indicates that biomass yield can be influenced by different farming systems and grazing management practices. The variation in biomass was significant ($P \leq 0.05$) due to the interaction effect between farming system and grazing management systems. The mean biomass of the grassland recorded was 1903.1 kg ha^{-1} (Table 6). The *enset*-livestock-cereal farming system had the highest mean biomass while the lowest biomass was recorded in the dominantly livestock-*enset* farming system. The benchmark grazing area has the highest mean biomass followed by enclosure grazing areas while the communal grazing area has the lowest mean biomass.

3.2. Herbaceous Species Richness and Its Response to the Interaction Effect

Altogether 50 plant species (34 species of grasses, 4 species of legumes, 3 species of sedges and 9 species of forbs) were recorded in the grassland (Table 7). Even though the majority of the plant species share the different farming system and grazing management types, the highest number of species (39) was recorded in the *enset*-livestock farming system. The identified species belonged to 11 families of which the family *Poaceae* dominates (68%) the herbaceous species. Getachew (2005) and Gemedo (2006) reported similar results that most grazing areas have been dominated by grasses of few species. Out of the total grass species identified, the highly desirable, intermediate desirable and least desirable species comprise for 58, 24 and 19%, respectively. The higher proportion of desirable plant species in the study area in general implies that the area is characterized as good grazing condition.

Table 5. Analysis of variance for the interaction effect of farming system and grazing type on dry matter biomass in the Kokosa District.

Source	Degrees of freedom	Sum of square	Mean of square	F-Value	Pr > F
Farming system	2	869285.5	434642.76	13.85	0.000
Grazing type	3	85237086.0	28412362.10	905.08	0.000
Farming system x grazing type	6	494255.9	82375.98	2.62	0.048

R^2= 0.99; Root MSE = 177.18; Coefficient of variation (CV) = 8.96%

Table 6. Interaction effect of farming system and grazing management on biomass (kg ha^{-1}) production.

Farming system	Grazing management*				Mean	LSD (0.05)
	Communal	Enclosure	Stream bank	Benchmark		
Dominant livestock-*enset*	335.0	2683.0	418.0	3116.0	1638.0	367.9
Enset-livestock	345.0	2889.0	609.0	3885.0	1932.0	408.5
Enset-livestock-cereal	609.0	3193.0	589.0	4166.0	2139.3	267.6
Mean	429.7	2921.7	539.3	3722.3	1903.1	
SE (±)	39.1	141.6	51.5	109.8		

**LSD = Least significant difference; SE = Standard error*

Table 7. List of plant species recorded in the montane grassland of Kokosa District.

Botanical name	Life time	Family name	Desirability
		Grasses	
Agrostis lanchnatha	Annual/Perennial	*Poaceae*	Highly desirable (decreaser)
Agrostis schimperana	Annual	*Poaceae*	Highly desirable (decreaser)
Andropogon chrysostachyus	Perennial	*Poaceae*	Least desirable (invader)
Andropogon gayanus	Perennial	*Poaceae*	Highly desirable (decreaser)
Bromus leptoclade	Annual	*Poaceae*	Highly desirable (decreaser)
Cynodon dactylon	Perennial	*Poaceae*	Highly desirable (decreaser)
Danthonia subulata	Perennial	*Poaceae*	Least desirable (invader)
Digitaria decumbens	Perennial	*Poaceae*	Intermediate desirable (increaser)
Digitaria adscendens	Annual	*Poaceae*	Intermediate desirable (increaser)
Digitaria scalarum	Perennial	*Poaceae*	Intermediate desirable (increaser)
Digitaria velutina	Annual	*Poaceae*	Intermediate desirable (increaser)
Eleusine floccifolia	Perennial	*Poaceae*	Least desirable (invader)
Enneapogon cenchroides	Annual/Perennial	*Poaceae*	Intermediate desirable (increaser)
Eragrostis atroverens	Perennial	*Poaceae*	Intermediate desirable (increaser)
Eragrostis curvula	Perennial	*Poaceae*	Intermediate desirable (increaser)
Eragrostis racemosa	Annual	*Poaceae*	Highly desirable (decreaser)
Eragrostis superb	Perennial	*Poaceae*	Intermediate desirable (increaser)
Eragrostis sp	Annual/Perennial	*Poaceae*	Intermediate desirable (increaser)
Eriochrysis pallid	Perennial	*Poaceae*	Intermediate desirable (increaser)
Eragrostis tenuifolia	Annual	*Poaceae*	Intermediate desirable (increaser)
Lolium multiflorum	Annual	*Poaceae*	Highly desirable (decrease)
Microchloa kunthii	Perennial	*Poaceae*	Intermediate desirable (increaser)
Pennisetum glabrum	Perennial	*Poaceae*	Least desirable (invader)
Pennisetum schimperi	Perennial	*Poaceae*	Least desirable (invader)
Pennisetum stramineum	Perennial	*Poaceae*	Intermediate desirable (increaser)
Pentaschistis borussica	Perennial	*Poaceae*	Least desirable (invader)
Phalaris arundinacea	Perennial	*Poaceae*	Highly desirable (decreaser)
Poa leptoclade	Annual	Poaceae	Highly desirable (decreaser)
Poa sp.	Annual	*Poaceae*	Intermediate desirable (increaser)
Setaria incrassate	Perennial	*Poaceae*	Highly desirable (decreaser)
Setaria sphacela	Perennial	*Poaceae*	Highly desirable (decreaser)
Sporobolus natalensis	Perennial	*Poaceae*	Least desirable (invader)
Sporobolus pyramidalis	Perennial	*Poaceae*	Intermediate desirable (increaser)
Sporobolus spicatus	Perennial	*Poaceae*	Intermediate desirable (increaser)
		Legumes	
Indigofera spinosa	Perennial	*Papplinoideae*	
Indigofera volkensii	Perennial	*Papilionoieae*	
Trifolium rueppellianum	Annual	*Papilionoideae*	
Trifolium sp	-	*Papilionoideae*	
		Sedge species	
Cyperus flavenscens	Perennial	*Cyperaceae*	
Cyperus teneristolon	Perennial	*Cyperaceae*	
Cyperus obtusiflorus	Annual	*Cyperaceae*	
		Forbs	
Amaranthus dubius	Annual	*Amaranthaceae*	
Asystasia schimperi	Annual	*Acanthaceae*	
Bidens hildebrandtii	Annual	*Asteraceae*	
Commelina forskalaei	Annual	*Commelinaceae*	
Coriandrum sativum	Annual	*Umbelliferacea*	
Echinops pappi	Perennial	*Acanthaceae*	
Haplocoelum foliolosum	Annual	*Rosaceae*	
Kedrostis foetidissima	Perennial	*Cucurbitaceae*	
Ocimum basilicum	Annual	*Lamiaceae*	

The mean species richness in a sample quadrat of 1 m² varied slightly for grazing types and farming systems. Table 8 indicates that the mean species richness in the communal, enclosures, stream bank and benchmark grazing areas varied from 4.1-4.7, 4.6-5.5, 3.8-4.4 and 3.0-4.3, respectively. The study suggested that in the predominantly livestock-*enset* farming system, there was a significant difference ($P \leq 0.05$) in the richness of the herbaceous species between the communal areas and the enclosures, between the enclosures and the stream banks, and between the enclosures and benchmarks. This result is supported by previous findings of Gross *et al.* (2000), Virtanen *et al.* (2000) and Oba *et al.*(2001). However, there was no significant variation between the communal areas and the stream banks. The highest species richness was observed in the enclosure grazing areas while the least was recorded in the benchmark sites that were protected from livestock grazing for a longer period of time in the dominant livestock-*enset*. This might be because moderate grazing enhanced the richness of plant species by suppressing the dominant species that might otherwise take dominance in the area and then eliminate the less competitive species in the system (Fuhlendorf, 2001).

This result implies that grazing promoted the richness of the herbaceous species although that depended on the intensity of the grazing pressure on the vegetation cover. According to this and other studies (Zerihun and Saleem, 2000; Kamau, 2004), the high species richness in the moderately grazed enclosure areas and the declined species richness in the benchmark sites indicated that livestock grazing played an integral role in maintaining and dispersing the herbaceous species thereby increasing the richness of species in the areas with moderate grazing intensity. Similarly, McNaughton (1979) reported that the reason for the decline of the species richness in the enclosed Serengeti grasslands was due to the enclosing of the area for long period of time.

In this study, the mean species richness in a quadrat of 1 m² was found to be 4.3, 4.9, 4.2 and 3.4 in the communal, enclosure, stream bank and benchmark areas, respectively (Table 8). This result was similar with the overall species richness (2.5 to 4.1) reported by Guretzky *et al.* (2005) in pastures that were managed with continuous and rotational grazing areas. Similarly, in his study in the central highlands of Ethiopia, Zerihun (1985) reported that species richness in quadrats vary from 5 to 24 with an average of 12 species richness. Likewise, study by Muluberhan *et al.* (2006) in northern Ethiopia reported 4.3 and 3 herbaceous species richness in the enclosed and grazed areas of 1 m², respectively. On their part, Oba *et al.* (2001) found 5.3 to 8.3 species richness per 1 m² in enclosed areas when compared to 5.1 to 7.5 species in 1 m² in open plots. The differences in species richness within farming systems and grazing management types were statistically significant ($P \leq 0.05$). There was also a significant variation of species richness when farming system and grazing management systems are analyzed together. Gross *et al.* (2000), Virtanen *et al.* (2000), Oba *et al.* (2001) reached a similar conclusion when they reported that the difference may occur when a range of different habitats are analyzed together.

Table 8. Interaction of ffect of farming system by grazing management on mean (± SE) species richness per quadrat (m²) in montane grassland at Kokosa District.

Farming system*	Grazing management: Communal	Enclosure	Stream bank	Benchmark	Mean	CV (%)
Dominant livestock-*enset*	4.1±0.10b	4.6±0.39a	4.3±0.14.00b	3.0±0.39c	4.0	12.50
Enset-livestock	4.3±0.17ab	4.6±0.21a	3.8±0.04c	4.0±0.08b	4.2	5.80
Enset-livestock-cereal	4.7±0.05b	5.5±0.15a	4.4±0.20b	4.3±0.08b	4.7	4.95
Mean	4.3	4.9	4.2	3.4	4.2	

**Means within a row followed by the same letter are not significantly different at $P \leq 0.05$. SE = Standard error; CV = Coefficient of variation*

3.3. Relationship between Biomass Production and Plant Species Richness

The current study indicated the existence of differences in the mean biomass accumulated between the enclosed and open grazing areas. The study showed that the highest species richness occurred in the enclosed grazing areas with an intermediate biomass production. Grime (1997) and Oba *et al.* (2001) reported similar findings. As can be seen in Figures 2 and 3, the species richness first raised and then declined following the constant increase in the biomass. In contrast, the study suggested that an increase in the biomass in the benchmark was not related to an increase in species richness (Figure 2). Similarly, Oba *et al.* (2001) reported that the optimum richness corresponds to a given biomass level and age of enclosures.

This might be due to an increase in the competition intensity at the increased rate of the biomass production that became the cause for the elimination of the less competitive species from the community at peak biomass production (Grime, 1973; Huston, 1994; Bonser and Reader, 1995). The study, therefore, implied that the less competent species and the newly emerging seedlings might have been eliminated in the benchmark sites. This tendency may in turn cause decline in the richness of the species. Similar findings were reported by Kamau (2004), Oba *et al.* (2001), Huston (1994) and Guo (1996) that the long term grazing exclusion did not increase the richness of species although there was a substantial increase in the aboveground biomass.

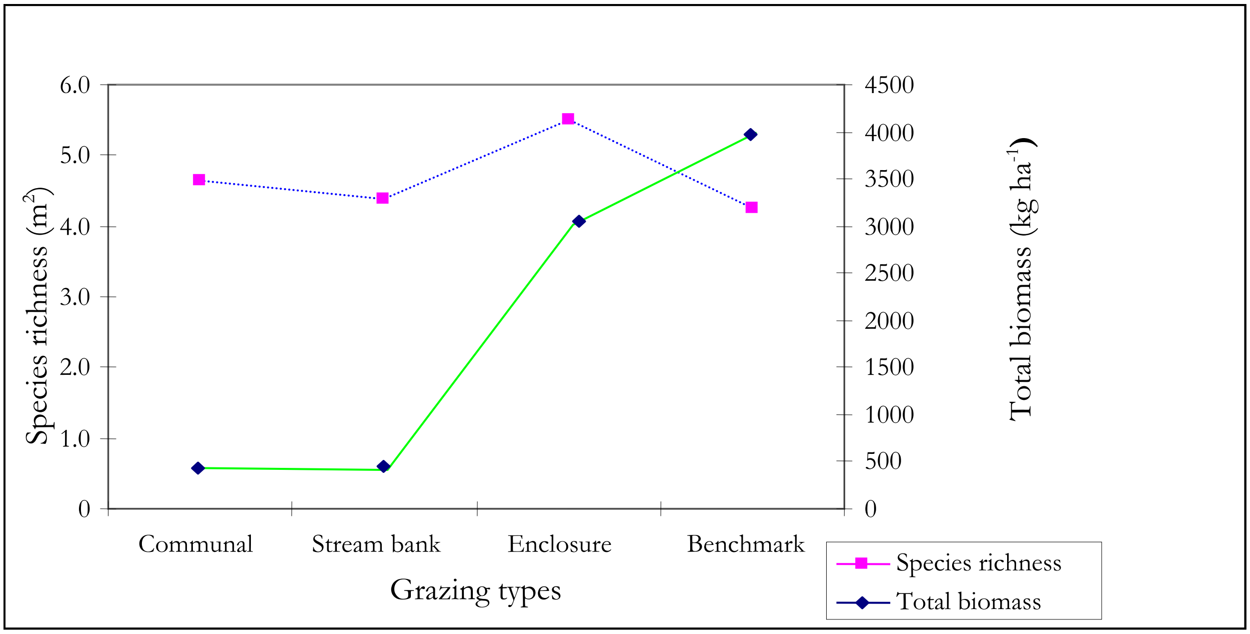

Figure 2. The relationship between biomass and plant species richness.

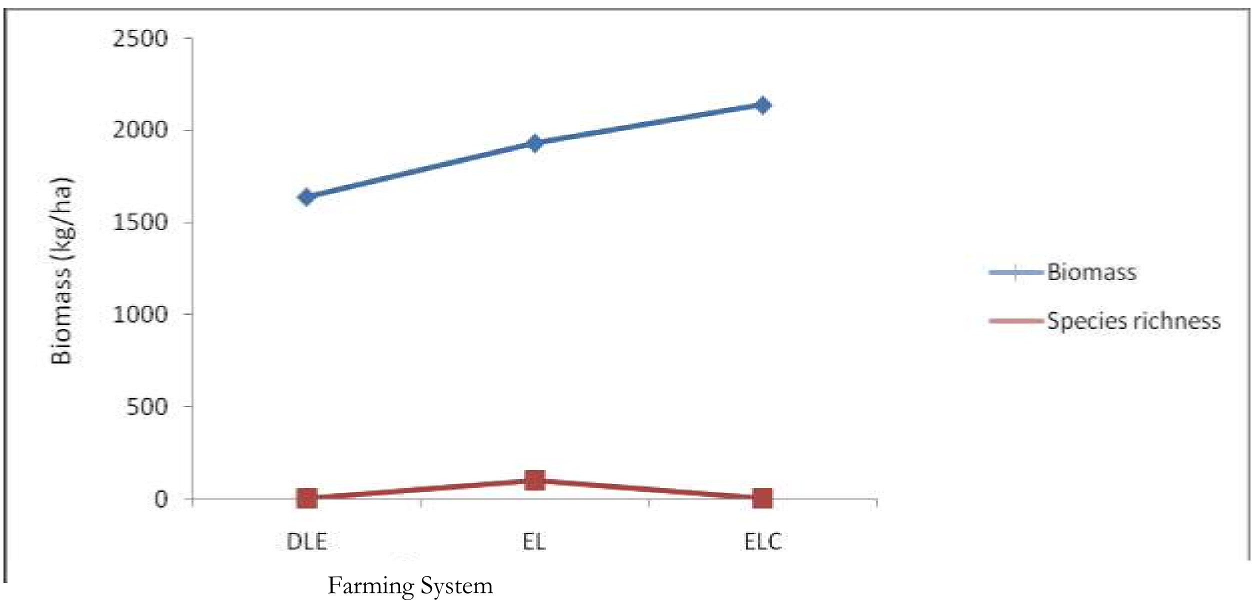

Figure 3. Relationship between mean biomass and plant species richness in different farming systems.

4. Conclusions

The study revealed that the aboveground biomass of the plant species was significantly ($P \leq 0.05$) different depending on the extent of the grazing pressure. The study suggested that light disturbance could help reduce the cover of dead shoot and facilitate the seed soil contact and foster the re-growth of plants. Grass dry biomass and total dry biomass were found to be significantly high in the *enset*-livestock-cereal farming system having lower dry matter biomass of forbs. The dominant livestock-*enset* farming system which had a high number of livestock and was characterized as lower condition class had a lower total dry matter biomass.

The species richness in a sample quadrat of 1 m² of the study areas varied slightly across the grazing types and the farming systems. A significantly higher ($P \leq 0.01$) richness occurred in the enclosure grazing areas and the *enset*-livestock farming system (where biomass is intermediate) while the least richness was observed in the benchmark sites and in the *enset*-livestock-cereal farming system, the highest biomass was recorded. The reason behind this might be the competitive elimination of the less competitor species from the community at peak biomass production

The current study suggested that the species richness is positively associated with the intermediate grazing pressure implying that livestock grazing management plays a crucial role in maintaining species richness in grassland communities. Although the environmental factors are considered much more important in the area, the importance of internal interaction should not also be overlooked in the biomass–species relationship. However, this still needs verification in further studies.

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Relationships between Plant Biomass and Species Richness under Different Farming Systems and Grazing Land Management in Montane Grasslands of Kokosa District, Southern Ethiopia

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Abstract: The study was conducted in a montane grassland of Kokosa District, West Arsi Zone of Oromia Region, southern Ethiopia. The objective of the study was to investigate the relationships between aboveground plant biomass and species richness in three farming systems and four grazing management systems. A total of 180 quadrats (each 1 m x 1 m) were sampled in the three farming systems (dominant livestock-*enset*, *enset*-livestock and *enset*-livestock-cereal) and four grazing management systems (communal, enclosure, stream bank and benchmark). All the farming system and grazing management have different management practices. Plant species composition and aboveground plant biomass at different sites were quantified. Altogether 50 plant species (34 grasses, 4 legumes, 3 sedges and 9 forbs) were recorded in the montane grassland of Kokosa District. Even though the majority of the plant species share the different farming systems and grazing management practices, the highest number of species (39) was recorded in the *enset*-livestock farming system, whereas the lowest (33) species were recorded in the *enset*- livestock-cereal farming system when all the grazing management and farming systems were combined. Significantly, the highest species richness (4.9 species m^{-2}) was recorded in the enclosure grazing management site whereas the lowest (3.4 species m^{-2}) was recorded in the benchmark grazing site when all grazing sites and farming systems were combined. The relationship between species richness and biomass was detected in the montane grassland. There was significant difference ($P \leq 0.05$) in species richness for a combination analysis of farming system by grazing management system of the montane grassland. The highest biomass was recorded in the benchmark grazing management sites while the lowest was recorded in the communal grazing sites. On the contrary, maximum species richness was found in the enclosure grazing management sites which had intermediate biomass yield and the lowest species richness was recorded in the benchmark grazing areas with the maximum biomass records. Thus, species richness was observed first to ascend along with biomass increment up to 1932 kg ha^{-1} and then declined at constant increase of biomass. An increase in biomass in the benchmark grazing sites was not accompanied by an increase in species richness suggesting the dominance of few species in these sites. The rationale behind this might be due to the competitive exclusion of the less competent species from the community at peak biomass production.

