Development of Methanol Sensing Devices with Cobalt-dopted $SrFeO_{2.5+x}$ Thin-films Perovskites Prepared by Pulsed Laser Deposition (PLD): Towards the Fabrication of Methanol Sensors for Direct Methanol Fuel Cell Applications

Steve De Cliff*[1], Michael L. Post[2] and Don Segall[3]

[1]University of Burundi, Faculty of Sciences, Department of Chemistry, 2 Unesco Avenue, P O Box 1550, Bujumbura, Burundi.
[2]National Research Council of Canada, Institute for Chemical Process and Environmental Technology, Ottawa, Ontario K1A 0R6, Canada.
[3]The Armstrong Monitoring Corporation, 215 Colonnade Road South, Nepean, Ontario K2E 7K3, Canada.

Abstract: Thin films of gas sensitive materials based on the $SrFeO_{2.5+x}$ non-stoichiometric perovskite family were deposited onto an interdigitated gold electrode construction device by room temperature pulsed excimer laser deposition (RT-PLD). Two films sensors based on the $SrFe_{1-y}Co_yO_{2.5+x}$ oxides perovskite family, with y = 0.75 and 0.5 respectively, have been presented. Their ability to very quickly respond to the presence of low concentrations of methanol makes them attractive for construction of methanol sensing devices, as gases monitoring sensors for either environmental applications, or as an automated feedback sensor for concentration measurement and control in a micro direct methanol fuel cell (µ-DMFC) power supply. In this paper, we report unpublished hitherto results first presented as poster during an *Electrochemical Society* Symposium session held at Queen University, Kingston, Ontario, Canada.

Keywords: Fuel Cell; Methanol; Perovskite; Pulsed Laser Deposition; Sensor; Thin Film

1. Introduction

1.1. Statement and Motivation of the Necessity of Gas Sensors

Among the increasing number of driving forces leading to the need for monitoring gases can be improvements in indoor air quality, safety, spill detection, automotive, food, pharmaceutical, petrochemical, etc., where sensor technology is ever more important for determining real-time physical parameters and chemical concentration of complex analytes. Gas sensors are also needed in process control or efficiency, productivity, safety, and also addressing regulatory requirements. Of particular relevance in these areas is the fabrication of miniature devices by integration of chemical sensor materials with platforms, whereby the functionality of the created device is significantly improved. The approach is to provide a sensor which is compact, inexpensive, low power, low maintenance, and yet with a capability of real time response with analyses of multicomponents in a given environment. Such a device can be conveniently deployed in multipoint locations to satisfy a range of monitoring requirements over a large area.

One of the most interesting applications of gas sensing is the fuel monitoring and control in direct methanol fuel cells (DMFC) power supply. DMFC is a renewable energy source which works at near room temperature, and allows for easier liquid fuel storage, which makes it a potential power supply candidate. Unlike a hydrogen polymer electrolyte fuel cell (H_2-PEMFC), the DMFC does not require ancillary components such as a separate humidifier, fuel processor, or cooling system. At the beginning of this new millennium, several organizations including Motorola (Bostaph *et al.*, 2001), Jet Propulsion Laboratory (Narayanan *et al.,* 2001), the University of Minnesota (Kelly *et al.*, 2000) and the National Research Council of Canada (NRC) have undertaken aggressively research programs aimed to develop micro direct methanol fuel cells for MEMS applications. Within the methanol fuel cell, electricity is produced by a simple anodic methanol oxidation reaction, shown as:

$$CH_3OH + H_2O \longrightarrow 6e^- + 6H^+ + CO_2 \qquad (1)$$

In the above reaction, the production of the CO_2 bubbles forces the flow upward to the exit of the anode plate. As this CO_2 is not returned back in the feed system, the concentration of methanol, the fuel, is continuously decreased. Therefore, pure methanol must be added to the solution loop to maintain the required concentration. Thus, the concentration of methanol in the fuel circulation loop of any DMFC system is an important operating parameter, because it determines the electrical performance and efficiency of the system. The methanol concentration in the circulating fuel stream can be measured continuously and maintained at a predefined level with a suitable sensor. A calculated molarity value of methanol is used as the input to a decision making loop that control the methanol feed pump. Various methods of sensing methanol concentration have been proposed over the past decade (Narayanan *et al.,* 1998) for robust systems but at our knowledge, nothing has yet been done concerning micro-DMFC constructions.

*Corresponding author. E-mail: steve.decliff@ub.edu.bi

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The results presented in this paper are the findings of a preliminary study performed in the framework of a vast research within multidisciplinary program undertaken at the National Research Council of Canada (NRC). Thus, the extent of work reported here represents only a small part of an ongoing investigation on certain complex systems that include the methanol/water mixture for use in a Direct Methanol Fuel Cell (DMFC). To be more precise, the present research work addresses the development of thin-films of complex metal oxides of the nonstoichiometric perovskite family for methanol sensing, as a preliminary step for further application in the fabrication of cantilever-based methanol sensors for a DMFC power supply integrated in complex MEMS devices. One of the strategic economic applications behind the above research program is the fabrication of a MEMS device that can be used as a radio-frequency (RF) remote control system for pipelines installations monitoring or for various advanced defense applications.

1.2. Background and Structure of Perovskite $SrFeO_{2.5+x}$

Perovskite is a calcium titanium oxide mineral species composed of calcium titanate, with the chemical formula of $CaTiO_3$. The mineral was discovered in the Ural Mountains of Russia by Gustav Rose in 1839 and is named after Russian mineralogist, L. A. Perovski (1792–1856). Since then, perovskite lends its name to the class of compounds which have the same type of crystal structure as $CaTiO_3$ (ABO_3) known as the perovkite structure (Hench and West, 1990). The perovskite crystal structure was first published in 1945 from X-ray diffraction data on barium titanate by the Irish crystallographer Helen Dick McGaw (1907–2002).

It is a ternary compound of the formula ABO_3 for which A and B cations differ in size. It is considered to be an FCC-derivative structure in which the larger A cation and oxygen together form an FCC lattice while the smaller B cation occupies the octahedral interstitial sites in the FCC array. There is only oxygen being B cation's nearest neighbor. The structure is a network of corner-linked oxygen octahedra, with the smaller cation filling the octahedral holes and the large cation filling the dodecahedral holes (Goldschmidt, 1926). The unit cell of a perovskite cubic structure is shown in Figure 1. Oxides with perovskite and related structures with mixed electronic ionic conductivity are of interest as electrode materials, oxidation catalysts, ion-transport membrane materials and in thin film sensors. For the latter application, the group of Nanostructured Materials of the Institute for Chemical Process and Environmental Technology (ICPET)/NRC, has extensively studied thin films of the non-stoichiometric perovskite $SrFeO_{2.5+x}$ grown onto sapphire substrates by the pulsed excimer laser deposition (PLD) technique (Post *et al.*, 1999a; Post *et al.*, 1999b; Tunney and Post, 2000; Grudin *et al.*, 2002).

The structure, electrical conductivity and phase behavior of bulk samples of $SrFeO_{2.5+x}$ have been examined by several other groups (Tofield *et al.*, 1975; Takeda *et al.*, 1986; Mizusaki *et al.*, 1992; Kozhevnikov *et al.*, 2001). At high oxygen partial pressures, $SrFeO_{2.5+x}$ adopts the perovskite structure and transforms to the vacancy-ordered brown millerite structure when the oxygen partial pressure is lowered. At lower temperatures, other intermediate vacancy-ordered structures are known.

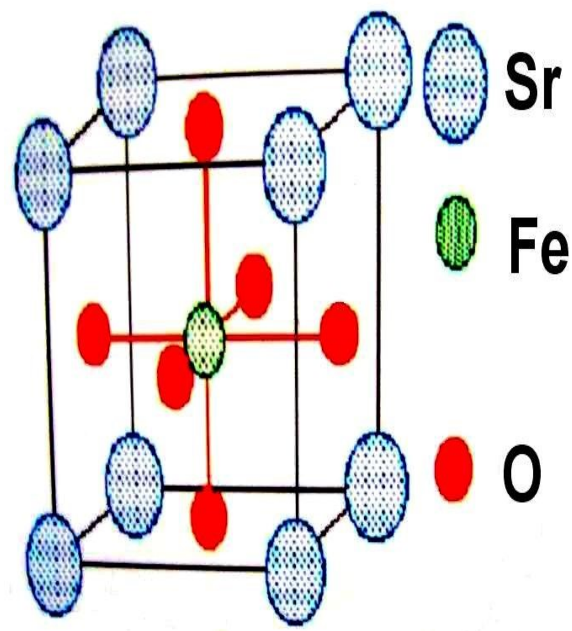

Figure 1. General structure of the SFO perovskite.

The chemistry of the strontium-iron-based $SrFeO_{2.5+x}$ perovskite materials predicts a catalytically induced reduction of the SFO when in contact with a gas phase of a reducing analyte, e.g. methanol. It has been also observed that the perovskite structure $ABO_{2.5+x}$ is tolerant to elemental substitution in both the A and B sites. For this research, the parent $SrFeO_{2.5+x}$ perovskite compounds and their thin films have been chemically and morphologically modified to focus on the cobalt substituted series of the $SrFe_{1-y}Co_yO_{2.5+x}$, abbreviated as SFCO's family, for $0<y<1$ (Post *et al.,* 1999a). Such a cobalt substitution confers upon these compounds a higher degree of mixed ionic/electronic conductivity (Grudin *et al.*, 2002) than is present in $SrFeO_{2.5+x}$. These attributes provide a more tunable sensor response with respect to the chemical-sensor orthogonality. Additionally, at ambient temperature, SFO films were found to have sheet resistance greater than 220 MΩ/sq, while the cobalt-substituted films were found to have a measurable electrical resistance and a sheet resistance in the range of 30–40 MΩ/sq.

1.3. Theoretical Background and Gas Sensing Requirements

The gas sensing activity of thin film sensors works by thermal activation of charge carriers:

$$\sigma = A\sigma_0 e^{-\left[\frac{E_c - E_t}{kT}\right]} \quad (2)$$

where σ is the minimum conductivity after the adsorption of a reducing gas; σ_0 is the conductivity in a steady gas flow; A is a constant; E_c is the energy of the conduction band, and E_t is the energy of the surface state. The oxygen defect equilibrium:

$$O_O^x \leftrightarrow V_{\ddot{O}} + \tfrac{1}{2}O_2 + 2e^- \quad (3)$$

$$2B^{n+} + 2e^- \rightarrow 2B^{(n-1)+} \quad (4)$$

$$O_O^x + 2B^{n+} \leftrightarrow V_{\ddot{O}} + 2B^{(n-1)} + \tfrac{1}{2}O_2 \quad (5)$$

Equation 3 is the formation of an oxygen vacancy with loss of two electrons. Equation 4 is the reduction of the metal from B^{n+} to $B^{(n-1)+}$. Under a rich-oxygen environment, the equilibrium in equation 5 is moved to left, which is responsible for the formation of electron holes, which provide more active sites.

In the case of the MeOH/H_2O system, the MeOH behavior (vapor pressure VP vs molar fraction of MeOH in water) in a DMFC is better described by the Antoine equation as:

$$\log_{10}P^* = A - \frac{B}{T + C} \quad (6)$$

where P^* is the vapor pressure in mm Hg and T is the heat temperature in degree Celsius. Figure 2 shows the variation of the vapor pressure of a MeOH/water system at different concentrations of methanol. As methanol has the properties of a reducing gas, the sensitivity (*S*) of *p*-type SFOC semiconductor thin films gas sensors would be determined using the following equation:

$$S = \frac{R_{gas} - R_{air}}{R_{air}} \quad (7)$$

where R_{air} and R_{gas} are the electrical resistance in air and in an atmosphere containing a constant gas concentration to be monitored, respectively. For such a system, the following mechanism for methanol sensing is proposed:

$$CH_3OH(g) + 3O^{2-}(s) \rightarrow CO_2(g) + 2H_2O(g) + 6e^- \quad (8)$$

When the composition of the air surrounding the device is altered by the presence of a reactive gas, i.e. methanol, an interaction occurs which results in a change in the availability of electronic conductors. Then the impedance changes as result of chemically induced change to the sensor material. This resistance is then used as a measure of the concentration of the trace gas. In order to obtain sufficiently fast kinetics for film–gas chemistry and to provide a rapid sensor response, the thin film must be heated to approximately 500 °C or higher (Post *et al.*, 1999b). The electrical resistance of the film is then measured before, during and after exposure to the analyte gas stream to yield a form of sensor transduction signal which can then be simply monitored by an on-board circuitry for analysis and processing (Tunney and Post, 2000).

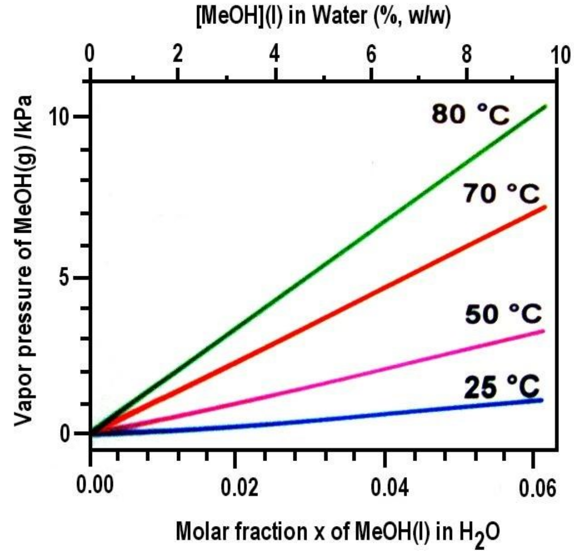

Figure 2. Variation of the vapor pressure of methanol in a MeOH/H_2O system for different concentrations and different temperatures.

Due to the *p*-type conductivity of the sensing film, certain interesting characteristics are obtained. For example, the resistance of the film increases in a reducing environment. This extends the measurement range of these films to concentrations beyond those accessible to commonly available conventional SnO_2 sensors, which are *n*-type semiconductors, and approach an $R = 0\Omega$ value at higher gas exposure concentrations.

1.4. Background on Films Deposition and Characterization

$SrFe_{1-y}Co_yO_{2.5+x}$ thin films of good quality are obtained by pulsed laser deposition (PLD) and characterized by x-ray diffraction (XRD). Inductively coupled plasma-Auger electron spectroscopy (ICP–AES) has shown them to be single phase with a well defined chemical composition (Grudin *et al.*, 2002), thus confirming congruent transfer during PLD. It was also determined that for the SFCO family, films could be successfully deposited by PLD onto substrates over a range of temperatures from room temperature (then denoted as SFCO-RT) to 300 °C, with subsequent annealing during a preconditioning step to optimize sensor functionality (in contrast to the parent $SrFeO_{2.5+x}$). The *p*-type semiconducting films obtained by such a procedure are found to adhere onto the substrate they are deposited, with a uniform thickness of approximately 200 nm. The avoidance of higher temperatures (i.e., T > 300 °C) during PLD is advantageous for minimizing the thermal stress that may be experienced by the host electrode substrate, then preserving its integrity. Investigations of the reduction–oxidation properties of the $SrFe_{1-y}Co_yO_{2.5+x}$ family (Post *et al.,* 1999a; Grudin *et al.*, 2002) have determined that the optimum composition for enhanced sensing functionality is with y = 0.75.

2. Materials and Methods

2.1. Synthesis and Characterization of Materials

The $SrFe_{1-y}Co_yO_{2.5+x}$ (y = 0.50 and y = 0.75) targets were prepared by conventional ceramic preparation techniques. $SrCO_3$, Fe_2O_3 and Co_3O_4 powders (> 99.9% pure on a metal basis) were mixed and ground together in the required quantity, followed by heat treatment at 1100 °C under oxygen atmosphere. The sample was ground up again and characterized by XRD. Once the single-phase product was obtained in powdered form, the powder was pelletized and sintered at 1150 °C in oxygen. After XRD analysis confirmed the pellet to be single phase, the pellet was used as the target material for the deposition of either $SrFe_{0.50}Co_{0.50}O_{2.5+x}$ or $SrFe_{0.25}Co_{0.75}O_{2.5+x}$ films by PLD.

2.2. Material Deposition and Device Fabrication

$SrFe_{0.50}Co_{0.50}O_{2.5+x}$ or $SrFe_{0.25}Co_{0.75}O_{2.5+x}$ films were deposited by the PLD technique on interdigitated gold electrode substrates using a Lambda-Physik LPX305i excimer laser operating with Kr/F at 248 ηm. All depositions were carried out under a background oxygen pressure of 100 m Torr. The films, typically 200 nm thick, were fabricated by ablating the $SrFe_{1-y}Co_yO_{2.5+x}$ target with the laser operating at 8 Hz and at an energy fluence of 1.5 J cm^{-2}. The average deposition rate was 10 ηm $minute^{-1}$. For the device construction, we have used a seven-pin sensor platform provided by the Armstrong Monitoring Corporation (Figure 3).

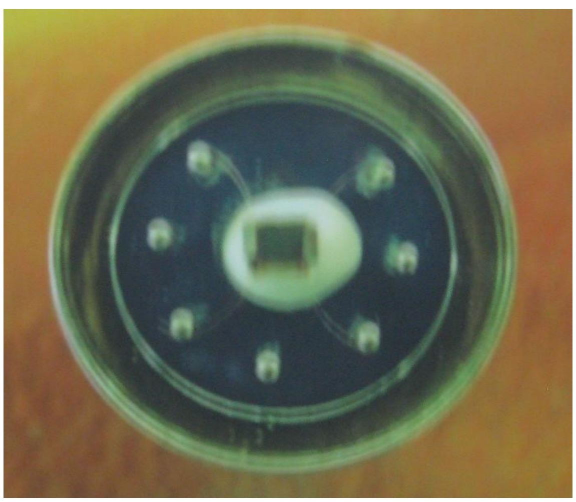

Figure 3. A seven-pin sensor platform with a wire-bonded thin film.

An interdigitated gold electrode substrate (Figure 4) onto which we have deposited the sensor film material by PLD was then wire-bonded and mounted on the above seven-pin sensor platform. This platform was connected to a readout circuit with two pins connected to a heater circuit to warm the film sensor to an "active" temperature and a measurement circuit in which the impedance of the semiconductor material is measured and displayed.

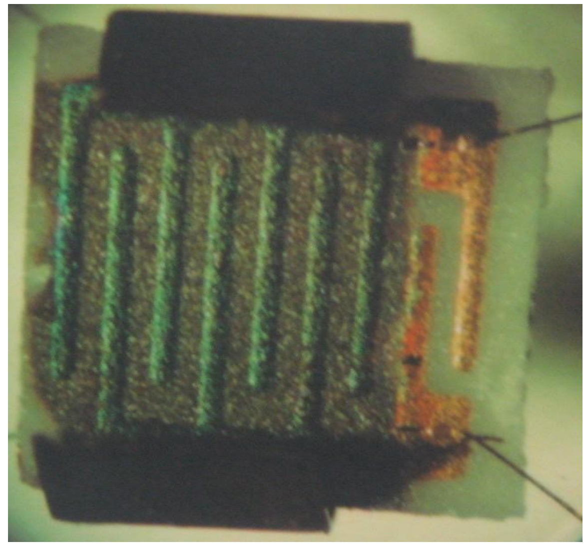

Figure 4. An interdigitated gold electrode thin film substrate with a SFOC film.

The gas-sensing device was then suspended in a reactive chamber made of a four-liter Pyrex glass container. A plastic drain plug mounted and sealed on the top of the Pyrex container was equipped with a series of ports that served to introduce the sensor in the Pyrex container, to perform an injection of methanol into the reactive chamber, to flush out the methanol after reaction and sometimes to introduce oxygen from ambient air by simple opening.

3. Results and Discussion

In this study, the methanol sensing of two SFOC semiconductors *p*-type materials has been investigated. Gas sensor functionality was determined by in-situ measurement of the electrical conductivity of the sensors in a custom fabricated chamber made of a Pyrex container and a gas injection system.

Even if some literature seems to favor a SFCO material with a doping in Fe/Co in the proportions of 0.25/0.75, we have recognized that the difference in sensitivity observed between the 0.50/0.50 and the 0.25/0.75 systems was not considerable (Figure 5).

Both compositions, especially the 0.50/0.50 system, have a good stability upon heating and present a very stable region of temperature in which the sensor was thermodynamically stable, i.e. the region in which the resistance does not fluctuate with time (Figure 6). An important shift of the resistance is also observed after multiple and repetitive exposures (ageing) of the sensor to methanol (Figure 7). Ageing a film sensor seems to enhance its sensitivity for MeOH.

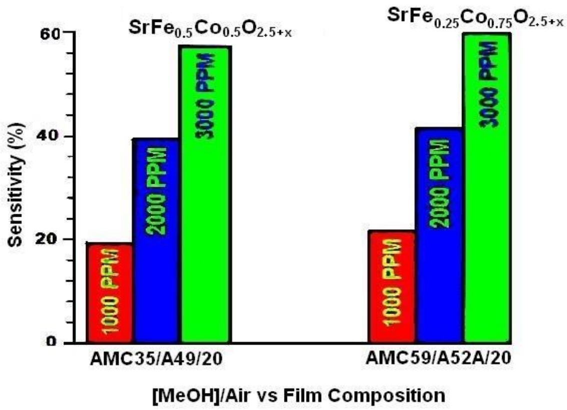

Figure 5. Effect of composition and doping ratio of Fe/Co into the SFO thin-films sensors exposed to different concentrations of MeOH/air mixture.

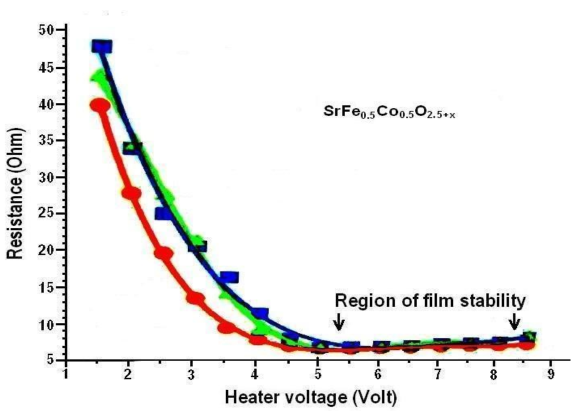

Figure 6. Variation of the electrical resistance of a $SrFe_{0.5}Co_{0.5}O_{2.5+x}$ thin-film sensor in air at different heat treatments.

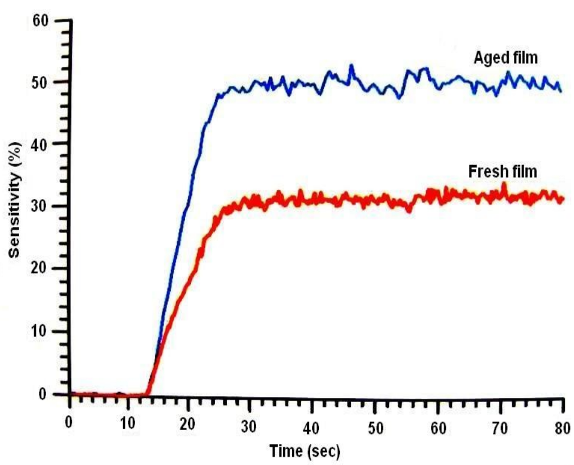

Figure 7. Sensitivity of a fresh and a previously aged $SrFe_{0.5}Co_{0.5}O_{2.5+x}$ thin-film sensor exposed to 700 ppm of methanol/air.

Another important observation was that the starting resistance point was always reproduced for any single test scan and the recovery time, i.e. the necessary time required before the sensor may be re-used, was roughly 10 to 20 seconds (Figure 8). As expected, high concentrations of MeOH led to longer recovery times because of possible poisoning due to the saturation of the sensor active surface by the reducing gas. Moreover, all the film sensors tested have shown a very remarkable ability to reproduce signal readings when they were consecutively exposed to the same concentration of methanol (Figure 8). There was a well-defined linear relationship between the sensitivity and concentration of methanol (Figure 9). This is an important observation that makes these materials good candidates for use in methanol sensor devices.

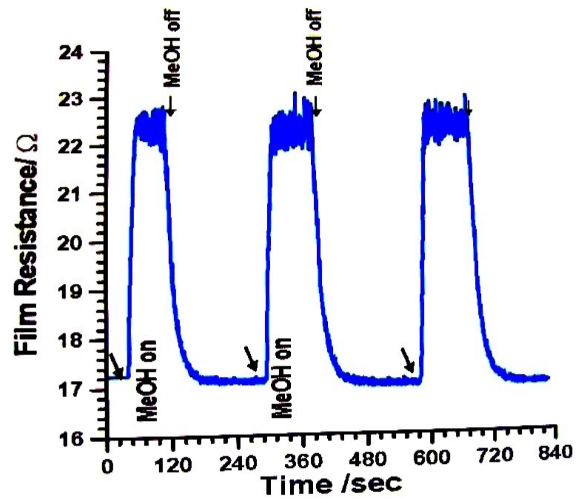

Figure 8. Typical response and recovery transients of a $SrFe_{0.5}Co_{0.5}O_{2.5+x}$ thin-film sensor quickly exposed to 700 ppm of methanol in air.