Keywords: Biomass; Farming System; Grazing Management; Montane Grassland; Species Richness

1. Introduction

Species richness is the most commonly reported diversity measurement within the community (Sanderson *et al.*, 2004). Variation in the patterns of species richness across geographical and environmental gradients has long attracted the interest of ecologists. As a result, several theories of species diversity have so far been advanced (Tilman, 1982; Huston, 1994; Rosenzweig, 1995; Gaston, 2000).

Investigation on the relationships between species richness and biomass or productivity has been a central focus in the community ecology (Mittlebach *et al.,* 2000; Cornwell and Grubb, 2003; Fox, 2003; Venterink *et al.,* 2003). This relationship has been investigated since the mid-1960s, but the causal mechanisms have been in dispute for long period (Oksanen, 1996; Brocque and Buckney, 2003). The relationship between herbaceous biomass and richness often has a hump-shape with a peak in species richness at a low to intermediate level of biomass (Grime, 1997). At a very low level of biomass, richness is primarily limited by the inability of a species to survive the abiotic conditions. In this range, an increase in biomass reflects a decrease in the harshness of the environment. Above some point roughly corresponding to the peak species richness, the abiotic environment is presumably amenable to most species.

At higher levels of biomass, the decline in species richness is believed to be due to competitive exclusion (Grime, 1973; Huston, 1994). Rosenzweig (1995) emphasized that it is the decline in species richness at high biomass level that is the unsolved puzzle, whereas the positive correlation between richness and biomass is inevitable and some authors report as more biomass, more individuals, and higher probability for more species (May, 1975; Oba *et al.*, 2001). Accordingly, the decline of species richness at high biomass production levels is the crucial question for its application in conservation and management of grassland (Van der Maarel, 1997; Oba *et al.*, 2001).

Several studies have indicated that the relationship may differ when a range of different habitats are analyzed together (Gross *et al.*, 2000; Virtanen *et al.*, 2000; Oba *et al.*, 2001). Thus, regional differences in species richness for a community type should be observed at all spatial scales. Species richness is correlated with productivity in most situations (Huston, 1994; Rosenzweig, 1995). In this

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regard, most of the studies, where biomass has been related to species richness, have been done in temperate grasslands (Waide *et al.*, 1999; Rydin and Barber, 2001) and wetlands (Grace and Jutila, 1999). Moreover, the relationship may differ depending on the geographical or taxonomical contexts the mechanisms underlying it being still unclear (Rosenzweig and Abramsky, 1993; Gaston, 2000). Cornwell and Grubb (2003) concluded that as ecology is a science of 'contingent generalizations', studies in varied biomes must continue to refine knowledge about where, at what scale and for which taxa the relationship of species richness and biomass is unimodal. However, no study has, to the best of our knowledge, evaluated the relationship between biomass and species richness in montane grasslands in Ethiopia. Therefore, the current study was designed to investigate the relationships between biomass and species richness in the montane grasslands of the Kokosa District under varied grazing management and farming systems.

2. Materials and Methods

2.1. Description of the Study Area

2.1.1. Geographical Location and Climate

The study was conducted in the Kokosa District in West Arsi Zone of Oromia Region, Southern Ethiopia (Figure 1). The mean altitude of the District is 2650 meters above sea level (masl) with a mean annual rainfall of 1600 mm and mean annual temperature of 16 ºC. The District is characterized by a bimodal rainfall (two **t**imes showers within a year) with a total rainy season lasting over eight months in a year. The main rainy season is from late March to September. The short rainy season occurs from October to November. The typical dry season is from December to February.

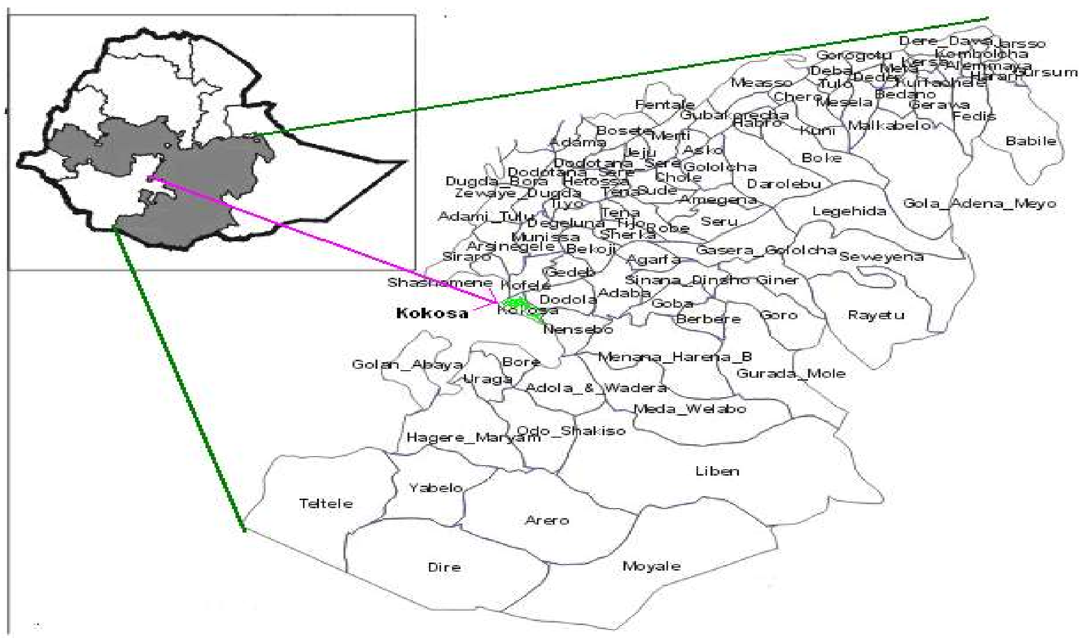

Figure 1. Location map of the study area.

2.1.2. Topography and Vegetation

The topography of the District consists of complex features of landscape comprising of medium steep to gentle slope, hilly, mountainous and undulating features. Seasonally waterlogged grounds, which are less favorable for cereal crop cultivation, are common. The vegetation of the District is predominantly natural grassland with few patches of scattered trees. The forests occurring in limited areas are characterized by species such as *Juniperus procera*, *Podocarpus fulcatus*, *Hagenia abyssinica,* etc.

2.1.3. Farming System and Land Cover

In the Kokosa District, highland pastoralism has been the predominant farming system type for the last four to five decades (ABRDP, 1999; Daniel, 1999) where livestock production is the main source of livelihood and crop cultivation is a recently introduced component. At present, livestock production and *enset* cultivation are the major sources of livelihood. Barley, wheat and maize are among the few crops grown in the area mixed with *enset* cultivation. Cereal crop cultivation is less suitable in most areas of the District due to periodic frost attack and seasonally waterlogged grounds. The major grazing types in the District are enclosures, communal grazing lands, stream sides and bottom lands.

2.1.4. Human and Livestock Population

Kokosa District is one among the densely populated areas in the country. There are 169 persons per square kilometer (Zerihun, 2002). Human population of the District is about 117,401. Similarly, the livestock population constitutes 304,000 cattle, 80,154 small ruminants and 40,162 equines (MoARD, 2006).

2.2. Sampling Methods

The study was conducted from August to October, 2006 when most of the plant species are expected to be at peak flowering stages. Stratified random sampling method was used to determine the biomass and species richness at the study sites (Sokal and Rolf, 1981; Bowen and Starr, 1982). The study District was stratified into different farming systems (dominant livestock-*enset*, *enset*-livestock and *enset*-livestock-cereal) based on secondary information; site observations; and discussions with experts of respective agricultural development offices, community members and elders of the area. Each farming system was further stratified into communal, enclosure, stream bank grazing areas and benchmark sites.

The dominant livestock-*enset* lands are areas which have large number of livestock rearing and less *enset* cultivation. *Enset*-livestock lands are areas where *enset* cultivation is dominant and livestock production is a secondary activity. The *enset*-livestock-cereal lands are areas where integrated *enset*, livestock and cereal crop production is practiced. These areas are characterized with intensive grazing pressure due to cereal crops and *enset* encroachment.

The benchmark sites represent areas, which were protected from livestock grazing for about 5-10 years and had a relatively low grazing intensity and used for comparison purpose. School, church or mosque compounds were identified and used as benchmark sites in each farming system. The communal grazing areas are areas which are exposed to continuous defoliation, whereas the enclosure grazing areas are areas which were enclosed for one season to one year and intermediately grazed. The stream bank sites are grazing areas which are found at the periphery of water bodies and intensively grazed.

As the area coverage of each grazing type under the three land use systems were proportionally comparable, equal number of grazing sites were considered in each grazing type. Thus, a total of 12 sites (4 sites each) were considered in all the three farming systems. In each grazing site, a sampling block of 1000 m x 50 m was demarcated in continuous or in a separated form. The demarcated area was again further sub-divided into three plots of 250 m x 50 m. In each of the sub-divided plot, a belt transect of 20 m x 10 m was randomly laid out across the plots (Abule, 2003) towards north-south direction. Finally, five quadrats in each of the communal, enclosure, stream bank and benchmark areas each measuring 1 m x 1 m were randomly established at each corner and center of the belt transects. Accordingly, a total of 180 quadrats (each 1 m x 1 m) were sampled to estimate aboveground biomass (Brand and Goetz, 1986; Mannetje, 2000; Whaley and Hardy, 2000). In the entire quadrat, the herbaceous vegetations (grasses, legumes and forbs) were clipped at ground level using hand shears. The clipped herbaceous species were then sorted according to their species (grasses, legumes and forbs) and packed in labeled paper bags. Then the fresh herbages of each plant class were first air dried and finally oven dried at 70 ºC for 48 hours and weighed (Brand and Goetz, 1986; Roberts *et al*., 1993; Whaley and Hardy, 2000) using sensitive balance for oven dry matter weight determination. All the vascular plants rooted inside the 1 m^2 plots of the 180 quadrats were recorded. The altitude, longitude and latitude readings of the sampled grazing management sites within the farming system types were measured and recorded using GPS (Table 1).

Table 1. Altitude, longitude and latitude readings of the sampling (grazing) sites within a farming system.

Farming system	Altitude (masl)	Longitude (E)	Latitude (N)
	2594	38^0 48'	6^0 27.84'
Dominant livestock-*enset*	2580	38^0 50'	6^0 27.78'
	2575	38^0 47'	6^0 27.12'
	2600	38^0 47'	6^0 25.80'
Enset-livestock	2629	38^0 47'	6^0 26.40'
	2636	38^0 47'	6^0 26.40'
	2740	38^0 09'	6^0 28.92'
Enset-livestock-cereal	2720	38^0 41'	6^0 28.32'
	2710	38^0 47'	6^0 26.52'

2.3. Statistical Analysis

The sampling quadrats of 1 m^2 from a belt transect of 20 m x 10 m were considered for biomass and species richness data analysis. This was done by sorting the data into separate farming system and the grazing types as well as for their combination to elucidate the relationship between species richness and biomass. Furthermore, logarithmic data transformation of biomass was made for the biomass data that did not fulfill the assumption of the analysis of variance. A two-way analysis of variance was computed to investigate the effects of farming system and the grazing type on aboveground biomass and richness of plant species following the Generalized Linear Model (GLM) procedure of SAS Version 8.1 (SAS Institute Inc., 1999). The least significant difference (LSD) test was employed for mean comparison.

3. Results and Discussion

3.1. Biomass Production

3.1.1. Dry Matter Biomass Production in Dominant Livestock-*Enset* Farming System

Table 2 depicts that the total dry matter biomass was highest in the benchmark sites followed by the enclosures while the least was recorded in the communal grazing areas. However, there were no significant variations in legume and grass dry matter biomass between benchmark and enclosure on the one hand and between communal and stream bank grazing areas on the other. The dry matter biomass contribution of grasses was very high while the contribution of legumes to the dry matter was the least. The dry matter biomass contribution of grasses, forbs and legumes in the predominantly livestock-*enset* farming system were about 81, 15 and 4%, respectively. The variation in dry matter yield among the grazing management systems might be due to the differences in the conditions of the grazing sites. There were fair condition in the communal grazing areas and along the stream banks and good to excellent condition class in the enclosure and benchmark grazing sites (Bekele, 2007). This result was in line with the earlier findings of Zerihun (1986), Gemedo (2004) and Manske (2004) who reported dominance of poor to fair range conditions of grazing areas exposed to continuous defoliation both in lowland and highland grazing areas.

Table 2. Mean (± SE) dry matter biomass production (kg ha^{-1}) by species of the different grazing types in the predominantly livestock-*enset* farming system.

Plant species*	Grazing management types				Coefficient of variation (%)
	Communal	Enclosure	Stream bank	Benchmark	
Grasses	286±53.7b	2234.0±163.8a	335.13±33.3b	2366.67±105.5a	13.5
Legumes	2.67±1.7b	190.67±38.4a	14.43±6.2b	116.17±39.9a	59.5
Forbs	46.67±37.7c	258.67±52.6b	69.30±10.6bc	633.11±97.9a	40.4
Total biomass	335.33±37.3c	2683± 167.9b	418.87±18.5c	3116±183.8a	11.9

**Means within a row followed by the same letter are not significantly different at P ≤ 0.05. SE = Standard error*

3.1.2. Dry Matter Biomass Production in *Enset*-Livestock Farming System

The study showed that the dry matter production of the grasses, legumes and forbs in the benchmark sites in the predominantly *enset*-livestock farming systems were significantly (P ≤ 0.05) higher than in the other grazing types (Table 3). On the other hand, the dry biomass yield of legumes showed an increasing trend when the grazing intensity changed from the heavily grazed communal and stream bank areas to the moderately grazed enclosure and benchmark grazing areas. The lower contribution of the overall legume dry biomass in the communal and stream bank grazing areas might be attributed to the higher trampling pressure and the inability of legumes to withstand heavy grazing pressure. The low legume dry matter biomass on the other hand might indicate the poor forage quality of the natural pasture in the District (Kidane, 1993; Tsige-yohannes, 1999). In line with this, van Soest (1982) and Sleugh *et al.* (2000) also confirmed that legumes increase the quality and quantity of pastures through atmospheric N-fixation.

3.1.3. Dry Matter Biomass Production in *Enset*-Livestock-Cereal Farming System

Table 4 below depicts the dry matter biomass in the *enset*-livestock-cereal farming system. The Table reveals that the benchmark grazing areas had a significantly (P ≤ 0.05) higher grass and legume biomass than the other grazing types. The study indicated that the total dry matter biomass of the herbaceous plants in the grasslands changed from 609 kg ha^{-1} in the heavily grazed communal grazing areas to 4166 kg ha^{-1} in the benchmark sites in the *enset*-livestock-cereal based farming system of the study area (Table 4).

Table 3. Mean (± SE) dry matter biomass production (kg ha^{-1}) by species of the different grazing types in the predominantly *enset*-livestock farming system.

Plant species*	Grazing management types				Coefficient of variation (%)
	Communal	Enclosure	Stream bank	Benchmark	
Grasses	323.33±22.0d	2398.00±65.0b	582.23±65.0c	2798.33±105.0a	6.32
Legumes	0.433±0.4c	227.10±67.0b	2.67±2.3c	355.10±30.9a	43.74
Forbs	21.23±10.0c	369.10±109.0b	24.43±8.7c	732.40±39.6a	35.33
Total biomass	345.00±23.0c	2889.00±144.0b	609.33±69.0c	3885.00±7.7a	11.07

**Means within a row followed by the same letter are not significantly different at P ≤ 0.05. SE = Standard error*

Table 4. Mean (± SE) dry matter biomass production (kg ha^{-1}) by species of the different grazing types in the predominantly *enset*-livestock-cereal farming system.

Plant species*	Grazing management types				Coefficient of variation (%)
	Communal	Enclosure	Stream bank	Benchmark	
Grasses	595.53±62.0c	2818.20±91.0b	560.93±56.0c	3238.53±80.0a	7.1
Legumes	4.23±3.0c	96.36±47.0b	2.33±0.0c	226.53±0.0a	49.9
Forbs	9.23±3.0b	315.13±55.0a	26.47±14.0b	455.64±91.0a	46.2
Total biomass	609.00±57.0c	3193.00±113.0b	589.73±67.0c	4166.00±138.0a	6.8

**Means within a row followed by the same letter are not significantly different at $P \leq 0.05$. SE = Standard error*

3.1.4. Interaction Effects of Farming System and Grazing Management on Dry Biomass Production

The variation in mean biomass was highly significant ($P \leq 0.001$) due to farming systems and grazing management types (Table 5). The change in biomass yield may be due to the overriding influences of grazing intensity, size of pasture land and length of grazing periods. This indicates that biomass yield can be influenced by different farming systems and grazing management practices. The variation in biomass was significant ($P \leq 0.05$) due to the interaction effect between farming system and grazing management systems. The mean biomass of the grassland recorded was 1903.1 kg ha^{-1} (Table 6). The *enset*-livestock-cereal farming system had the highest mean biomass while the lowest biomass was recorded in the dominantly livestock-*enset* farming system. The benchmark grazing area has the highest mean biomass followed by enclosure grazing areas while the communal grazing area has the lowest mean biomass.

3.2. Herbaceous Species Richness and Its Response to the Interaction Effect

Altogether 50 plant species (34 species of grasses, 4 species of legumes, 3 species of sedges and 9 species of forbs) were recorded in the grassland (Table 7). Even though the majority of the plant species share the different farming system and grazing management types, the highest number of species (39) was recorded in the *enset*-livestock farming system. The identified species belonged to 11 families of which the family *Poaceae* dominates (68%) the herbaceous species. Getachew (2005) and Gemedo (2006) reported similar results that most grazing areas have been dominated by grasses of few species. Out of the total grass species identified, the highly desirable, intermediate desirable and least desirable species comprise for 58, 24 and 19%, respectively. The higher proportion of desirable plant species in the study area in general implies that the area is characterized as good grazing condition.

Table 5. Analysis of variance for the interaction effect of farming system and grazing type on dry matter biomass in the Kokosa District.