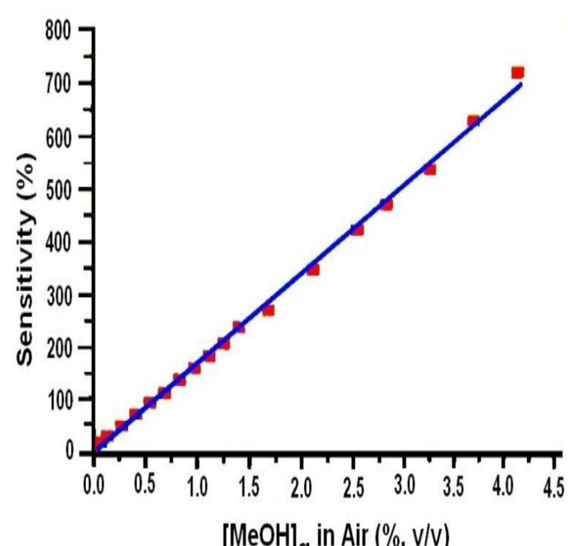

Figure 9. Maximum sensitivity of a $SrFe_{0.5}Co_{0.5}O_{2.5+x}$ thin-film sensor exposed to different concentrations of methanol in air.

Finally, the speed of response, i.e. the time required for a film sensor to reach a certain fraction of its real maximum sensitivity, was also very good as displayed on Figure 10 for the $SrFe_{0.5}Co_{0.5}O_{2.5+x}$ system. The results showed rapid response and high sensitivity; the gap of resistance covered predicts good sensitivity even down to concentrations in the low ppm range.

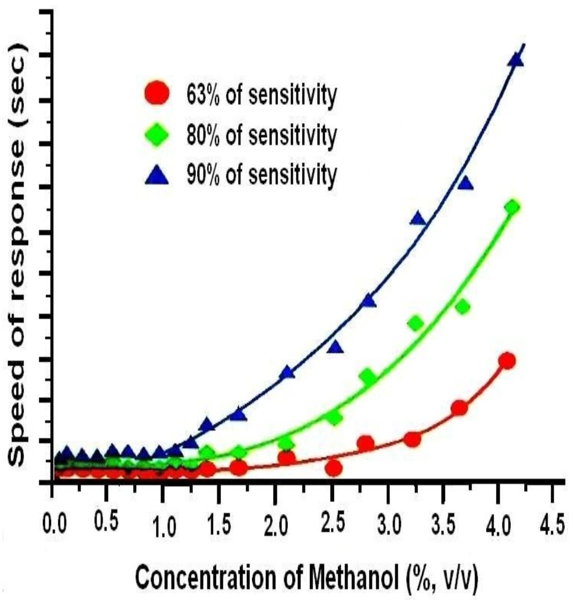

Figure 10. Typical speed response of a $SrFe_{0.5}Co_{0.5}O_{2.5+x}$ thin-film sensor exposed to different concentrations of methanol in air for selected sensitivities.

4. Conclusion

To summarize, thin-films of gas sensitive materials based on the $SrFeO_{2.5+x}$ nonstoichiometric perovskite family were deposited by RT pulsed excimer laser deposition onto an interdigitated gold electrode substrate, wire-bonded and mounted on a seven-pin sensor platform. Two films sensors based on the $SrFe_{1-y}Co_yO_{2.5+x}$ oxides perovkite family, with y = 0.25 and 0.5, have been considered. Their ability to very quickly respond to the presence of low concentrations of methanol makes them attractive for the construction of methanol sensing devices, such as gas monitoring. This research work was a preliminary study for complex systems such as the methanol/water mixture. Further studies are underway and are aimed to the development and optimization of a micro methanol sensor for a micro direct methanol fuel cell (μ-DMFC) powered device.

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Effects of Nitrogen and Phosphorus Fertilizer Application on Yield Attributes, Grain Yield and Quality of Rain Fed Rice (NERICA-3) in Gambella, Southwestern Ethiopia

Shiferaw Nesgea[1]*, Heluf Gebrekidan[2], J.J. Sharma[2] and Tareke Berhe[3]

[1]Gambella Regional Agricultural Research Institute, P O Box 62, Gambella, Ethiopia
[2]Colleges of Agriculture and Environmental Sciences, Haramaya University, P O Box 138, Dire Dawa, Ethiopia
[3]SASAKAWA Africa Association`s, Regional Rice Program, Addis Ababa, Ethiopia

Abstract: A field experiment was carried out during the 2008 and 2009 crop seasons at Imla, Gambella Zuria District, Gambella, southwestern Ethiopia, to establish the application rates of N and P fertilizers for rice variety NERICA-3 (*Oryza sativa x Oryza glaberrima*). The treatments consisted of factorial combinations of four rates each of N (0, 46, 92 and 138 kg N ha^{-1}) and P (0, 23, 46 and 69 kg P ha^{-1}) laid down in a randomized complete block design (RCBD) with three replications. The effects of year showed significant ($P \leq 0.05$ for some and $P \leq 0.01$ for most) differences for leaf area index (LAI), 1000-grain weight, plant height, panicle length and grain qualities. Similarly, the effects of N were significant ($P \leq 0.01$) for productive tillers plant^{-1}, grains panicle^{-1}, LAI, plant height, panicle length, grain yield, crude protein, ether extract and crude fiber. Growth, yield, and quality components did not differ significantly ($P > 0.05$) due to application of P except crude fiber. Conversely, the effects of year by N interaction were significant ($P \leq 0.05$ and/or $P \leq 0.01$) for LAI, panicle length, grains panicle^{-1}, crude fiber, plant height and ether extract. Effects of year by P interaction were significant only for crude fiber whereas the interaction effects of N by P and year by N by P on growth, yield and quality parameters were not statistically significant ($P > 0.05$). Rice grain yield increased from 3.54 to 5.90 tons per hectare (t ha^{-1}) with increase in level of N from the control to 92 kg N ha^{-1} but decreased with further increase of N. In conclusion, sensitivity analysis on coexisting changes in field prices of inputs and rice grain (±15%) showed that 92 kg N gave the highest (681.53%) marginal rate of return (MRR) followed by 23 kg P ha^{-1} (117.44%). Therefore, application of 92 kg N ha^{-1} to improve grain yield of rain fed NERICA-3 rice might be more profitable even under risky market situations in and around the study area.

Keywords: Economic Analysis; Grain Quality; Grain Yield; Nitrogen; Phosphorus; Yield Attributes

1. Introduction

Rice (*Oryza sativa* L.) is the most important food security crop for about half of the world's population (Brohi *et al*., 1998) and ranks third in area after wheat and second both in production and productivity after maize worldwide (FAOSTAT, 2012). It supplies more calories per 100 g portion than maize and wheat and provides more than one fifth of calories consumed worldwide by human (FAOSTAT, 2012; USDA, 2012). The total world rice production has risen steadily from about 200 million tons (t) of paddy rice in the 1960 to over 678 million tons in 2009. In the 2010/2011 and 2011/2012, the world paddy productions were estimated at 691.3 and 713.8 million tons, respectively. Globally, 158.9 million hectare (ha) of rice was harvested during the 2011/2012 (USDA, 2012).

In Ethiopia, the number of rice producing farmers, area under rice and its production and productivity rose from 53, 302, 18, 527 ha, 42, 825 tons and 2.31 t ha^{-1} in 2006 to 284, 868, 155, 886 ha 498, 332 tons and 3.2 t ha^{-1} in 2009, respectively. In the Gambella Region, although there is a 3,164, 230 ha of land of which 373, 848 ha is highly suitable, 2, 752, 345 ha is suitable and 38, 037 ha is moderately suitable for rice production, the crop occupied only 1, 314 ha with annual production of 4, 456 tons in the 2008 (MoARD, 2010). Owing to its recent introduction to the country, the research and development effort so far undertaken on rice in Ethiopia is of limited scale. However, its productivity, varied uses, existence of vast suitable conditions (swampy, waterlogged, rain fed and irrigable land) and possibilities of growing it where other food crops do not perform well make rice among the promising alternative crops available for cultivation in Ethiopia. As a result, rice is among the target commodities of the millennium development of the country that is named "Millennium crop" as it is expected to contribute greatly towards ensuring household as well as national food security in the country.

Rice can produce grain yield as high as 10-18 t ha^{-1} in countries advanced in its cultivation (Yuan, 2002). However, its productivity in Ethiopia in particular (2.31 t ha^{-1} of paddy rice) and in Africa at large is much below its world average (4.35 t ha^{-1} of paddy rice) due to improper crop management practices. The research and extension efforts made so far for promoting its production are also limited to certain areas. Fertilizer type, level and time of application are among the

*Corresponding author. Email: nesgeashiferaw@yahoo.com
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prioritized rice production input constraints set in Ethiopia (MoARD, 2010).

Daniel and Soloman (2008) from their soil nutrient variability study results of the Barro River basin plain, Gambella, reported that the amount of total nitrogen (N) ranged from 0.06 to 0.31%. Of the area surveyed, 44.4, 40.7 and 14.2% fall under very low, low and medium total N categories, respectively. They added that the amount of available phosphorus (P) ranged from absolutely deficit to excess levels. Furthermore, no information on recommended rates of N and P fertilizers for profitable rice production in the Region is available. Use of nutrients particularly N, P and potassium (K) in optimum quantities with appropriate sources, application methods and application time can markedly increase the yield and improve the quality of rice grain (Place *et al*., 1970). Judicial use and management of nutrients improves and maintains soil fertility while sustaining an economically viable and environmentally friendly agriculture that will meet the requirements of the future (Moro *et al*., 2008).

Nitrogen makes up 1-4% of the dry matter of plants and a good supply of N to the plant stimulates root growth and development as well as uptake of other nutrients (Brady and Weil**,** 2002), which in turn increases the grain yield by increasing the magnitude of yield attributes such as number of panicles m^{-2} and panicle length (Sewenet, 2005; Heluf and Mulugeta, 2006). Proper use of fertilizer increases crop yields significantly, particularly in cereals. Rice may benefit from the use of mineral and organic fertilizers to compensate exported nutrients. It is estimated that for every one ton of rice grain harvested, about 1.5-2.0% N, 0.2-0.3% P and 1.5-2.0% K are removed from the soil. With the introduction of new and high yielding rice varieties, soil nutrient mining will be on the increase when mineral fertilizer additions are absent or not in adequate amounts (Moro *et al.,* 2008). Bajwa and Rehman (1998) found that imbalanced ratio of NPK nutrients promoted excessive vegetative growth and led to reduced yield and productivity of the soil. In earlier studies, Malik *et al*. (1994) reported that the optimum nutrient requirement of fine rice is 84/41/49 kg N/P/K ha^{-1} and indicated that the response curve was of a quadratic trend to N and P and linear trend to K. At the Fogera plain, northwestern Ethiopia, the highest rice mean yield obtained due to the applications of 60/13.2 kg N/P ha^{-1}, representing an increase of 38.5% over the control (Heluf and Mulugeta, 2006). Rehman *et al*. (2006) studied the response of rice to different combinations of fertilizers in a farmer's field at Maghoki (Hafizabad) in a permanent field layout and found a significant improvement in paddy rice yield (3.30-4.35 t ha^{-1}) during the two experimental years with the application of recommended doses of N and P fertilizers. Panda *et al*. (1995) reported increased grain yield of rice due to increased N and P uptakes in response to external application of both N and P fertilizers. The present field experiment was conducted to evaluate the effects of inorganic N and P fertilizer application rates on growth, yield and grain quality of rice (NERICA-3) under rain fed conditions in the Gambella lowlands, and to determine the levels of N and P fertilizers required for obtaining maximum marginal rate of return on investment.

2. Materials and Methods

2.1. Description of the Study Site

The experiment was conducted at *Imla* (8^o 14' 46.36" N latitude; 34^o 35' 17.75" E longitude; altitude 450 meters above sea level) found in Gambella Zuria District, southwestern Ethiopia during the 2008 and 2009 main cropping seasons. The area is characterized by hot humid tropical lowland climate. The soil texture was clay, consisting of 4.08% organic carbon (OC), 0.51% total N and 65.00 mg kg^{-1} available P with a pH of 6.43 (Table 1). The weather data during the two experimental seasons (2008 and 2009) are presented in Figure 1.

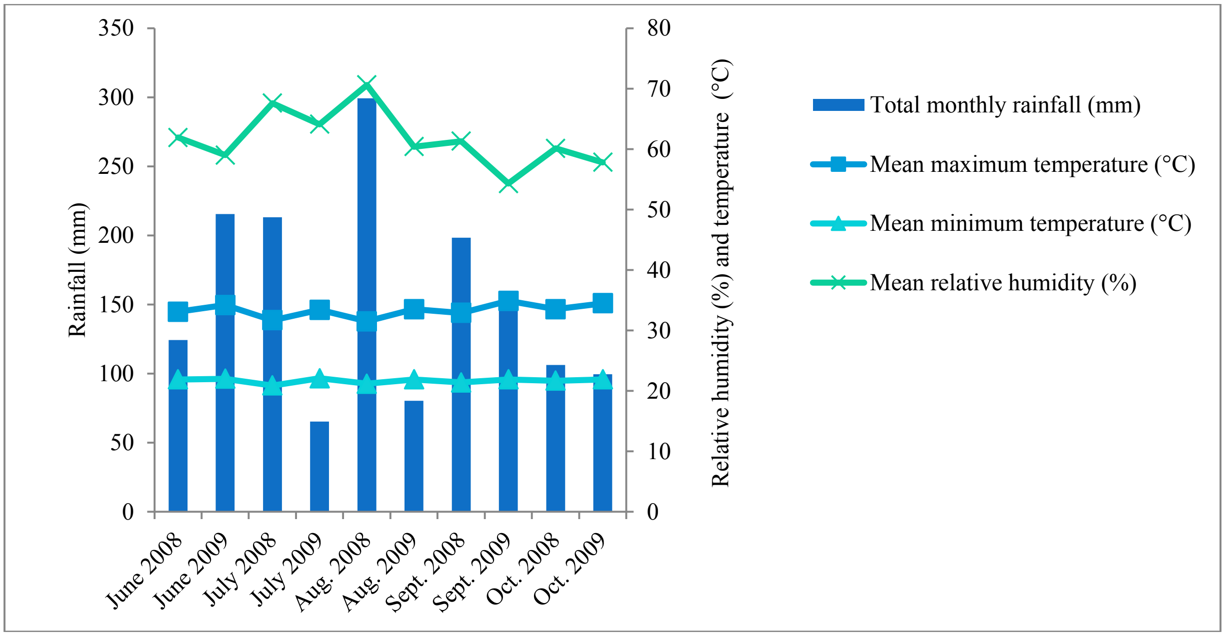

Figure 1. Monthly weather data for the 2008 and 2009 cropping seasons (Source: Gambella Meteorological Service Branch Office).

2.2. Treatments, Experimental Design and Procedures

The treatments consisted of factorial arrangement of 4 levels each of N (0, 46, 92 and 138 kg N ha^{-1}) and P (0, 23, 46 and 69 kg P ha^{-1}) in a randomized complete block design in three replications. To estimate the seeding rate, germination percentage of the rice seeds was determined through controlled test using newspaper (absorbent material), waterproof tray, randomly sampled mixed rice seed lot and tape water for 10 days before sowing on the field. Each day, the number of germinated seeds was recorded. Germination (%) was calculated as the ratio of number of seeds germinated to number of seeds on the tray and recorded as 96.1% in the 2008 and 94.8% in the 2009. The land was plowed by a tractor in April 2008. A suitable seedbed was prepared to get proper germination and root development. The plot size was 4 m x 4 m (16 m^2).

The rice variety NERICA- 3 was sown in the last week of July and harvested in the third week of October each year. Nitrogen fertilizer was applied in splits, ⅓ each at sowing, tillering and panicle initiation stages as urea, while whole P (TSP as source of P) and uniform dose of 20 kg K (KCl) ha^{-1} were applied at sowing. Rice seeds were drilled by hand in rows at 20 cm apart at the rate of 100 kg ha^{-1}. All the recommended agronomic practices were followed.

There were 20 rows in each plot and two outer most rows and 0.5 m row length at both ends of each plot were considered as borders. The second, third and fourth rows on both sides of the plots were designated for destructive sampling, non-destructive sampling and guard rows, respectively. Of the 4 m x 4 m (16 m^2) gross plot size, 3.0 m x 2.4 m (7.2 m^2) was harvested when two-third of the length of panicle axis in 50% of the plant population attained yellow color.

2.3. Soil Sampling and Analysis

A composite surface soil (0-30 cm depth) sample was collected with a gauge auger in the 2008. Before plowing, the experimental field was blocked into three parts depending upon land uniformity. Plant residues on the sampling soil surface were removed. Eight soil sub-samples each for a composite surface soil and core (undisturbed) samples per block were collected for characterization of selected soil physicochemical properties. The sample was analyzed for soil texture using the hydrometer method (Jackson, 1967). Bulk density (Db) of the soil was measured from the undisturbed soil sample collected using core sampler, which was weighed at the field and after drying the pre-weighed core soil sample to a constant weight in an oven at 105 ^{o}C according to the procedure described by Okalebo *et al.* (2002). Particle density (Dp) was determined by the pycnometer method (Rowell, 1997) and total porosity (%) [(1-(Db/Dp) x 100] was calculated.

Soil pH was determined in a 1:2.5 soil-water suspension using a combination of glass electrode. Organic carbon was estimated by the wet digestion method (Okalebo *et al.*, 2002) and organic matter was calculated by multiplying the percent organic carbon (OC) by a factor of 1.724. Exchangeable K, calcium (Ca) and magnesium (Mg) were extracted with 1 M ammonium acetate solution adjusted to pH 7.0 (Hesse, 1971). From the extract, exchangeable K was determined using a flame photometer while Ca and Mg were determined using an atomic absorption spectrophotometer. Further, sulfur (S) was extracted with $Ca(H_2PO_4)_2$ in $2NH_4OAc$ and measured turbidmetrically (Hoeft *et al.*, 1973). To determine the cation exchange capacity (CEC), the soil sample was first leached using 1 M ammonium acetate, washed with ethanol and the adsorbed ammonium was replaced by sodium (Na). Then, the CEC was determined titrimetrically by distillation of ammonia that was displaced by Na (Hesse, 1971).

Total soil N was measured using the micro-Kjeldahl digestion, distillation and titration procedure as described by AOAC (1994). After extraction of the soil sample by sodium bicarbonate solution as per the procedure outlined by Olsen *et al.* (1954), available P was determined by measuring its absorbance using spectrophotometer. The investigated soil properties are shown in Table 1.

Table 1. Physiochemical properties of the experimental soil (0-30 cm depth) before sowing.

Soil property	Value	Rating	Source
Sand (%)	17.68	-	-
Silt (%)	32.72	-	-
Clay (%)	49.60	-	-
Textural class	Clay	-	-
Bulk density (g cm^{-3})	0.73	-	-
Particle density (g cm^{-3})	2.98	-	-
Porosity (%)	0.76	-	-
pH 1:2.5 (H_2O)	6.43	Slightly acidic	Tekalign (1991)
ECe (dS m^{-1})	2.42	-	-
Organic matter (%)	7.03	Very high	Tekalign (1991)
Total N (%)	0.51	Very high	Murphy (1968)
Available P (mg kg^{-1})	65.00	Adequate	DEFRA (2007)
S (mg kg^{-1})	63.00	-	-
Exchangeable Ca ($cmol_c$ kg^{-1})	2.14	Low	FAO (2006)
Exchangeable Mg ($cmol_c$ kg^{-1})	6.55	High	FAO (2006)
Exchangeable K ($cmol_c$ kg^{-1})	0.60	High	DEFRA (2007)
CEC ($cmol_c$ kg^{-1})	35.60	High	Landon (1991)

2.4. Crop Data Collection

Leaf area index (LAI) was determined using the length-width method (Reddy, 2006) during panicle initiation using 0.725 adjustment factor (Tsunoda, 1964). Number of hills m^{-2} was recorded using a 1 m x 1 m quadrat at physiological maturity. Plant height (cm) was obtained by measuring the length from the base to the tip of panicle at harvest from randomly sampled 20 plants. The productive tillers were counted during physiological maturity from 1.5 m row length of non-destructive rows of both sides of each harvestable net plot. Number of grains $panicle^{-1}$ was counted per plot from 20 randomly sampled panicles. Thousand-grain weight was recorded by weighing thousand grains per treatment using sensitive balance. Grain yield was obtained from the net plot area (7.2 m^2), and adjusted to 14% moisture using hygrometer and expressed as t ha^{-1}. Milled grain percentage was obtained from one kg of grain per plot by hand pounding with a mortar and pestle. Crude protein, ether extracts (fats) and crude fiber contents were determined from a grain sample to reveal their responses to N and P fertilizers were determined (AOAC, 1994). Grain N content of rice was analyzed from the respective sample collected using the micro-Kjeldahl digestion, distillation and titration procedure as described by AOAC (1994). Crude protein (N x 6.25), ether extract and crude fiber were also determined according to the AOAC (1994).

2.5. Economic Analysis

To assess the costs and benefits associated with different treatments (N and P fertilizer levels), the partial budget technique as described by CIMMYT (1988) was applied. Economic analysis was done using the prevailing market prices for inputs at planting and for outputs at the time the crop was harvested. All costs and benefits were calculated on ha basis of Ethiopian Birr (EtB). The inputs and/or concepts used in the partial budget analysis were the mean grain yield of each treatment in both years, the field price of NERICA-3 rice grain (sale price minus the costs of harvesting, threshing, winnowing, bagging and transportation), the gross field benefit (GFB) ha^{-1} (the product of field price and the mean yield for each treatment), the field price of N or P kg^{-1} (the nutrient cost plus the cost of transportation from the point of sale to the farm), the field cost of N or P (the product of the quantity required by each treatment and the field price of fertilizer), the total costs that varied (TCV) which included the sum of field cost of fertilizer, its application and the interest at 6% rate. The net benefit (NB) was calculated as the difference between the GFB and the TCV. Actual yield was adjusted downward by 30% to reflect the difference between the experimental yield and the yield farmers could expect from the same treatment. There were optimum plant population density, timely labor availability and better management (e.g. weed control, better security) under the experimental conditions (CIMMYT, 1988; Moro *et al.*, 2008).

The dominance analysis procedure as detailed in CIMMYT (1998) was used to select potentially profitable treatments from the range that was tested. The discarded and selected treatments using this technique were referred to as dominated and undominated treatments, respectively. The undominated treatments were ranked from the lowest to the highest cost. For each pair of ranked treatments, the percent marginal rate of return (MRR) was calculated. The MRR (%) between any pair of undominated treatments was the return per unit of investment in fertilizer. To obtain an estimate of these returns the MRR (%) was calculated as changes in NB divided by changes in cost. Thus, a MRR of 100% was used indicating for every one EtB expended there is a return of one EtB for a given variable input.

Sensitivity analysis for different interventions was also carried out to test the recommendation made for its ability to withstand price changes. Sensitivity analysis simply implied redoing marginal analysis with the alternative prices. Through sensitivity analysis, maximum acceptable field price of an input was calculated with the minimum rate of return as described by Shah *et al.* (2009).

2.6. Statistical Analysis

The data were statistically analyzed using SAS statistical software version 9.10 (SAS Institute Inc., 2003). Treatment means were then compared using the Duncan's Multiple Range Test at 5% probability level.

3. Results and Discussion

3.1. Effects of N and P Fertilizers on Growth

3.1.1. Number of Hills

Analysis of variance (Table 2) showed no significant difference ($P > 0.05$) due to year, N and P application, as well as their interactions on the number of hills (rice main stem with its tillers) m^{-2}. This could be due to enough rainfall (Figure 1) for the establishment and growth of seedlings during both the cropping years. The availability of applied and reserve nutrients for the crop might have also been enhanced. Similarly, Singh and Khan (2000) reported no significant variation in the number of hills of rice with the application of N and P fertilizers.

3.1.2. Leaf Area Index

Leaf area index (LAI) of rice responded significantly to cropping year ($P \leq 0.05$), N ($P \leq 0.01$) and year by N interaction ($P \leq 0.05$), but insignificant ($P > 0.05$) to the main effects of P, interactions of year by P, N by P and year by N by P (Table 2). The rice plant attained higher LAI (0.97) in 2008 than in 2009 (0.79) cropping year (Table 4).

Table 2. Mean square from combined analysis of the effects of N and P fertilizer rates on growth, yield attributes, yield and grain quality of rice during 2008 and 2009 cropping years, Gambella, southwestern Ethiopia.