Source	Degrees of freedom	Sum of square	Mean of square	F-Value	Pr > F
Farming system	2	869285.5	434642.76	13.85	0.000
Grazing type	3	85237086.0	28412362.10	905.08	0.000
Farming system x grazing type	6	494255.9	82375.98	2.62	0.048

R^2= 0.99; Root MSE = 177.18; Coefficient of variation (CV) = 8.96%

Table 6. Interaction effect of farming system and grazing management on biomass (kg ha^{-1}) production.

Farming system	Grazing management*				Mean	LSD (0.05)
	Communal	Enclosure	Stream bank	Benchmark		
Dominant livestock-*enset*	335.0	2683.0	418.0	3116.0	1638.0	367.9
Enset-livestock	345.0	2889.0	609.0	3885.0	1932.0	408.5
Enset-livestock-cereal	609.0	3193.0	589.0	4166.0	2139.3	267.6
Mean	429.7	2921.7	539.3	3722.3	1903.1	
SE (±)	39.1	141.6	51.5	109.8		

**LSD = Least significant difference; SE = Standard error*

Table 7. List of plant species recorded in the montane grassland of Kokosa District.

Botanical name	Life time	Family name	Desirability
		Grasses	
Agrostis lanchnatha	Annual/Perennial	*Poaceae*	Highly desirable (decreaser)
Agrostis schimperana	Annual	*Poaceae*	Highly desirable (decreaser)
Andropogon chrysostachyus	Perennial	*Poaceae*	Least desirable (invader)
Andropogon gayanus	Perennial	*Poaceae*	Highly desirable (decreaser)
Bromus leptoclade	Annual	*Poaceae*	Highly desirable (decreaser)
Cynodon dactylon	Perennial	*Poaceae*	Highly desirable (decreaser)
Danthonia subulata	Perennial	*Poaceae*	Least desirable (invader)
Digitaria decumbens	Perennial	*Poaceae*	Intermediate desirable (increaser)
Digitaria adscendens	Annual	*Poaceae*	Intermediate desirable (increaser)
Digitaria scalarum	Perennial	*Poaceae*	Intermediate desirable (increaser)
Digitaria velutina	Annual	*Poaceae*	Intermediate desirable (increaser)
Eleusine floccifolia	Perennial	*Poaceae*	Least desirable (invader)
Enneapogon cenchroides	Annual/Perennial	*Poaceae*	Intermediate desirable (increaser)
Eragrostis atroverens	Perennial	*Poaceae*	Intermediate desirable (increaser)
Eragrostis curvula	Perennial	*Poaceae*	Intermediate desirable (increaser)
Eragrostis racemosa	Annual	*Poaceae*	Highly desirable (decreaser)
Eragrostis superb	Perennial	*Poaceae*	Intermediate desirable (increaser)
Eragrostis sp	Annual/Perennial	*Poaceae*	Intermediate desirable (increaser)
Eriochrysis pallid	Perennial	*Poaceae*	Intermediate desirable (increaser)
Eragrostis tenuifolia	Annual	*Poaceae*	Intermediate desirable (increaser)
Lolium multiflorum	Annual	*Poaceae*	Highly desirable (decrease)
Microchloa kunthii	Perennial	*Poaceae*	Intermediate desirable (increaser)
Pennisetum glabrum	Perennial	*Poaceae*	Least desirable (invader)
Pennisetum schimperi	Perennial	*Poaceae*	Least desirable (invader)
Pennisetum stramineum	Perennial	*Poaceae*	Intermediate desirable (increaser)
Pentaschistis borussica	Perennial	*Poaceae*	Least desirable (invader)
Phalaris arundinacea	Perennial	*Poaceae*	Highly desirable (decreaser)
Poa leptoclade	Annual	Poaceae	Highly desirable (decreaser)
Poa sp.	Annual	*Poaceae*	Intermediate desirable (increaser)
Setaria incrassate	Perennial	*Poaceae*	Highly desirable (decreaser)
Setaria sphacela	Perennial	*Poaceae*	Highly desirable (decreaser)
Sporobolus natalensis	Perennial	*Poaceae*	Least desirable (invader)
Sporobolus pyramidalis	Perennial	*Poaceae*	Intermediate desirable (increaser)
Sporobolus spicatus	Perennial	*Poaceae*	Intermediate desirable (increaser)
		Legumes	
Indigofera spinosa	Perennial	*Papplinoideae*	
Indigofera volkensii	Perennial	*Papilionoieae*	
Trifolium rueppellianum	Annual	*Papilionoideae*	
Trifolium sp	-	*Papilionoideae*	
		Sedge species	
Cyperus flavenscens	Perennial	*Cyperaceae*	
Cyperus teneristolon	Perennial	*Cyperaceae*	
Cyperus obtusiflorus	Annual	*Cyperaceae*	
		Forbs	
Amaranthus dubius	Annual	*Amaranthaceae*	
Asystasia schimperi	Annual	*Acanthaceae*	
Bidens hildebrandtii	Annual	*Asteraceae*	
Commelina forskalaei	Annual	*Commelinaceae*	
Coriandrum sativum	Annual	*Umbelliferacea*	
Echinops pappi	Perennial	*Acanthaceae*	
Haplocoelum foliolosum	Annual	*Rosaceae*	
Kedrostis foetidissima	Perennial	*Cucurbitaceae*	
Ocimum basilicum	Annual	*Lamiaceae*	

The mean species richness in a sample quadrat of 1 m^2 varied slightly for grazing types and farming systems. Table 8 indicates that the mean species richness in the communal, enclosures, stream bank and benchmark grazing areas varied from 4.1-4.7, 4.6-5.5, 3.8-4.4 and 3.0-4.3, respectively. The study suggested that in the predominantly livestock-*enset* farming system, there was a significant difference ($P \leq 0.05$) in the richness of the herbaceous species between the communal areas and the enclosures, between the enclosures and the stream banks, and between the enclosures and benchmarks. This result is supported by previous findings of Gross *et al.* (2000), Virtanen *et al.* (2000) and Oba *et al.*(2001). However, there was no significant variation between the communal areas and the stream banks. The highest species richness was observed in the enclosure grazing areas while the least was recorded in the benchmark sites that were protected from livestock grazing for a longer period of time in the dominant livestock-*enset*. This might be because moderate grazing enhanced the richness of plant species by suppressing the dominant species that might otherwise take dominance in the area and then eliminate the less competitive species in the system (Fuhlendorf, 2001).

This result implies that grazing promoted the richness of the herbaceous species although that depended on the intensity of the grazing pressure on the vegetation cover. According to this and other studies (Zerihun and Saleem, 2000; Kamau, 2004), the high species richness in the moderately grazed enclosure areas and the declined species richness in the benchmark sites indicated that livestock grazing played an integral role in maintaining and dispersing the herbaceous species thereby increasing the richness of species in the areas with moderate grazing intensity. Similarly, McNaughton (1979) reported that the reason for the decline of the species richness in the enclosed Serengeti grasslands was due to the enclosing of the area for long period of time.

In this study, the mean species richness in a quadrat of 1 m^2 was found to be 4.3, 4.9, 4.2 and 3.4 in the communal, enclosure, stream bank and benchmark areas, respectively (Table 8). This result was similar with the overall species richness (2.5 to 4.1) reported by Guretzky *et al.* (2005) in pastures that were managed with continuous and rotational grazing areas. Similarly, in his study in the central highlands of Ethiopia, Zerihun (1985) reported that species richness in quadrats vary from 5 to 24 with an average of 12 species richness. Likewise, study by Muluberhan *et al.* (2006) in northern Ethiopia reported 4.3 and 3 herbaceous species richness in the enclosed and grazed areas of 1 m^2, respectively. On their part, Oba *et al.* (2001) found 5.3 to 8.3 species richness per 1 m^2 in enclosed areas when compared to 5.1 to 7.5 species in 1 m^2 in open plots. The differences in species richness within farming systems and grazing management types were statistically significant ($P \leq 0.05$). There was also a significant variation of species richness when farming system and grazing management systems are analyzed together. Gross *et al.* (2000), Virtanen *et al.* (2000), Oba *et al.* (2001) reached a similar conclusion when they reported that the difference may occur when a range of different habitats are analyzed together.

Table 8. Interaction of ffect of farming system by grazing management on mean (± SE) species richness per quadrat (m^2) in montane grassland at Kokosa District.

	Grazing management					
Farming system*	Communal	Enclosure	Stream bank	Benchmark	Mean	CV (%)
Dominant livestock-*enset*	4.1±0.10b	4.6±0.39a	4.3±0.14.00b	3.0±0.39c	4.0	12.50
Enset-livestock	4.3±0.17ab	4.6±0.21a	3.8±0.04c	4.0±0.08b	4.2	5.80
Enset-livestock-cereal	4.7±0.05b	5.5±0.15a	4.4±0.20b	4.3±0.08b	4.7	4.95
Mean	4.3	4.9	4.2	3.4	4.2	

**Means within a row followed by the same letter are not significantly different at $P \leq 0.05$. SE = Standard error; CV = Coefficient of variation*

3.3. Relationship between Biomass Production and Plant Species Richness

The current study indicated the existence of differences in the mean biomass accumulated between the enclosed and open grazing areas. The study showed that the highest species richness occurred in the enclosed grazing areas with an intermediate biomass production. Grime (1997) and Oba *et al.* (2001) reported similar findings. As can be seen in Figures 2 and 3, the species richness first raised and then declined following the constant increase in the biomass. In contrast, the study suggested that an increase in the biomass in the benchmark was not related to an increase in species richness (Figure 2). Similarly, Oba *et al.* (2001) reported that the optimum richness corresponds to a given biomass level and age of enclosures.

This might be due to an increase in the competition intensity at the increased rate of the biomass production that became the cause for the elimination of the less competitive species from the community at peak biomass production (Grime, 1973; Huston, 1994; Bonser and Reader, 1995). The study, therefore, implied that the less competent species and the newly emerging seedlings might have been eliminated in the benchmark sites. This tendency may in turn cause decline in the richness of the species. Similar findings were reported by Kamau (2004), Oba *et al.* (2001), Huston (1994) and Guo (1996) that the long term grazing exclusion did not increase the richness of species although there was a substantial increase in the aboveground biomass.

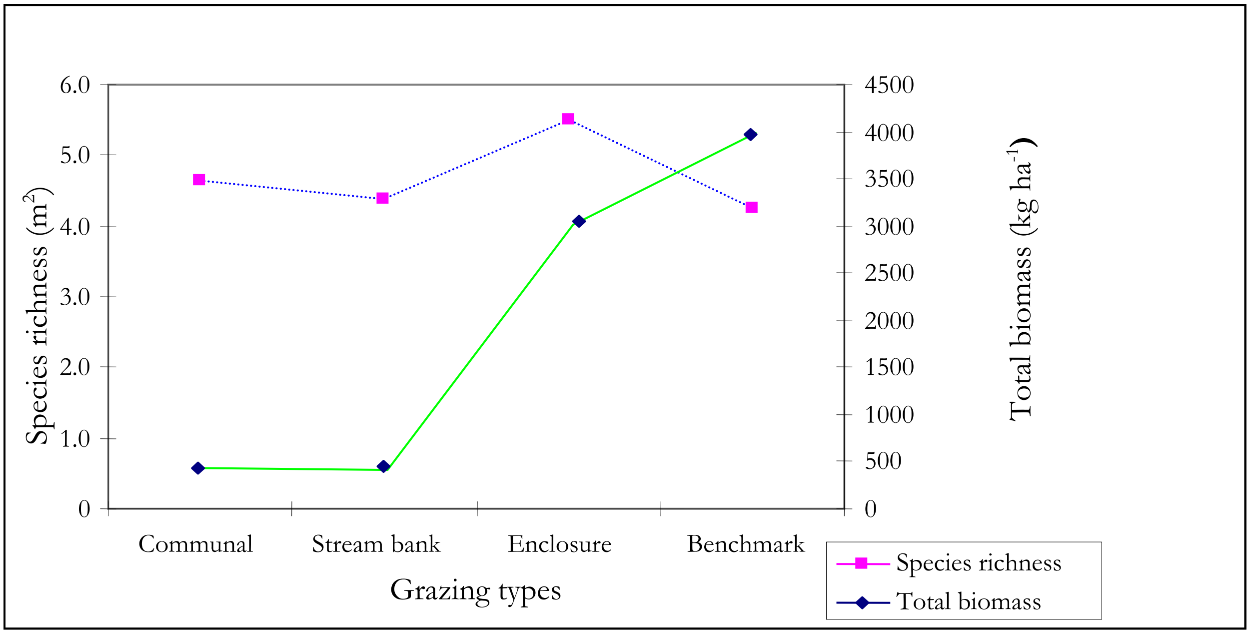

Figure 2. The relationship between biomass and plant species richness.

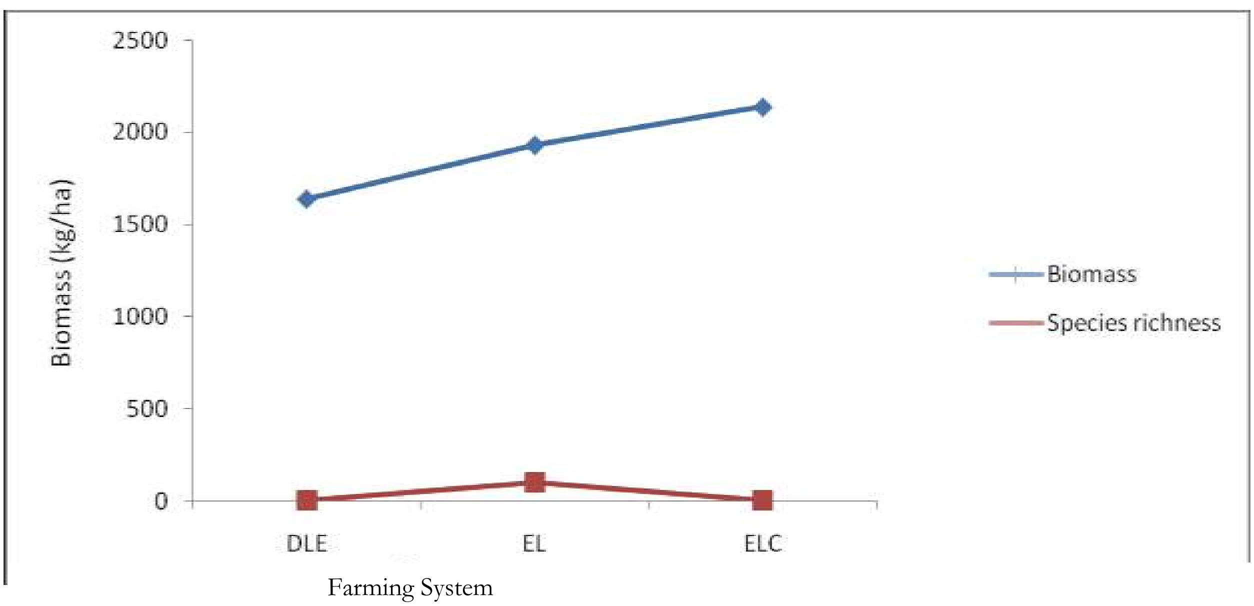

Figure 3. Relationship between mean biomass and plant species richness in different farming systems.

4. Conclusions

The study revealed that the aboveground biomass of the plant species was significantly ($P \leq 0.05$) different depending on the extent of the grazing pressure. The study suggested that light disturbance could help reduce the cover of dead shoot and facilitate the seed soil contact and foster the re-growth of plants. Grass dry biomass and total dry biomass were found to be significantly high in the *enset*-livestock-cereal farming system having lower dry matter biomass of forbs. The dominant livestock-*enset* farming system which had a high number of livestock and was characterized as lower condition class had a lower total dry matter biomass.

The species richness in a sample quadrat of 1 m^2 of the study areas varied slightly across the grazing types and the farming systems. A significantly higher ($P \leq 0.01$) richness occurred in the enclosure grazing areas and the *enset*-livestock farming system (where biomass is intermediate) while the least richness was observed in the benchmark sites and in the *enset*-livestock-cereal farming system, the highest biomass was recorded. The reason behind this might be the competitive elimination of the less competitor species from the community at peak biomass production

The current study suggested that the species richness is positively associated with the intermediate grazing pressure implying that livestock grazing management plays a crucial role in maintaining species richness in grassland communities. Although the environmental factors are considered much more important in the area, the importance of internal interaction should not also be overlooked in the biomass–species relationship. However, this still needs verification in further studies.

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Storage Technologies to Enhance Longevity in Paddy (*Oryza sativa L.*) Seed of Parental Lines IR58025A and IR58025B of Hybrid PRH-10

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Abstract: Storage conditions, storage containers and seed treatments prior to storage are important factors responsible for retaining seed longevity. But ideal storage environment are seldom available for the precious seed, especially under tropical conditions. Maintenance of seed germination in vulnerable parental lines IR 58025A (6A) and IR 58025B (6B) of paddy (*Oryza sativa* L.) during storage was investigated using integration of different treatments as storage containers (jute bags/ polylined jute bags), storage conditions (ambient/LTLH i.e. low temperature, low humidity or controlled) and seed dressings (captan/thiram) at Karnal seed godowns in North India during 2000-2007. Ten kg of seed was stored per treatment. Seed was taken from the fields of Indian Agricultural Research Institute, Regional Station, Karnal (India). The initial moisture content of paddy seeds was kept 13% which is a standard. The results revealed that there was significant difference in the storability of paddy seeds under different storage conditions. Under LTLH storage conditions (temperature:15 °C and relative humidity:30%) paddy seeds maintained germination above the minimum seed certification standards (80%) up to 60 months after seed treatment as against 24 months when stored under ambient conditions. The germination of seeds stored under LTLH conditions (86.1%) and in polylined jute bags (75.3%) was significantly higher than seeds stored under ambient condition (61.9%) and in jute bags (72.8%) after 60 months of seed treatment. Treatment with thiram/captan also showed improved seed germination by 7% as against untreated control. Seed vigour also followed a trend similar to seed germination. The incidence of seed mycoflora was 54.8% and 45.2% in seeds of 6A and 6B, respectively. This was significantly higher in seeds stored under LTLH conditions (62.1%) and in jute bags (39.1%) compared to seeds stored under ambient condition (64.7%) and in polylined jute bags (47%). In all 16 fungi were found associated with paddy seeds. However, the fungal incidence in treated seeds was 29.2% as against 70.8% in untreated control. Seed moisture content did not vary much amongst different treatments though it was higher in seeds stored under ambient storage conditions (11.7%) as against seeds stored under LTLH- low temperature, low humidity conditions (9.2%).

Keywords: Paddy-Rice; Seed Germination; Seed Mycoflora; Seed Storage; Storage Condition

1. Introduction

The germination of paddy varieties in storage does not suffer much as compared to other cereals (Paderes, *et al.*, 1997). However, paddy seed stored for long- term is invariably exposed to climatic adversities e.g. extreme summer, winter and monsoons and requires a great deal of effort to safeguard it. There is hardly any recommendation available to maintain seed quality during storage. The breeders engaged in hybrid rice research also confront germination problem associated with the parental lines especially with one of the male sterile parent 6A. This parent loses its viability at fast rate when in storage and poses the problem of poor germination at the time of next sowing season.

Seed deterioration during storage is a gradual and inevitable process causing considerable losses. Seeds tend to lose viability and vigour during storage and information on storability of seed lots from harvest until the next planting season and also for carry over purposes is of immense importance in any seed production programme. Availability of good quality seed of parental lines is essential for any successful hybrid seed production. Seed mycoflora has been recognized as an important factor responsible for deterioration in quality of seeds during storage (Gupta and Aneja 2001). Hence, an understanding of how best these seeds can be stored at a relatively low cost with minimal deterioration in quality for periods extending over one, two or more seasons will be of great interest to the seed industry. Seed longevity depends upon a number of factors such as the genetic constitution, initial seed quality, storage environment, packaging material and pre-storage seed treatments. It has been ascertained (Gupta 2003; Jakhar *et al.*, 2003) that pre-storage treatments protect the seed from microbial infestation and also enhance the storage potential of seeds. The present study was undertaken to prolong or sustain the seed longevity in parental lines of paddy by pre-storage seed dressings and interaction thereof with storage containers and storage environments.

Rice is by far the most important food crop in many developing countries, providing two-thirds of calorie intake of more than 3 billion people in Asia, and one-third of the calorie intake of nearly 1.5 billion people in Africa and Latin America (FAO, 1995). Approximately 11% of the world arable land is planted annually to rice (Chakravarthi and Naravaneni, 2006).

Postharvest operation methods have strong effects on seed quality. The main purpose of seed storage is to secure the supply of good quality seed for planting program whenever needed. Hence, seeds must often be stored during the period from harvest to sowing. The

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storage time could be short-term (less than a year) or long- term (more than a year) (Perry, 1978).

The main constraints in seed storage are high temperature and moisture which affect the maintenance of seed quality in storage. High temperature and moisture favour the development of insects, bacteria and fungi. Storage structures and practices should also protect the seed against damage by rodents. Storage structures for food are often designed for the same purpose.

Traditional storage structures, such as those using mud walls or underground spaces, are often well-designed and provide efficient isolation to keep temperatures moderately low. Ideally airtight containers are used to store well-dried seed (Greve and Van, 1983). In some countries 50 kg capacity bags of laminated polythene/aluminum foil are available; in other areas, multi-layer polythene-lined oil drums are used. Airtight containers also solve possible insect problems because the insects suffocate as soon as oxygen in the container is used up (Thijssen *et al*., 2008).

In situations when the storage season is warm and humid it is extremely important that seed lots in airtight containers should be dried very well before the container is closed for fear of respiration, thus increasing the relative humidity in the container. A seed lot of high seed vigour will produce greater percentage of seedling than a low vigour lot. The rate and uniformity of germination and emergence are also included among the vigour characters.

Assuming a good storage environment, the most practical way to further extend the storage life of seeds is to begin with seed of the highest possible vigour. Seed storage reduces vigour more than viability. The danger in long term storage is subtle that damage can occur to the seed which is undetectable by germination tests under favourable conditions. This is dangerous for sowing purpose since the ability of the seed to resist stress is impaired. Factors affecting seed vigour include genetic background, the process of seed development, and handling during harvest and storage conditions and length (Bhaskaran *et al*., 2005).

Seed health testing is important for three reasons (1) seed-borne inoculums may give rise to progressive disease development in the field and reduce commercial value of the crop, (2) imported seed lots may introduce disease into new regions, and (3) the disease may attack seedlings, and causes poor germination or field establishment (Fairey and Hampton, 1997).

Some microorganisms associated with seeds either as saprophyte or pathogens promote seed rot and reduce germination while others may cause destruction in storage. Seed health testing can, therefore, check on the effects of seed-borne diseases and can supply an important measure of overall seed quality and control of crop diseases. Seeds can serve as vehicles for dissemination of plant pathogens, which can result in disease outbreaks.

The present study was undertaken to prolong or maintain the seed longevity in parental lines of paddy by pre-storage treatments and interaction thereof with containers and storage environments.

2. Materials and Methods

Freshly harvested seeds of parental lines of paddy IR58025A (6A) and IR 58025B (6B) were obtained and sampled. Two samples of each parent were treated with fungicides thiram/ captan as dry dressing @ 2.5 g/kg seed, respectively, and the third sample was left untreated which served as control. Four sub- samples of each treatment were prepared and two sub- samples were kept in jute bag and the other two were put in polylined jute bag (polythene bag of 400 gauge inside a jute bag) for each parental line and sealed and closed. One set of seed samples was stored under controlled or low temperature low humidity (LTLH) conditions and the other set was stored under ambient conditions in seed godowns at Karnal in North India. Treatments were in completely randomized design in replications. Initial record on seed germination, seed moisture, seed vigour and seed mycoflora was recorded and subsequent record were taken at bimonthly intervals up to 60 months of storage after seed treatment. For seed germination, the 100 x 4 seeds were tested in "between paper" (B.P) substrata at 25 ^{0}C temperature by keeping in seed germinator as per ISTA (1999). For seed moisture determination, the paddy seeds were determined by hot air oven method. Ground material and was kept at 130 ^{0}C temperature for 2 hours in hot air oven. For seed vigour test the seed vigour Index I was determined by the following formula (Abdul-Baki and Anderson, 1973)

Seed vigour Index I = Standard germination x shoot + root length (cm).

For seed mycoflora, the seeds were planted on specific medium after treatment with 1-2% sodium hypochlorite (NaOCl) and incubated. The fungi were identified based on colony characteristics using compound microscope. For seedling emergence for different treatments was determined in the field during the *Kharif* season in three consecutive years by the following formula (Maguine, 1962):

$$\frac{\text{Seedling emergence on first count}}{\text{Number of days planted}} + \frac{\text{Seedling emerged at final count}}{\text{Number of days at final count}}$$

The collected data were statistically analyzed as per CRD. Different types of software were used.

3. Results and Discussion

3.1. Environmental Conditions During Storage

The minimum temperature of the seed godown under ambient conditions varied from 16.1 to 33.6 °C and the maximum temperature varied from 17.1 to 34.8 °C. The relative humidity for the corresponding period varied from a minimum of 35.9% to a maximum of 75.5%. Under controlled conditions, temperature and relative humidity of the seed godown was maintained at 15° C and 30%, respectively.

3.2. Seed Germination

Seed germinability of the rice cultivars was not affected significantly up to a period of 24 months by the storage condition, storage containers or seed treatments (Table 1). The germination of seeds of both the parental lines stored under LTLH conditions remained above the acceptable levels (>80%) up to 60 months of storage after seed treatment and 64 months of storage after seed harvest, irrespective of treatments. Highest germination (87.8%) was recorded in treated seeds packed in polylined jute bags and stored under LTLH conditions on 60 months of storage after seed treatment. The germination of seeds stored under ambient conditions could be maintained above minimum seed certification standard (MSCS) up to 24 months of storage only. However, seeds treated with thiram/captan retained more than 83% seed germination up to 28 months, irrespective of storage containers and on further storage the germination in the seeds stored under ambient conditions declined below MSCS but the germination of seeds stored under LTLH conditions remained above 80%, irrespective of storage containers /seed treatments. Maximum decline in seed germination was observed in the untreated seed lots stored in jute bags under ambient storage conditions. The germination of seeds stored under LTLH conditions (86.1%) and in polylined jute bags (75.3%) was significantly higher than seeds stored under ambient condition (61.9%) and in jute bags (72.8%) after 60 months of seed treatment.

Table 1. Effect of storage conditions, storage containers and seed treatments on germination (%) of paddy seed.

Storage condition	Storage container	Seed treatment	Storage duration (months)								
			0	8	12	16	24	28	36	48	60
Ambient	Jute bag	Treated*	86.1a	90.8b	86.9a	90.3b	89.9c	83.3b	42.5e	0.9e	0.0c
	Jute bag	Untreated	81.8c	88.0d	82.4b	82.5e	75.4f	61.9d	29.5f	0.1e	0.0c
	Polylined bag	Treated	86.6a	91.2b	89.1a	93.0a	90.2bc	83.8b	69.6c	12.9c	0.0c
	Polylined bag	Untreated	82.6c	86.9d	81.9bc	82.8e	82.4e	71.0c	50.5d	4.4d	0.0c
LTLH	Jute bag	Treated	86.4a	91.0b	87.5a	90.5b	94.1a	83.9b	82.4a	88.0a	82.0b
	Jute bag	Untreated	83.8bc	89.3c	83.4b	88.1c	90.3bc	83.5b	76.8b	84.5b	80.6b
	Polylined bag	Treated	85.5ab	92.5a	88.2a	88.8bc	92.2ab	87.9a	84.8a	87.0a	87.8a
	Polylined bag	Untreated	83.5bc	91.1b	80.0c	84.8d	87.9d	83.9b	82.3a	83.5b	80.3b
	LSD 0.01		2.8***	1.5***	3.0***	2.6***	2.7***	4.4***	5.1***	2.6***	3.4***

**Seed treated with Thiram or Captan @ 2.5 g/kg seed*

Amongst the two parental lines, seeds of 6B (IR 58025B) maintained about 3% higher seed germination at all storage intervals than 6A (IR 58025A), irrespective of treatments (Figure 1). The results also revealed about 40 percent increase in germination when the seeds were stored under LTLH conditions as against seeds stored under ambient conditions. Similarly, 3% and 7% increase in germination was observed in seeds packed in polylined jute bags and in treated seeds over seeds packed in jute bags and untreated seeds, respectively.

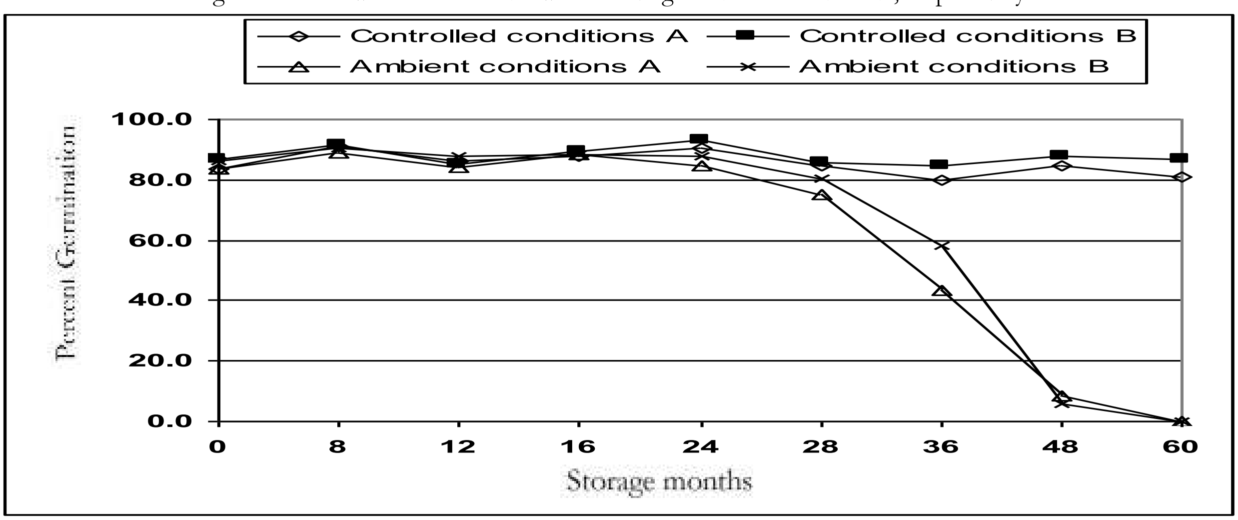

Figure 1. Effect of storage conditions on seed germination in parental lines of Paddy during storage.

The effect of two storage containers on seed germination was insignificant during early period of storage up to 24 months but on further storage about 4 percent higher germination was recorded in seeds stored in polylined bags as against in seeds stored in jute bags (Figure 2). Freire and Mumford (1986) also observed rapid deterioration of seeds in permeable containers as against hermetically sealed laminated aluminum foil packages and metal cans.

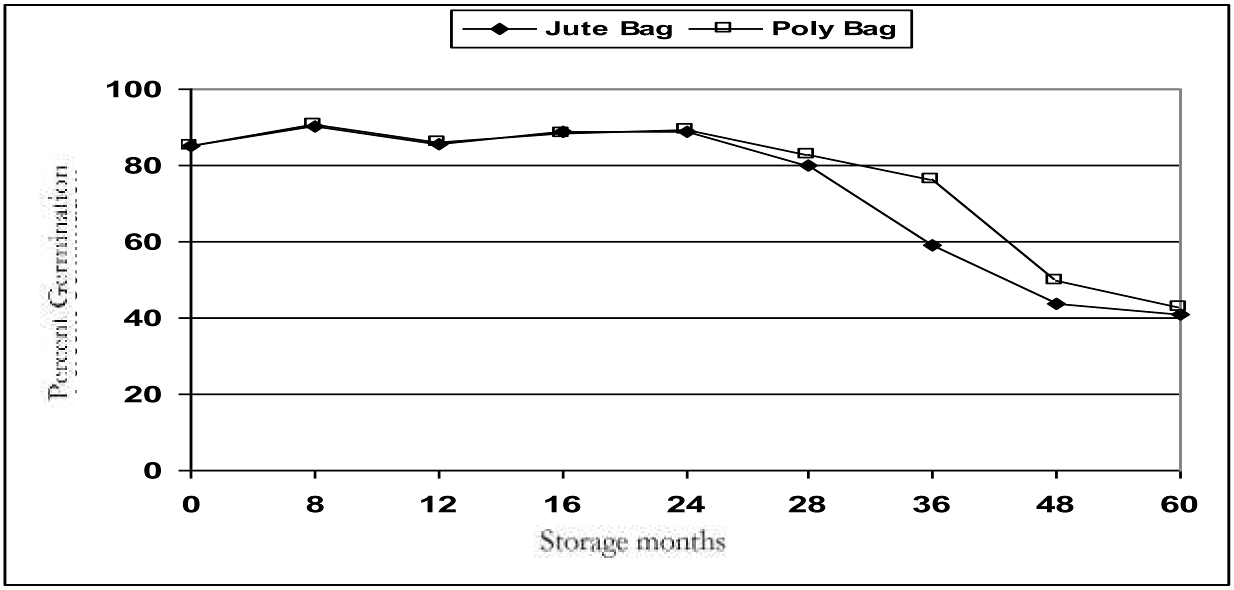

Figure 2. Effect of storage containers on seed germination in parental lines of Paddy during storage.

The effect of seed dressings on germination percentage of paddy seeds was apparent at all storage intervals (Figure 3). Germinability of treated seeds was significantly higher than untreated seeds at all storage intervals up to 28 and 60 months under ambient months and LTLH storage conditions, respectively. Though germination of paddy seed stored under LTLH conditions was above MSCS irrespective of storage containers but higher germination was recorded in treated seed as against untreated seed stored in same type of container. Both thiram and captan seed dressings were equally effective in maintaining seed germination. Thus, storage of seeds in polylined containers and under controlled conditions was superior to storage of seeds in jute bags and under ambient conditions, respectively, especially at later storage period.

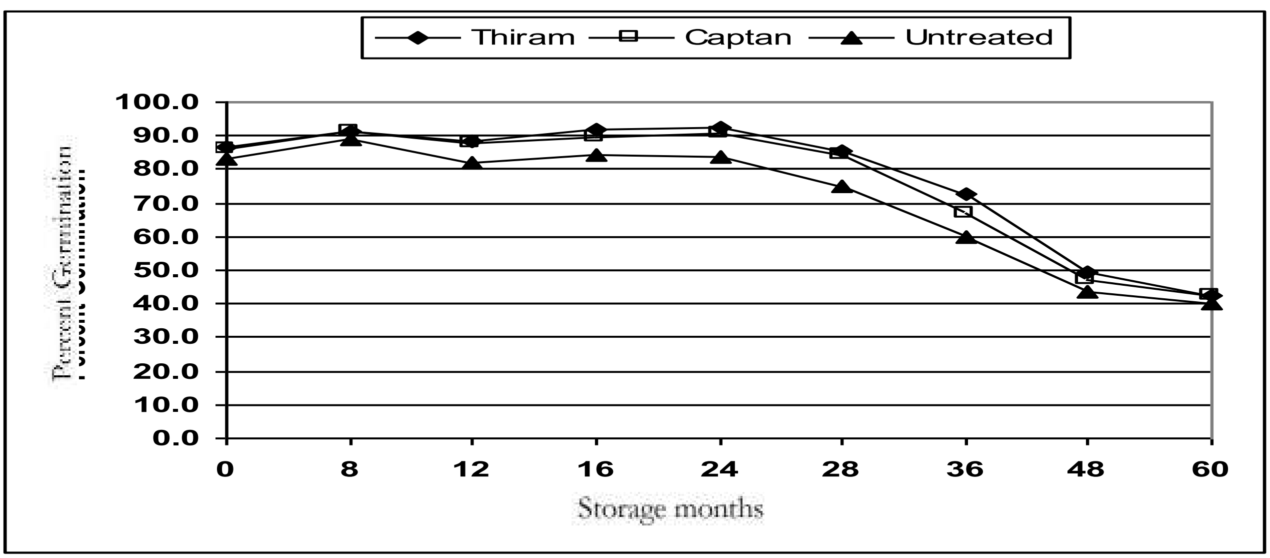

Figure 3. Effect of seed treatments on seed germination in parental lines of paddy during storage.

3.3. Seed Vigour

Seed vigour also followed a trend similar to seed germination, i.e., it increased with the storage duration up to 24 months and then declined before the fall in seed germination ?? (Table 2). Comparatively higher seed vigour was recorded in seeds of 6B (1528.0) than in seeds of 6A (1496.0); in seeds stored in polylined containers (1241.6) than in seeds stored in jute bags (1167.9); in treated seeds (1275.8) as against untreated seeds (915.4) and in seeds stored under LTLH environment (1424.0) than in seeds stored under ambient conditions (985.5). Treated seeds showed 28.3% higher seed vigour than untreated seeds during storage. About 18% increase in seed vigour was also recorded in seeds stored under controlled conditions as against seed stored under ambient conditions and 5.9% increase in seed vigour was recorded in seeds stored in polylined bags as against jute bags.

The superiority of fungicide treatments and polylined containers for maintenance of viability of hybrid seed has also been confirmed by Jakhar *et al.* (2003). They reported that non-systemic fungicides were more effective than systemic fungicides in maintaining viability of pearl millet seeds during storage.

Amongst deteriorative changes, membrane degradation has been proposed as the primary event in ageing (Dadlani and Agarwal, 1983). But paddy seed has a husk covering thereby protecting the seed under adverse conditions and hence the rate of deterioration in paddy seed though is low but it is important to save the precious seed against deterioration.