Parameter	Mean square for source of variation: Year (1)	N (3)	P (3)	Y x N (3)	Y x P (3)	N x P (9)	Y x N x P(9)	Error (60)
Growth parameters								
Number of hills m^{-2}	277.81	402.28	213.81	80.99	655.05	1225.26	1198.97	764.76
Leaf area index	0.75*	0.88**	0.12	0.56*	0.01	0.12	0.11	0.08
Plant height (cm)	713.41**	940.94**	90.90	349.65**	77.22	45.64	57.27	40.75
Yield attributes and yield								
Productive tillers $plant^{-1}$	0.83	1.98*	0.48	1.48	0.21	0.24	0.49	0.60
Panicle length (cm)	39.58**	17.80**	0.28	7.29*	1.32	1.83	0.93	1.46
Grains $panicle^{-1}$	616.61	1276.42*	134.62	1497.73*	322.54	188.59	429.70	346.15
1000-grain weight (g)	27.46*	1.80	4.85	2.37	3.90	1.92	2.99	3.76
Grain yield (tons ha^{-1})	3.25	23.05**	2.95	0.77	1.09	1.00	0.57	1.38
Grain quality								
Milled grain (%)	1307.59**	17.00	1.92	3.90	6.67	5.15	3.69	6.99
Crude protein (%)	102.78**	36.70**	3.56	6.92	1.75	3.90	4.71	4.84
Ether extract (%)	55.82**	7.99**	0.08	5.47**	0.53	0.93	0.67	0.73
Crude fiber (%)	327.86**	1.83**	0.49*	0.49*	0.64**	0.15	0.15	0.13

*Figures in parenthesis = Degrees of freedom; ** = Significant at $P \leq 0.01$; * = Significant at $P \leq 0.05$; Y = Year; ha = Hectare.*

The interaction effect of year by N showed that the LAI increased linearly with an increase in N levels up to the highest N (138 kg ha^{-1}) in 2008 while it increased insignificantly up to 92 kg N ha^{-1} in 2009. Consequently, the application of 138 kg N ha^{-1} in the 2008 cropping season had significantly higher LAI (1.40) than any other N rates by cropping year treatment combination (Table 3). The application of 92 kg N ha^{-1} showed a significant increase in LAI over its lower rates of application while no significant variation was observed between 46 kg N ha-1 and the control in 2008. The increase in LAI due to the application of 138 and 92 kg N ha-1 was 105.9 and 52.9%, respectively, over the control. The increase in LAI with the increased N application might be due to the increased availability of N that increased number of functional leaves and production of higher tiller number per unit area (Tables 3 and 4). Xue *et al.* (2004) and Onasanya *et al.* (2009) also reported an increase in LAI with increasing rate of N application. In general, the increased tiller number at higher N application rates might have contributed to the increase in LAI.3.1.3. Plant Height

The rice plant height showed significant variation with cropping year, N and the interactions of cropping year by N ($P \leq 0.01$) while P, interactions of year by P, N by P and year by N by P had no significant effect on it (Table 2). Assefa *et al.* (2009) also reported a significant influence of N on plant height in upland rice in hot humid part of Northern Ethiopia. The interaction of cropping year with N showed insignificant difference in plant height between 92 kg (113.9 cm) and 138 kg (113.5 cm) N ha^{-1} in 2008, but had significant increase in height over other interactions (Table 3).

The increase in plant height in response to application of N fertilizer was also probably due to enhanced availability of N, which enhanced cell division and more leaf area resulting in higher photo assimilates and thereby resulted in more dry matter accumulation (Abd El-Rahman *et al.*, 2003). Sewenet (2005) observed a significant increase in plant height with the application of 46 and 69 kg N ha^{-1} over control. Haque *et al.* (2006) reported the tallest and the shortest plant height with 120 kg N ha^{-1} and without N application, respectively. In 2008 application of 46 kg N ha^{-1} was statistically in parity with the control, but revealed no significant difference in plant height among the N levels during 2009 (Table 3). However, while comparing the same level of N between 2008 and 2009 cropping years, unlike LAI application of 92 kg N ha^{-1} recorded significantly higher plant height in 2008 compared to 2009

Table 3. Interaction effect of cropping year and N application on leaf area index, plant height and panicle length of rice.

	Leaf area index		Plant height (cm)		Panicle length (cm)	
N (kg ha^{-1})	2008	2009	2008	2009	2008	2009
0	0.68^{c}	0.65^{c}	94.7^{c}	94.7^{c}	20.65^{d}	22.29^{c}
46	0.74^{c}	$0.83b^{c}$	99.9^{b}	102.0^{b}	20.78^{d}	23.46^{ab}
92	1.04^{b}	$0.89b^{c}$	113.9^{a}	100.7^{b}	22.60^{bc}	22.97^{abc}
138	1.40^{a}	$0.79b^{c}$	113.5^{a}	102.7^{b}	$23.25a^{bc}$	23.69^{a}

Means of the same parameter in a column followed by the same letter are not significantly different at $P > 0.05$ by Duncan's Multiple Range Test.

3.2. Effects of N and P Fertilizers on Rice Yield Attributes and Yield

3.2.1. Productive Tillers

Analysis of variance revealed that the number of productive tillers $plant^{-1}$ was significantly ($P \leq 0.05$) influenced by application of N whereas, effects of year, P, interactions of year by N, year by P, N by P and year by N by P were not ($P > 0.05$) (Table 2). The number of productive tillers $plant^{-1}$ increased with an increase in N application rates in which application of 138 kg N ha^{-1} resulted in a significant increase over the control and 46 kg N ha^{-1} (Table 4). Similarly, no significant difference existed among control, 46 and 92 kg N ha^{-1} treatments.

Enhanced tillering by increased N application might be attributed to more N supply to plant at active tillering stage (Ishizuka and Tanaka, 1963). Behera (1998) also reported that application of N increased the number of effective tillers per hill in rice. Whereas Haque *et al.* (2006) reported the highest number of tillers with 120 kg N ha^{-1} but was statistically similar to 60 kg N ha^{-1} application. Akinrinde and Gaizer (2006) showed no significant difference in number of tillers across six rice genotypes with P application. In contrast, Alam *et al.* (2009) reported 29% increase in effective tillers with the application of 72 kg P ha^{-1} over the control.

Table 4. Main effects of cropping year, N and P application on growth and yield attributes of rice, Gambella, southwestern Ethiopia.

Treatment	Growth parameters			Yield attributes	
	NH	LAI	Plant height (cm)	Productive tillers	Panicle length (cm)
Year					
2008	94.9	0.97[a]	105.5[a]	2.45	21.82[b]
2009	98.3	0.79[b]	100.0[b]	2.27	23.10[a]
N (kg ha^{-1})					
0	92.5	0.66[b]	95.7[b]	2.10[b]	21.47[c]
46	102.2	0.78[b]	100.0[b]	2.16[b]	22.12[bc]
92	96.3	0.97[a]	107.3[a]	2.43[ab]	22.78[ab]
138	95.3	1.10[a]	108.1[a]	2.73[a]	23.47[a]
P (kg ha^{-1})					
0	99.7	0.83	100.8	2.22	22.54
23	92.6	0.82	105.1	2.31	22.40
46	97.7	0.98	101.5	2.35	22.34
69	96.2	0.88	103.6	2.55	22.56
CV (%)	28.64	31.14	6.21	32.94	5.39

Means of the same parameters in a column followed by the same letter are not significantly different at P > 0.05 by Duncan's Multiple Range Test. NH = Number of hills m^{-2}; LAI = Leaf area index; CV = Coefficient of variation

3.2.2. Panicle Length

There was a significant difference in rice panicle length due to cropping year, N ($P \leq 0.01$) and interaction of year by N ($P \leq 0.05$), while the effects of P, interactions of year by P, N by P and year by N by P had no significant ($P > 0.05$) influence on panicle length (Table 2). The interaction effect of cropping year with N showed that panicle length was significantly more with the application of 92 and 138 kg N ha^{-1} than the control and 46 kg N ha^{-1} in 2008 while in 2009 such difference was observed with 46 kg N ha^{-1} also. Consequently, the maximum panicle length (23.69 cm) was found with the application of 138 kg N ha^{-1} followed by 46 and 92 kg N ha^{-1} in 2009 which was statistically at par with panicle length recorded at 138 kg N ha^{-1} in 2008 (Table 3). The longer panicles obtained in treatments receiving higher N rates might probably be due to better N status of plant during panicle growth period. The increment in panicle length with increased N application is in agreement with the findings of Heluf and Mulugeta (2006) who noted increase in rice panicle length with increasing N supply up to 90 kg N ha^{-1}. Similarly, Salem (2006) reported a significant increase in panicle length with the increased N levels in two years of experimentation.

Table 5. Interaction effect of cropping year and N application on number of grains per panicle^{-1} of rice, Gambella, southwestern Ethiopia.

N (kg ha^{-1})	2008	2009
0	107.5[c]	124.8[b]
46	112.2[bc]	131.4[a]
92	129.0[ab]	126.0[ab]
138	139.6[a]	126.4[ab]

Means of the same parameter in a column followed by the same letter are not significantly different at P > 0.05 by Duncan's Multiple Range Test.

3.2.3. Grains Per Panicle

Effects of N fertilizer and its interaction with cropping year significantly influenced grain number panicle^{-1} ($P \leq 0.05$), while effects of cropping year, P, interactions of year by P, N by P and cropping year by N by P were not ($P > 0.05$) significant (Table 2). Application of 138 kg N ha^{-1} resulted in maximum (139.6) grains panicle^{-1} which significantly varied only with the control and 46 kg N ha^{-1} in 2008. Kamara *et al.* (2011) also reported that N application had a significant effect on number of grains panicle^{-1} in rice. During 2009, there was no significant difference in number of grains (124.8-131.4) due to N application. The data (Table 5) revealed that among 92 and 138 kg N ha^{-1} there was no significant difference between 2008 and 2009 years whereas, the control and 46 kg N ha^{-1} had significantly more grains panicle^{-1} in 2009 than that of 2008. The interaction effect indicated statistical parity among 92 and 138 kg N ha^{-1} in 2008 and with all the N application rates in 2009, while the control plots in 2008 recorded significant decrease in number of grains panicle^{-1} compared to other interaction effect except 46 kg N ha^{-1} in the same year. The more number of grains panicle^{-1} at higher N rates were probably due to better N status of plant during panicle growth period. Heluf and Mulugeta (2006), however, reported increased number of grains panicle^{-1} in the absence of both N and P fertilizers.

3.2.4. 1000-Grain Weight

Thousand grain weight of rice differed significantly due to cropping year ($P \leq 0.05$), whereas effects of N, P, interactions of year by N, year by P, N by P and year by N by P were not ($P > 0.05$) (Table 2). Significantly higher 1000-grain weight (27.46 g) was recorded in 2008 than in 2009 (26.39 g) which was higher than it by about 4.1%. Erratic rainfall, higher air temperature and inadequate rainfall during grain filling period in 2009 might have adversely affected the grain filling process resulting in lower 1000-grain weight. Grain weight is a genetically controlled trait, which is greatly influenced by environment during the process of grain filling, but it also appeared that the application of N increased the protein percentage, which in turn increased the grain weight (Kausar *et al*., 1993).

3.2.5. Grain Yield of Rice

The analysis of variance (Table 2) showed significant ($P \leq 0.01$) difference in rice grain yield due to the effect of N application, whereas effects of cropping year, P, interactions of cropping year by N, cropping year by P, N by P and cropping year by N by P were not significant($P > 0.05$). The grain yield during 2008 was lower than in 2009 despite significantly higher 1000-grain weight. The increased grain yield in 2009 might have been contributed by higher panicle length (Table 4) and number of grains panicle^{-1} (Table 6).

Nitrogen supply directly or indirectly affects chlorophyll content, LAI, canopy coverage and other biophysical parameters (Daughtry *et al*., 2000; Serrano *et al*., 2000). The effect of N showed significant increase in grain yield from 3.54 to 5.9 t ha^{-1}with an increase in the level of N from the control (no N) to 92 kg ha^{-1}and significantly decreased with further increase of applied N rate to 138 kg N ha^{-1} (Table 6). The highest grain yield (5.90 t ha^{-1}) obtained with the application of 92 kg N ha^{-1} was 66.7% higher over the control. In spite of insignificantly higher number of grains panicle^{-1} in 138 kg N ha^{-1} treated plots, the more 1000-grain weight obtained from 92 kg N ha^{-1} treated plots might have contributed to significant increase in yield. In addition, the higher OC (4.08%) and native total N (0.51%) contents in the experimental field might have also negatively affected crop response and the increment in rice yield at higher application doses of applied N.

In line with this study, Singh *et al.* (2000) found the response of rice to N averaged over P levels was curvilinear with significant response up to 80 kg ha^{-1}. Spanu and Pruneddu (1997) also noted higher paddy yield with 150 and 250 kg N ha^{-1}, respectively. Similar results with higher N rates were also reported by Dixit and Patro (1994) and Meena *et al.* (2003). Further, Heluf and Mulugeta (2006) found significant increase in grain yield of rice up to 60 kg N ha^{-1}.

Fageria and Baligar (2001) found that the grain yield in rice is a function of panicle per unit area and 1000-grain weight. During the experimental period the plants in plots supplied with N were found to have longer and droopy leaves those might have collected more raindrops overloading the culm. Consequently, the two experimental years average lodging percentage of plants in the control, 46, 92 and 138 kg N ha^{-1} treated plots was 1.1, 6.6, 22.7 and 34.4%, respectively (data not shown). Thus, the plant supplied with higher N lodged even under the influence of light wind as a result of heavy panicles during milking stage. Finally, reduction of light-interception due to lodging and other mechanical effects produced depressed rice grain yield in 138 kg N ha^{-1} treated plots (1997; IAEA, 2008).

Application of P failed to bring significant difference in grain yield, which varied between 4.26 to 5.02 t ha^{-1}. This may be due to higher amount of inherent available P (65.00 mg kg^{-1} soil) in the soil (Table 1). In addition, P is generally most available to plants when the soil pH is between 6.0 and 6.5. Singh *et al.* (2000) reported inconsistent rice yield response to applied P during the earlier years of application, however there was a consistent increase in yield later on. Similarly, George *et al.* (2001) reported that the application of P had only little effect on grain yield in spite of increased P uptake by the plant.

3.3. Effects of N and P on Rice Grain Quality

3.3.1. Milled Grain

Analysis of variance (Table 2) showed significant ($P \leq 0.01$) differences in milled grain in the two cropping years/seasons. The milling percentage was significantly higher (78.2%) in 2009 than that of 2008 (70.8%). The result of milling percent was in agreement with the findings of Blumenthal *et al.* (2008), who reported the milling percentage of white rice was about 70% of the rough rice.

3.3.2. Crude Protein

The crude protein content varied significantly ($P \leq 0.01$) due to cropping years and N fertilizer, but not ($P > 0.05$) with P, interactions of year by N, year by P, N by P and year by N by P (Table 2). In variation to the percent milled grain, the protein content was significantly higher in 2008 (9.29%) than that of 2009 (7.22%) (Table 6). Differences in rainfall during the two cropping years (Figure 1) might have adversely affected the availability and uptake of N by the plants thereby reducing accumulation of N in the grain resulting in low protein content in 2009. The average crude protein content of milled rice in the two cropping years was 8.26%, which is in agreement with Dalia`s (2006) study results which showed milled rice flour had 7.95% protein content.

Table 6. Effects of cropping year, N and P application on yield attributes, yield and grain quality of rice at Gambella, southwestern Ethiopia.

Treatment	Yield attributes		Grain yield	Grain quality (%)			
	NG	TGW	(t ha^{-1})	MG	CP	EE	CF
Year							
2008	122.1	27.46^{a}	4.52	70.8^{b}	9.29^{a}	2.00^{b}	0.95^{b}
2009	127.1	26.39^{b}	4.89	78.2^{a}	7.22^{b}	3.53^{a}	4.64^{a}
N (kg ha^{-1})							
0	116.1^{b}	27.12	3.54^{c}	73.5	6.66^{c}	2.00^{c}	3.15^{a}
46	121.8^{ab}	26.72	4.49^{b}	75.3	8.03b^{c}	2.65^{b}	2.85^{b}
92	127.5^{a}	27.20	5.90^{a}	75.1	8.74^{ab}	3.30^{a}	2.69^{bc}
138	133.0^{a}	26.66	4.90^{b}	74.1	9.58^{a}	3.12^{ab}	2.49^{c}
P (kg ha^{-1})							
0	121.2	26.37	4.60	74.9	8.69	2.84	2.71^{b}
23	126.6	26.92	5.02	74.5	8.17	2.71	2.74^{b}
46	125.0	26.93	4.26	74.3	8.38	2.74	3.01^{a}
69	125.6	27.48	4.95	74.3	7.77	2.77	2.72^{b}
CV (%)	14.93	7.20	24.97	3.55	26.67	30.86	12.64

Means of the same parameter in a column followed by the same letter are not significantly different at P = 0.05 according to Duncan's Multiple Range Test. NG= Number of grains panicle^{-1}; TGW = 1000-grain weight (g); GY = Grain yield (t ha^{-1}); MG = Milled grain (%); CP = Crude protein (%); EE = Ether extract (%); CF = Crude fiber (%); CV = Coefficient of variation.

The perusal of the data (Table 6) further revealed that crude protein content increased with the increase in N application up to the highest N (138 kg ha^{-1}) level. Accordingly, the highest grain protein (9.58%) was obtained with the application of 138 kg N ha^{-1}, which was 43.8% more than that of the protein content found in control treatment. Salem (2006) also reported significant increase in grain protein content of rice up to 83.3 and 166.7 kg N ha^{-1} in first and second seasons, respectively. Whereas Kirrilov and Pavlov (1989) reported that applied N increased wheat grain protein content by 20.29% over the control treatment. The increase in grain protein content might be the enhancement of amino acid formation with the application of N, which is primarily reflected in greater amount of storage protein located in protein bodies with in starchy endosperm (Oo *et al*., 2010).

Rice protein content has earlier been found to be in the range of 7.63-10.30% (SD, 2005) and 13.0% (Ambreen *et al*., 2006) however, in most commercial varieties grain protein content has been reported below 10% (Blumenthal *et al.,* 2008). The lower percent of milled rice in 2008 might be due to higher protein content than in 2009 (Table 6) as the higher protein has been reported to make the grain more resistant to cracking and breakage during abrasive milling than the low protein grain (Blumenthal *et al.,* 2008). An erratic and poor distribution of rainfall with high temperature was observed in 2009 (Figure 1). This might have enhanced the loss of N through volatilization as ammonia gas and reduced nutrient availability and its uptake by rice.

3.3.3. Ether Extract

The cropping year, N and their interaction had significant (P ≤ 0.01) effect on ether extract of rice grain, but the effect of P, interactions of year by P, N by P and year by N by were insignificant (Table 2). The ether extract was comparatively high (3.53%) in 2009 compared to 2008 (2.01%) (Table 6).

Increasing N rates from control to 138 and from control to 92 kg N ha^{-1} increased the ether extracts of rice grain from 1.42 to 2.86 and 2.59 to 4.69% in 2008 and 2009, respectively. As a result applied 138 and 92 kg N ha^{-1} showed significantly highest ether extracts compared to other interactions of 2008 and 2009 year by N rates application, respectively.

Table 7. Rice grain ether extract (%) in response to N fertilizer rates in 2008 and 2009.

N (kg ha^{-1})	2008	2009
0	1.42^{e}	2.59^{cd}
46	1.83^{de}	3.47^{b}
92	1.91^{de}	4.69^{a}
138	2.86^{bc}	3.37^{b}

Means across columns followed by the same letter are not significantly different at P > 0.05 by Duncan's Multiple Range Test.

However, significantly highest ether extracts obtained with 92 kg N ha^{-1} over the other cropping years by N rates treatment combination. Cameron and Wang (2005) reported that milled rice flour had 0.34% ether extracts content while, Reddy (2006) reported that the rice ether extracts is low (around 2%) since much of it is lost during milling.

3.3.4. Crude Fiber

The crude fiber content of rice grain significantly varied due to effects of cropping year, N (P ≤ 0.01), P, interactions of cropping year by N (P ≤ 0.05) and cropping year by P (P ≤ 0.01) whereas, effects of N by P and cropping year by N by P were insignificant (P >

0.05) on this parameter. Also at both N and P rates, the crude fiber content was significantly higher in 2009 than in 2008 (Tables 6 and 8). These differences in the average rice grain crude fiber might have resulted due to meteorological data variation between the two years (Figure 1) that maintained better equilibrium of soil nutrients as well as applied N and P for better plant uptake. Interaction of year by N showed that the crude fiber decreased with the increase in N rates up to the highest (138 kg ha^{-1}) level in both years. Consequently, the control plots recorded the highest crude fiber compared to N applied plots in both cropping years. Likewise, the application of N at 138 kg ha^{-1} significantly decreased the crude fiber over the control in both years.

Oo *et al.* (2010) reported decreased amount of crude fiber content in rice grain with the increase in N levels. These findings were in harmony with the results of Shallan *et al.* (2010) and SD (2005) who reported that the brown rice (high amylase-24) had the highest value of crude fiber (1.33%) compared with brown rice (low amylase); and rice cultivars grain showed 4.45% crude fiber of which 1.15 and 2.15% was insoluble and soluble fiber, respectively.

Table 8. Interaction of N and cropping year, and P and cropping year on crude fiber of rice grain at Gambella, southwestern Ethiopia.

	Crude fiber (%)			Crude fiber (%)	
N (kg ha^{-1})	2008	2009	P (kg ha^{-1})	2008	2009
0	1.11[d]	5.19[a]	0	0.95[c]	4.46[b]
46	0.99d[e]	4.70[b]	23	1.01[c]	4.48[b]
92	0.88d[e]	4.50[b]	46	0.92[c]	5.10[a]
138	0.80[e]	4.19[c]	69	0.91[c]	4.54[b]

Means of the same parameter across columns followed by the same letter are not significantly different at P > 0.05 by Duncan's Multiple Range Test.

On the other hand, the response of rice grain crude fiber (0.91-1.01%) to rates of P fertilizer in 2008 was not significant, while it was significant during 2009 (Table 8). Increasing P rates up to46 kg ha^{-1}in 2009 cropping year significantly ($P \leq 0.05$) increased crude fiber.In this year, application of 46 kg P ha^{-1} had the maximum crude fiber content (5.1%) that was significantly higher than the other P levels by cropping year treatment combination. The application of 23 and 69 kg P ha^{-1} did not bring significant variation in crude fiber content compared to the control within a year while significant between the years.

3.4. Economic Viability of N and P Fertilizer Rates

Analysis of variance (Table 2) showed that N fertilizer had a significant ($P \leq 0.05$) effect on grain yield of rice, whereas response to P was not significant. An economic analysis on the combined results using the partial budget technique was thus appropriate (CIMMYT, 1988). The result of the partial budget analysis and the data used in the development of the partial budget are given in Tables 9 and 10.

Dominance analysis (Table 9) led to the selection of treatments 0/0, 0/23, 46/0, 138/0, 46/69 and 92/0 kg N/P ha^{-1} ranked in increasing order of total costs that vary. The treatments having MRR below 100% was considered low and unacceptable to farmers; thus, 46/0 and 138/0 kg N/P ha^{-1} were eliminated (CIMMYT, 1988). This was because such a return would not offset the cost of capital (interest) and other related deal costs while still giving an attractive profit margin to serve as an incentive. Therefore, this investigation remained with changes to 92/0, 46/69 and 0/23 kg N/P ha^{-1} as promising new practices for farmers under the prevailing price structure since they gave more than 100% MRR. This might suggest the use of inputs that result in maximum net benefits (Bekele, 2000).

Market prices are ever changing and as such a recalculation of the partial budget using a set of likely future prices *i.e.*, sensitivity analysis, was essential to identify treatments which may likely remain stable and sustain satisfactory returns for farmers despite price fluctuations. This study indicated that an increase in the field price of both N and P of Birr 0.51 per kg and a fall in the price of grain of Birr 0.6 per kg (Table 11) which represented a price variation of 15%.

These price changes are realistic under the liberal market conditions prevailing in Gambella among the lowland dwellers at the time of experimentation. Some of the considerations in projecting prices were increased rice supply due to aid for refugees' imports from abroad and a deteriorating business environment in Gambella. The new prices were thus used to obtain the sensitivity analysis (Table 11)

Table 9. Partial budget with dominance to estimate net benefit for application of N and P fertilizer rates at current prices.

	Partial budget with dominance				
N/P (kg ha^{-1})	Total grain yield (t ha^{-1})	Adjusted yield (t ha^{-1})	GFB (EtB ha^{-1})	TCV (EtB ha^{-1})	NB (EtB ha^{-1})
0/0	3.26	2.28	9128	2576	6552U
0/46	3.25	2.28	9100	3149	5951D
0/69	3.37	2.36	9436	3534	5902D
0/23	4.26	2.98	11928	3657	8271U
46/0	4.43	3.10	12404	3965	8439U
46/23	4.29	3.00	12012	4145	7867D
46/46	4.24	2.97	11872	4396	7476D
138/46	3.83	2.68	10724	4999	5725D
138/0	4.90	3.43	13720	5264	8456U
46/69	5.02	3.51	14056	5302	8754U
92/0	5.81	4.07	16268	5518	10750U
92/23	5.92	4.14	16576	5896	10680D
92/46	5.73	4.01	16044	6037	10007D
138/23	5.60	3.92	15680	6108	9572D
138/69	5.27	3.69	14756	6428	8328D
92/69	6.15	4.31	17220	6659	10561D

GFB = Gross field benefit; TCV = Total cost that varied; NB = Net benefit; Field price of N = Birr 3.38 per kg; Field price of P = Birr 4.38 per kg; FA = Fertilizer application; EtB = Ethiopian Birr; Wage rate = Birr 25 per day; Labor to apply fertilizer per ha = 2 man-day; L Retail price of grain = Birr 4000 per ton; HTW = Harvesting, threshing and winnowing cost = Birr 1000 per ton; BMT= Bagging, material and transport cost = Birr 65 per ton.

Table 10. Partial budget with estimated marginal rate of return (%) for application of N and P fertilizer rates at current prices.