Agarwal (1980) observed that leaching of sugars declined during storage of paddy cultivars, which was maximum after 6-8 months of storage but minimum after 22 months of storage because during storage soluble sugars in seeds decreased. They also observed less leakage of water soluble sugars and amino acids in cooler months than in warmer months. The conductivity of seed leachates increased about two-folds during storage for soybean cultivars (Trawatha *et al.*, 1995). Hence, storage under LTLH conditions restricts the metabolic activity of seeds and thereby leaching of solutes. Gupta and Aneja (2004) also observed leaching of solutes to be inversely correlated to seed germination in soybean seeds. The longevity of pearl millet seeds could also be prolonged two-folds when the seeds were stored under LTLH conditions (Gupta, 2007).

Seeds of different cultivars of paddy treated with thiram also recorded 9.96% and 13.04% increase in seed germination and seed vigour, respectively over untreated. The enhancement in germination and vigour observed in fungicide treated seeds on stored seeds are in agreement with the results of the studies undertaken by Mishra and Dharamvir (1991) and Sachan and Agarwal (1994). However, Kauraw (1986) observed adverse effect of fungicide dressings on the shoot and root length of the seedlings.

Table 2. Effect of storage conditions, storage containers and seed treatments on vigour of paddy seed.

Storage condition	Storage container	Seed treatment	Storage duration (months) 0	12	24	36	48	60
Ambient	Jute bag	Treated*	1451.8a	1526.4a	1597.4c	580.1e	7.2c	0.0c
	Jute bag	Untreated	1355.9b	1121.6e	1304.0d	389.5f	1.1c	0.0c
	Polylined bag	Treated	1469.2a	1467.2ab	1565.3c	935.8c	179.0b	0.0c
	Polylined bag	Untreated	1297.2b	1362.5bc	1403.2d	745.8d	46.0c	0.0c
LTLH	Jute bag	Treated	1456.0a	1293.5cd	1748.7ab	1466.5a	1744.7a	1201.5b
	Jute bag	Untreated	1294.1b	750.9g	1634.2bc	1313.8b	1718.5a	1321.6a
	Polylined bag	Treated	1325.2b	1156.9de	1816.0a	1503.3a	1730.2a	1358.3a
	Polylined bag	Untreated	1191.5c	956.4f	1749.3ab	1435.5a	1662.3a	1347.9a
	LSD 0.05		87.9***	136.8***	114.4***	74.5***	80.8***	117.2***

**Seed treated with Thiram or Captan @ 2.5 g/kg seed*

3.4. Seed Moisture

The moisture content of seeds did not vary much amongst the two parental lines 6A (10.6%) and 6B (10.3%). Amongst the seed dressings, it was 10.5 and 10.3% in treated and untreated seed, respectively. However, the moisture content of seed packed in jute bag varied from 7.8 to 13.7% (average 10.7%) as against 7.8 to 12.9% (average 10.1%) moisture in seed packed in polylined bag (Figure 4). However, higher variation in the moisture content was recorded in seeds stored under ambient conditions (7.8-13.7%; average 11.7%) as against moisture content of seed stored under LTLH conditions (7.8-11.1%: average 9.2%). Under LTLH conditions, the moisture content appeared more stable and did not exhibit much variation. Increase in the moisture content of seeds stored under ambient conditions probably is an important factor responsible for early decline of seed germinability. Earlier studies by Gupta (2003) reported negative correlation between seed longevity and seed moisture in stored soybean seeds. Gowda and Bhole (1989) had also observed variability in seed viability due to different storage environments.

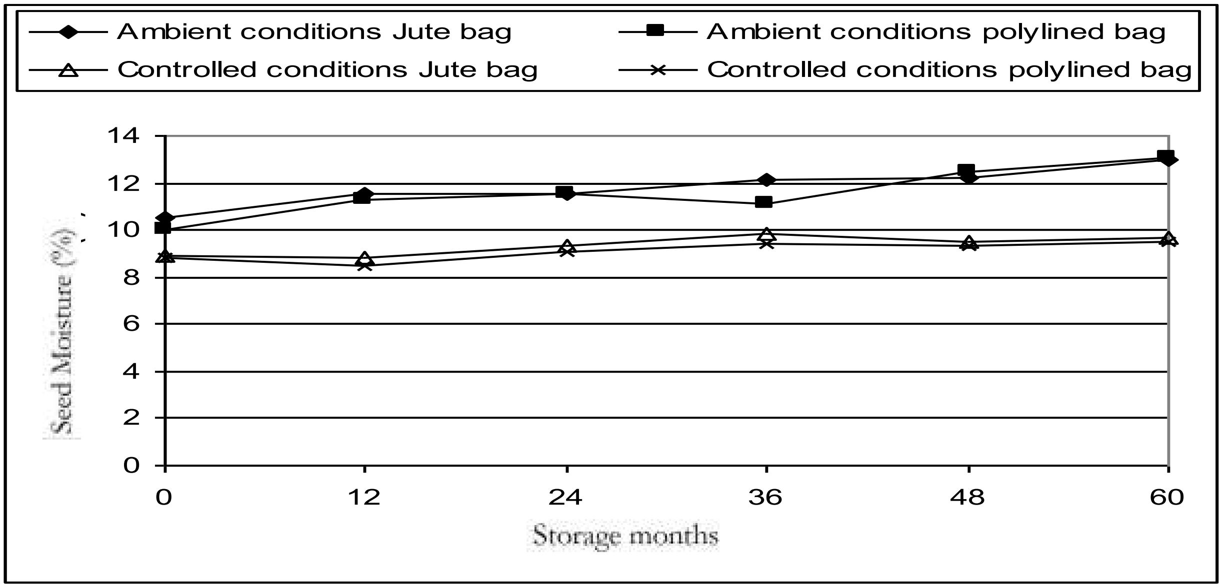

Figure 4. Moisture content of paddy seed in different storage treatments.

3.5. Seed Mycoflora

In all 16 fungi were found associated with paddy seed. The main fungi encountered on paddy seeds were *Fusarium moniliforme*, *F. semitectum*, *F. graminearum*, *Drechslera oryzae*, *Curvularia lunata*, *C. oryzae*, *Alternaria alternate*, *A. padwickii*, *Aspergillus flavor*, *Penicillium* sp. and *Rhizopus stolonifer*. Low to very low incidence of *Aspergillus Niger*, A. *fumigatus*, *A. terreus*, *Cladosporium* sp. and *Curvularia clavata* were also found associated with paddy seeds. The incidence of mycoflora decreased after 12 months of storage and increased thereafter under both the storage conditions. The fungal flora decreased by 58.4% under ambient storage conditions as against 15.7% under LTLH conditions on 12 months of storage after seed treatment. Maximum increase in the incidence of fungi was observed after 36 months of storage (39.6%) under ambient storage conditions as against 114% increase at 48 months of storage under LTLH storage conditions. After 60 months of storage there was decrease in the fungal flora by 25% under ambient storage conditions and it increased by 35% under LTLH storage conditions.

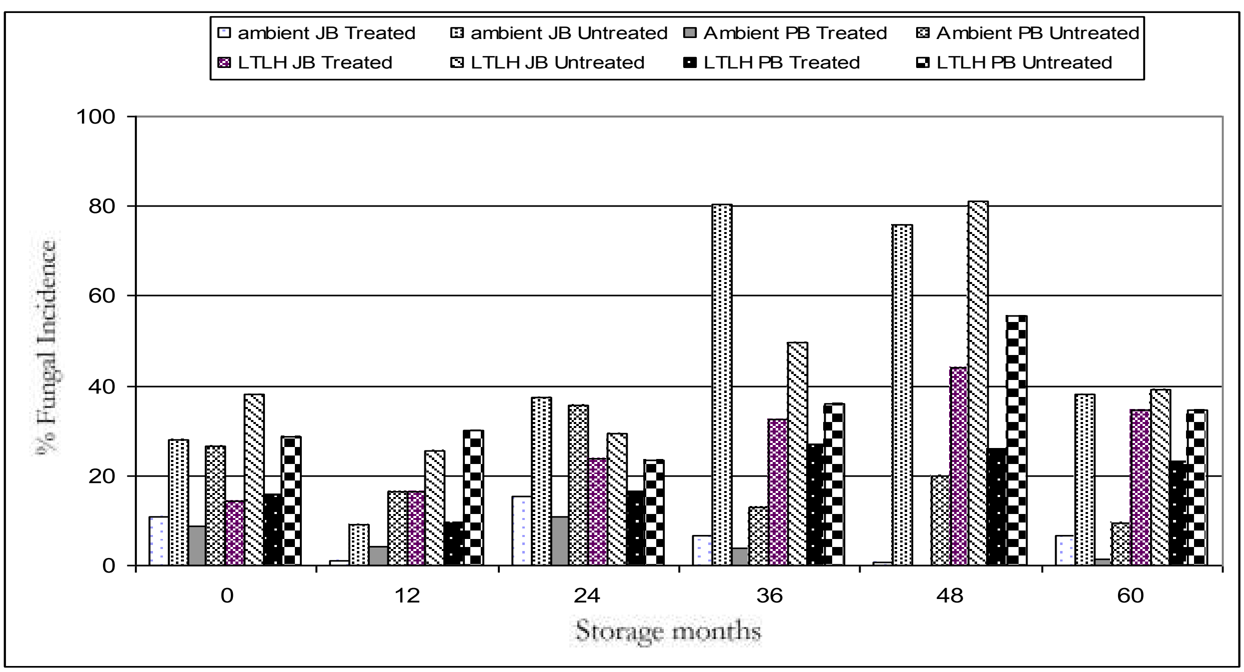

Figure 5. Effect of different storage treatments on fungal incidence during storage of paddy seed.

The incidence of mycoflora in 6A parental line was 54.8 percent as against 45.2 percent in 6B. Higher percent incidence of mycoflora was also recorded on seeds stored in jute bags (60.9%) as against 39.1 percent incidence on seeds stored in polylined bags. Treatment with thiram/captan was found to be very effective in reducing the mycoflora incidence from 70.8 percent in untreated seed to 29.2 percent in treated seed during the entire storage period (Figure 5). The fungal load on paddy seed under ambient and LTLH storage conditions were 37.9 and 62.1%, respectively. The incidence of mycoflora decreased up to 12 months of storage but thereafter it increased mainly due to the appearance of storage fungi like species of *Aspergillus* and *Rhizopus*.

The incidence of *Curvularia lunata* and *Alternaria padwickii* was high on seeds stored under controlled conditions and low to very low on seeds stored under ambient conditions whereas incidence of *Aspergillus flavus* and *Rhizopus stolonifer* was high on seeds stored under ambient conditions as against seeds stored under LTLH conditions.

Seed treatment with thiram and captan could control 61 and 56% fungi, respectively as against untreated control (Figure 6). The efficacy of seed dressings was more pronounced under ambient storage conditions in both the type of containers, but under LTLH conditions the seed dressings appeared to have become inactive but the seeds were viable and hence the fungal flora flourished under LTLH storage conditions.

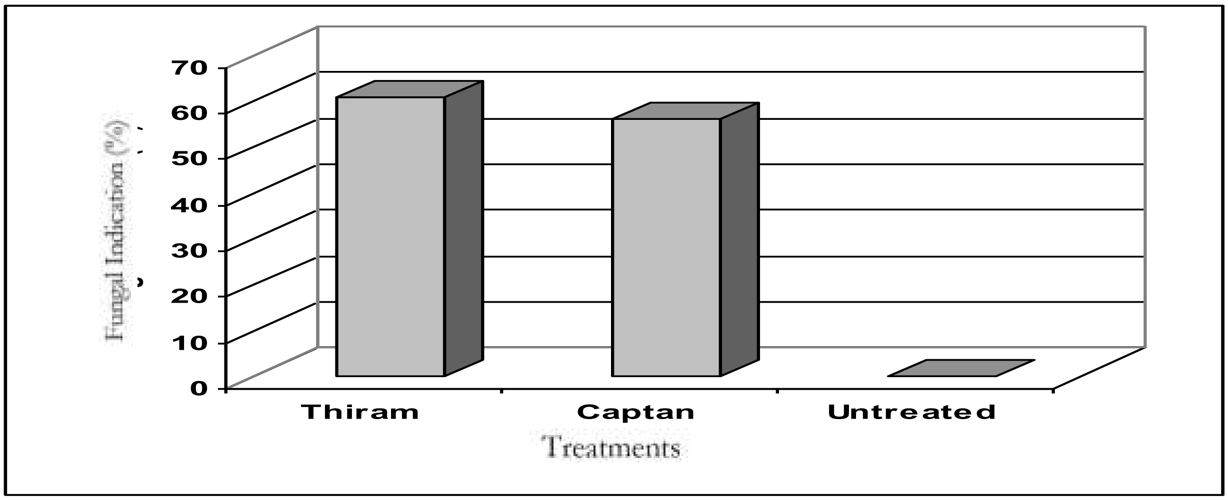

Figure 6. Efficacy of seed treatments on fungal load in paddy seed.

In earlier storage study in our laboratory on different cultivars of paddy, thiram and captan gave more than 96 and 90% control of seed mycoflora, respectively. The positive effect of the seed dressings has also been reflected in earlier works (Jakhar *et al.,* 2003; Gupta and Aneja, 2004). Seed mycoflora has been recognized as an important factor responsible for deterioration in quality of seeds during storage (Gupta and Aneja, 2001). Control of seed mycoflora may be one of the reasons for maintenance of seed viability during storage. As long as the seed remained viable under LTLH conditions, fungi also remained viable and grew luxuriantly. Fungal growth is more in jute bags as compared to polylined bags probably because of higher seed moisture. Ghosh and Nandi (1986) observed that while one organism affects maximum loss in germination but maximum reduction in seedling growth was induced by another species. In some of the earlier studies (Paderes *et al*., 1997; Mazen *et al*., 1993) it has been reported that the seed mycoflora increases with the increase in seed moisture and results in seed rotting and loss in seed viability.

3.5. Seedling Emergence in the Field

Seedling emergence during *Kharif* 2002, 2003 and 2004 seasons was 43, 52 and 42 percent, respectively. The results of field emergence studies conducted during the three seasons revealed that as in seed germination, field emergence was also better in seeds of the parent 6B (51%) as against 49% in 6A. The seedling emergence of treated seed (55%) was higher as against untreated seed (45%). Though the seedling emergence got reduced over the storage time but it was higher in seeds stored under LTLH conditions (57%) as against seed stored under ambient conditions (43%). Seeds stored in polylined jute bags also exhibited higher seedling emergence (52%) under field conditions than the seeds stored in jute bags (48%).

4. Conclusions

The germination of seeds stored under low temperature and low humidity conditions was recorded 86.1% and in polylined jute bags 75.3% which was higher as compared to ambient condition (61.9%) and in jute bags (72.8%) after 60 months of seed treatment.

The storage of seeds in polylined containers and under controlled conditions was recorded superior as compared to storage of seeds in jute bags and under ambient conditions respectively.

The treated seeds showed 28.3% higher vigour Index I than untreated seeds during storage.

Higher variation in the moisture content was recorded in seeds stored under ambient conditions as compared against seed stored under low temperature and low humidity (LTLH) conditions.

Treatment with thiram/captan was found to be very effective in reducing the mycoflora incidence from 70.8% in untreated seed to 29.2% in treated seed during the entire storage period.

Seeds stored in polylined jute bags exhibited higher seedling emergence (52%) under field conditions than the seeds stored in jute bags (48%)

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Short Communication

Effect of Plowing Frequency and Weeding Methods on Weeds and Grain Yield of Wheat at Arsi Negelle, Ethiopia

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Abstract: The effect of repeated tillage and weed control methods on weed infestation and grain yield of wheat was evaluated at Arsi Negelle, southern Ethiopia, from 1993 to 1995 cropping seasons. Five tillage practices (zero, one, two, three and four times tillage) as main plot and four weed control methods (Duplosan sprayed at 2.5 l ha^{-1}, Duplosan plus one hand weeding at 30 days after emergence (DAE); one and two hand weeding at 30, and 30 and 60 DAE, respectively) as subplots were arranged in split plot design with three replications. Broadleaf weeds comprised 73% of the total weed population in the experimental plots. Effect of tillage and weed control was dependent on year. Increased frequency of tillage reduced weed infestation ($r = -0.34^{**}$) and increased plant height ($r = 0.42^{**}$), biomass ($r = 0.51^{**}$) and grain ($r = 0.43^{**}$) yields of wheat. Weed density in zero-till and three times plowing was 78 and 35%, respectively, more than four times. Weed density in plots treated with Duplosan alone and its combination with 1HW was 38.4 and 19.5% more, respectively, while it was 5.9% less with 1HW alone compared with 2HW. About 33 and 26% of the total variations in weed infestation were due to tillage and weed control methods, respectively. Grain yield reduction in zero-till and three times plowing was 59 and 21%, respectively, compared with four times' plowing. Twice weeding reduced weed population by 28% and increased wheat grain yield by 3.3% compared to Duplosan alone. Fifty five, 95 and 43% of the total variations in wheat grain yield in 1993, 1994, and 1995, respectively, were attributed to the regression. Frequent tillage reduced weed infestation and increased grain yield by 11 and 21.9%, respectively, compared to weed control. Generally, four times plowing significantly reduced weed infestation and increased wheat grain yield with considerable economic benefit.

Keywords: Herbicide; Repeated Plowing; Southern Ethiopia; Tillage; Weed Density; Wheat; Weed Infestation; Weed Population

1. Introduction

Bread wheat (*Triticum aestivum* L.) is one of the major crops in Arsi Negelle and Shashemene areas and covers 13.7% of the total cultivated area. Bread wheat covers about 19.29% of the total cereal areas in Oromia region with an average yield of 1957 kg ha^{-1} (CSA, 2010). Shortage of plowing oxen and labor constrain wheat production in these areas. A pair of oxen is needed to till the land, but many farmers own only a single ox and fail to prepare the land properly and timely. Often farmers practice two to three plowings before wheat sowing (Yohannes, 1982) and this increases infestation of both broad-leaf and grass weeds (personal comm., Regional Ministry of Agriculture, 1997) resulting in low productivity. Weed infestation, which is the result of poor land preparation and unavailability of labor to control weed on time, is one of the major constraints in wheat production. The report indicates that in Ethiopia weed competition reduced wheat yields by up to 36.4% (Rezene, 1989). Wheat grain yield ranges between 600 and 2500 kg ha^{-1} depending on weather conditions, crop management factors and soil type (Yohannes, 1982). Tillage is supplemented with the application of herbicide especially with, 2, 4-D 30 to 40 days after wheat emergence.

Tillage practices vary with the prevailing weather conditions and have an influence on soil moisture (Johnson *et al*., 1989; Kamwaga, 1990; Bonfil *et al.,* 1999). Where there is drought (moisture stress), no-till can produce better grain yield (Bonfil *et al*., 1999) resulting in yield increase by 18 to 75% in continuous wheat and 62 to 67% in wheat fallow rotation with no-till relative to conventional tillage in moisture stress areas**.** Aulakh and Gill (1988) observed that zero tillage, due to retention of crop residue, had more yields and lower bulk density than conventional tillage that had low yield due to higher soil bulk density and lower soil water availability to the crop. Zero tillage applied with straw mulch had more grains per spike and gave similar grain yield of wheat as compared to 6 to 8 plowings (Dhinam and Sharma, 1986 cited by Majid *et al*., 1988). The reason for better performance of zero till was due mainly to uniform placement of seeds, which resulted in better plant emergence and less weed infestation than the conventional tillage.