Treatments	TCV (EtB ha^{-1})	NB (EtB ha^{-1})	Raised cost	Raised benefit	MRR (%)
N/P (kg ha^{-1})					
0/0	2576	6552	-	-	-
0/23	3657	8271	1081	1719	159.02
46/0	3965	8439	308	168	54.55
138/0	5264	8456	1299	17	1.31
46/69	5302	8754	38	298	784.21
92/0	5518	10750	216	1996	924.07

Field price of N = Birr 3.38 per kg; Field price of P =Birr 4.38 per kg; Retail price of grain = Birr 4000 per ton; TCV = Total cost that vary; NB = Net benefit; MRR = Marginal rate of return; EtB = Ethiopian Birr.

Changing from treatments 0/0 to 0/23 and 0/23 to 92/0 kg N/P ha^{-1} gave 117.44 and 681.53% MRR, respectively (Table 11) which were above the minimum acceptable MRR of 100% except 46/69 which was below the minimum acceptable MRR. These results agree with Saha *et al.* (1994) whose findings from coastal Kenya on maize showed that the application of 30 kg N ha^{-1} consistently gave acceptable economic returns.

Table 11. Sensitivity analysis of rice production after different practices based on a 15% rise in total cost and rice price of gross field benefit fall.

Treatment	TCV (EtB ha^{-1})	NB (EtB ha^{-1})	Increment cost	Increment benefit	MRR (%)
N/P (kg ha^{-1})					
0/0	2962	5569	-	-	-
0/23	4206	7030	1244	1461	117.44
46/69	6097	7441	1895	411	21.69
92/0	6346	9138	249	1697	681.53

Field price of N = Birr 3.89 per kg; Field price of P =Birr 5.04 per kg; Retail price of grain = Birr 3400 per ton; TCV = Total cost that vary; NB = Net benefit; MRR = Marginal rate of return; EtB = Ethiopian Birr.

Therefore, with 23 kg P and 92 kg N ha^{-1} give an economic yield response and also sustained acceptable even under a projected worsening trade conditions in Gambella. On a tentative basis farmers could thus choose any of the two new fertilizer rates depending on their resources. The results of this research can be used to make tentative recommendations, which can be refined through multi-location testing over a wider area.

4. Conclusions

The growth, yield components and yield of the rice variety NERICA-3 responded strongly to N fertilizer application. Accordingly, higher magnitudes of increase in almost all the parameters studied were obtained with applied N fertilizer. In this study, number of effective tillers $plant^{-1}$ and number of grains $panicle^{-1}$ were the most important yield forming attributes causing significant variation in grain yield of rice. From the range of treatments tested, 92 kg N ha^{-1} gave significantly higher grain yield. Crude protein and ether extract with N and crude fibre both with N and P application were significantly influenced. Application of 23 kg P or 92 kg N ha^{-1} gave an economic yield response. However, P application had no significant impact on rice growth, yield attributes and yield except crude protein. Hence, on a tentative basis, farmers at and around *Imla* site, Gambella Zuria District) could use either of the two rates of nutrients (23 P alone or 92 N kg ha^{-1}) in order to achieve economic grain yield of NERICA-3 rice grown on brown clay soils under rain fed conditions. Therefore, in the light of the significant response of rice to N fertilizer, further studies aimed at promoting integrated soil fertility management and formulation of fertilizer recommendation based on soil and plant tests over locations will be useful.

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Effect of Winged Subsoiler and Traditional Tillage Integrated with *Fanya Juu* on Selected Soil Physico-Chemical and Soil Water Properties in the Northwestern Highlands of Ethiopia

Desale Kidane Asmamaw[1], Melesse Temesgen Leye[2] and Abdu Abdelkadir Mohammed[3]

[1]Watershed Management, Samara University, P O Box 132, Samara, Afar, Ethiopia
[2]Civil Engineering Department, Addis Ababa Institute of Technology, P O Box 380, Addis Ababa, Ethiopia
[3]Wondo Genet College of Forestry and Natural Resources, P O Box 128, Shashemene, Ethiopia

Abstract: Prolonged water-logging, soil degradation and decline in water productivity due to hard pans created because of repeated cross plowing using the traditional plow is the major problem in the northwestern highlands of Ethiopia. To reduce these problems, alternative tillage and soil management practices have to be implemented. Thus, the effects of winged subsoiler and traditional tillage practices on tillage depth, bulk density, infiltration, and soil moisture conditions were assessed in an on-farm experimental study in the northwestern highlands of Ethiopia. The experiment was laid out in a randomized complete block design (RCBD) with two treatments (winged subsoiler and traditional tillage) and four replicates. The study was conducted from 2011 to 2012 cropping seasons. Soil samples were collected from 0-10, 10-20, 20-30 and 50-60 cm of soil depths and analyzed for bulk density, soil texture and organic matter contents. Soil moisture was measured using 10HS automatic soil moisture sensors (CaTec®) which were inserted at 10 cm depth under both tillage types. Four readings, once every week were taken both at the lower and upper parts of the plots. Using the double ring infiltrometer, infiltration measurements were made in the experimental units treated by both tillage practices. Soil evaporation was estimated by a conceptual model whereby leaf area index, canopy cover, crop root length, moisture at saturation and field capacity were used as inputs. Substantially higher tillage depths were observed due to the winged subsoiler while dry bulk density was slightly higher in the traditional tillage. Significantly ($P \leq 0.05$) different soil moisture contents between the upper and lower sides of the *fanya juus* were observed under traditional tillage practice (0.305±0.003 and 0.323±0.003 $m^3 m^{-3}$, respectively). Infiltration rate and cumulative infiltration in the winged subsoiler treated plots exceeded that of the traditionally plowed plots. Compared with the traditional tillage, the winged subsoiler treated plots resulted in better moisture retention, high infiltration, high tillage depth and low soil evaporation. The result indicated that if the winged subsoiler is properly implemented and integrated with fanya juu, it is an important and effective conservation practice for sustainable soil and water management for smallholder farmers in the northwestern Ethiopia.

Keywords*:* Ethiopia; Plow Pan; Soil Moisture; Traditional Tillage; Winged Subsoiler

1. Introduction

The Ethiopian highlands represent one of the most productive parts of the country, but have suffered from extensive resource degradation (Hurni, 1990, 1993; Nyssen *et al*., 2007; Tewodros *et al*., 2009, Melesse *et al*., 2012) Land degradation in the form of soil erosion and declining soil quality is a serious challenge to agricultural productivity and economic growth in these highlands (Mulugeta *et al*., 2005). The northwestern highlands of the country suffer from such extreme land degradation due to repeated cross-plowing of the steep lands (Gete, 2000; Bezuayehu *et al*., 2002; Melesse *et al*., 2009). Repeated traditional tillage damages the soil structure through excessive pulverization and increased rate of mineralization leading to reduction in soil organic matter content and aggregate stability (Mwendera and Mohamed, 1997; Melesse *et al*., 2009). This results in soil compaction over the plowed layer, surface crust and plow pan formation that reduce infiltration increase both soil erosion and loss of soil moisture (Lal, 1997). Traditional tillage reduces water uptake by plants because root growth is restricted to the plowed layer. For instance, using *teff* crop in Wuolenchtiy, Ethiopia, sub-soiling resulted in the lower surface runoff ($Qs = 23$ mm season^{-1}), higher crop transpiration ($T = 53$ mm season^{-1}), higher grain yield ($Y = 1180$ kg ha^{-1}) and higher water productivity using total evaporation ($W_{PET} = 0.42$ kg m^{-3}) compared to traditional tillage ($Qs = 34$ mm-season^{-1}, $T = 49$ mm season^{-1}, $Y = 1070$ kg ha^{-1}, $W_{PET} = 0.39$ kg m^{-3}) (Melesse, 2007). Similarly, water holding capacity of the soil can be reduced due to the loss of organic matter and soil compaction, which results in less water availability for useful transpiration by crop. This suggests the need for changing and improving the tillage systems.

Based on the conservation agriculture (CA) experimental research conducted in 2006 at Gumselasa, Tigist *et al*. (2010) founded that permanent bed reduced runoff volume by 50% and Terwah by 16% compared to traditional tillage. The same author also reported that permanent bed reduced soil loss by 86% and Terwah by 53% in comparison to traditional tillage.

Soil erosion and high surface runoff due to high tillage frequency (5-6 passes) using traditional tillage and

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*Corresponding author. Email: kidanedesu@gmail.com

improper implementation of soil and water conservation structures have seriously affected over 25% of the Ethiopian highlands (Chuma, 1993; Bezuayehu *et al.*, 2002;). Such detrimental effect of soil erosion can be improved to some extent by improved management options like the use of winged subsoilers. In this study, contour plowing was made with winged subsoiler, a modified *Maresha* plow alternating with traditional *Maresha* plow that cuts soil deeper than achieved with the traditional tillage (Figure 1). This tillage system disrupts the hard pan formed due to repeated cross-plowing using traditional tillage. Winged subsoiler reduced surface runoff by 48% with the daily averages of 4.8 and 2.5 mm ha^{-1} recorded at fields plowed using traditional tillage (TT) and winged subsoiler (WS) by allowing more infiltration through disrupting plow pan and by redirecting flow along the contour using invisible barriers created by the system, respectively (Melesse *et al.*, 2012).

Figure 1. Treatments **(**TT and WS) employed in the present study edges.

Winged subsoiler is aimed at altering the rainfall partitioning such that there will be more infiltration at the expense of surface runoff leading to increased root water uptake, thus more useful transpiration at the expense of evaporation (Melesse *et al.*, 2012). The objectives of this study were, therefore, to evaluate the effect of winged subsoiler on soil moisture distribution along the contour and between bunds and to assess the effect of winged subsoiler on infiltration capacity of the soil.

2. Materials and Methods

2.1. Description of the Study Area

2.1.1 Location and Climate

The study was conducted at Enerata located in East Gojjam Zone of Amhara Regional state, Ethiopia. It is situated between 10^0 25'-10^0 30' north and 37^0 42'-37^0 44' east, and located approximately 300 km north west of Addis Ababa and 7 km north of Debremarkos (Figure 2). The altitude ranges approximately from 2380 to 2610 meter above sea level (masl) and it is characterized by humid climatic condition and typically represents the 'Dega' (2300-3200 masl.) zone of the traditional agro-climatic classification system of Ethiopia. The average annual rainfall and temperature are 1300 mm and 15 ^{0}C, respectively, measured at the Debremakos Meteorological Station located 7 km from the experimental plots. The rainfall pattern is unimodal and much of the rainfall occurs from June to September, locally known as "kiremt" season (Woldeamlak, 2003).

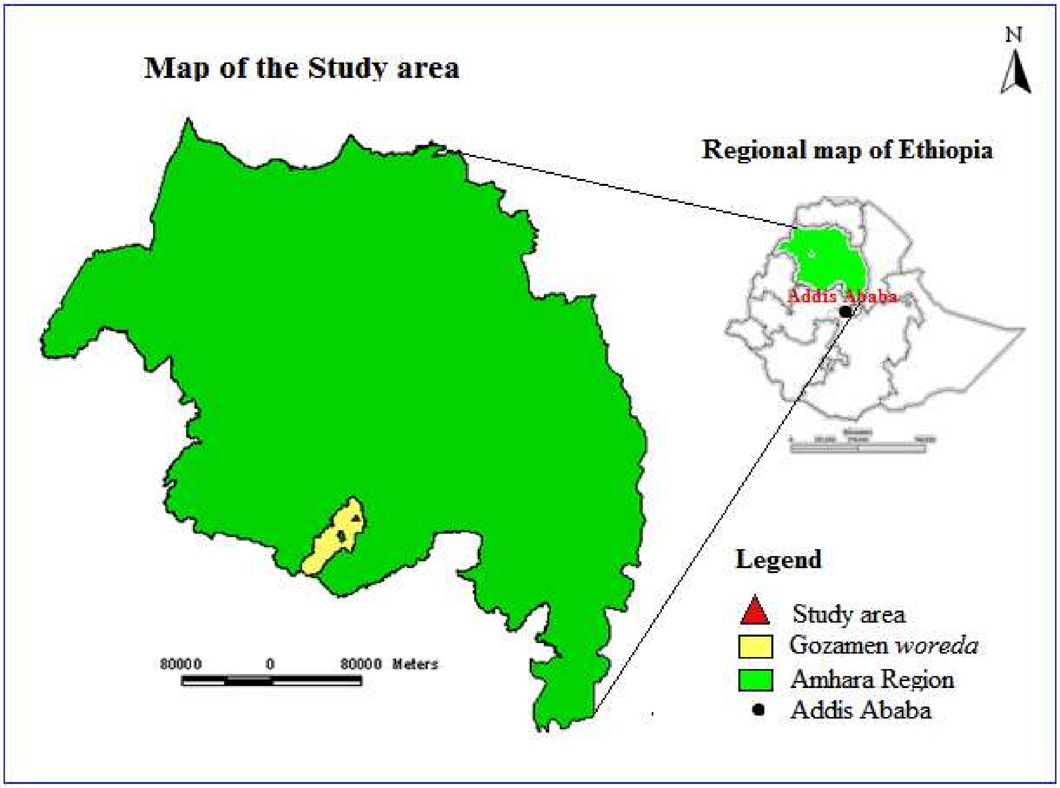

Figure 2. Location map of the study area.

2.1.2. Geology and Soil

Geologically, the micro-watershed is part of the highlands that largely owe their altitude to the uplift of the Arabo-Ethiopian land mass and subsequent outpouring of basaltic lava flows during the tertiary period (Woldeamlak and Sterk, 2005). Thus, the surface geology is of basaltic rocks, which are the parent materials for the overlying soils. The soil type that covers the micro-watershed is Nitisols (Woldeamlak, 2003) and the textural class is clay loam and uniform over the 0-60 cm layer.

2.1.3. Farming System

The farming system of the study area is typically mixed crop-livestock system of the highlands of Ethiopia, where livestock provide the draught power needed for the farming operation and a good part of the crop residues are fed to livestock. Barley (*Hordeum vulgare*), *Engdo* (*Avena Spp.*) wheat (*Triticum aestivums)* and *teff* (*Eragrostis tef*) are the dominant cultivated crops. Tillage is exclusively carried out using the traditional *Maresha* plow (Figure 1). Repeated cross-plowing is done before sowing because farmers believe that it controls weeds and improves crop yields. According to interview results and field observations, farmers plow 8 to 10 passes for *teff* crop, and 5-7 times for wheat, barley and oat crops.

2.2. Experimental Setup

Four farmers were selected and trained on the concepts and field applications of winged subsoiler (WS here after) in addition to the supervision during field works. The experimental set up was first explained to and discussed with the participating farmers. Each participating farmer was provided with a WS. The study compared the current farming practices of using traditional tillage (TT here after) versus the newly introduced winged subsoiler. The experiment was laid out in a randomized complete block design (RCBD) with 4 replications and 2 treatments (WS and TT). All experimental fields were treated with *fanya juu* as part of the routine soil conservation works of the local communities. Blocks were selected such that the two experimental plots have similar slopes in each replication, which ranged between 9 and 11%. All the experimental plots have similar plowing cropping and land cover types prior to the experimentation and found in the same micro-watershed.

Fertilizer application and controlling weed were the same for all experimental units. Experimental plots were delineated inside the fields by fencing the three sides with galvanized iron sheets (Figure 3). The fences covered the three sides while *Fanya juus* bordered the lower sides of each plot. Plot sizes were 5 m x 30 m each. Delineation of experimental plots was carried out immediately after sowing. Sowing of wheat crop was made on 23 June 2011 in both treatments. The WS treated appeared in the upper side in two of the replications while TT took that position in the other two. All experimental plots received a primary tillage by the TT plow. Then four plots were plowed twice using the WS while the remaining four plots received TT (control), with the same frequency of plowing as the former (Figure 1). During the third pass, the TT was used along the same lines to make the furrows wider and more visible for the next subsoiling. Finally, all plots were plowed as a final treatment using traditional tillage and wheat was sown by broadcasting in all plots. A total of five tillage operations had been used for the experimentation

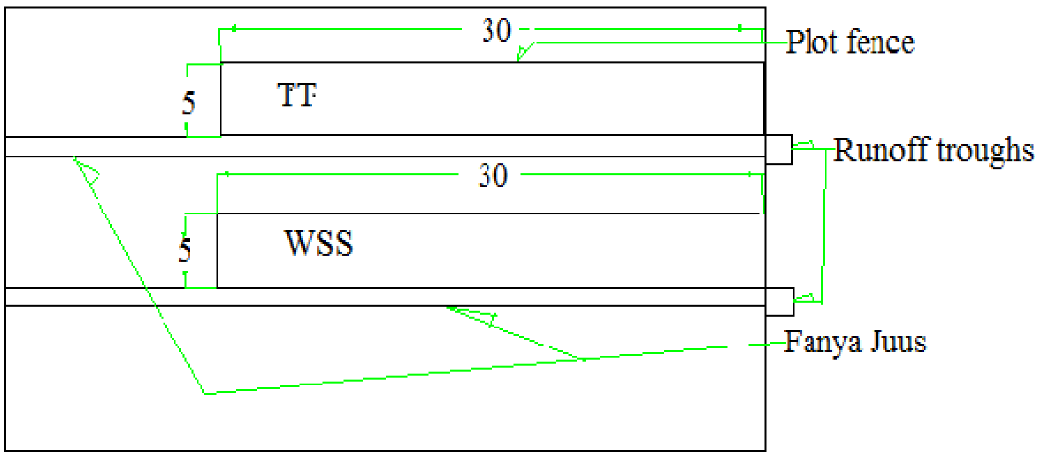

Figure 3. Layout of a single replication (one farmer's field).

2.3. Data Collection

2.3.1 Rainfall Pattern

An automatic meteorological equipment was installed at the experimental plots. The equipment recorded rainfall, temperature, relative humidity and sunshine duration every five minutes. For the triangulation of the automatic recorded data, a manual raingauge was also installed for daily rainfall measurement. A total of 338.2 mm rainfall was received during the study period at the experimental site and 38.8 mm rainfall was recorded as the maximum daily rainfall.

2.3.2. Soil Sampling and Analysis

Soil samples were collected from two randomly selected representative locations of each plot. At each location, samples were taken at four depths: 0-10, 10-20, 20-30 and 50-60 cm. Composite soil samples were collected from excavated soil pits at the respective depths for determination of soil texture, and organic matter. Soil texture was determined at Debremarkos Soil Laboratory using the hydrometer method (Day, 1965) and soil organic matter content was tested using the Walkley-Black oxidation method (Schnitzer, 1982). Soil bulk density was determined using samples obtained by core method (Blake and Hartge, 1986). Undisturbed cylindrical core samples were taken and weighed for the determination of dry bulk density. The samples were oven dried for 24 hours at 105 ^{0}C and the dry mass was determined.

2.3.3. Soil Moisture Measurement

Soil moisture was measured using 10HS automatic soil moisture sensors (CaTec®) which were inserted at 10 cm depth under both tillage systems. The sensors were programmed to record soil moisture data every five minutes. To assess soil moisture distribution between bunds, four readings, once every week, were taken both at the representative spots of the lower and upper parts of the plots (256 measurements).

2.3.4. Soil Water Infiltration

Infiltration measurements were carried out in all the experimental plots treated both under conservation and traditional tillage. Altogether, 48 measurements were taken using double ring infiltrometer. Six spots were randomly selected in each experimental plot for measurement. Both the inner and outer rings of a double-ring infiltrometer were 25 cm high and inserted 5 cm into the soil carefully using a sledge hammer, leaving 20 cm above the ground surface. The inner rings had diameters of 28, 30 and 32 cm and the outer rings had 53, 55 and 57 cm. Water was then poured into the rings to maintain the desired depth and constant head was maintained throughout all measurements. Changes in water levels were recorded at time increments of 1, 3, 5, 10, 15, 20, 30, 40, 50 and 60 minutes for calculating infiltration rate and cumulative infiltration. A pool of water was maintained approximately the same level in the outer ring to reduce the amount of lateral flow from the inner ring. The soil was moist at the time of all measurements due to the occurrence of rainfall in the previous day.

2.3.5. Measurement Evaporation

To determine the treatment effect on soil evaporation, L_{AI} was measured at 30 (bare soil cover), 60 (moderate crop cover) and 90 (maximum crop cover) days after planting of wheat crop. These days were purposely selected to measure evaporation loss of water below crop canopy cover and open field to see crop cover effect on evaporation, and water retention as evaporation is highly affected by surface cover. Leaf area index (LAI) was determined using direct method. The LAI expressed as $m^2\ m^{-2}$ was estimated by measuring the average width and length of leaves from 5 randomly selected plants using 'X' plot sampling pattern in each treatment, with a pocket meter. The leaf area (*A*) was calculated with the equation of Stewart and Dwyer (1999) as:

Thus,

$$A = aW_ML \qquad (1)$$

where *a* is coefficient, W_M is the average width of the leaf (m) and L is the average length of the leaf (m). LAI was computed by adding the areas of all the leaves in each plant, and dividing the sum by the area of land covered by each plant (Melesse*,* 2007), which also means multiplying the total area of a single leaf by the population P_0 as:

$$LAI = P_O \sum_{x=i}^{n} Ai \qquad (2)$$

where P_0 is plant population per m^2, n *is* the number of leaves in each plant and Ai is leaf area. Daily based meteorological data such as wind speed, relative humidity, temperature, rainfall, atmospheric pressure, and solar radiation were used as inputs. The LAI data was used to estimate the proportion of evaporation under wheat crop treated with the treatments.

2.3.6. Soil Moisture Contents at Field Capacity and Permanent Wilting Point

Moisture content at field capacity (S_{FC}) was determined at Debreziet Soil Laboratory (Ethiopia). Undisturbed soil samples were taken using core samples from two randomly selected locations in each treatment at the depth of 0-10, 10-20, 20-30 and 50-60 cm. The samples were added on a plate in the lab and water was added until the soil was completely saturated. After saturation, the soil was entered into the 0.33 bars pressure plate apparatus where it stayed until the moisture above field capacity was drained out. The wet samples were weighed before placing it in an oven at 105 ^oC. The S_{FC} in weight basis was determined as the ratio of the weights of the oven dried samples to the wet samples. The same procedure was employed to determine moisture at permanent wilting point (S_{wp}) with the saturated soil subjected to a suction of 15 bars. Moisture at S_{wp} was determined after oven drying.

Estimation of *Es* (soil evaporation) was carried out using a conceptual model (Melesse, 2007)

$$Es = \max\left((1 - L_{AI}Cc)(Ks\,Ep - I), 0\right) \max\left[\min\left(\frac{S}{(1-r)S_{FC}}, 1\right), 0\right] \qquad (3)$$

where *Es* is soil evaporation (mm-day^{-1}), L_{AI} is leaf area index ($m^2\ m^{-2}$), *Cc* is crop cover factor, *Ks* is soil factor, E_P is pan evaporation, *I* is interception (mm-day), S_{FC} is moisture at field capacity ($m^3 m^3$), *S* is stored water in the root zone ($m^3\ m^3$) and (1-*r)* is fraction of S_{FC} above which $E_{To} = E_T$

2.4. Data Processing and Analysis

Statistical analyses were performed using SAS statistical package version 9 (TS MO), 2002. Two-way analysis of variances (ANOVA) was made for infiltration and soil physical properties using general linear model (GLM). Duncan's multiple- range test was used for mean separation were statistically significant differences at $P < 0.05$ are observed whereas one-way analysis of variance was made for soil moisture content. Tillage depth was analyzed using descriptive statistics and graphical illustrations.

3. Results and Discussion

3.1. Depth of Tillage

The overall depth of the winged sub-soiled plots was greater than the traditionally tilled ones (Figure 4). Average tillage depths for the first plowing were 17.95 and 10.1cm while average depths for the last plowing were 22.3 and 12.2 cm (420 measurements) for the winged subsoiler and the TT treated plots, respectively. Farmers commented that the draft power requirement of the subsoiler becomes higher as the depth of tillage increases. Field observations revealed that there was water logging behind conservation structures and rill formation in the upper parts of the plots in the TT plots. On the other hand, uniform moisture distribution was observed in plots treated with WS. There was a strong positive correlation between tillage depth and frequency of plowing for TT with $R^2 = 0.898$, 210 number of observation (measurements) and for WS with $R^2 = 0.986$, 210 number of observations (Figure 4).

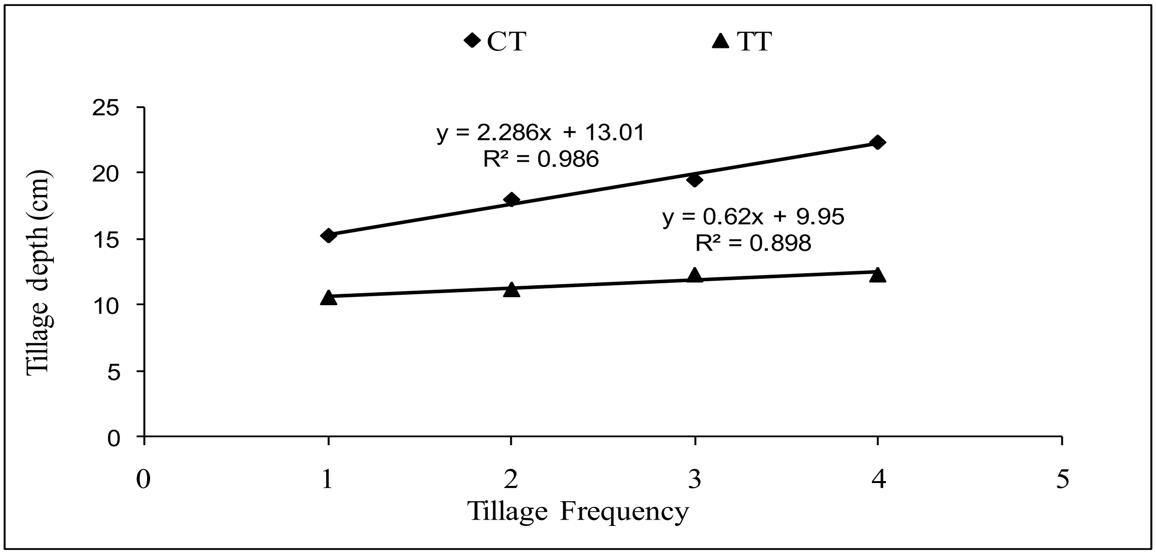

Figure 4. Plow Depth and tillage frequency in relation to winged subsoiler and traditional tillage.

The lower tillage depths of TT can be explained by the geometry of the V-shaped *Maresha* plow that creates hard pan in the plowing soil layers. Different authors have measured average tillage depths by TT (*maresha)* plow; 7 cm (Fleur, 1987); 10.1–15.3 cm (Goe, 1999); 10.1–12.5 cm (Gete, 1999); 8.1 cm (Nyssen *et al.*, 2000); and 11.2 - 12.9 cm (Melesse *et al.,* 2009). On the other hand, tillage depth from winged sub-soiler was substantially higher than the depths obtained by traditional tillage (Figure 4). This is an indication that through the use of winged sub-soiler the problems of soil compaction and shallow depth could be addressed to improve the soil-water conditions of agricultural fields.

3.2. Soil Texture, Bulk Density and Organic Matter
Sand was the highest fraction at all depths across both treatments. The clay and silt fractions, on the other hand, constituted a relatively low amount in both soil layers (Table 1). Clay content tended to increase while sand content tended to decrease with depth. Moreover, clay content was substantially less in the upper most layers (0-10 cm) layer as compared with the underlying soil layers.

Table 1. Particle size, dry bulk density, organic matter under winged subsoiler and traditional tillage treated plots (Mean ±SE).

Tillage types		Soil particle size				
	Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Bulk density (g cm^{-3})	Organic matter (%)
Traditional tillage	0-10	22±0.913[a]	32±0.707[a]	45.8±0.48[a]	1.54±0.005[a]	2.503±0.008[a]
(TT)	10-20	26±0.85[a]	24±0.41[b]	50±0.93[a]	1.48±0.004[a]	2.10±0.001[a]
	20-30	36±0.29[b]	16±0.41[b]	48±0.41[a]	1.49±0.004[a]	1.77±0.008[a]
	50-60	32±0.63[b]	20±0.91[b]	48±0.41[a]	1.55±0.004[b]	1.75±0.004[a]
Winged subsoiler	0-10	22.4±0.913[a]	32±0.70[a]	45.8±0.48[a]	1.51±0.004[b]	2.51±0.002[a]
(WS)	10-20	25.75±0.85[a]	24±0.41[b]	50±0.93[a]	1.47±0.004[b]	2.12±0.005[a]
	20-30	36.5±0.29[b]	16±0.41[b]	36.5±0.41[b]	1.48±0.004[a]	1.77±0.009[a]
	50-60	31.75±0.63[b]	20±0.91[b]	48.3±0.41[a]	1.54±0.006[a]	1.75±0.004[a]
P-value						
Depth		< 0.0001	< 0.0001	< 0.0001	0.0002	0.0001
Tillage types		0.51	0.55	0.312	< 0.001	< 0.044
Depth*tillage type		0.179	0.37	0.788	0.016	0.20

Treatment means followed by the same letter(s) in the same column are not significantly different (P < 0.05).and means followed by different letters across depth at TT and WS treatments are not significant due to tillage but varied due to translocation of particles.

There were significant differences in dry bulk density in the top 10 cm soil layer between tillage systems and was less in the top 10 cm of surface soil than the underlying layers in the WS plots. There were no significant differences ($P > 0.05$) in dry bulk density in the subsurface soil layer (50-60 cm) between WS and TT.

There were no significance differences between tillage practices in soil organic matter across all depths. However, there appears a declining trend in organic matter content as soil depth increased.

Tillage practice had greater bearing on the soil physical properties, which in turn influenced soil-water relations. Accordingly, the result of dry bulk density revealed that plots treated with WS had relatively low bulk density compared to TT. This can be attributed to the breakdown of compacted soil and improved porosity at the surface layer by the subsoiler. Conversely, repeated cross plowing using traditional *Maresha* plow resulted in higher bulk density which ultimately resulted in poor water conduction.

The mean values for clay fractions indicated that there may be processes of selective erosion and migration of clay material down to the soil profile, which was evidenced by the higher clay contents at the subsurface layers than the overlying layers (Woldeamlak, 2003). However, the soil texture remained almost similar between tillage practices. This is because alteration of soil property by tillage requires longer period. The findings agreed with those of Lal (1989), Lal (1997) and Melesse (2007) also studied the effect of long-term tillage on maize crop and soil properties and concluded longer period of time is required to see the effects of tillage on soil water content.

3.3. Soil Moisture Content

Soil moisture distribution treated with WS and TT is shown in Table 2. There were significant differences ($P < 0.0001$) in soil moisture content between tillage treatments as well as in the upper and lower sides of the plots. The observed volumetric mean moisture content in the traditionally treated plots was 0.305 ± 0.003 & 0.323 ± 0.003 $m^3 m^{-3}$ for the upper and lower sides of the plots, respectively. Thus, soil moisture content was consistently higher at the lower side as compared to the upper side of the bund in the traditionally plowed plots. On the other hand, the mean moisture content in plots treated with WS was 0.275 ± 0.003 and 0.278 ± 0.002 $m^3 m^{-3}$ for the upper and lower sides of the plot, respectively. These mean values of volumetric moisture content have indicated that stored soil water under WS was nearly uniform between the upper and lower sides of the plots. The relatively lower but adequate soil moisture in the WS showed better drainage as opposed to water logging problems observed in the TT behind fanya juu (Figure 5).

Figure 5. Illustration of variation in topsoil moisture content between bunds under TT (A) and WS (B) treated plots respectively. On the left, water logging has turned the crop yellow, stunted and sparse whereas on the right greener and better stand is shown behind the *fanya juus*.

Table 2. Soil moisture content under winged subsoiler and traditional tillage treatments (Mean± SE).

Tillage types	Moisture(m^3 m^{-3}) at upper sides of the plot	Moisture(m^3 m^{-3}) at lower sides of the plot
WS	0.275±0.003[a]	0.278±0.002[a]
TT	0.305±0.003[b]	0.323±0.003[c]
P-values	< 0.0001	< 0.0001

Means denoted by the same letter(s) across row and columns are not significantly different at P > 0.05.

As it can be seen in Table 2, soil moisture at 10cm depth in the upper parts of plots under traditional tillage is significantly (P < 0.0001) lower than that in the lower part. This might be attributed to the formation of plow pan created by repeated cross plowing using traditional tillage, which hinders infiltration but encourages surface runoff and water logging behind bunds. Melesse *et al.* (2012) conducted a research with the same experimental setup and treatments and showed that surface runoff appeared to be reduced under WS by 48 and 15 %, for wheat and tef crops, respectively. The study further reported that, WS reduced sediment yield by 51 and 9.5 %, for wheat and *teff* crops, respectively. Various investigations have been carried out to observe the effect of tillage on soil erosion and concluded that intensive tillage exposes the soil to more erosion (Hoogmoed, 1999; Biamah and Rockström, 2000; Benties and Ashburner, 2001). Similarly, Babalola and Opara-Nadi (1993) and Lal (1997) noted that conservation tillage was found to double infiltration rate and increase water uptake over the traditional tillage. Conversely, under WS tillage, there was uniform moisture distribution at the upper and lower parts of the plot. The disruption of plow pan through deep contour plowing using WS tillage could be the reason for enhanced infiltration, and more uniform distribution of soil moisture leading to less water logging.

3.4. Soil Water Infiltration

There were significant differences (P < 0.0001) in infiltration rates in the soils between WS and TT treated plots (Table 3). The initial and steady state (60 min) infiltration rates under WS plots were 0.84±0.005 and 0.1±0 cm min^{-1}, respectively. On the other hand, 0.54±0.006 and 0.05±0.004 cm min at 01 and 60 min were observed under the TT treated plots (Table 4). The lowest values of the steady state infiltration rate could be explained by the occurrence of rainfall in the previous days before the measurement was taken.

Table 3. ANOVA summary for infiltration rate and cumulative infiltration under winged subsoiler and traditional tillage.

Source of variation	DF	Infiltration rate	Cumulative infiltration
		P-values	P-values
Time	9	< 0.0001	< 0.0001
Tillage type	1	< 0.0001	< 0.0001
Time*tillage type	9	< 0.0001	< 0.0001

Table 4. Infiltration rates (cm min^{-1} and cumulative infiltration under WS and TT (Mean ±SE) at initial and steady states.

Infiltration rate (cm min^{-1})	Tillage types	
	Winged subsoiler	Traditional tillage
Time (min)	WS	TT
01	0.842±0.005[a]	0.545±0.006[b]
60	0.1±0.00[c]	0.05±0.004[d]
CI I(cm)	16.92±0.17[a]	11.6±0.11[b]

Means followed by the same letter(s) are not significantly different at (P < 0.05); CI = Cumulative infiltration.

The infiltration rate in the WS treated plots was twice higher than the TT tilled plots. The time series graphical comparison of infiltration rate and cumulative infiltration also showed that the residence time for the TT treated plots was significantly higher (P < 0.0001) compared to the WS treated plots (Figure 6 and 7). Similarly, cumulative infiltration under WS was considerably higher compared to the TT with values of 16.92±0.17 and 11.6±0.11 cm, respectively.

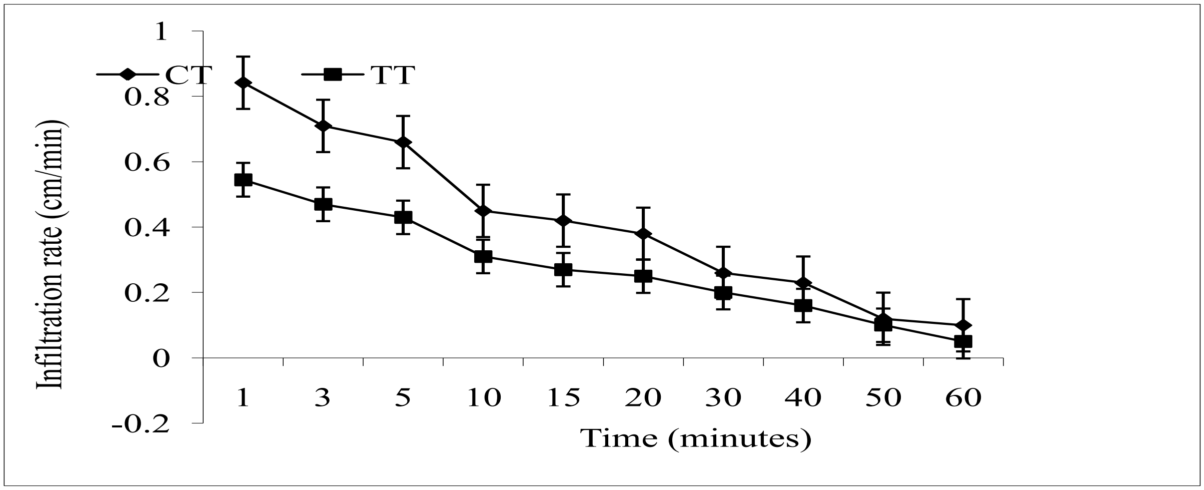

Figure 6. Infiltration rate under winged subsoiler and traditional tillage treated plots.

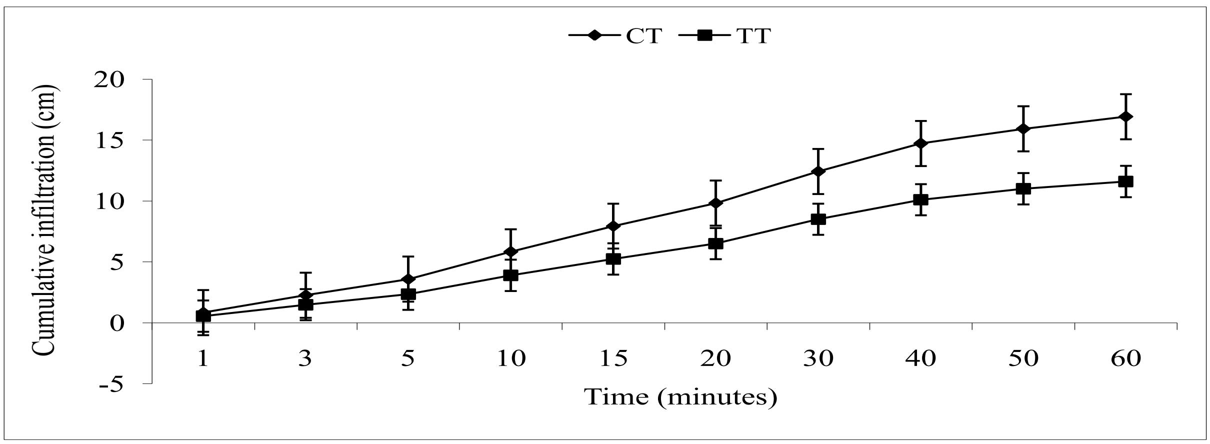

Figure 7. Cumulative infiltration under winged subsoiler and traditional tillage treated plots.

The higher values for the infiltration rate in WS treated plots might be attributable to the opening of the channel by the winged subsoiler and breakdown of hard pans thus making an easy entry of water into the root zone. Mohanty *et al.* (2006) found that subsoilers had similar effects on soil physical properties within the plowing zone and infiltration rate as well as water transmitivity increased with increasing intensity of sub-soiling. Zibilske and Bradford (2007) also indicated that increased moisture content in the root zone is associated with greater infiltration resulting from improvement of water transmission and macro porosity due to sub-soiling. A plot level tillage study showed higher infiltration rates under conservation tillage than the conventionally tilled plots (Marashi and Scullion, 2004). In addition, WS has been found to reduce surface runoff volume over TT that involves repeated passes (Mickelson *et al.*, 2001). Tillage practices can affect multiple soil physical and chemical properties including soil moisture content, mechanical resistance, and organic matter, nitrate and ammonium contents (Lal, 1989). These indicated that the wider adoption of this promising technology by resource poor smallholder farmers in northwestern Ethiopia is utmost important as it is economically beneficial due to the fact that the winged subsoiler was developed as modifications of the *Maresha* Plow, which is locally made and inexpensive.

On the other hand, the lower infiltration capacity under TT could be explained by the hard pan created by *Maresha* plow at the plowing zone, which encourages surface runoff and erosion while diminishing soil moisture storage at the root zone. The presence of plow pans in the study area has been confirmed by value of penetration resistance (Melesse *et al.*, 2012). Bailey *et al.* (1988) also confirmed that excessive compaction causes undesirable effects such as decreased infiltration of water, restrictions of root growth and increased runoff. Similarly, Abu-Hamdeh (2003, 2004) point out that the detrimental effects of soil compaction on soil physical properties is the drastic reduction of soil hydraulic conductivity, which ultimately results in soil erosion and reduced crop yields due to reduced infiltration, increased runoff, and poor drainage.

3.5. Evaporation

Soil evaporation results from the conceptual model showed that evaporation was generally low under both treatments due to summer season and Dega climate zone (Figure 8). Soil evaporation under the TT plots was higher compared to the WS treated plots. The loss of water via soil evaporation under WS and TT treated plots declined as the crop cover increased. Relatively higher soil evaporation was observed under the traditional tillage plots revealing that traditional tillage techniques using *Maresha* plow, do not promote infiltration and, on the contrary, create a hard pan on the soil in the long run and open the soil for further evaporation (Rockstrom *et al.,* 2003; Makurira *et al.*, 2009). Similar studies (Rockstrom *et al.,* 1998; Rockstrom, 2000) in the arid regions of Tanzania showed that soil evaporation can easily account for more than 50% of the rainwater. The implementation of traditional tillage does not promote infiltration and creates hard pans below the plowing layer in the long run, which encourages soil evaporation (Rockström *et al.* 2003). Considering the limitation of traditional tillage, use of winged sub-soiler could reduce soil evaporation through encouraging water holding capacity of the soil, increased infiltration, and soil moisture availability could be a viable option.

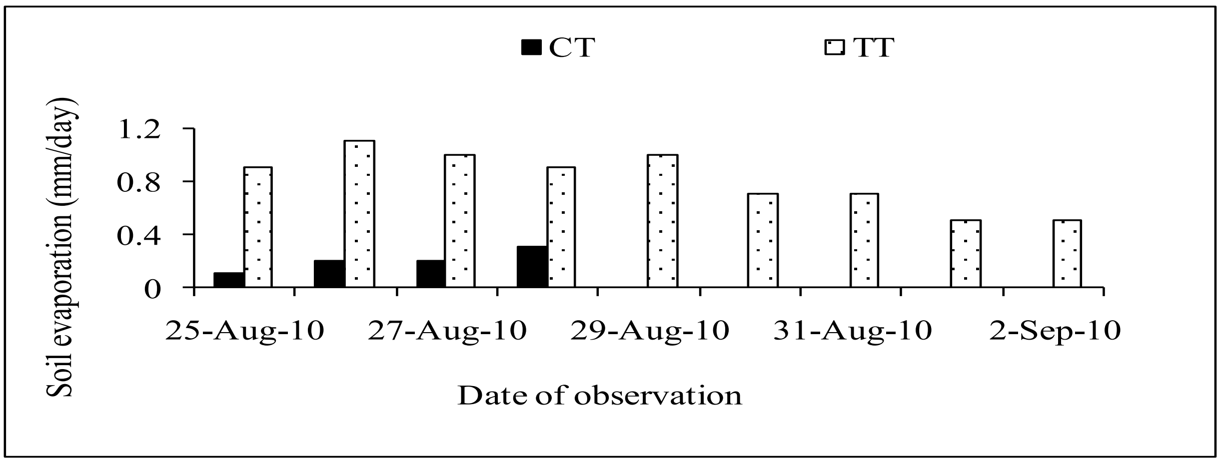

Figure 8. Effect of tillage systems on soil evaporation (mm day^{-1}) at the experimental site.

4. Conclusions

Our study demonstrated that, tillage depth using WS had been substantially higher compared to traditional plow. The WS plow through deep contour plowing and disrupt the hard pan which has been created as a result of repeated cross plowing for many years. We have found significant different silt and clay particles results across depth within TT and WS treatments independently. However, there is no significant textural change across treatments. Although its influence on soil properties reflected a less pronounced changes, the result showed that through opening up of channels by the winged subsoiler and breakdown of hard pans, an easy entry of water into the root zone was created. This in turn increased the infiltration capacity, reduced surface runoff, lowered soil evaporation at different crop growing stages and increased soil moisture availability for sufficient crop growth.

Generally, the northwestern highlands of Ethiopia are highly affected by soil compaction due to repeated cross plowing practices and consequently threatened by severe soil erosion and low land productivity. Low infiltration capacity, higher surface runoff, frequent water logging, yellowish and stunted crop growth is common features of these highlands. Therefore, the adoption and properly implementation of winged subsoiler incorporated with fanya juu soil and water conservation structure will have a far reaching impact on land productivity through improving the overall site conditions and reversing soil degradation.

5. Acknowledgement

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Effect of Intra-row Sett Spacing on Yield and Yield Components of Sugarcane Varieties at Metahara Sugar Estate

Netsanet Ayele[1*], Abiy Getaneh[1], Tadesse Negi[1] and Nigussie Dechassa[2]

[1]Sugar Corporation, Research and Training Directorate, Wonji, P O Box 15, Wonji, Ethiopia
[2] Haramaya University, School of Plant Sciences, P O Box 138, Dire Dawa, Ethiopia

Abstract: Sugarcane stalk population is a key determinant of cane yield. However, increasing cane stalk population requires denser planting, which incurs additional costs of planting material. Therefore, an experiment was conducted at Metahara Sugar Estate plantation from 2005-2010 to determine the effect of four intra-row sett spacing [10 cm between setts, 5 cm between setts, setts placed end-to-end, and setts placed ear-to-ear (5 cm overlapping)] on the performance of three sugarcane varieties (B52298, NCo334 and B41227). The experiment was carried out on class II (light) and class IV (heavy) soils in a split plot design. Combined analysis of the data over soils indicated that sucrose percent of cane, cane yield, and estimated sugar yield did not show significant differences in response to spacing as well as due to the interaction effect of spacing and variety. However, the number of millable canes at harvest was significantly ($P \leq 0.01$) affected by the main effect of spacing for the plant cane and mean of crops (plant cane and ratoons). Ten (10) cm intra-row spacing between setts was found to be best to use since it economized planting material of all three sugarcane varieties without compromising both cane and sugar yields.

Keywords: Ear-to-ear; Intra-row Spacing; Plant Cane Crop; Ratoon Crop; Sett Spacing; Sugarcane

1. Introduction

Sugarcane (*Saccharum officinarum* L.) is an important industrial crop propagated vegetatively under commercial production (Verma, 2004) and its yield is affected primarily by the stalk population. According to Roach (1976), cane yield is a function of stalk population, cane height and cane weight, where stalk population accounts for nearly 70% of the variation in cane yield. Therefore, stalk population is the key component in determining cane yield (Roach, 1976) and is affected primarily by the density of planting (Ahmed and Khaled, 2008). According to Collins (2002), sugarcane planting density is a function of inter and intra-row spacing, in addition to varietal differences (Sundara, 2000) and environmental conditions (Amolo and Abayo, ND; Verma, 2004).

In many sugarcane-growing countries, it is common to use high density planting through planting canes setts by partially overlapping them (Faucconier, 1993; Verma, 2004). The amount of setts required for planting a unit area depends on the way the cane sets are arranged in the furrow during planting. The importance of optimal planting density is to obtain optimum sprouts for an adequate initial stand establishment. High density planting results in higher cane population with weak and thinner stalks (Rao, 1990). Furthermore, high density planting reduces the number of tillers produced per planting material due to mutual shading and competition for light, nutrients and water (Verma, 2004). On the other hand, sub-optimal density planting results in a loss of yield due to inefficient use of the land space (Azhar *et al.*, 2007).

The use of large numbers of planting materials incurs high costs to sugar estates resulting in shortages of planting materials to cover commercial fields planned-annually for planting. The use of large numbers of planting material also leads estates to allocate large areas of land to seed cane production, which competes for fertile land that could be used for production of crop for milling. This is because partial overlapping (ear-to-ear) method of propagation requires large quantities of planting materials to cover a unit area (Verma, 2004). Therefore, optimization of planting density is vital for sugarcane production due to its effect on stalk population, which is an important component of yield.

Studies in other countries indicated that with low density planting, it was possible to minimize the planting material required per unit area. An experiment conducted on plant cane and ratoon cane with pre-seasonal planting indicated that cane girth, number of millable canes per clump and average cane weight were significantly ($P \leq 0.01$) higher at the intra-row spacing of 90 cm rather than at the intra-row spacing off 30 cm and 60 cm (Raskar and Bhoi, 2003). This indicated that naturally sugarcane has the capacity of tillering and compensating for population densities and maintaining potential yields under different plant spacing.

Metahara Sugar Estate uses ear-to-ear (5 cm overlapping) alignment of two budded setts within a furrow at the time of planting and even denser planting due to fears of failure of the sett buds to sprout. Previous studies conducted in Ethiopian sugar estates have indicated the possibilities of reducing planting material through manipulation of sett alignments and spacing. Results of an experiment conducted on plant cane crop

*Corresponding author E-mail: netsanet77@gmail.com
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on two soil types at Wonji-Shoa Sugar Estate using three varieties (B52298, B41227 and NCo334) with five different sett spacing (10 cm overlapping, 5 cm overlapping, end-to-end, 5 and 10 cm spacing between setts) indicated that there were significant ($P \leq 0.01$) differences among the varieties in most of the characters studied (Tsehay, 1993). However, the studies indicated that none of the intra-row spacing of setts resulted in significant differences in cane and sugar yields Similarly, a study conducted at Finchaa Sugar Estate in Central Western Ethiopia using different planting densities (5 cm overlapping, end-to-end, double and double + end-to-end alternatively) for the varieties B41227, B52298, Co449 and NCo334 indicated that the four planting densities had non-significant ($P \geq 0.01$) differences in the main sugarcane yield parameters and the ultimate sugar yield of the plant cane (Girma, 1997). Furthermore, the study indicated the possibility of reducing the amount of seed cane from 21-33%, by shifting from the 5 cm overlapping to end-to-end (butt-to-butt) alignment.

However, all of the studies conducted earlier in the country did not show the residual effect of different planting densities on the succeeding ratoon crops, and concentrated only on the plant crop. This casts doubts on the use of low density planting for commercial production due to fear of declining ratoon cane yields, which covers more than 73.1% of the annual cane harvested area of the estates (MSF, 2012). Furthermore, no appreciable work has been done on density of planting at Metahara. Therefore, this study was conducted to evaluate the effects of different intra-row spacing on both plant and ratoon sugarcane yields.