In fact, minimum tillage can cost less since the power and time requirement is minimal (Dawelbeit and Salih, 1994). In addition, minimum tillage allows earlier sowing**,** reduces soil erosion and there can be less potential for pesticide contamination of surface water (Brecke and Shilling, 1996). On the other hand, Kamwaga (1990) found no significant yield variation between conventional and reduced tillage over a two year period at various locations because of uniform distribution of rainfall. He also noted higher grain yield of wheat in minimum tillage

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under erratic rainfall. Similarly, Bordovsky *et al.* (1998) reported that under rainfed condition, both reduced and conventional tillage produced equal yields of wheat in Texas. According to Macharia *et al.* (1997), tillage frequency conducted for three consecutive seasons showed no significant variation on wheat yield. As reported by Assefa *et al.* (2000), nitrogen content and N uptake of wheat straw increased under conventional (four times plowing) compared with minimum tillage (one time plow).

Repeated tillage stimulates weed seed germination before the final tillage leading to reduced seed bank and weed infestation (Johnson *et al.*, 1989). Reports of ICARDA (1984), Dorado *et al.* (1998), and Thompson and Whitney (1998) showed that weed density was higher in no-till plots than in repeatedly plowed plots. Assefa *et al.* (2000) investigated that one time plowing (minimum tillage) reduced wheat seedling density at emergence while four times plowing (conventional) increased straw and grain N uptake. The density of some weeds (*Bromus pectinnatus* and *Galinsoga parviflora)* was also reported to increase under minimum tillage (Assefa *et al.*, 2000). In contrary, despite application of residue to both, reduced tillage had lower grain yield of wheat relative to the conventional tillage due mainly to decreased plant populations caused by poor seed-to-soil contact during sowing (Bordovsky *et al.*, 1998). Repeated tillage reduced weed infestation by more than 50% compared with zero tillage (ICARDA, 1984). Others reported that zero tillage reduced weed competition and produced higher grain yield (Brecke and Shilling, 1996). Chemical weed control, tillage, and hand weeding, and integrated weed management are of the many alternatives available for weed control. Hand weeding and chemicals are effective to control weeds (ICARDA, 1984). Availability of labor on time is a problem during weeding due to overlapping of farm activities and is costly. Availability, costliness, efficacy, and its effect on human health are problems to consider using herbicides. However, herbicide is commonly used by some farmers of Arsi Negelle for the control of wheat weeds. On the other hand, because of few plowings/passes due to shortage of oxen, control of weeds was minimal thus competing and reducing grain yield of wheat. The overall objective of this study was, therefore, to investigate the effect of season, repeated tillage and weed control methods on weed infestation and grain yield of wheat.

2. Materials and Methods

2.1. Site Description

The study was conducted at Arsi Negelle, Ethiopia for three consecutive years, 1993-95. It is located at an altitude of 1960 m.a.s.l. Mean annual rainfall of of Arsi Negelle district varies between 800 and 1400 mm while the soil type of the experimental area is sandy loam. Wheat is the major cereal crop widely grown in and around Arsi Negelle and Shashemene areas.

2.2. Experimental Description

The treatments were: plowing frequencies (zero, one, two, three, and four times plowing at an interval of 15 days for the repeated plowings) as main plots, and weed control methods (post-emergence herbicide Duplosan (D2.5) at the rate of 2.5 l ha^{-1} applied after 5-leaf stage of wheat; Duplosan (2.5 l ha^{-1}) plus one time hand weeding (1HW) at 30 days after emergence (DAE); one time hand weeding at 30 DAE and two times hand weeding (2HW) at 30 and 60 DAE, which is recommended) as subplot were arranged in split plot design with three replications. The subplot size was 15 rows of 0.2 m row spacing and 5 m length. Glyphosate (round up) herbicide at the rate of 4.5 l ha^{-1} (recommended) was applied on zero-till plots 15 to 20 days before sowing since no-till plot is not plowed, which is commonly used in zero-till plots. The seed rate of Dashen wheat variety was 125 kg ha^{-1} and was drilled in furrows using hoes and Diammonium phosphate (DAP) fertilizer at the rate of 18/46 N/P_2O_5 kg ha^{-1}, respectively, was side banded at sowing. The land was tilled with traditional oxen-drawn plow. The crop was sown on 22 July 1993 and 1994, and 4 August 1995.

An iron rod quadrat size of 25 cm length by 25 cm width was used for weed count. A mean of weed population count from four throws in each plot was recorded and weeds were identified as grass and broadleaf weeds. Data on weed types and population m^{-2} (1993 and 1994), plant height (1993-1995), spike length (1994 and 1995), grains per spike (1993), thousand kernel weight (1993-1995), biomass (1994 and 1995) and grain (1993-1995) yields were recorded. Log transformation was used for weed count. Duncan's Multiple Range Test was used to differentiate treatment means (Gomez and Gomez, 1983). Combined analysis over years was carried after test of homogeneity. Multiple regression model was used to predict yield response to frequency of tillage and simple Pearson's correlation coefficient analysis was performed. Economic analysis was carried out using the procedure of CIMMYT (1988).

3. Results and Discussion

3.1. Rainfall

Rainfall was adequate in 1993 and 1994, but moisture shortage was high in 1995 cropping season with intermittent shortages of rainfall beginning at sowing, which has seriously affected the crop (Table 1). Amount and distribution of rainfall in the first two years was better and resulted in relatively better crop performance and biomass and grain yields. Total amount of rainfall in 1995 compared with the long-term was 18.4% less. Thus, the rainfall in 1995 was so short that wheat development stages (vegetative growth, grain filling) were significantly affected and resulted in low biomass and grain yields. Despite shortage of rain in 1995, plots plowed three and four times had relatively better growth, and biomass and grain yields, possibly due to conservation of soil moisture through crop canopy cover which had better seedling establishment and growth, and reduced weed competition.

Table 1. Amount of rainfall (mm) during the growing season of wheat at Arsi Negelle.

Month	Year			Long-term
	1993	1994	1995	1994-2002
July	116.1 (-9.2%)	134.7 (+5.3%)	83.7 (-34.5%)	127.8
August	124.6 (-1.0%)	163.0 (+32.1%)	93.7 (-24.1%)	123.4
September	134.1 (-9.4%)	192.1 (-29.8%)	136.0 (-8.1%)	148.0
October	112.1 (+67.3%)	99.1 (+47.9%)	67.0 (0.0%)	67.0
Total	486.9 (+4.4%)	588.9 (+26.3%)	380.4 (-18.4%)	466.2

Note: Number in parenthesis is percent of rain over the long-term; The negative numbers show shortage of rain relative to the long-term

3.2. Weed Type and Infestation Level

The prominent weed species recorded during the study were broad leaf and grass weeds, broadleaf being dominant (Table 2) covering 73% of the total weeds in the experimental plots during 1993 season (Table 3). Significant variation in broad-leaf and grass weeds was not observed among tillage practices but weed control methods showed significant variation. Grass weed was low in one and two weedings compared with Duplosan alone or its combinatation with one hand weeding. On the other hand, application of Duplosan together with one hand weeding significantly reduced broad-leaf weeds by 47.9, 66.8 and 49% when compared with the application of Duplosan alone, hand weeding once and twice, respectively.

There was a significant effect of season, tillage, and interaction of season with tillage and weed control methods on most parameters measured (Table 4). There was no interaction effect of frequency of tillage and weed control methods on most parameters except spike length. The result of combined analysis showed significant ($P \leq 0.05$) variation in weed density due to tillage, interaction of season with tillage and weed control methods. Effect of tillage on weed was dependent on seasonal rainfall in which tillage responded differently to the different years (Table 5). Four times plowing consistently reduced weed population in both years while no-till and two times tillage had more weeds in 1994 than 1993 because of variation in years. Weed population in plots plowed four times was significantly 25 and 57% less compared with no-till in 1993 and 1994, respectively. Weed density in three plowings was 21.7 and 51.2% more than plowing four times in the respective years. It shows that effect of tillage on weed infestation was variable from one year to the other because of variation in rainfall amount and distribution.

Frequency of tillage was negatively correlated with weed infestation (r = -0.34**). Weed population due to tillage was reduced by 20 and 26% in comparison with no-till in 1993 and 1994 seasons, respectively. Repeated tillage, before the final tillage, might stimulate weed seed germination and would reduce the seed bank and subsequent weed densities (Akobundu, 1987; Johnson *et al*., 1989). The finding at ICARDA (1984) shows that repeated tillage compared to no-till reduced weed infestation by 50%. Dorado *et al.* (1998) and Thompson and Whitney (1998) reported low weed population in repeated tillage. Others (Assefa *et al*., 2000) also reported reduced weed density (*Bromus pectinnatus* and *Galinsoga parviflora*) under minimum tillage (one time plow). Wallace and Bellinder (1989) also noted high redroot pigweed (*Amarnhus hybridus* L.) in reduced tillage compared with more plowings. On the other hand, Brecke and Shilling (1996) observed more weed biomass of sicklepod (*Senna obtusifolia* L.) in conventional tillage (45%).

Table 2. Weed species identified at Arsi Negelle during the experimental seasons (1993-1995).

Weed species
Broad leaf weeds
Plantago lanceolata
Galinsoga parviflora
Bidens pilosa
Commelina benghalensis
Nicandra physalodes
Guizotia scabra
Anagalis arvensis
Grassy weeds
Eragrostis spp
Couch grass

Table 3. Effect of weed control methods on grass and broad leaf weeds (No. m^{-2}) at Arsi Negelle in 1993.

Tillage frequency (No.) and weed control method	Weed types by density	
	Grass weeds	Broad leaf
Tillage frequency*		
Zero tillage	37.9	179.2
One time tillage	54.2	129.2
Two times tillage	55.8	129.2
Three times tillage	90.0	163.3
Four times tillage	32.0	129.2
Weed control method*		
Duplosan: 2.5 l ha^{-1}	67.0ab	142.0ab
Duplosan +hand weeding once	73.0a	74.0b
Hand weeding once	25.0c	223.0a
Hand weeding twice	51.0bc	145.0ab

*Means within a column of the same factor followed by the same letter are not significantly different at P > 0.05

Weed infestation was not significantly affected by the interaction effect of tillage by weed control methods. Significant interaction effect of year and weed control methods observed implies that mainly seasonal rainfall affected the effect of weed control due to variable rainfall pattern and thus responded differently to the different years. In 1994, weed infestation in plots weeded twice was significantly low by 52.5% compared with plots treated with Duplosan alone (Table 5). However, weed density was significantly high (39.6% more) in 1993 compared with 1994 in plots treated with weeding twice. Weed density over seasons was 38 and 19% more in plots treated with Duplosan alone and its combination with one hand weeding, respectively, compared with those hand-weeded twice. The finding indicates that hand weeding twice will benefit the crop for better growth and yield due to reduced weed competition for moisture and soil nutrients. According to ICARDA report (1984), twice hand weeding significantly reduced weed infestation and was better than chemical weed control. Similarly, Chugunov *et al.* (1988) reported that two hand weedings reduced weed infestation and gave higher grain yield of wheat.

The regression equation indicates that 59% of the total variations in weed infestation/density were attributed to the model:

$$Y = 482.9-43.6T-63.7Wc \ (R^2 = 0.59^{**}),$$

where Y-weed infestation/density, T-tillage frequency, and Wc-weed control method. Of these 32.6 and 26.4% of the variations were due to frequency of tillage and weed control method, respectively.

Table 4. Effect of tillage frequency, weed control and season on the different parameters of wheat in Arsi Negelle, Ethiopia.

Parameter	Y/S	T	W	Y*T	Y*W	T*W
Plant height (cm)	**	**	ns	**	ns	ns
Spike length (No.)	**	**	ns	**	ns	ns
Seed weight (g)	**	ns	ns	**	ns	ns
Grain yield (kg)	**	**	ns	**	**	ns
Biomass yield (kg)	**	**	ns	**	ns	ns
Weed density (No.)	ns	**	**	**	**	-

*Y/S = Year/Season; T = Tillage frequency; W = Weed control; and interaction of Y*T, Y*W, T*W and Y*T*W; ** = Significant at $P \leq 0.01$; ns = Not Significant at $P > 0.05$*

Table 5. Combined effect of year with tillage frequency and weed control on weed density (No. m^{-2}) (combined over years), Arsi Negelle.

Tillage frequency (no.) and weed control method	Year	
	1993	1994
Tillage frequency*		
Zero tillage	215abc	300a
One time tillage	172bc	287a
Two times tillage	162cd	275ab
Three times tillage	196abc	194cd
Four times tillage	161cd	128d
Weed control method*		
Duplosan: 2.5 l ha^{-1}	188bc	324a
Duplosan +hand weeding once	144c	297ab
Hand weeding once	178bc	170bc
Hand weeding twice	215ab	154c

**Means within a column of the same factor followed by the same letter are not significantly different at $P > 0.05$*

3.3. Wheat Plant Height

Wheat plant height was significantly ($P \leq 0.05$) affected by season, tillage frequency, and season combined with tillage and weed control methods. Plant height was affected by the different tillage practices in the seasons (Table 6). Plant height in plots with four times plowing was not different from three times plowing in 1993 and 1995 seasons; however, four times plowing increased plant height by 12.7 cm in 1994 (compared with three times plowing) and by 41.4 cm (compared with zero tillage). In all years plowing four times increased plant height compared with other tillage treatments while no-till and plowing one time had the lowest plant height. The overall trend, averaged across seasons, showed that increase in tillage frequency was accompanied by increase in wheat plant height and the increase over the other tillage practices varied between 6.8 cm and 25.6 cm. In contrary, Tolera *et al.* (2009) found increased plant height from minimum tillage (no-till) over years.

Weed control methods also performed differently across years; however, plant height was not significantly affected by the interaction effect of tillage by weed control methods. Hand weeding twice resulted in significantly shorter plant heights in all years compared with other weed control methods although it had no significant variation in some years. Four times plowing reduced weed infestation and improved vegetative growths of wheat, which might be attributed to better soil tilth, soil moisture conservation, and reduced soil evaporation through better ground cover.

3.4. Spike Length, Grains Spike^{-1} and Thousand Kernel Weight

There was a significant (P $\leq$ 0.05) variation in spike length due to year, tillage frequency and interaction of year with tillage. Frequency of plowing showed significant variation in spike length at different years. In both years the trend showed an increase in spike length as frequency of plowing increased (Table 7). In 1994 four times plowing significantly increased spike length but not significantly variable from three times plowing. Spike length in plots plowed four times was 57.8, 36.5 and 10.9% more compared with no-till, one and two times plowing, respectively. A similar trend was also observed in 1995 although it was significantly low compared with the other year. This was due to variation in amount and distribution of rainfall from one year to the other. But the report of Tolera *et al* (2009) showed significant increase in spike length from minimum tillage (applied with round-up before three weeks) compared with conventional tillage (five times plow with oxen drawn maresha) only for one year while the other year did not show.

Year and its interaction with frequency of tillage significantly affected kernel weight of wheat. However, kernel weight was not affected by the interaction effect of tillage and weed control methods (Table 7). There was an increase in thousand seed weight in two, three and four times plowing in 1994 compared with no-till and one time plowing. However, low seed weight was observed in plots plowed four times in 1993 and 1995 season which was related to the rainfall of each year. This finding disagrees with the observation of Aulakh and Gill (1988) and Tolera *et al* (2009) who reported no significant variation among tillage practices.

Though there was a one year data on grains per spike, the trend showed that repeated tillage significantly increased the number of grains per spike (Table 7). There was an increase in grains per spike as frequency of tillage increased in spite of the non-significant variation between three and four times plowing. Grains per spike were 104 and 34% greater with four plowings than those with no till and two times plowing, respectively. Similarly, Assefa *et al.* (2000) found significant increase in grains per spike in conventional tillage than minimum tillage in one out of the five seasons.

Table 6. Interaction effect of season with frequency of tillage and weed control methods on plant height of wheat (combined over years), Arsi Negelle.

	Plant height (cm)		
Tillage frequency*	1993	1994	1995
Zero tillage	99.8b	58.5f	63.1ef
One time tillage	100.3b	60.1f	59.1f
Two times tillage	108.0ab	73.4de	66.8ef
Three times tillage	108.2ab	87.2c	80.6cd
Four times tillage	115.5a	99.9b	81.0cd
CV (%) = 7.15; SE (±) (Season x tillage) = 3.37			
Weed control method*			
Duplosan: 2.5 l ha^{-1}	104.5ab	74.0cd	75.1cd
Duplosan + hand weeding once	108.6a	78.0c	68.1e
Hand weeding once	109.5a	76.5c	69.2de
Hand weeding twice	102.7b	74.9cd	68.0e
CV (%) = 7.15; SE (±)(Season x weed control) = 1.90			

* *Interaction means within a column and row in each factor (tillage or weed control) followed by the same letter are not significantly different at P > 0.05*

Table 7. Combined effect of season and frequency of tillage on spike length, thousand seed weight and grain spike^{-1} (combined over years).

	Spike length (cm)*		Thousand seed weight (g)*			Grain spike^{-1}*
Tillage frequency	1994	1995	1993	1994	1995	1994
Zero tillage	4.5e	4.9de	46.7c-f	46.9c-f	41.5fg	13.5c
One time tillage	5.2de	4.6e	49.5bcd	48.6cde	43.6ef	18.3bc
Two times tillage	6.4bc	5.1de	44.0ef	51.1abc	46.0c-f	20.6bc
Three times tillage	6.9ab	5.4d	45.6def	54.9a	33.6h	24.5ab
Four times tillage	7.1a	5.6cd	41.6fg	53.9ab	37.6gh	27.6a
CV (%) = 10.78; SE (±)(Season x tillage) = 0.23			CV (%) = 15.04; SE (±)(Season x tillage) = 1.57			

**Means within a column and row in each trait (spike length, seed weight and grain spike^{-1}) followed by the same letter are not significantly different at P > 0.05*

3.5. Grain Yield

Significant ($P \leq 0.05$) variation in grain yield due to year, tillage, and interaction of year with tillage and weed control methods was observed. Interaction effect of tillage by weed control methods had no significant effect on grain yield of wheat. The trend showed an increase in grain yield of wheat as frequency of tillage increased (Table 8). Although tillage effect was variable from one year to the other, it showed that plowing four times gave significantly ($P \leq 0.05$) higher yield than the other tillage treatments in the first two years (1993 and 1994). Grain yield was affected positively and linearly by frequency of tillage in the experimental years. In 1993, increase in grain yield due to four times plowing was 33 and 16% over the two and three times plowing, respectively, while the respective increase in 1994 was 146 and 51%. The response of grain yield to four times tillage was variable with years as indicated in the result due to variation in amount and distribution of rainfall. The high wheat yield obtained from frequent plowing might be due to better root growth (Jongdee, 1994), less weed infestation and better seedling establishment (Assefa *et al.*, 2000), which indirectly increased grains per spike and biomass yield. According to Austin *et al.* (1998), yields of wheat and barley were strongly dependent on seasonal rainfall.