2. Materials and Methods

2.1. Site Description

Metahara Sugar Estate is located in the Rift Valley region of Ethiopia at latitude of 8^0 51' N and longitude of 39^0 52' E with an elevation of 950 meters above sea level. The area has a mean annual maximum temperature of 32.6 ^{0}C and a mean annual minimum temperature of 17.5 ^{0}C. The area has a mean annual rainfall of 554 mm. The experiment was conducted from 2005-2010 on plant cane and two successive ratoon crops.

2.2. Treatments and Experimental Design

The treatments consisted of four intra-row spacing [10 cm between setts, 5 cm between setts, setts placed end-to-end and setts placed ear-to-ear (5 cm overlapping)]. The last spacing mentioned here was used as a check since it is the spacing conventionally used by the Sugar Estate. The sugarcane varieties used were B52298, NCo334 and B41227. The study was carried out on Class II (light) and Class IV (heavy) soils (Anonymous, 2009) and three crop types viz-; plant cane (PC), first ratoon (RI) and second ratoon (RII). The sugarcane varieties were selected for their high yielding potential and large area coverage in the Sugar Estate.

The experimental design was split-plot with three replications. The main plots and sub plots were sugarcane varieties and intra-row spacing of setts, respectively. The size of each experimental plot was 29 m^2 (four furrows of 5 m length and 1.45 m width). The distance between adjacent plots and replications were 1.5 and 2.9 meters, respectively. The plant cane crop was raised using healthy stalk planting materials selected from an 8 month-old seed cane field for planting. Ammonium sulphate nitrate (26% N) fertilizer was applied as a source of nitrogen. The fertilizer was applied at the rates of 400, 500 and 650 kg ha^{-1} for the plant cane, first ratoon crop and second ratoon crop, respectively. Furthermore, a foliar application of ferrous sulphate ($FeSO_4$) was done at the rate of 30 kg ha^{-1} with a spray volume of 300 L ha^{-1} for the ratoons as soon as iron deficiency symptoms were detected in the 2nd week after harvesting. Weeds were removed manually as required until full canopy coverage was attained. Irrigation was provided according to the norm of the Estate.

2.3. Data Collection and Measurement

Plant population count data were recorded starting from the 4th month of planting until the plant age of 8 months. The number of millable canes in each plot was counted at the age of 10 months. An average cane weight of 20 stalks was taken per plot at harvest.

For cane quality analysis, juice was extracted from 10 stalk samples using a sample mill. Percent recoverable sucrose (*rendiment*) was calculated using the Winter Carp indirect method of cane juice analysis (Kassa, 2010):

Rendiment (%) = [pol percentage - (percent brix – percent pol) non-sugar factor]*cane factor

In this calculation, the non-sugar factor was 0.70. The cane factors used both for the varieties B52298 and NCo334 were 0.75, 0.75 and 0.73 for the three crops (plant cane, first ratoon and second ratoon), respectively. However, for the third variety B41227, the factors were 0.76, 0.75 and 0.72, respectively, for the three crops (plant cane, first, and second ratoons).

Cane yield was taken from the middle two rows and calculated on a hectare basis. Then, commercial sugar yield per hectare was calculated as follows:

$$ESY\ (t/ha) = CYH\ (t/ha)\ x\ ERS\ (\%)$$

where ESY is estimated sugar yield, ERS is estimated recoverable sucrose (%) and CYH is cane yield per hectare The cane and sugar yields were described as suggested by Sweet and Patel (1985) according to the COTCHM method (corrected tones cane per hectare per month).

Finally, the data collected were subjected to analysis of variance using SAS software (SAS Institute, 2002).

Comparisons among treatment means with significant differences for the measured and counted parameters were done based on the Duncan Multiple Range Test (DMRT).

3. Results and Discussion

3.1. Plant Population Dynamics

The results on plant population dynamics showed a sharp declining trend (Figure 1). In the plant cane, earthing-up drastically affected plant population. This may be because heavy earthing-up apparently buried small tillers and checked further formation of new tillers. This practice did not modify the differences between sett spacing treatments. Generally, after earthing-up, the population remained more or less stable indicating minimum rates of stalk mortality. In agreement with this result, Sundara (2000) also stated that earthing-up checks further tillering.

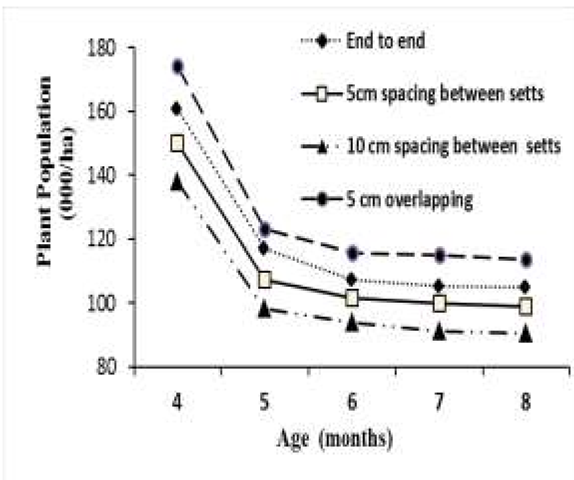

Figure 1. Mean sugarcane plant population dynamics as influenced by sett spacing at the Metahara Sugar Estate.

3.2. Effect of Intra-row Spacing on the Number of Millable Canes

Combined analysis of the data over the two soil types revealed that the main effect of spacing significantly ($P \leq 0.01$) affected the number of millable canes of the plant cane crop as well as the mean values of the plant and the ratoon crops. The results revealed that high density planting (ear-to-ear) significantly (($P \leq 0.01$)) outperformed the low density planting in terms of the number of millable stalks of the plant crop (Table 1). However, in the first and second ratoon crops, there were no statistically significant($P \geq 0.01$) differences among the spacing treatments in terms of the number of millable canes produced (Table 1). This may be attributed to formation of more number of stalks in the plant cane for the high density planting than in the ratoon crops, which might have enhanced proliferation of more tillers (Raskar and Bhoi, 2003). Consistent with the results of this study, Bashir *et al.* (2000) reported that there was a positive relationship between seeding density and plant population of sugarcane. In the first and second ratoons, no significant differences were observed in the number of millable canes. This could be ascribed to growth of higher number of tillers in the wide-spaced ratoon crops owing to the presence of well-established stools containing ample underground buds compared to the number of buds present in the plant cane.

The correlation analysis of millable stalk populations at harvest with mean cane weight for plant cane and mean of the crops (plant cane and ratoons) showed a highly significant ($P \leq 0.01$) negative correlation. The Pearson correlation coefficients for the plant cane and mean of the crops (plant cane and ratoon cane) were $r = -0.85$ and -0.88, respectively, indicating strong negative correlations between millable stalk population density and stalk weight (Figure 2). Concurrent with the current finding, Ehsan *et al.* (2011) reported an inverse relationship between planting density and mean cane weight. This could probably be attributed to less stiff intra-plant competition for growth factors among the widely spaced plants than the plants spaced densely. The difference in stalk weight at least in part could be accounted for by sett spacing, which might have resulted in the significant variations in the stalk population. Consequently, treatments with more stalk populations produced stalks with lower weight. This could also be linked to the direct relationship between tiller population before earthing-up and millable stalk numbers at harvest, which had a positive and significant ($P \leq 0.01$) correlation ($r = 0.79$) (Figure 3).

Table 1. Main effects of soil, variety and spacing on the number of millable canes, cane yield, percent sucrose cane and estimated sugar yield at Metahara from 2005-2010.

Source of variation	Number of millable cane (000 ha^{-1})				Cane yield (t ha^{-1} m^{-1})			
	PC	RI	RII	Mean	PC	RI	RII	Mean
Soil (So)								
Light (Class II)	106.7^{a}	119^{a}	100	109^{a}	12.4^{b}	14.1^{a}	12.4	12.9
Heavy (Class IV)	97.4^{b}	94^{b}	94.6	95^{b}	15.5^{a}	11.1^{b}	12.7	13.1
LSD (5%)	**	**	Ns	**	**	**	Ns	Ns
Variety (V)								
B52298	110^{a}	97.4^{b}	93.2^{b}	100^{b}	13.3	11.6^{b}	12.6	12.5^{b}
NCo334	111^{a}	118.8^{a}	111^{a}	114^{a}	14.8	13.6^{a}	13	13.8^{a}
B41227	85b	103.5^{b}	87.9^{b}	92^{c}	13.8	$12.6a^{b}$	12	12.7^{ab}
LSD (5%)	**	**	**	**	Ns	**	Ns	*
Spacing (S)								
10 cm between setts	91^{c}	101	98	97^{b}	13.2	11.9	12.2	12.4
5 cm between setts	99^{b}	103	96	99^{b}	13.5	12.5	12	12.6
End-to-end	105^{b}	110	92	102^{b}	14.5	13	12.3	13.3
Ear-to-ear (Check)	114^{a}	112	104	110^{a}	14.7	13	13.6	13.8
LSD (5%)	**	Ns	Ns	*	Ns	Ns	Ns	Ns
CV (%)	9.3	21	22.1	9.9	12.7	15.2	22.1	14.3

Means followed by the same letter in a column are not significantly different from each other; PC = Plant cane; RI = First Ratoon; RII = Second Ratoon; m = month; CV = Coefficient of Variation, LSD = Least significant Difference; t = tone; ha = hectare

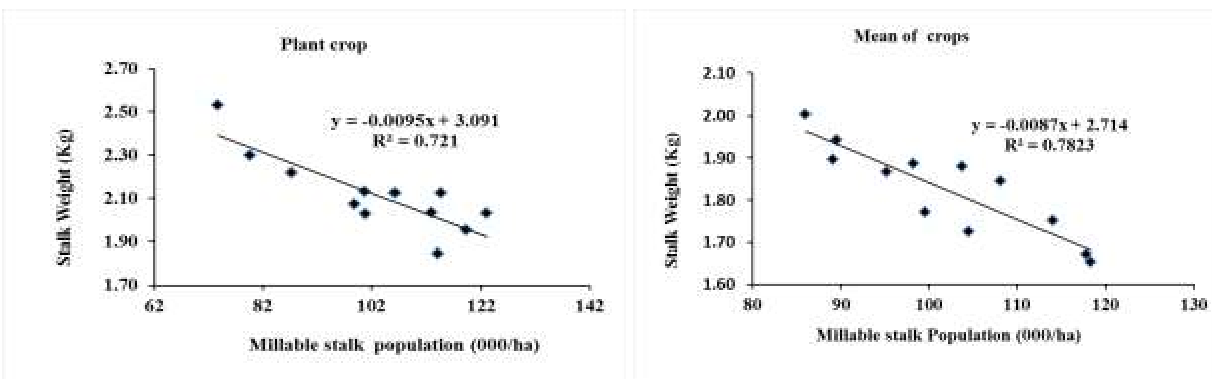

Figure 2. Relationships between millable stalk population and stalk weight at harvest at Metahara for the plant cane and mean of crops (plant cane and ratoons).

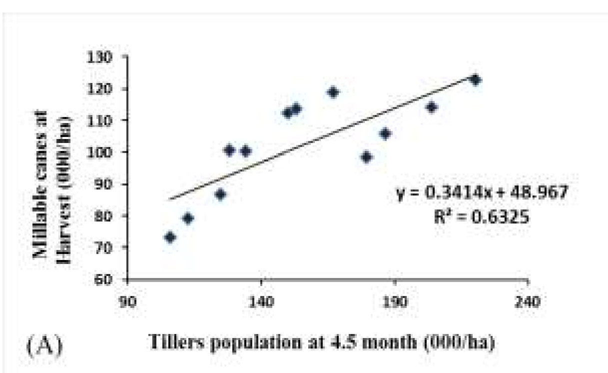

Figure 3. Relationship between mean early tillering and millable stalk population at harvest for sugarcane plant cane at Metahara

3.3. Effect of Intra-row Spacing on Cane Yield

Cane yield was significantly ($P \leq 0.01$) affected by the main effect of soil for plant cane and first ratoon crop as well as by the main effect of variety in the first ratoon and mean of crops (Table 1). However, none of the spacing treatments affected cane yield. In accord with this result, similar studies conducted earlier revealed that cane yield was influenced by soil type (Tsehay, 1993) and the crop type (Shah *et al.*, 2008). Furthermore, the current result indicated that planting at a high density may not necessarily result in a correspondingly high yield under the normal growth and management conditions.

In general, the cane yields obtained from the widely and densely spaced planting were in statistical parity (Table 1). Previous studies conducted at the Wonji-Shoa and Finchaa Sugar Estates in Ethiopia revealed a similar result (Tsehay, 1993; Worku, 2001). This means a widely-spaced planting compensates for the low stalk population. The presence of sufficient incident sunlight might have resulted in high photoassimilate production and partitioning of dry matter during the heavy tillering and root proliferation in the wider spaced planting, thereby avoiding diversion of carbohydrate away from the stalks. This may be attributed to the phenomenon that where sunlight quality and intensity are limiting, cane yield reductions arise due to the diversion of photosynthate away from the primary stalks. It is for this reason that high density planting is practiced in some countries (Amolo and Abayo, ND; Nayamuth and Koonjah, 2003).

The differences in the number of millable canes due to the treatments in the plant cane and mean of the crops were not reflected in the cane yield (Figure 2). This could be ascribed to the increased stalk weight in the wider sett spacing treatments, which might have favoured the stalks to accumulate more dry matter due to absence of stiff interplant competition. This means the lower number of stalks in the widely spaced planting might have compensated the lower stalk population by producing heavier cane stalks (Figure 2).

3.4. Effect of Intra-row Spacing on Cane Sucrose Percent

Cane sucrose percent was significantly ($P \leq 0.01$) affected by the main effect of soil in plant cane and mean of crops (plant cane and ratoons). Percent cane sucrose was also affected by the main effect of variety in all crop types and mean of crops (Table 2). However, the main effect of spacing and its interaction with variety did not have a significant influence on this parameter (Tables 2).

Table 2. Main effects of soil, variety and spacing on number of sucrose (%) and estimated sugar yield at Metahara from 2005-2010.

	Sucrose (%)				Estimated sugar yield (t $ha^{-1}m^{-1}$)			
Source of variation	PC	RI	RII	Mean	PC	RI	RII	Mean
Soil (So)								
Class II/Luvisol	14.1[a]	14.1	12	13.4[a]	1.75[b]	1.97[a]	1.49	1.74
Class IV/Vertisol	13.5[b]	13.8	12.1	13.1[b]	2.08[a]	1.54[b]	1.53	1.72
LSD (5%)	**	Ns	Ns	**	**	**	Ns	Ns
Variety (V)								
B52298	14.2[a]	14.5[a]	12.3[a]	13.6[a]	1.88	1.68[b]	1.54	1.70[ab]
NCo334	13.7[b]	13.6[b]	12.2[a]	13.2[b]	2.0	1.85[a]	1.6	1.82[a]
N14	13.6[b]	13.8[b]	11.7[b]	13.0[b]	1.86	1.73a[b]	1.4	1.66[b]
LSD (5%)	**	**	**	**	Ns	*	Ns	*
Spacing (S)								
10 cm between setts	13.7	13.8	12	13.2	1.79	1.65	1.47	1.64
5 cm between setts	14.2	14	12.1	13.4	1.91	1.75	1.46	1.7
End-to-end	13.7	13.9	12.1	13.3	1.97	1.8	1.78	1.75
Ear-to-ear (Check)	13.7	14	12	13.2	1.99	1.82	1.63	1.82
LSD (5%)	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
CV (%)	4.3	3.8	5.1	3.04	13.5	14.1	22.6	13.4

Means followed by the same letter in column are not significantly different from each other; ESY = Estimated sugar yield; PC = Plant Crop; RI = First Ratoon; RII = Second Ratoon; CV = Coefficient of Variation, LSD = Least significant Difference; t = tone; ha = hectare

The current result indicated differences in response across crops (plant cane and ratoons) for main effects of soil and variety. This could be because cane sucrose percent is influenced by many factors, which include variety (Yousaf *et al.*, 2002), soil type, weather and management practices employed during ripening (Sundara, 2000). Furthermore, the main effect of spacing and its interactions with the other factors did not affect cane sucrose percent (Tables 2). This result corroborates that of Sundara (2003) who reported that sett spacing did not affect sucrose content. Corroborating the results of this study, previous experiments conducted at the Wonji-Shoa Sugar Estate also indicated that can sucrose percent was not affected by sett spacing (Tsehay, 1993).

3.5. Effect of Spacing on Estimated Sugar Yield

Estimated sugar yield (ESY) was significantly ($P \leq 0.01$) affected by the main effect of soil in the plant cane and first ratoon, and by the main effect of variety ($P \leq 0.05$) in the first ratoon and mean of the crops. However, it was affected neither by the main effect of spacing nor by its interaction with the other factors (Table 2). The absence of differences in cane yield and cane sucrose percentages in response to the different intra-row spacing obtained in this study is consistent with the results of a similar study done previously at the Wonji-Shoa and Finchaa Sugar Estates (Woku, 2001; Tsehay, 1993).

4. Conclusion

The results of this study revealed that sett spacing influenced neither cane yield nor sugar yield. Therefore, it is recommended that Metahara Sugar Estate should use the intra-row spacing of 10 cm between setts for all three varieties instead of the conventional ear-to-ear 5 cm overlapping intra-row sett spacing that the Estate is currently using. This is because the spacing of 10 cm between setts ensures economy of planting material without sacrificing both cane and sugar yields.

5. Acknowledgment

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Genetic Gain in Yield and Yield Related Traits of Groundnut [*Arachis hypogea* (L.)] in Central Rift Valley of Ethiopia

Fikre Hagos[1*], Habtamu Zeleke [2] and Bulcha Woyossa[3]

[1] Department of Plant Sciences, Debre Tabor University, P O Box 272, Debre Tabor, Ethiopia
[2] School of Plant Sciences, Haramaya University, P O Box 138, Dire Dawa, Ethiopia
[3] Ethiopian Institute of Agricultural Research, Holeta Agricultural Research Center, Ethiopia

Abstract: The progress made to improve groundnut varieties through breeding in Ethiopia has not been yet assessed. Therefore, in this study genetic gain in grain yield and yield related traits of 14 groundnut varieties developed by the Ethiopian Lowland Oil Crops Research Program (now Ethiopian Lowland Oil Crops Research Project) from 1976 to 2009 was assessed. The varieties were evaluated in RCBD design with three replications in the 2010 main cropping season at Melka Werer Agricultural Research Center and Miesso experimental fields. The analysis of variance indicated significant differences among the varieties for all traits except days from sowing to emergence. Positive genetic gains were observed for the yield traits (grain yield and yield components), while negative genetic gains were obtained for the phenological traits (50% flowering and pod filling periods). Grain yield was increased from 1.52 to 2.74 tons ha^{-1} during the last 33 years and the overall increase in seed yield of the latest variety *Fetene* over the oldest variety *Shulamith* was estimated to be 1.142 tons ha^{-1} or 71.4%. Based on the regression analysis, the estimated average annual rate of increase in grain yield potential was 0.03 tons ha^{-1} year $^{-1}$ with an annual relative genetic gain of 1.89%. These results demonstrated the efficiency of the adopted breeding strategies in developing varieties with higher grain yields and earlier maturity. This suggests that groundnut breeders can use similar breeding strategies to exploit the genetic potential of the crop for enhanced production.

Keywords: *Arachis hypogea*; Genetic Gain; Groundnut; Yield Plateau

1. Introduction

Groundnut (*Arachis hypogea* L.) is a member of the legume family and is native to South America, Mexico and Central America, though it also grows in other parts of the world (Sigmund and Gustav, 1991). It is high in edible oil (40-50%) and protein (25%) contents and a good source of essential vitamins and minerals (Andrew and Catherine, 2010). The average seed yield of groundnut in Ethiopia is 1.117 tons (t) hectare (ha)$^{-1}$ (CSA, 2010). The total land coverage and yield of groundnut in Ethiopia are estimated to be 41,761 ha and 46,887.2 t, respectively (MoARD, 2009).

Estimation of genetic progress is useful as it helps breeders to make decisions about what breeding strategy they should follow, whether they ought to pursue or if changes are required (Ribeiro *et al*., 2008). Hence, plant breeders have been trying to measure breeding progress by growing varieties developed and released over a long period of time in the same environment (Tefera *et al*., 2009).

The Lowland Oil Crop Improvement Program at Melka Werer Agricultural Research Center has conducted several research activities (from 1976 to 2009) to improve groundnut production in Ethiopia and released 14 groundnut varieties so far for commercial production. Nevertheless, the progress made in the breeding activities over the last three decades has not been assessed. Therefore, the purpose of this study was to estimate the rate of gain per year in yield and yield related traits and document the progress made in improving the genetic yield potential of groundnut.

2. Materials and Methods

2.1. Experimental Site

The experiment was conducted in 2010 cropping season at two locations, namely Melka Werer Agricultural Research Center (WARC) and Miesso under irrigated and rain fed conditions, respectively. Melka Werer and Miesso are located at the distances of 255 and 300 km to the east of Addis Ababa, respectively. Melka Werer is located at 40^0 9ˈE Longitude, 9^0 16ˈ N latitude and an altitude of 750 meter above sea level (masl). Miesso is located at 45^0 12ˈ E Longitude, 10^0 18ˈ N latitude and an altitude of 1600 masl. These locations were purposely selected as they are among the potential areas for groundnut production in Ethiopia.

2.2 Experimental Materials

Fourteen improved groundnut varieties which were released by Melka Werer Agricultural Research Center (1976 to 2009) were used in this study (Table 1).

*Corresponding author. Email: fkrhagos5@gmail.com

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Table 1. Varieties used for the study.

No	Name of variety	Year of release	Pedigree/origin
1	*Shulamith*	1976	Introduced
2	NC-4X	1986	Introduced
3	NC-343	1986	Introduced
4	*Sedi*	1993	Developed through selection
5	*Bulki*	2002	Developed through hybridization
6	*Lote*	2002	Developed through hybridization
7	*Wer-961*	2004	Developed through hybridization
8	*Wer-962*	2004	Developed through hybridization
9	*Wer-963*	2004	Developed through hybridization
10	*Wer-964*	2004	Developed through hybridization
11	*Tole-1*	2008	Developed through selection
12	*Tole-2*	2008	Developed through selection
13	*Fayo*	2008	Developed through selection
14	*Fetene*	2009	Developed through hybridization

2.3. Treatments and Experimental Design

The treatments consisted of 14 groundnut varieties planted in a randomized complete block design (RCBD) with three replications. Each plot consisted of four rows of 3 m long and 60 cm apart. The distance between plants and spacing between plots were 10 cm and 1.2 m, respectively. The net plot size was 3.6 m^2.

Experimental Procedures: After preparing the experimental fields, groundnut seeds were sown in May 2010 and the treatments were cared for recommended agronomic practices like weeding, earthling-up and fertilizer application. After physiological maturity, harvesting was done by hand between end of September and mid of October.

2.4. Data Collection and Measurement

Data on different traits were collected on plot and plant basis as indicated below.

2.4.1. Phenological Traits

Date of emergence: It was recorded when 50% of plants in the plots emerged, and was used to calculate days to flowering and days to maturity.

Days to 50 % flowering: This was recorded as the number of days from emergence to the time when 50% of the plants in the plots started flowering.

Pod filling period: It was calculated as the number of days from flowering to physiological maturity.

2.4.2. Yield Attributes

Primary branches: It was taken as the average number of primary branches from five sampled plants.

Secondary branches: It was taken as the average number of secondary branches from five sampled plants.

Number of seeds per pod: It was determined by dividing the total number of seeds from five sampled plants by the total number of pods.

Number of mature pods per plant: It was determined as the average number of well-filled pods of five randomly taken plants.

Seed yield per plant (g): It was determined as the average weight of seeds obtained from five sampled plants after one week sun drying

2.4.3 Data Collected on Plot Basis

100-seed weight (g): Hundred seeds per plot were randomly taken using an electronic seed counter, after sun drying for one week, and weighed using electronic sensitive balance.

Pod yield/plot (g): It was recorded by weighing total number of pods obtained from the net plot area after sun drying for one week. The data were converted to kg ha^{-1}.

Seed yield/plot (g): This was recorded by weighing seeds obtained from the net plot area after sun drying for one week. The data were used to calculate seed yield ha^{-1}.

Oil content: It was determined by Nuclear Magnetic Resonance (NMR) Spectroscopy at Holeta Agricultural Research Center (HARC).

2.5. Statistical Analysis

Data were subjected to analysis of variance (ANOVA) using PROC ANOVA of SAS software to assess differences among varieties as per the procedures suggested by Gomez and Gomez (1984). Homogeneity of error mean square between the two sites was tested by the F-test on variance ratio. Combined analysis of variance was performed for those parameters when error mean squares were homogenous using PROC

GLM procedure of SAS version 9.0, taking both genotypes and locations are fixed. Before analyzing data, seeds per plant and grain yield per plant were transformed by using log transformation according to Gomez and Gomez (1984) and mean separation was done using Duncan's Multiple Range Test (DMRT).

The annual rate of gain in grain yield potential and changes produced on yield related traits were estimated by regressing the mean value of each character for each variety against the year of release for that variety. The relative gains obtained over the year of release period for traits under consideration were determined as the ratio of genetic gains to the corresponding mean value of the oldest variety and expressed as percentages. Correlation coefficients for the traits under consideration were computed using means of varieties.

3. Results and Discussion

3.1. Grain Yield Potential

The analyses of variances indicated that there were significant differences among the varieties for all characters (Table 2), demonstrating the varieties are highly variable. The mean grain yield of all groundnut varieties, averaged over locations, was 2.124 t ha^{-1} (Table 3). The most recently released variety, *Fetene,* had significantly ($P \leq 0.01$) higher grain yield than all varieties represented in the trial, and exceeded the old variety, *Shulamith*, by 1.142 t ha^{-1} (Table 4). The average grain yield of the varieties released in 1976, 1986, 1993, 2002, 2004, 2008 and 2009 were 1.598, 1.622, 1.919, 2.041, 2.286, 2.336 and 2.740 t ha^{-1}, respectively. These values indicate increases of 1.5%, 20.1%, 27.7%, 43%, 46.2% and 71.4% t ha^{-1}, respectively, over the old variety (*Shulamith*) (Table 4). The overall increase in grain yield over the old variety, *Shulamith* was estimated to be 0.526 (32.9%) t ha^{-1} considering all varieties in the trial. Hence, grain yield increased substantially with the release of new improved groundnut varieties. The results obtained in this study are in agreement with those of Naeem *et al.* (2009) who reported that improved groundnut varieties produced 10.96% higher pod yield and 23.83% higher seed yield over the check variety. Tefera *et al.* (2009) also reported that the average grain yield of soybean ranged from 1.117 to 1.710 t ha^{-1} for the period of 1980 to 1996. Demissew (2010) also reported an achievement of highest grain yield of new soybean varieties over that of the first old variety. This gives an insight for possible future opportunities to exploit the genetic potential of the crop for enhanced production.

Table 2. Mean square of characters from combined analysis of yield and yield attributing traits of groundnut varieties.

	Sources of variation						
Character	Location (l)	Variety (13)	L x V (13)	Error (12)	Mean	CV%	R^2
GY	16160587.210**	676247.140**	81456.290**	40492.780	2.124	9.470	0.920
PY	143113385.200**	4083075.400**	202027.300**	27682.200	4.492	3.700	0.990
BY	63847720.300**	8052162.500**	1866580.300**	108484.700	7.793	4.230	0.970
HI	0.061**	0.003**	0.002*	0.001	0.270	9.970	0.750
TPP	56156.540**	523.230 **	355.620**	18.830	44.930	9.660	0.990
MPP	34676.490**	45.500**	428.440**	11.530	33.490	10.140	0.990
Spod	0.030**	1.139**	0.287**	0.092	2.250	13.490	0.790
100sw	3572.439 **	1159.111 **	76.962*	21.250	59.030	7.810	0.940
100pw	20246.153**	11979.783**	349.910	412.527	188.24	10.790	0.890
Splant	7.232**	0.113**	0.003	0.004	1.75	3.420	0.980
PB	0.093	7.088**	0.941*	0.273	5.6000	9.290	0.880
SB	273.602**	30.584**	15.038**	0.153	3.100	12.610	0.990
MP%	832.805**	529.837**	70.186**	24.058	71.680	6.840	0.870
50%F	1008.107**	12.092**	6.158**	0.574	32.220	2.350	0.960
PFP	1029.000**	372.396**	0.076	0.852	97.550	0.950	0.990
Oilcont	54.241**	36.026**	20.939**	0.562	47.580	1.580	0.960
GYP	9.811**	0.112**	0.002	0.003	1.500	3.720	0.990

*** = Significant at $P \leq 0.05$; ** = Significant at $P \leq 0.01$; GY = Grain yield (kg/ha); BY = Biomass yield (kg/ha); PY = Pod yield (kg/ha); HI = Harvest index; TPP = Total pod/plant; MPP = Mature pod/plant, Spod = Seed/pod, 100sw = 100 seed weight(g); 100pw = 100 pod weight (g); Splant = Seed/plant; PB = Primary branches; SB= Secondary branches; MP% = Maturation percentage; 50%F = 50% flowering; PFP = Pod filling period; oil cont= oil content; GYP = Grain yield per plant (g).*

Table 3. Mean value of characters obtained from combined analysis of yield and yield components of groundnut varieties.

	Grain yield and yield components									
Variety.	GY	PY	BY	HI	TPP	MP	Spod	Splant	MP%	GYP
Shulamith	1.598^{f}	3.045^{g}	5.912^{h}	0.270^{bc}	34.8^{e}	20.9^{g}	2.0^{c}	1.52368^{h}	58.2^{g}	1.26468^{J}
NC-4X	1.628^{f}	3.358^{f}	6.441^{g}	0.256^{c}	34.9^{e}	22.2^{g}	1.9^{c}	1.52688^{h}	65.9^{ef}	1.34413^{I}
NC-343	1.617^{f}	3.380^{f}	6.308^{g}	0.256^{c}	36.4^{e}	23.9^{g}	2.1^{c}	1.64648^{g}	63.7^{efg}	1.39775^{hi}
Sedi	1.920^{e}	3.707^{e}	6.406^{g}	0.297^{ab}	37.8^{de}	22.3^{g}	3.0^{a}	1.70774^{fg}	65.1^{ef}	1.34272^{i}
Bulki	2.075^{cde}	4.837^{d}	7.379^{f}	0.277^{bc}	43.5^{bc}	30.8^{ef}	2.0^{c}	1.72200^{fg}	67.4^{de}	1.43775^{gh}
Lote	2.007.^{de}	4.277^{d}	7.512^{f}	0.264^{bc}	46.8^{bc}	27.7^{f}	2.0^{c}	1.74006^{ef}	60.1^{fg}	1.49727^{fg}
Werer-961	2.300^{bc}	4.857^{c}	8.776^{bc}	0.260^{c}	46.6^{bc}	29.6^{ef}	2.4^{b}	1.79926^{de}	65.7^{ef}	1.42755^{h}
Werer-962	2.266^{bc}	4.878^{c}	8.128^{de}	0.275^{bc}	46.1^{bc}	34.3^{cd}	2.0^{c}	1.74690^{ef}	74.6^{c}	1.54162^{ef}
Werer-963	2.243^{bcd}	4.847^{c}	7.990^{e}	0.277^{bc}	46.2^{bc}	36.7^{c}	3.1^{a}	1.89305^{bc}	75.2^{c}	1.56772^{de}
Werer-964	2.334^{bc}	4.837^{c}	8.235^{de}	0.279^{bc}	46.7^{bc}	35.0^{c}	2.9^{a}	1.91532^{b}	72.6^{cd}	1.58839^{cde}
Tole-1	2.355^{b}	5.198^{b}	9.055^{ab}	0.258^{c}	42.8^{cd}	37.1^{c}	2.1^{bc}	1.68336^{fg}	83.8^{ab}	1.62075^{cde}
Tole-2	2.295^{bc}	5.146^{b}	9.362^{a}	0.243^{c}	44.7^{bc}	37.7^{bc}	2.1^{c}	1.71715^{fg}	81.9^{b}	1.63859^{abc}
Fayo	2.359^{b}	5.348^{b}	9.191^{a}	0.256^{c}	49.1^{b}	41.6^{b}	2.0^{c}	1.83081^{cd}	81.5^{b}	1.67020^{ab}
Fetene	2.740^{a}	5.659^{a}	8.409^{cd}	0.327^{a}	72.7^{a}	65.5^{a}	1.9^{c}	2.01155^{a}	88.0^{a}	1.70359^{a}
Mean	2.124	4.492	7.793	0.27	44.93	33.49	2.25	1.75	71.68	1.50
CV%	9.47	3.70	4.23	9.97	9.66	10.14	13.49	3.42	6.8	3.72

Means followed by the same letter within a column were not significantly different at P ≤ 0.05, according to Duncan's Multiple Range Test; GY = Grain yield (t/ha); BY= Biomass yield (t/ha); PY = Pod yield (t/ha); HI = Harvest index; TPP = Total pods/plant; Spod = Seeds/pod, Splant = Seeds/plant; MP% = Maturation percentage; GYP= Grain yield per plant (g).

Table 4. Average grain yield, pod yield and biomass yield (t ha^{-1}) of groundnut varieties and increment over the first released variety, *Shulamith*.

Variety	Year of release	Mean grain yield (t ha^{-1})	Increment over *Shulamith*		Mean pod yield (t ha^{-1})	Increment over *Shulamith*		Mean biomass yield (t ha^{-1})	Increment over *Shulamith*	
			t ha^{-1}	%		t ha^{-1}	%		t ha^{-1}	%
Shulamith	1976	1.598	-	-	3.045	-	-	5.912	-	-
NC-4X										
NC-343	1986	1.622	0.024	1.5	3.369	0.324	10.7	6.375	0.462	7.8
Sedi	1993	1.919	0.321	20.1	3.707	0.662	21.7	6.406	0.493	8.3
Bulki										
Lote	2002	2.041	0.442	27.7	4.557	1.512	49.7	7.446	1.533	25.9
Wer-961										
Wer-962										
Wer-963										
Wer-964	2004	2.286	0.687	43.0	4.855	1.810	59.4	8.282	2.370	40.1
Tole-1										
Tole-2										
Fayo	2008	2.336	0.738	46.2	5.231	2.186	71.8	9.203	3.290	55.7
Fetene	2009	2.740	1.142	71.4	5.659	2.614	85.8	8.409	2.497	42.2

The yield levels varied significantly from 1.598 to 2.740 t ha^{-1} among the 14 varieties (Table 3). A linear regression equation showed that the relationship between yield and year of release was highly significant (P ≤ 0.01) as indicated in figures 1. Across 33 years of groundnut breeding, 32.9% improvement of yield or 1.89% increase per year was achieved (Table 7). Ntare and Waliyar (1994) reported similar result for the large-seeded Virginia type groundnut, with a relative genetic gain of 1.3-3.2% per year, which is in agreement with the findings of this study. Similarly, in other related crops, Kebere *et al.* (2006) reported a 3.24% genetic gain per year in common bean and Lange and Federizzi (2009) reported a 1.2% yield increase in soybean due to genetic improvement made in the United States. Hailu *et al.* (2009; 2010) also reported 2.20% and 1.99% year^{-1} improvements, respectively, in early and medium maturing soybean at ITTA, Nigeria.

There was no indications of yield potential plateau in groundnut varieties over the period of the study (Figure 1) which indicates that further improvement is possible to increase yield and this provides clues for breeders to further exploit (increase) the yield potential of the existing groundnut varieties.

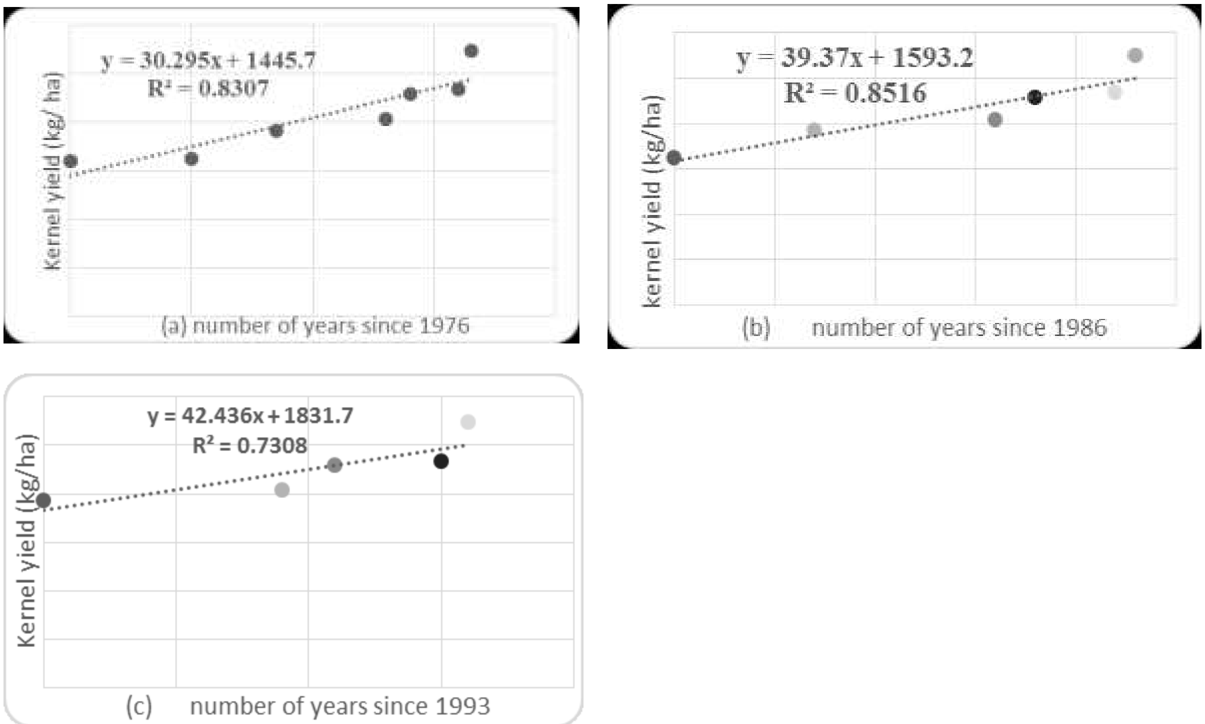

Figure 1. Relationship between mean grain yield (kg) of 14 groundnut variety and the year of release expressed as the number of years since 1976.

3.2. Harvest Index

Harvest index (the ratio of seed yield to the above ground biomass) obtained in this study ranged from 0.243 to 0.327 with a mean of 0.270 (Table 3). It can be seen from the table that there was no significant trend of increasing in harvest index. The findings of the present study is in agreement with the findings of Kebere *et al.* (2006) who reported unchanged harvest index for common bean for the period of genetic improvement. Tefera *et al.* (2009) also reported that soybean varieties did not show significant differences for harvest index over the period of the genetic improvement. Contrary to this result, Jin *et al.* (2010) found that the harvest index (HI) increased significantly with year of release, averaging 0.40% per year, rising from 0.31 to 0.38 for soybean cultivars released from 1950 to 2006 in Northeast China.

3.3. Pod Yield and Biomass Yield

Pod yield and biomass yield also showed a trend similar to that of seed yield during the 33 year period, and recently released varieties had more pod and biomass yields than old ones. In additions, significant ($P < 0.05$) difference in different yield related characters was observed among the varieties released in the same period (Table 6). The most interesting finding in the present study is that the top yielding variety both for seed (2.740 t ha^{-1}) and pod (5. 659 t ha^{-1}) yields was *Fetene* but the top yielder for biomass yield (9.362 t ha^{-1}) was Tole-2 (Table 3). This demonstrates that both grain and pod yields have been increasing during the research period.

In this study, total number of pods per plant was highly significantly and positively correlated with biomass yield (r = 0.61), pod yield (r = 0.89) and harvest index(r = 0.64) (Table 10). On the other hand, biomass yield was significantly and positively associated with pod yield (r = 0.83) and total number pod of per plant (r = 0.61) but it was not significantly correlated with harvest index (Table 10). Similarly, Vaithiyalingan *et al.* (2010) reported that pod yield had highly significant and positive associations with pods per plant, dry matter production, seed weight and harvest index. This ensures the contribution of these traits in increasing the yield potential of groundnut during the genetic progress made in the last 33 years with.

There were genotype x location interactions for pod yield, biomass yield, and harvest index (Table 2) indicating that the performance of groundnut varieties was significantly affected by the interaction effect of genotype x environment, particularly by the amount and distribution of rainfall. The results obtained in this study are in agreement with findings of Sayed *et al.* (2003) who reported that the performance of Bambara groundnut landraces tested over different seasons. The overall increases in pod and biomass yields over the old variety for Melka Werer, Miesso, and combined over locations were 1.806 (45.3%), 1.087 (51.8%) and 1.447 t ha^{-1} (47.5%), respectively. s.

Table 5. Mean values, coefficient of determination (R^2), and regression coefficients (b) of various yield attributing traits against the year of release for the varieties.

Character	1976-2009 Mean	R^2	b	1986-2009 Mean	R^2	b	1993-2009 Mean	R^2	b
PY	4.346	0.92	0.077**	4562.85	0.96	95.43**	4801.58	0.97	113.84**
BY	7.433.	0.84	0.093**	7686.69	0.85	116.94*	7949.11	0.87	155.41*
HI	0.28	0.09	0.0006	0.28	0.09	0.0006	0.28	0.001	-0.0002
TPP	44.93	0.520	0.76	47.2	0.53	1.07	49.51	0.48	1.46
MPP	33.49	0.53	0.89	35.91	0.54	1.26	38.45	0.54	1.84
Spod	2.25	8E-05	0.00	2.26	0.06	-0.012	2.31	0.67	-0.06
100sw	59.02	0.02	0.14	56.68	0.04	0.28	55.64	0.30	1.25
100pw	188.24	0.010	0.33	176.65	0.006	0.39	176.31	0.02	1.17
Splant	1.71	0.95	0.008*	1.74	0.90	0.008	1.77	0.80	0.006
50%F	32.23	0.23	-0.06	32.03	0.23	-0.09	31.57	0.02	0.03
PB	5.60	0.70	0.14*	5.02	0.60	0.17	4.40	0.36	0.16
SB	3.10	0.59	0.05*	3.27	0.58	0.07	3.15	0.66	0.11
MP%	73.14	0.67	0.72*	72.57	0.59	0.87	74.13	0.67	1.37
GYP	1.47	0.85	0.012*	1.51	0.81	0.014*	1.54	0.94	0.021*
Oil cont	47.58	0.42	0.13	48.41	0.02	0.02	48.69	0.15	-0.093
PFP	97.55	0.23	-0.39	94.40	0.04	-0.21	92.54	0.09	0.46
DET	7.99	0.12	-0.009	7.89	0.03	-0.006	7.88	0.04	-0.01

*** = Significant at P ≤ 0.05; ** = Significant at P ≤ 0.01; PY = Pod yield (kg/ha); BY= Biomass yield (kg/ha); HI = Harvest index; TPP = Total pod/plant; MPP = Mature pod/plant, Spod = Seed/pod, 100sw = 100 seed weight(g); 100pw = 100 pod weight (g); Splant = Seed/plant; 50%F = 50% flowering PB = Primary branches; SB = Secondary branches; MP% = Maturation percentage; GYP= Grain yield per plant(g); Oil cont = Oil content; PFP = Pod filling period; DET = Date to 50% emergency.*

Table 6. Mean value of yield related attributes obtained from combined analysis of variance for groundnut varieties grown at Melka Werer and Miesso.

Variety*	Yield related components							
	100sw	100pw	PB	SB	DTE	50%F	PFP	Oil content (%)
Shulamith	55.883[e]	169.82[def]	7.2000[a]	4.9667[b]	8.1667[abc]	33.1667[bc]	107.5000[a]	43.2500[g]
NC-4X	66.200[bc]	191.83[cd]	6.5500[bc]	6.9167[a]	7.6667[abc]	34.6667[a]	104.1667[b]	45.8667[e]
NC-343	57.500[de]	164.78[ef]	6.2333[bcd]	4.7167[bc]	8.1667[abc]	34.0000[ab]	103.1667[bc]	48.1833[dc]
Sedi	43.433[g]	162.12[ef]	4.3000[g]	1.4833[f]	8.0000[abc]	30.5000[e]	82.1667[j]	50.1000[a]
Bulki	52.750[ef]	153.72[fg]	5.5333[ef]	4.4667[c]	8.0000[abc]	33.8333[ab]	102.1667[cd]	50.1167[a]
Lote	57.600[de]	172.67[def]	6.1333[cde]	3.9000[d]	7.5000[bc]	33.1667[bc]	103.1667[bc]	48.8667[bc]
Werer-961	46.567[g]	134.00[gh]	4.1667[g]	0.3000[g]	8.0000[abc]	29.8333[e]	88.1667[i]	44.6333[f]
Werer-962	62.633[cd]	180.93[de]	5.9000[cde]	4.8000[bc]	8.0000[abc]	31.6667[d]	94.5000[h]	49.9167[a]
Werer-963	46.300[g]	212.12[bc]	4.1000[g]	0.2333[g]	7.6667[abc]	32.0000[d]	101.1667[de]	43.6667[g]
Werer-964	46.317[g]	221.08[b]	4.0000[g]	0.1500[g]	8.3333[ab]	31.5000[d]	97.5000[g]	45.9833[e]
Tole-1	87.250[a]	265.12[a]	6.4833[bcd]	3.2333[e]	8.1667[abc]	32.3333[dc]	100.8333[e]	49.2667[ab]
Tole-2	84.817[a]	267.33[a]	6.8333[ab]	3.0000[e]	8.5000[a]	31.8333[d]	99.1667[f]	49.8000[ab]
Fayo	69.800[b]	222.17[b]	5.8667[de]	5.1000[b]	8.3333[ab]	32.1667[d]	99.1667[f]	47.6167[d]
Fetene	49.350[fg]	117.70[h]	5.1667[f]	0.1333[g]	7.3333[c]	30.5000[e]	82.8333[j]	48.9167[bc]
Mean	59.03	188.24	5.60	3.100	7.99	32.23	97.55	47.58
CV%	7.81	10.79	9.287297	12.61	8.88	2.35	0.95	1.58

Means followed by the same letter within a column weren't significantly different at P ≤ 0.05, according to Duncan's multiple range test; 100sw = 100 seed weight (g); 100pw = 100 pod weight (g); PB =Primary branches (no.); SB = Secondary branches (no.); DET = Date to 50% emergency (no.); 50%F = 50% flowering (no.); PFP = Pod filling period (no).

The average rate of increase in total number of pods per year of release, estimated from the slope of the graph was 0.76 (Table 5). The relative annual gains of this trait was 2.17% over the 33 years (Table 7), indicating that genetic improvement for this trait was important for seed yield enhancement in groundnut varieties during the period of study. Similarly, Hossein (2008) found that yield increment in groundnut resulted from the increase of number of pods per plant. Awal and Ikeda (2003) also reported that the number of flowers, pegs, and pods are the most important yield components that affect the yield potential of groundnut. Consistent with this result, Royo *et al.* (2007) found out that seed yield improvement in groundnut has been associated with increases in the number of seeds per plant.

Varieties developed through hybridization and selection yielded an average yield of 0. 666 t ha^{-1} (41.3%) and 0. 618 t ha^{-1} (38.3%), respectively, higher than varieties derived from introduction (Table 8) This indicates the importance of hybridization and selection for improving the genetic potential of groundnut varieties to increase yield over the past 33 years. Moreover, averaged over the two locations, the mean pod yield of varieties developed through hybridization and selection was higher than the mean pod yield of varieties developed through introduction by 1.623 t ha^{-1} (49.8%) and 1.589 t ha^{-1} (48.7%), respectively (Table 8).

Table 7. Annual relative genetic gain and correlation coefficients for grain yield and different attributes of groundnut varieties.

Character	Relative genetic gain (% $year^{-1}$)	Correlation coefficient (r)
Grain yield	1.89	
Pod yield	2.53	0.979**
Biomass yield	1.57	0.843**
Harvest index	0.22	0.537**
Total pod	2.17	0.863**
Mature pod	4.27	0.892**
Seed per pod	0.00	0.025
Seed per plant	0.52	0.854**
Hundred seed weight	0.26	0.408**
Hundred pod weight	0.19	0.364*
Maturation percentage	1.23	0.653**
Primary branch	1.99	0.092
Secondary branch	1.03	0.543**
50% flowering	-0.19	-0.836**
Pod filling period	-0.36	-0.568**
Oil content	0.29	0.392*
Grain yield per plant	0.95	0.904**

Table 8. Average grain, pod and biomass yield increment of varieties derived from selection and hybridization over varieties derived from introduction.

Breeding strategy of variety	Mean grain yield ($t\ ha^{-1}$)	Increment over introduction derived		Mean pod yield ($t\ ha^{-1}$)	Increment over introduction derived		Mean biomass yield ($t\ ha^{-1}$)	Increment over introduction derived	
		t ha^{-1}	%		t ha^{-1}	%		t ha^{-1}	%
Derived from introduction	1.614	-	-	3.261	-	-	6.221	-	-
Derived from selection	2.232	0.618	38.3	4.850	1.589	48.7	8.504	2.283	36.7
Derived from hybridization	2.281	0. 666	41.3	4.885	1.623	49.8	8.061	1.841	29.6

3.4. Seed Yield and Some Yield Component Traits

There were significant differences ($P \leq 0.05$) among the varieties in yield and most of the measured yield components (Table 2). From the present result, the modern variety *Fetene* produced the highest seed yield per plant (64.59 g). The estimated annual gain of grain yield per plant over the past 33 years was 1.04 g and it was significantly ($P \leq 0.05$) different from zero (Table 4). The relative genetic gains for hundred seed weight and grain yield per plant were 0.26 and 0.95% per year, respectively (Table 7).

Seed yield per plant was positively and significantly associated with pod yield (r = 0.93), biomass yield (r=0.71), seed per plant (r = 0.91), mature pod per plant (r=0.93), maturation percentage (r = 0.53), hundred seed weight (r = 0.48) and hundred pod weight (r = 0.40) (Table 10). Similar results were reported by Savitha (2008) that the number of seeds, number of pods, number of branches and 100 seed weight were positively correlated with yield per plant of avare (*Lablab Purpureus* (L.) Sweet).

The average annual rate of gain of seed over the 33 years was 0.008 seeds plant^{-1} year^{-1} (Table 5). This gain was significantly different from zero, showing that this yield component trait was increased parallel with the release of new varieties, and relative genetic gain was estimated to be 0.52% per year (Table 7). Likewise, Kebere *et al.* (2006) found a significant increase in seed number per plant of common bean over the period of genetic improvement.