The low yield in reduced tillage (zero-till, one and two plowings) was due to high weed infestation and probably low seedling emergence, which is consistent with the work of Wallace and Bellinder (1989) who noted 16 and 22% reduction in plant stand and tuber yield of potato, respectively. Similarly, Dhinam and Sharma (1986) cited by Majid *et al.* (1988) showed six times plowing gave more grain yield of wheat than five and no-till. Getinet (1988) also noted higher grain yield of wheat from four times plowing either in red or dark grey soil. Kreuz (1993) reported low seedling density, number of spikes m^{-2}, and straw and biomass yields in zero-till. The low grain yield of wheat in zero-till was due to high weed infestation and probably low crop establishment, which is in line with the findings of Thompson and Whitney (1998) and Assefa *et al.* (2000) who reported low grain yield with no-till plots. The finding of Antapa and Mariki (2000) indicated significantly high grain yield of wheat from conventional tillage while zero-till produced the lowest. In contrary, Tolera *et al* (2009) reported significantly high grain yield of wheat from minimum tillage (no-till plots) compared with conventional tillage (plowing five times with oxen drawn maresha).

Effect of weed control methods was variable from one year to the other. Grain yield from application of Duplosan alone and its combination with one hand weeding was not significantly different from two hand weedings in 1993. On the other hand, grain yield of bread wheat in two hand weedings in 1994 was 27.4 and 14.8% more than yields obtained from plots treated with Duplosan alone and its combination with one hand weeding, respectively (Table 8). Grain yield response to weed control methods showed a decrease from one year to the other, which was dependent mainly on the rainfall of each year. Twice hand weeding was effective in controlling weed infestation and increased wheat grain yield, which is in accordance with the finding of ICARDA (1984) and Chugunov *et al.* (1988) who showed twice hand weeding was most effective in reducing weed infestation and increasing wheat grain yield.

Grain yield had a significant and positive association with tillage ($r = 0.43^{**}$), plant height ($r = 0.89^{**}$) and seeds per plant ($r = 0.24^{*}$). In this study, 55, 95 and 43% of the total variations in grain yield were explained by the regression equation during 1993, 1994 and 1995, respectively (Table 9). The equation points that grain yield and effect of tillage on grain yield were dictated by the rainfall during the crop growing season when low moisture resulted in decline in yield.

It appeared that repeated tillage created conducive environment for better plant establishment, growth and production because of reduced weed competition and possibly better root growth, while reduced tillage (no-till, one and two times weeding) had lower plant height, biomass and grain yields, but higher weed infestation. This study indicated that repeated tillage reduced weed competition for moisture, which probably was important in the 1994 and 1995 resulting in improved yield and yield-related characters of wheat. Besides reducing weed competition repeated tillage probably helped in situ soil moisture conservation (through its canopy cover because of better root and vegetative growth) in which wheat crop utilized the moisture for better growth and grain yield. This was reflected by the positive response of plant height, spike length, grains $spike^{-1}$, and biomass yield to repeated plowing. Four times' plowing might probably have resulted in better seedling emergence and thus more yields because of reduced weed competition for moisture and soil nutrients and presumably in situ moisture conservation.

Table 8. Interaction effect of year with tillage frequency and weed control methods on grain yield of wheat (combined over years), Arsi Negelle.

Tillage frequency (no.) and weed control method	Grain yield (kg ha^{-1})		
	1993	1994	1995
Tillage frequency*			
Zero tillage	1923.0d	623.1f	276.9f
One time tillage	2369.1c	500.0f	253.8f
Two times tillage	2530.7c	1184.6e	261.5f
Three times tillage	2899.9b	1930.7d	553.8f
Four times tillage	3369.1a	2915.3b	553.8f
Weed control method*			
Duplosan: 2.5 l ha^{-1}	2830.7a	1261.5d	361.5e
Duplosan + hand weeding once	2646.0a	1399.9cd	415.4e
Hand weeding once	2384.5b	1453.8cd	361.5e
Hand weeding twice	2607.6ab	1607.6c	384.6e
CV (%) 7.15			
SE (±)(Season x weed control) 1.90;			

* *Interaction means within a column and row in each factor (tillage or weed control) followed by the same letter are not significantly different at P > 0.05*

Table 9. Multiple regression analysis of tillage by weed control methods experiment on grain yield (kg ha^{-1}).

Year/Season	Regression equation	R^2
1993	$Y = 1882.1 + 315.0\ T$	0.55**
1994	$Y = 591.5\ T + 99.9\ W$	0.95**
1995	$Y = 184.4 + 84.5\ T$	0.43**

*T = Tillage frequency; Y = Yield (kg ha^{-1}); W = Weed control method; and S = Season; ** = Significantly different at P > 0.01*

3.6. Biomass Yield

Biomass yield was significantly ($P \leq 0.05$) affected by season, tillage frequency and interaction of season and tillage. However, biomass yield was not affected by the interaction effect of tillage by weed control method. Biomass depended on the interaction between tillage and year in which the 1994 season resulted in greater biomass yield (Table 10). In 1994 the biomass in four times plowing was significantly higher than the other tillage practices while significant difference was not observed between three and four times plowing in 1995. The biomass in four times plowing was 48.8% higher in 1994 than that obtained from three times plowing whereas the difference in 1995 was only 18.2% which was attributed to variation in rainfall. When averaged across years, there was an increase in biomass yield as frequency of tillage increased from one to four times plowing that varied between 1227 kg ha^{-1} (one time plowing) and 6199.8kg ha^{-1} (four times plowing). Wallace and Bellinder (1989) found decreased potato stand by 16% due to reduced tillage when averaged over seasons, and reported a 22% reduction in potato yield in reduced tillage compared with yields in conventionally tilled plots. The findings of Thompson and Whitney (1998) also noted poor crop stands in no-till plots, which imply reduction in biomass yield.

3.7. Economic Analysis

An increase in net benefit was achieved through frequent plowing. For every birr the farmer invests in plowing the crop land four times, the farmer in turn gets a marginal rate of return (MRR) of 1120%. It means that the farmer can benefit 11.2 birr for every birr he invests in plowing four times (Table 11). Similar results were also obtained in the sensitivity analysis. Even if the cost of tillage and selling price of the crop changes, the farmer can still get a MRR of 914 and 790% for every birr the farmer expends in plowing the land four times, respectively. But the finding of Tolera *et al.* (2009) showed higher net return from minimum tillage compared with conventional which was plowed four times.

Table 10. Interaction effect of season and plowing frequency on biomass yield (kg ha^{-1}) (combined over years).

Tillage frequency	Biomass yield (kg ha^{-1}) 1994	1995
Zero tillage	1869.2def	1038.4f
One time tillage	1453.9ef	1000.0f
Two times tillage	3253.7c	1300.0ef
Three times tillage	6415.1b	2415.3cde
Four times tillage	9545.8a	2853.7cd
CV (%) = 22.13; SE (±)(Season x tillage) = 323.1		

* *Interaction means within a column and row followed by the same letter are not significantly different at P > 0.05*

Table 11. Marginal rate of return (MRR) and sensitivity analysis of tillage frequency by weed control methods, 1993-1995, Arsi Negelle.

Tillage frequency	Total cost (Birr ha^{-1})	Net benefit (Birr ha^{-1})	MRR (%)
Sensitivity analysis assuming one pass tillage at 100 Birr ha^{-1} and wheat field price (current) 2.8 Birr kg^{-1}			
One time tillage	100	2525.8	-
Two times tillage	200	3143.2	614
Three times tillage	300	4222.6	1080
Four times tillage	400	5339.7	1120
Sensitivity analysis assuming one pass tillage at 120 Birr ha^{-1} and wheat field price (current) 2.8 Birr kg^{-1}			
One time tillage	120	2505.8	-
Two times tillage	240	3103.2	498
Three times tillage	360	4162.6	883
Four times tillage	480	5259.7	914
Sensitivity analysis assuming one pass tillage at 100 Birr ha^{-1} and wheat field price (current) 2 Birr kg^{-1}			
One time tillage	100	1775.6	-
Two times tillage	200	2188.0	412
Three times tillage	300	2910.0	722
Four times tillage	400	3699.8	790

4. Conclusions

Effects of tillage and weed control methods were dependent on seasonal rainfall as it was indicated in the result of this study. Plowing four times reduced weed infestation and increased plant height, spike length, grains spike^{-1} and biomass and grain yields of wheat. Poor crop performance was observed in reduced tillage that finally resulted in low yield. On the other hand, two times weeding significantly reduced weed infestation compared with Duplosan alone or its combination with one hand weeding. The finding revealed that effect of repeated tillage was more than the weed control methods, and the benefit obtained from tillage in reducing weed infestation, and increasing plant height and grain yield was higher than the effect of weed control. Overall, plowing four times is beneficial to farmers due to reduced weed infestation and increased grain yields of wheat, reduced costs for weeding and herbicide as it minimizes the use of labor and herbicide.

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Registration of *Kulumsa-1* Linseed (*Linum usitatissimum* L.) Variety

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Abstract: *Kulumsa-1* is a common name for the linseed variety developed through selection from the variety known as Chilallo, the linseed variety released nationally in 1992, which is a population. *Kulumsa-1* was selected, developed and released by Kulumsa Agricultural Research Center for major linseed growing areas of Ethiopia. Specifically, it was tested at Kulumsa, Bekoji, Asasa, Sinana, Holetta, Adet and Areka for three years (2002/2003-2004/2005) and verified in 2005/2006 on these locations for official release. Consequently, *Kulumsa-1* consistently produced better mean seed yield than the standard check *(Belay-96)* and the local check over three years. Likewise, it proved to be more resistant to powdery mildew *(Oidium sp.)* and pasmo *(Septoria linicola)* diseases than the checks. The results of the multi-location trials revealed that *Kulumsa-1* was superior in seed yield performance across years and locations. Besides, it is stable variety based upon the two stability parameters, deviation from regression (S^2_{di}) and coefficient of determination (R^2_i).

Keywords: Edible Oil; *Kulumsa-1*; Linseed; Variety Registration

1. Introduction

Linseed (*Linum usitatissimum* L.) is one of the oldest oilseeds cultivated for food and fiber (Lay and Dybing, 1989). Ethiopia is considered the secondary center of diversity, and now the 5th major producer of linseed in the world after Canada, China, United States and India (Adugna, 2007). It is a self-pollinated crop. Linseed has long history of cultivation by smallholder farmers, exclusively for its oil in the traditional agriculture of Ethiopia (Hiruy and Nigussie, 1988). It is a major oilseed and the second most important oil crop after noug (*Guizotia abyssinica* Cass.) in Ethiopia. The crop performs best in altitudes ranging from 2200 to 2800 meters above sea level (masl). Linseed grows well within temperature ranges of 10 to 30 °C; but it performs best between 21 to 22 °C. Optimum soils for linseed are well drained but moisture retentive and medium to heavy textured such as clay loams and silty clays. Linseed will not perform well on soils with pH less than 5 and above 7 and is sensitive to soil salinity (Adugna, 2007). It is widely cultivated in the high elevations area of Arsi, Bale, Shewa, Gojam, Gonder, Wollo and Wellega (Getinet and Nigussie, 1997).

Linseed oil is suitable for human consumption, and is used as a nutritional supplement. It is rich in omega-3 fatty acids, especially alpha-linolenic acid (C18:3) that is beneficial for heart disease, inflammatory bowel disease, arthritis and a variety of other health conditions. It also contains a group of chemicals called lignans that play a significant role in the prevention of cancer (Budwing, 1994). The meal, which remains after oil extraction, is a valuable feed to animals as a protein supplement (Getinet and Nigussie, 1997). There is also a growing demand in the world market for linseed due to its numerous health benefits, especially in Europe (Wijnands *et al.*, 2007). However, opportunities for oilseeds export are not fully exploited yet because of low productivity, inadequate quality, improper post-harvest handling, poor infrastructure and poor market information.

The Ethiopian edible oil sector consists of two groups of producers: the local, small-scale processors (>1000) and a few medium and large scale enterprises (~20). The entire sector produces approximately 20,000 tons of edible oil annually; while domestic demand is estimated at 200,000 tons. Consequently, Ethiopia imports up to 160,000 tons of edible oil annually and this figure is increasing every year (PPPO, 2009). The increase of import suggests a potentially large domestic market. Main edible oil imports are palm and soybean oils from Malaysia and Indonesia. Substitution of these oils by domestic production is encouraged by high domestic prices. Export oil (like sesame and linseed) is hardly being produced locally, since the export price of seed is usually very attractive and sesame seed is hardly locally consumed (PPPO, 2009). It can be seen as a business opportunity to increase the local capacity to produce linseed and sesame oils for export, increasing added value, foreign exchange and employment opportunity. In order to improve the Ethiopian edible oil sector, the Government should create equal taxation system for both domestically produced and imported edible oils, undertake feasibility study for increased production of oilseeds, and develop good manufacturing practices for the Ethiopian mill sector.

Area of linseed was increased from 142,899 hectares (ha) in 2003/2004 to 180,873 ha in 2008/2009. In the same years, its production and average yield were also increased from 0.77 to 1.56 million quintals and from 541 to 863 kg ha^{-1}, respectively. Despite the wide values of linseed in terms of nutritional, industrial, and export earnings; productivity and production of linseed is still low (CSA, 2004, 2009). Currently, there is a huge shortage of edible oil in the country (PPPO, 2009). Hence, concerted research, development and promotion efforts are needed, at all levels, in order to reverse the current situations. This paper presents the overall performances of the recently developed and released linseed variety (*Kulumsa-1*) with the aim to play a significant role in solving the chronic edible oil shortage in the country, and to exploit its linseed production capacity for domestic uses and export purposes.

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2. Varietal Evaluation

Chilallo/16 or *Kulumsa-1* was derived through selection from earlier *Chilallo* linseed variety, which is a population and released nationally in 1992. As *Kulumsa-1* outshined several linseed selections, accessions and lines in observation and preliminary yield trials, it was advanced to national variety trial to be tested across wide locations over years to further test its overall performances. The linseed national variety trial consisting 12 linseed genotypes including the standard check (*Belay-96*) and the local check was conducted at major linseed growing regions including Shewa (Holetta), Arsi (Kulumsa, Bekoji and Asasa), Bale (Sinana), Gojam (Adet) and SNNPR (Areka) for three growing seasons (2002/2003 to 2004/2005). In these locations, the altitude ranges from 2200 masl (Kulumsa) to 2780 masl (Bekoji), and average annual rainfall ranges from 620 mm in Asasa to 1100 mm in Bekoji. The genotypes were tested across seven locations in RCB design with four replications. Plot size was six rows of 20 cm apart and 5 m long. A seed rate of 25 kg ha^{-1} and fertilizer rate of 23/23 kg ha^{-1} N/P_2O_5 was applied at planting at each location. Other recommended cultural practices were also applied. Necessary agronomic performances and disease reactions were recorded.

Kulumsa-1 consistently out yielded other tested linseed entries over three years. The average yield of *Kulumsa-1* was 1,151, 1,514 and 1,467 kg ha^{-1} in 2002/2003, 2003/2004 and 2004/2005 across seven locations (data not shown). Mean seed yield of the tested genotypes in 2002/03 cropping season was low (1,151 kg ha^{-1}) mainly due to moisture stresses at several locations. Combined years over locations analysis revealed that it had produced an average yield of 1,348 kg ha^{-1} (Table 2). Thus, *Kulumsa-1* was verified at seven locations (at on-station and two on-farms at each location) in 2005/2006 for official release. Consequently, *Kulumsa-1* showed superior overall agronomic performances over the standard check (*Belay-96*) and the local check under verification trial too. Likewise, it proved to be more resistant to powdery mildew (*Oidium sp.*) and pasmo (*Septoria linicola*) diseases than the checks. The results of the multi-location trials revealed that *Kulumsa-1* was superior in seed yield performance, oil content and diseases resistance across years and locations. Besides, it is stable variety based upon the two stability parameters, deviation from regression (S^2_{di}) and coefficient of determination (R^2_i). Thus, it is logical and important to register and promote *Kulumsa-1*.

3. Agronomic and Morphological Characteristics

In an attempt to develop *Kulumsa-1*, higher yield and resistance to major linseed diseases were important traits of consideration. *Kulumsa-1* flowered from 68 to 93 days and matured from 136 to 161 days after emergence depending on growing environment (Table 1). The standard check, *Belay-96*, matured earlier than *Kulumsa-1* by two days. On average, *Kulumsa-1* was 85 cm tall, but *Belay-96* was 77 cm tall, implying better competitive ability of *Kulumsa-1* with weed species. Besides, *Kulumsa-1* possessed 41 to 72 pods per plant with a mean of 57 pods per plant and eight seeds per pod. Both *Kulumsa-1* and *Belay-96* are brown and bold seeded. The average weight of 1000-seeds was 5.54 g for *Kulumsa-1*, which is greater by two and fifteen percent than that of *Belay-96* and the local check, respectively (Table 3). *Kulumsa-1* is a variety suitable for rain-fed, low inputs and organic farming on different soil types as long as the pH value is within the range of 6.0 to 7.6. However, it is not suitable for water logged or poorly drained soils. A summary of agronomic and morphological characteristics of the variety are presented in Table 1.

4. Yield Performance

Considering the over all seed yields, *Kulumsa-1* (Chilalo/16) produced better seed yield than the standard check (*Belay-96*) across locations (Table 2). This variety consistently performed better than the checks over three years. *Kulumsa-1* was 6.8% high yielder than the standard check (*Belay-96*) and 29.7% high yielder than the local check. It had 5.0% oil yield and 2.8% oil content advantage over *Belay-96*. Likewise, it had 22.4% oil yield and 5.5% oil content advantage over the local check. It was taller than checks, implying its better competence with weeds.

5. Stability Performance

Yield stability in 12 genotypes of linseed was studied for two years (2003/2004 and 2004/2005) at four locations (Kulumsa, Bekojji, Asasa and Holetta) using different stability parameters such as (*bi*) the regression coefficient (Finlay and Wilkinson, 1963), (S^2_{di}) deviation from regression (Eberhart and Russel, 1966) and (R^2_i) coefficient of determination (Pinthus, 1973) as shown on Table 4. The stability of varieties was defined by high mean yield, regression coefficient (*bi* = 1.0) and deviations from regression ($S^2_{di} = 0$) as small as possible (Akcura *et al.*, 2005) and maximum coefficient of determination (R^2_i). The results of the study showed that *Kulumsa-1* and *Belay-96* were stable linseed varieties based upon the two stability parameters (S^2_{di} and R^2_i) and were superior in mean seed yield. However, these varieties are unstable based upon regression coefficient (*bi*), indicating greater specificity of adaptability to high yielding environments.

6. Disease Reaction

On the standard rating scale of 0-5, 0 being highly resistant, and 5 highly susceptible, *Kulumsa-1* scored mean of 0.98, 0.75 and 0.81 for wilt (*Fusarium oxysporium*), powdery mildew (*Oidium sp.*) and pasmo (*Septoria linicola*) diseases, respectively (Table 2), indicating that the variety is resistant to major diseases of linseed. The resistance reaction of the variety could be integrated with other disease management methods such as crop rotation, managing infested debris, and fungicide seed treatments for better results.

7. Quality Analysis

Typically, linseed consists of approximately 40% fat, 28% dietary fiber, 21% protein, 4% ash and 6% carbohydrates such as sugars, phenolic acids, lignans, and hemi-cellulose (Vaisey-Genser and Morris, 2010). Linseed is rich in polyunsaturated fatty acids, particularly alpha-linolenic acid (ALA), the essential omega-3 fatty acid, and linoleic acid (LA), the essential omega-6 fatty acid. These two polyunsaturated fatty acids are essential for humans-that is, they must be obtained from the fats and oils in foods because our bodies can not make them. The omega-3 fatty acids have many biological effects that make them useful in preventing and managing chronic conditions such as type 2 diabetes, kidney disease, rheumatoid arthritis, high blood pressure, coronary heart disease, stroke and certain types of cancer (Connor, 2000). The composition of linseed can vary with genetics, growing environment, seed processing and method of analysis (Daun, *et al.*, 2003). The protein content of the seed decreases as the oil content increases (Daun and Declercq, 1994). The oil content of linseed can be altered through traditional breeding methods, and it is affected by geography. Linseed requires moderate to cool temperatures and adequate moisture during the growing season for optimum seed yield and quality. Good yield can be achieved with a temperature range of 10-30 °C, and a mid-day relative humidity of 60-70%, and a rainfall of 150-200 mm distributed over the growing periods. Extensive scientific research over the past few decades has revealed numerous nutritional benefits of linseed due primarily to its fat, lignan, dietary fiber, and protein contents.

In the present study, the results of laboratory tests (Table 2) indicated that *Kulumsa-1* had 9.8% oil yield and 2.8% oil content advantages over *Belay-96*. Likewise, it had 37% oil yield and 5.5% oil content advantages over the local check. Besides, *Kulumsa-1* had 2% and 15% more 1000 seeds weight than *Belay-96* (the standard check) and the local check, respectively. *Kulumsa-1* is also rich in essential fatty acids, lignan, fiber and protein. Hence, *Kulumsa-1* has better health, industrial and nutritional values.

8. Conclusions

Kulumsa-1 was the best yielding linseed variety. It is stable in seed yield performance over locations and years. It was resistant to major diseases of linseed that prevailed in the growing areas. *Kulumsa-1* possessed better number of pods per plant, produced higher seed and oil yields and contained better oil content. Farmers also preferred the variety for its superior performance over the existing local variety, which is manifested by tall plant height, better pods load and number of branches per plant. Likewise, the variety has better industrial and nutritional values. Hence, *Kulumsa-1* was verified and officially released for large scale production in major linseed growing areas of Ethiopia.

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Table 1. Agronomic and morphological characteristics of *Kulumsa-1* linseed variety.

Adaptation area	
Altitude (masl)	2000-2800
Rainfall (mm)	600-1100
Temperature (°C)	9.5-22.0
Soil pH	6.0-7.6
Fertilizer rate	
N (kg ha^{-1})	23
P_2O_5 (kg ha^{-1})	23
Planting date	Early to late June
Seed rate (kg ha^{-1})	
Row planting (20 cm between rows)	25
Broadcasting	35-40
Days to flowering	68-93
Days to maturity	136-161
Plant height (cm)	78-89
Number of pods per plant	41-72
Seed color	brown
Weight of 1000 seeds (g)	5.54
Reaction to major diseases	<1.0 (Resistant)
Oil content (%)	35.9-38.5
Seed yield (kg ha^{-1}) at research stations	985-2063
Seed yield (kg ha^{-1}) on farmers fields	730-1600
Year of release	2006
Breeder/Maintainer	Kulumsa Agri. Research Center

Table 2. Mean agronomic performance and disease reactions of 12 linseed genotypes tested in seven locations in Ethiopia in the years, 2002/2003-2004/2005.

		Days to		Plant	SY (kg	OC	Oil yield	Diseases (0-5 scale)		
No.	Genotype	Flower	Mature	height	ha^{-1})	(%)*	(kg ha^{-1})*	P. mildew	Pasmo	Wilt
1	PGRC/E 11382	81	140	79	1223	36.1	397	1.23	0.95	0.38
2	Chilallo/18	83	141	82	1187	35.7	382	1.41	0.78	0.52
3	CI-1525 X CI-1133/1	81	140	77	1055	35.3	352	1.34	1.08	0.53
4	PGRC/E 10052/3	83	142	79	1178	36	389	1.57	0.96	0.64
5	PGRC/E 11045/4	81	140	81	1141	36.6	385	0.98	0.90	0.47
6	Chilallo/16	82	141	85	1348	36.5	442	0.75	0.81	0.98
7	CDC 1747 V & E	83	141	78	1185	35.1	381	1.36	0.93	0.44
8	PGRC/E 11429/3	86	144	83	1004	35.2	334	1.29	0.92	0.40
9	CI-1525 X CI-13612/1	81	140	84	1204	36.9	400	1.75	0.89	0.42
10	PGRC/E 11263/1	79	138	80	1073	35.9	363	1.14	1.26	0.60
11	*Belay-96* (std. check)	78	139	77	1262	35.5	421	1.03	1.16	0.61
12	Local check	84	141	74	1039	34.6	361	1.66	1.07	0.67
	Grand mean	82	141	80	1158	-	-	-	-	-
	LSD (0.05)	0.547	0.661	1.487	60.12	-	-	-	-	-
	MSE	2.79	4.083	20.64	37496	-	-	-	-	-
	SED	1.18	1.43	3.21	136.92					
	CV%	2.04	1.44	5.69	16.72	-	-	-	-	-

** = Oil content and oil yield are based on data of 2 years at 4 locations; SY = Seed yield; OC = Oil content*

Table 3. Summary of pooled mean seed and oil yields, other data and disease reaction of *Kulumsa-1* and the checks across years and locations.

Variety	Days to flower	Days to maturity	Plant height (cm)	TSW (g)	SY (*kg ha^{-1}*)	OC (%)	OY (*kg ha^{-1}*)	Reaction to disease		
								PM	Pasmo	Wilt
Kulumsa-1	82	141	85	5.54	1348	36.5	492	0.75	0.81	0.98
Belay-96	78	139	77	5.43	1262	35.5	448	1.03	1.16	0.61
Local check	84	141	74	4.83	1039	34.6	359	1.66	1.07	0.67

TSW = 1000 seeds weight; SY = Seed yield; OC = Oil content; OY = Oil yield; PM = Powdery mildew

Table 4. Mean seed yield, regression coefficient (b_i), deviation from regression (S^2_{di}) & coefficient of determination (R^2_i) of 12 linseed genotypes tested at eight environments in Ethiopia (2003/04 and 2004/05).

No.	Genotype	Mean	b_i	S^2_{di}	R^2_i
1	PGRC/E 11382	1344.47	1.0429	7917.6684	98.3038
2	Chilallo/18	1326.41	0.8007	7805.9579	97.1945
3	CI-1525 X CI-1133/1	1189.59	0.9232	7645.7608	97.9177
4	PGRC/E 10052/3	1369.50	0.9669	17205.6889	95.8196
5	PGRC/E 11045/4	1187.59	0.9963	8965.7872	97.9037
6	Chilallo/16	1512.47	1.1526	9023.0168	98.4156
7	CDC 1747 V & E	1303.78	1.122	10548.5719	98.0523
8	PGRC/E 11429/3	1135.34	1.0381	11879.2832	97.4533
9	CI-1525 X CI-13612/1	1393.63	0.9781	15237.5148	96.3619
10	PGRC/E 11263/1	1306.41	1.0223	11491.9606	97.4597
11	Belay-96	1538.41	1.0662	6410.5599	98.6808
12	Local check	1256.97	0.8908	6256.7756	98.1651
	Mean	1322.05	1.000		

Linseed genotypes with values in bold are considered stable

Registration of *Morka* Maize (*Zea mays* L.) Variety

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Abstract: *Morka* is a common name given to the maize (*Zea mays* L.) variety with the pedigree *UCB* S_1 C_2 after its official release. It is an open pollinated variety developed by the Jimma Agricultural Research Center from *UCB* after two cycles of S_1 recurrent selection. *Morka* means "competent" in *Afan Oromo* language given to express its yield potential which is comparable to that of the popular hybrid variety, BH660, in the areas. Its performance was evaluated in field experiments carried out over two years in three locations environments where it gave mean grain yield of 8.7 t ha^{-1} and significantly ($P < 0.01$) out yielded the standard check (*UCB*) with a grain yield benefit of 30% (2.0 t ha^{-1}). Better grain yield potential, significantly ($P < 0.01$) shorter plant height and lower ear placement, and superior tolerance to diseases and resistance to lodging than the original *UCB* are the desirable traits of this variety. *Morka* was recommended for commercial production in the mid altitude (1600-1800 m above sea level) agro-ecologies of Jimma and Illu Ababora Zones.

Keywords: Maize; *Morka;* Open Pollinated Variety; Recurrent Selection; *Ukuruguru Composite B*

1. Introduction

Maize is the most important staple food in many parts of Ethiopia. It is the leading cereal in productivity and second to Tef in area of production in the country (CSA, 2006). The western parts of Ethiopia have very great potential for both its production and utilization. *Ukuruguru Composite B* (*UCB*) was the most adapted and well preferred open pollinated variety of maize in the southwestern part of Ethiopia; especially, in Jimma and Illu Ababora Zones since its release in 1975. This variety possesses adequate levels of resistance to major leaf diseases (Assefa, 1995; Dagne *et al.,* 2001) and storage pests (Demissew *et al.*, 2004). However, it grows tall, reaches a height of 350 centimeters (cm) and bears heavy cobs placed at 250 cm height that makes it susceptible to lodging. Contamination through cross pollination with pollen from nearby maize fields was the major factor for the accumulation of undesirable traits in *UCB*. Furthermore, no efforts were made to keep up its genetic purity throughout its long usage since it was commercialized in 1975. These conditions have resulted in the genetic deterioration and reduced yield potential of *UCB*. Thus, farmers were forced to withdraw from growing *UCB* since 1995. To alleviate this problem, the maize breeding team based at the Jimma Agricultural Research Center had been doing intensive improvement on *UCB* since 1998. The objective was to develop the improved version of UCB that can be released for commercial production as an option to the hybrid varieties.

The S_1 recurrent selection also called endogamic selection, involves repeated regeneration of the first selfed (S_1) progenies and subsequent evaluation of the progenies to select the superior ones that can be recommended to reconstitute improved version of the parent variety. In maize, this selection scheme is considered to be more efficient than other selection schemes in improving a broad based population as it exposes deleterious homozygous genes to be eliminated through selection. Burton *et al.* (1971) realized gains of 4.2% cycle^{-1} over four cycles of selection for grain yield. Besides its effectiveness in improving performance in terms of productivity, it has been useful in improving resistance to biotic stresses such as European corn borer (Penny *et al.*, 1967), stalk rot (Jinahyon and Russell, 1969) and downy mildew (De Leon *et al.*, 1993). Through two cycles of this selection program we have successfully improved grain yield, plant height and ear placement, tolerance to diseases and resistance to lodging in the tall and lodging susceptible *UCB* maize variety. Thus, the improved version, *UCB* S_1 C_2, (*Morka*) which has higher grain yield and reduced plant height and ear placement, was officially released in 2008 after ten years of continuous work. The released variety was given a new name *Morka* meaning "competent" in *Afan Oromo* language to express its yield potential which is comparable to that of the popular hybrid variety, BH660, in Jimma and similar areas. *Morka* fits best to areas receiving annual rainfall ranging from 1000-2000 mm and was recommended for commercial production in the mid altitude (1600-1800 masl) agro-ecologies of Jimma and Illu Ababora Zones in the western part of Ethiopia. Currently, there is a tremendously growing demand for *Morka* seed from farmers in west Wellega Zone of Oromia and the Kaffa and Dawaro Zones of the Southern Nations, Nationalities and Peoples' Region.

2. Varietal Evaluation and/or Testing

Morka was developed from the Tanzanian open pollinated variety, *UCB,* which was introduced to Ethiopia in the 1970s and released for commercial production in the southwestern part of the country in 1975. Two cycles of S_1 recurrent selection have been carried out to improve grain yield, plant height, ear placement, resistance to lodging and other desirable agronomic traits. Yield performance was evaluated in field experiments carried out at three locations (Jimma, Hurumu and Bako) for two years (2006 and 2007). *Kuleni*, Gibe composite, *UCB,* BH660 and BH670 were included as checks. Its verification trial was also conducted at two on-station and four on-farm locations. Planting was done from mid April to mid May depending on the onset of rain. A seed rate of 25 kg ha^{-1} and fertilizer of 46 kg N

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and 66 kg P_2O_5 ha^{-1} were used. All the other field management practices were applied following research recommendations specific to each location. Full procedures followed to develop the variety and evaluate yield performance in on-station and on-farm experiments are indicated in research paper submitted to East African Journal of Agricultural Science for parallel publication (Leta and Habte, in press).

3. Agronomic and Morphological Characteristics

Morka has shorter plant height, lower ear placement, higher grain yield and better resistance to diseases and tolerance to lodging than the original *UCB*. Its other distinguishing features are purple and white tassels, silks and stems (more than 60% white colored), white seed color, semi flint grain texture, medium grain size and thousand grain weight of 40 grams. It tends to be more prolific with wider spacing and good soil fertility though it bears about 1.5 ears per plant on average with the recommended row and plant spacing of 75 and 30 cm, respectively. It attains 50% tasseling and 50% silking within 90 and 94 days, respectively, after emergence. Its ear and plant heights are 160 and 285 cm, in that order (Table 1) with ear position of 0.55 which is almost at the middle of the plant.

4. Yield Performance

Morka gave the highest mean grain yield of 8.7 t ha^{-1} across five environments and significantly ($P < 0.01$) out yielded *UCB* with yield advantage of 30% (2.0 t ha^{-1}) and out yielded BH660 with statistically non significant grain yield of 0.8 t ha^{-1} (Table 2). Across two on-stations (Jimma and Hurumu) and four on-farm verification sites, *Morka* produced mean grain yield of 6.1 t ha^{-1} with yield advantage of 2.0 t ha^{-1} over the standard check, *UCB* (Table 3).

5. Stability of Performance

Yield stability was studied using data obtained from five environments as per Eberhart and Russell (1996). The result of the study showed that *Morka* had high yield across environments and less than unity regression coefficient indicating that it had above average stability and is better adapted to marginal conditions (Leta and Habte, unpublished data).

6. Disease Reaction and Lodging Resistance

Morka was superior in tolerance to diseases and resistance to lodging as compared to the standard check, *UCB*. Significantly ($P < 0.01$) lower mean severity of 1.83 and 2.00 were recorded for gray leaf spot and turcicum leaf blight (Table 2), respectively, in *Morka* in a 1-5 scale, where 1 indicates clean or no infection and 5 indicates severe disease.

7. Quality Analysis

Morka was found to have good *injera* baking quality. Its *injera* is soft, has good and attractive physical appearance or texture and longer shelf-life even without mixing it with *teff*. It has also proved to have more flour to grain ratio. The fresh green cobs of this variety are very sweet. Its white colored and semi flint textured kernels in straight and longer rows on the cobs are of unique importance in adding beauty to the boiled fresh maize and increases consumers preference. Its grains have better resistance to storage pests (Demissew *et al*., 2004) which allows farmers to store the grains for a longer time. These were found to be desirable qualities of *Morka* that attract consumers.

8. Conclusions

Morka was found to be a higher and more stable yielder than *UCB* with lower ear placement and shorter plant height. As a result of its short stature and low ear placement, it is more resistant to lodging. It was recommended for the mid altitude (1600-1800 masl) agro-ecologies of Jimma and Illu Ababora Zones and similar areas in the southwestern part of Ethiopia. After it was officially approved for full release by the National Variety Releasing Committee in February 2008, the variety was named "*Morka*" meaning "competent" in *Afan Oromo* language to express its yield potential which is comparable with the yield potential of the popular hybrid variety in the region.

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Table 1. Agronomical and morphological characteristics of *Morka*.

Characters	Values/description
Adaptation	Jimma and Illu Ababora Zones
Altitude (masl)	1600-1800
Rainfall (mm)	1000-2000
Fertilizer rate (kg ha^{-1})	
-Phosphorous as P_2O_5	46
-Nitrogen as N	46
Planting date	Mid April to mid May depending on the on set of rain
Seed rate (kg ha^{-1}):	25
Days to anthesis (pollen shading)	90
Days to silking	94
1000 seed weight (g)	40
Ear height (cm)	160
Plant height (cm)	285
Stem color	White and purple
Tassel color	White and purple
Seed color	White
Pollen color	Yellow
Grain texture	Semi flint
Grain size	Medium
Crop pest reaction	Tolerant to major leaf diseases (GLS, Blight and Rust)
Yield (t ha^{-1})	
-Research field	8-11
-Farmer field	5-6
Year of release	2008
Breeder/Maintainer	JARC/EIAR

Table 2. Mean grain yield and major agronomic traits of *Morka* and the standard checks combined across five environments.

Entry	Grain yield (t ha^{-1})	Plant height (cm)	Ear height (cm)	Ear position	Days to 50% Silking	Diseases (1-5 scale)[a]			Lodging (%)
						GLS	TLB	CR	
Morka	8.7a	289.8b	162.1c	0.55b	94b	1.83c	2.00c	1.15c	14.99
UCB	6.7b	320.6a	201.7a	0.63a	97a	2.15a	2.38a	1.23b	17.36
BH660	7.9ab	302.2b	179.7b	0.60a	95b	2.08b	2.10b	1.25a	22.47
LSD (0.01)	1.40	17.70	14.10	0.045	1.43	0.069	0.010	0.058	ns[b]

Values followed by the same letter(s) are not significantly different from each other; [a]1 = Clean or no infection and 5 = Severely diseased; [b]ns = No statistically significant difference; GLS = Gray leaf spot; TLB = Turcicum leaf blight; CR = Common rust

Table 3. Mean data combined across two on-station and four on-farm sites in variety verification trial.

Entry	Days to 50% silking	Plant height (cm)	Ear height (cm)	Diseases (1-5)[a]			Lodging (%)	Plant aspect (1-5)[b]	Ear aspect (1-5)[b]	Diseased ears (No)	Bare tips (No)	Grain yield (t ha^{-1})
				GLS	TLB	CR						
Morka	79	263	194	1.5	1.5	1.0	2.6	1.4	1.4	3	0	6.2
UCB	91	350	226	2.0	2.0	1.0	34.3	3.0	2.2	6	0	4.2

[a]1 = Indicates clean or no infection and 5 = Severely diseased; [b]1 = Good and 5 = Poor; GLS = Gray leaf spot; TLB = Turcicum leaf blight; CR = Common rust