However, unlike to other attributes, a non-significant relative gain per year was obtained for the number of seeds per pod during the whole period of yield improvement program (Table 7). This indicates that the challenges to increase the number of seeds per pod during the given period of time. Similarly, Kebere *et al.* (2006) found a non-significant trend of seeds per pod for common bean. On the other hand, Jin *et al.* (2010) reported that there was a smaller relationship between the year of release and seed number per pod and some of the yield gain of soybean across time comes from the increase in number of seed per pod.

Although there were variations among the varieties in oil concentration, insignificant change was observed during the past 33 years (Table 7). This may be due to that groundnut breeders may have focused more on the selection of high-yielding varieties, rather than genetic improvement in this quality trait. Similarly, Jin *et al.* (2010) also found that the absence of significant improvement in oil content among the soybean varieties over the 56 years of improvement work.

Although most recently released varieties possessed high number of primary and secondary branches, regression of mean primary and secondary branches of varieties over the year of variety release showed a non-significant trend (Table 5). The average relative annual gain of primary and secondary branches were 1.99 and 1.03% per year, respectively (Table 7), indicating that primary and secondary branches were slightly changed over the past 33 years. However, the correlation coefficient for secondary branches with yield was high and significant, which indicated the importance of this character for influencing seed yield indirectly. In this study, it was observed that secondary branch was significantly ($P \leq 0.01$) and positively correlated with number of pods per plant, number of seeds per plant, and grain yield per plant. This result is in agreement with the findings of Savitha (2008) who reported that the genetic associations between the number of branches and the number of pods and seeds per plant were high and positive.

3.5. Days to Emergence, 50% Flowering and Pod Filling Period

Mean days to emergence of all varieties represented in the trial was 7.99 days (Table 5). The combined analysis, averaged over the two locations, indicated non-significant differences among all genotypes for days to emergence but significant genotype x location interactions for this trait (Table 2). Separate location analysis indicated significant ($P \leq 0.05$) differences among genotypes at Melka Werer but non-significant difference at Miesso. The annual genetic gain for the number of days from sowing to emergence was negative (-0.009 days year^{-1}) (Table 5). This regression coefficient value was not significantly ($P \leq 0.05$) different from zero indicating that the recently released varieties emerged early compared with the old varieties. In contrast, Ribeiro *et al.* (2008) indicated that the genetic gain for days to emergence of common bean was positive (0.06 days year^{-1}), which is undesirable. Therefore, the reduction in days to emergence observed in the latest variety was an advantage obtained during the variety improvement period.

The number of days to 50% flowering for all varieties represented in this study ranged from 29.8 to 34.6 days with the mean value of 32.2 days (Table 6).The genetic gain for number of days to 50% flowering was negative (-0.06) and insignificant. This is mainly due to the early flowering character of some recently released varieties such as *Fetene.* (Table 6). But in general, there was no significant relationship between days to flowering and period of the variety released. The results obtained in this study are in agreement with the report of Kebere *et al.* (2006) who found similar results with common bean varieties. Ribeiro *et al.* (2008) also found a negative genetic gain for the number of days to 50% flowering in common bean.

Like days to 50% flowering, pod filling period also showed a decreasing trend from the oldest to the newest variety with annual genetic gain of -0.39 days/year, but insignificant (Table 5). The pod filling period of the old variety, Shulamith was 24.7 (29.8%) which is 8.3 (8.4%) days greater than the new varieties *Fetene* and *Fayo,* respectively (Table 5). Even though, increasing the length of seed filling period in soybean had been suggested as a means of increasing yield, (Kumari and Singh, 2008), Egli *et al.* (1978) reported no difference in the duration of growth of individual seed across five varieties of varying seed size and yield potential of soybean. This suggest that short pod filling period may have an advantage over the longer pod filling period of old varieties for escaping late drought due to erratic and unreliable rainfall.

3.6. Basis of Yield Gain-Morphological Characters Associated With Yield Potential Improvement

Grain yield was highly and significantly ($P \leq 0.01$) correlated with pod yield (kg/ha) ($r = 0.98$) and number of mature pods per plant ($r = 0.89$), whereas it was not significantly ($r = 0.025$) correlated with seed number per pod ($r = 0.03$). Faisal *et al.* (2006) observed that grain yield was positively and significantly correlated with number of pods per plant in their study with soybean. On the other hand, Savitha (2008) indicated that the correlations between the number of seeds per pod and the number of pods per plant with grain yield were highly significant, which indicates that these characters can attribute to yield increment. On the contrary, Sawant (1994) reported that number of seeds per pod was significantly correlated with grain yield of cowpea. Likewise Venkatesan *et al.* (2003) stated that the number of branches per plant, number of pods per plant and pod yield was positively correlated with seed yield. Generally, in this study, it was observed that number of pods per plant, biomass yield, pod yield, 100 seed weight and mature pod percentage had positive significant association with yield. Jason *et al.* (2009) also observed that new cultivars produced higher yields than old varieties as a result of higher biomass accumulation. Hence, these characters can be considered during variety selection for improving yield.

All phenological traits were significantly ($P \leq 0.01$) and negatively associated with grain yield (Table 10). Similar results were obtained by Ramteke *et al.* (2010) who showed that yield was negatively associated with days to 50% flowering and days to maturity. Faisal *et al.* (2006) also found negative association of grain yield of soybean with days to 50% flowering, days to flowering completion and days to maturity. This indicates that selection on the basis of these traits might lead to groundnut yield loss for late maturing groundnut varieties and yield gain for early maturing varieties. However, harvest index, seed number per plant, number of branches per plant, biomass yield, grain yield per plant and 100-seed weight had positive association with grain yield of groundnut varieties. Maximum associations were observed for biomass yield and grain yield per plant. This was also in agreement with Sawant (1994) who found that seed yield was significantly and positively correlated with branches per plant, pods per plant, seeds per pod, 100 seed weight and harvest index on cowpea varieties.

Despite a significant increase of regression coefficient ($P \leq 0.05$, $b = 0.14$) of primary branch per plant over the 33 years (Table 4), a non-significant ($P > 0.05$) and positive correlation was observed between primary branch per plant and grain yield (Table 10). Contrary to the present result, Savitha (2008) indicated that the genetic association of branches with yield was high and significant. Oil content of groundnut varieties have shown a significant ($P \leq 0.05$) and positive association with grain yield (Table 10), but the regression coefficient ($b = 0.13$) indicated that there was insignificant trend for this trait from the older to the newest variety. In contrary to the findings of this study, Faisal *et al.* (2006) reported that there was a negative association of oil content with grain yield of soybean. According to the author, genetic gain for grain yield was positive (59.8 kg ha^{-1} year^{-1}) due to the higher number of seeds per plant, higher grain yield per plant, higher pod yield and greater plant biomass yield. Similar result was also obtained by Ribeiro *et al.* (2008) in common bean. Hence, based on the findings of the present study, it could be concluded that genetic yield potential improvement program of groundnut varieties over the last 33 years has been mostly correlated with a corresponding increase of pod yield, grain yield per plant, seed number per plant and biomass yield. These principal yield components were significantly correlated with each other as well (Table 10).

Table 9. Step wise regression analysis of groundnut mean grain yield (dependent variable) on selected yield components (independent variable).

Independent variable	Constant	Regression coefficient	R^2 (%)
Pod yield	387.3	0.666**	97.4

*** = Significantly at P ≤ 0.01*

A stepwise regression analysis equation to explore the relationships between grain yield and the agronomic characters showed that PY (pod yield) was the most important character, which greatly contributed to 97.4% of the variation in grain yield among the varieties and neither of the other characters were in the best fit. In other previous studies on soybean, Demissew (2010) reported that biomass yield, harvest index and number of branches per plant were the traits that contribute most to the variation in grain yield among varieties. Similarly, Wondimu (2010) reported that harvest index, biomass yield and biomass production rate were the traits which contributed to gain in grain yield. Similarly, Yifru and Hailu (2005) and Kebere *et al.* (2006) found that biomass yield was the single most important trait that contributed most to the variation in grain yield among *teff* and haricot bean released varieties.

Table 10. Correlation coefficients of mean values of yield and yield related traits of groundnut varieties represented in the study.

Character	GY	BY	PY	HI	TPP	MPP	Spod	100sw	100pw	SPL	PB	SB	Mp%	50%F	Oil C
GY	-														
BY	0.84**	-													
PY	0.98**	0.83**	-												
HI	0.54**	0.03 ns	0.53**	-											
TPP	0.86**	0.61**	0.89**	0.64**	-										
MPP	0.89**	0.68**	0.90**	0.57**	0.97**	-									
Spod	0.03 ns	0.06 ns	0.03 ns	-0.06 ns	-0.05 ns	-0.05									
100sw	0.41**	0.39*	0.41**	0.25 ns	0.31*	0.34**	-0.38**	-							
100pw	0.36*	0.44**	0.39**	0.06 ns	0.22*	0.25*	0.04 ns	0.69**	-						
SPL	0.85**	0.64**	0.88**	0.58 ns	0.93**	0.92**	0.18 ns	0.13	0.19 ns	-					
PB	0.09 ns	0.23*	0.05 ns	-0.16 ns	-0.12 ns	-0.03 ns	-0.18 ns	0.41**	0.53**	-0.12	-				
SB	0.54**	0.34*	0.62**	0.53**	0.68**	0.59**	-0.278*	0.57**	0.38*	0.54**	0.03 ns	-			
MP%	0.65**	0.61**	0.57**	0.27*	0.41**	0.58**	-0.02 ns	0.43**	0.38**	0.44**	0.35*	0.17 ns	-		
50% F	-0.84**	-0.59**	-0.87**	-0.64**	-0.88**	-0.84**	-0.11 ns	-0.28*	-0.24*	-0.84**	0.18 ns	-0.64**	-0.377*	-	
Oil C	0.39*	0.35*	0.36*	0.14 ns	0.28*	0.34**	-0.16 ns	0.37**	0.16 ns	0.20 ns	-0.04 ns	0.21 ns	0.305*	-0.29*	-
GYP	0.90**	0.71**	0.93**	0.58**	0.92**	0.93**	0.01 ns	0.48**	0.40**	0.91**	-0.00 ns	0.69**	0.528**	-0.86**	0.38*

*** = Significant at P $\le$ 0.05; ** = Significant at P $\le$ 0.01; GY = Grain yield (kg/ha); BY= Biomass yield (kg/ha); PY= Pod yield (kg/ha); HI = Harvest index; TPP = Total pod/plant; MPP = Mature pod/plant, Spod = Seed/pod, 100sw = 100 seed weight(g); 100pw = 100 pod weight (g);* SPL *= Seed/plant; PB = Primary branches; SB= Secondary branches; MP% = Maturation percentage; 50%F = 50% flowering; Oil C = oil content; GYP= Grain yield per plant (g).*

4. Conclusions

The successively released new groundnut varieties in Ethiopia, between 1976 and 2009, by the Lowland Oil Crop Research Program clearly indicate the achievement gained to improve the yield of the crop through different breeding strategies. The results of this study show that there was significant increase in the grain yield potential of groundnut through consecutive release of varieties over the last 33 years. This clearly highlights the payoff from the research program. The study also shows that varieties developed through hybridization had higher progress than the introduced old varieties and the varieties developed through selection. Therefore, it is more likely that the productivity of groundnut in the future can also be increased by developing varieties using similar approaches.

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Application of Multilevel Logistic Model to Identify Correlates of Poverty in Ethiopia

Teshome Kebede Deressa

Department of Statistics, Haramaya University, P O Box 138, Dire Dawa, Ethiopia
E-mail**:** tashe.zgreat@gmail.com

Abstract: Implementation of multilevel model is becoming a common analytic technique over a wide range of disciplines including social and economic sciences. In this paper, an attempt has been made to assess the application of multilevel logistic model for the purpose of identifying the effect of household characteristics on poverty status in Ethiopia using household income, consumption and expenditure (HICE) survey data of 2011. Households are classified as either poor or non-poor based on the absolute poverty line set at yearly per capita consumption of Birr 3781. Accordingly, the random intercept only model indicates the existence of differences in poverty status among households across regions. The result of random intercept and fixed slope model show that the rates of poverty for households residing in Afar, Somali, SNNP, Benishangul-Gumuz and Gambela regions were higher than the average of all regions, while the rates for households residing in Harari and Addis Ababa regions were low compared to the average of all regions. The random coefficient model showed that the random effects of place of residence vary across regions in explaining poverty status. Further, this model was more appropriate to explain the regional variation than a model with fixed coefficients or empty model with random effects. Thus, researchers should take the advantage of multilevel models to identify correlates of poverty when the data structure is hierarchical like HICE survey.

Keywords: Correlates; Household; Multilevel; Poverty; Region

1. Introduction

The pursuit of a more efficient allocation of relatively scarce resources has led public decision makers in developing countries to a global reconsideration of public expenditure priorities. In this context, the analysis of poverty has always aroused the interest of researchers, public authorities and international organizations. In all economies of the contemporary world, serious objectives and priorities of public decision makers are to fight poverty, to improve the conditions of life for people and to reduce the gap between the social strata.

Poverty has a series of contested definitions and complex arguments that overlap and at times contradict each other. It is differently seen as a big or small phenomenon, as a growing or a declining issue, as an individual or a social problem, as a country or a regional problem and as urban or a rural problem (Chaudhry, 2003). This implies that the depth and dimension of poverty vary according to the country's situation. It is multi-dimensional and has to be looked at through a variety of indicators. Different indicators showed varied levels of poverty status for Ethiopia. For example, the life expectancy at birth in Ethiopia is approximately 54 years, which is substantially lower than the average of 77 and 67 years recorded for countries with high and medium human development indices, respectively (DIFD, 2008). The adult illiteracy rate was around 60 percent which is significantly higher than the average for Sub-Saharan Africa (SSA) and other developing countries. According to human development report in 2009, 38.7% of the total population was below absolute poverty line.

There were 676 maternal deaths for every 100,000 live births in the country (CSA and ICF, 2012). Information obtained from Ethiopian Demographic and Health Survey (EDHS) revealed that under-five mortality decreased from 166 deaths per 1,000 live births in the 2000 to 88 in 2011, while infant mortality decreased from 97 deaths per 1,000 live births in the 2000 to 59 in 2011. On the other hand, even though neonatal mortality rate decreased from 49 deaths per 1,000 live births in 2000 to 39 deaths per 1,000 live births in 2005, it has since then remained stable at 37 deaths per 1,000, as reported in the 2011 EDHS. In 2002, the proportion of population with access to safe and clean water was only 22% and it increased to 54% in 2011 (CSA and ICF, 2012).). The majority of households, 82%, used non-improved toilet facilities (91% in rural areas and 54% in urban areas) which in turn affect the health of the community. Moreover, there were 0.03 physicians per 1,000 people in Ethiopia (World Bank, 2005). Although the average annual growth rate in GDP was 9.5% in 2012/2013, accesses to health services were inadequate for the majority of the population, particularly in rural areas. Besides, women literacy rate has increased from 29% in 2005 to 38% in 2011 (CSA and ICF, 2012).).

Despite the above anomalies, Ethiopia is on the right track to achieve the Millennium Development Goal (MDG) № 1: *Halving Poverty by 2015*. In order to reduce poverty and achieve maximum benefit for the poor, the government of Ethiopia has formulated different poverty reduction strategies including the Growth and Transformation Plan (GTP), which is under implementation to attain rapid and broad-based economic

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growth (MoFED, 2012). However, to achieve the above objectives, it is necessary to have adequate information on the nature and determinants of poverty.

Most studies applied different statistical methods to investigate the correlates of household poverty using a combined data set, i.e. rural and urban settings, and typically at national level without considering the effects at regional and local indicators. However, some authors have pointed out the potential bias associated with this practice. For instance, some variables like asset ownership and other characteristics may exhibit different relationships with wealth at different levels (Vyas and Kumaranayake, 2006; O'Donnell and Van Doorslaer, 2008; Woldehanna, 2008). There are also cases where some variables are relevant in rural settings and not in urban settings and vice versa.

Bogale *et al*. (2005) investigated the determinants of rural poverty in Ethiopia. They used logit model to identify determinants of poverty using one-year rural household survey data collected in three rounds in three districts of Ethiopia. The results indicated that entitlement failures resulted in lack of household resource endowments to crucial assets such as land, human capital and oxen.

Sepahvand (2009), using data from the 1997 Ethiopian Rural Household Survey (ERHS), identified determinants of rural poverty using the Foster-Greer-Thorbecke model (Foster *et al*., 1984). He found that the incidence of rural poverty is high for villages that had less potential for agriculture. Moreover, the study also indicated that age of the household head and size of farmland are directly related to poverty status of households. Furthermore, households headed with less educated member were more vulnerable to incidence of poverty.

Mamo (1997) used multivariate analysis to analyze the determinants of standards of living in Addis Ababa using the first round Ethiopian Urban Household Survey (EUHS) conducted in 1994. He estimated a multinomial logit model to assess the likelihood of being poor using socioeconomic and demographic variables. The author found that education, access to credit, employment status, gender, marital status and food shortage were significant determinants of poverty status.

Generally, most previous studies on the correlates of poverty applied different models using nationally aggregated or to some extent urban/rural disaggregated data. However, given the diverse agro ecological and social setup of the country, application of aggregated data models to assess the status and intensity of poverty has little implication to design and implement sound policies and strategies. This implies the need for applying multilevel models that consider the effect of various regional and local level covariates. The main objective of this study was, therefore, to assess the application of multilevel models in identifying correlates of household poverty in Ethiopia.

2. Source of Data and Methodology

2.1. Source of Data

The 2011 Household Income, Consumption and Expenditure (HICE) survey for Ethiopia was used in this study. The data were collected to provide basic information on the standard of living of households, individuals and the society as a whole in Ethiopia. The survey that covered both rural and urban areas of the country was conducted by the Central Statistical Agency (CSA) in 2010/2011. For the purpose of representative sample selection, the country was divided into three broad categories, i.e., rural, major urban centers and other urban areas. Based on this division, two stage (for rural & major urban) and three stage (for other urban) stratified sampling technique were adopted to select a representative sample. After cleaning the data based on relevant variables, this study used information obtained from a total of 27,833 households.

2.2. Definition of Variables and Working Hypotheses

2.2.1. Dependent Variable

The dependent variable, poverty status of households, is measured based on per capita consumption of households. A household is considered to be poor if its total consumption per capita is below the official poverty line; that is ETB[1] 3781 per year (MoFED, 2012). The variable is, therefore, considered as binary which takes a value of 1 if the household is poor and 0 otherwise.

2.2.2. Independent Variables

Sex: It is widely believed that the gender of the household head significantly influences household poverty, and more specifically households headed by women are poorer than those headed by male**.** For example, Geda *et al* (2005) found that the households headed by males reduce the probability of being poor. This might be expected to be of particular importance in Ethiopia.

Age: Age of a household head is measured in complete years and is treated as a continuous variable. Households, whose heads is in higher age groups significantly lower the possibility of remaining poor (Khalid *et al*., 2005; Meng *et al.,* 2007; Qureshi and Arif, 2001).

Family Size: It is number of household members. It is hypothesized that the larger the household size, the higher the level of poverty incidence, and vice versa (Meng *et al*., 2007).

Dependency Ratio: It is the ratio of the number of family members not in the labor force (young or old) to those in labor force within household. One might expect a high dependency ratio will be associated with greater poverty (Minot and Boulch, 2005).

Employment Status: In order to take into consideration the different employment characteristics of the household

[1] ETB is the monetary unit in Ethiopia.

head, employment is distinguished as a categorical data comprised of the formal sector, informal sector and self-employed. Datt and Jolliffe (1997) found a positive relationship for sectors of employment (being self-employed and employed in formal sector) with per capita consumption. Similar result might be expected in the case of Ethiopia.

Educational Level: Educational attainment of the head of the household also significantly reduces the probability of remaining in the poor group. High educational attainment may imply a greater set of employment opportunities and specifically in the rural context, a better awareness of the full potential of new agricultural technologies and associated agricultural practices (Khalid *et al.*, 2005).

Location of Household: In order to know the importance of place of residence in the poverty status of the household, location dummy (rural/urban) was included.

Landholding: It is a dummy variable which takes a value of 1 if the household owns agricultural land and 0 otherwise. It is hypothesized that ownership of agricultural land has positive effect on pulling a household out of poverty trap.

Region: Ethiopia has nine regions namely: Tigray, Afar, Amhara, Oromiya, Somali, Benishangul-Gumuz, SNNP, Gambela and Harari and two Administrative Cities (Addis Ababa and Dire Dawa). Hence, to compare poverty across administrative regions, the dummies of region were included in the model.

2.3. Model Specification

2.3.1. Poverty Measures

For this research, Foster *et al.* (1984) P_α class of poverty measures were used to aggregate poverty and measure incidence, depth and severity of poverty. The general formula for the FGT class of poverty measures is:

$$P_\alpha = \frac{1}{N}\sum_{i=1}^{q}\left[\frac{z-y_i}{z}\right]^\alpha ; \alpha \geq 0 \qquad (1)$$

where y_i is the ranked welfare indicator (per capita consumption) and z is poverty line. The parameter α is a measure of the sensitivity of the index to poverty and the poverty line . Larger values of α put higher weight on the poverty gaps of the poorest people. By setting $\alpha = 0$, the equation reduces to a headcount index. If $\alpha = 1$, the above equation becomes a poverty gap index, aggregating the proportionate poverty gap, which shows the shortfall of the poor's income from the poverty line, expressed as an average over the whole population. If $\alpha = 2$, the equation indicates the squared poverty gap index, which indicates severity of poverty.

2.3.2 Multilevel Logistic Models

The household data used for this analysis are nested within regions. To avoid bias in the parameter estimates and to estimate the impact of region level variables on the reported poverty status, a multilevel modeling was employed. The multilevel strategy deals with the problem of clustering which arises as a result of the hierarchical nature of the data, and estimates a random effect term which in this paper represents the extent to which poverty status varied across regions (Stephenson, 2009). Since the data were from 11 regions, to analyze such data, Goldstein (1991; 1995) developed the basic (two level) multilevel model for a binary response which is written as follows:

$$y_{ij} = \pi_{ij} + \varepsilon_{ij} \qquad (2)$$

where $\varepsilon_{ij} \sim iid\ N(0,\sigma_\varepsilon^2)$, takes the value 0 or 1 for each household i (0 = non-poor, 1 = poor) in region j, π_{ij} is the probability of being poor for household i in region j and ε_{ij} is a household-level error.

Random Intercept Only Model

The empty two-level model for a dichotomous outcome variable refers to a population of classes (level-two units, i.e. regions) and specifies the probability distribution for class-dependent probabilities without taking further explanatory variables into account. This model only contains random classes and random variation within regions. It can be expressed with logit link function as follows (Snijders and Bosker, 1999).

$$\text{logit}(\pi_{ij}) = \gamma_{00} + u_{0j} \qquad (3)$$

where $u_{0j} \sim iid\ N(0,\tau_{00})$, γ_{00} is the population average of the transformed probabilities and u_{0j} is the random deviation from this average for region j.

Random Intercept and Fixed Slope Model

In the random intercept logistic regression model, the intercept is the only random effect meaning that the regions differ with respect to the average value of the response variable. It represents the heterogeneity between regions in the overall response. The logistic random intercept model expresses the log odds, i.e. the logit of π_{ij}, as a sum of a linear function of the explanatory variables and a random region-dependent deviation u_{0j} . That is,

$$\text{logit}(\pi_{ij}) = \beta_{0j} + \sum_{h=1}^{k}\beta_h x_{hij} \qquad (4)$$

where the intercept term β_{0j} is assumed to vary randomly and is given by the sum of an average intercept γ_{00} and region-dependent deviations u_{0j} . That is,

$$\beta_{0j} = \gamma_{00} + u_{0j} \qquad (5)$$

As a result

$$\text{logit}(\pi_{ij}) = \gamma_{00} + \sum_{h=1}^{k} \beta_{hj} x_{hij} + u_{0j} \quad (6)$$

Note that $\gamma_{00} + \sum_{h=1}^{k} \beta_{h} x_{hij}$ is the fixed part of the model and u_{0j} is called the random part of the model.

The Random Coefficient Model

So far, we have allowed the probability of being poor to vary across regions, but we have assumed that the effects of the explanatory variables are the same for each region. We will now modify this assumption by allowing the difference between explanatory variables within a region to vary across regions. To allow for this effect, we will need to introduce a random coefficient for those explanatory variables. So a random coefficient model represents heterogeneity in relationship between the response and explanatory variables. As mentioned above, the response variable in this study, poverty status was binary. Therefore, the statistical models used in this analysis will be the two-level random coefficient multilevel regression model. The model with *p* household-level predictors and *q* region-level predictors can be expressed as:

$$\text{logit}(\pi_{ij}) = \beta_{0j} + \sum_{h=1}^{p} \beta_{hj} x_{hij} + \sum_{h=1}^{q} u_{hj} x_{hj} \quad (7)$$

where

$\beta_{0j} = \gamma_{00} + u_{0j}$ $\quad i = 1, 2, 3, \ldots n_j; \quad j = 1, 2, 3, \ldots, J$

Now equation (7) can be rewritten as:

$$\text{logit}(\pi_{ij}) = \gamma_{00} + \sum_{h=1}^{p} \beta_{hj} x_{hij} + u_{0j} + \sum_{h=1}^{q} u_{hj} x_{hj} \quad (8)$$

The first part of equation $\gamma_{00} + \sum_{h=1}^{p} \beta_{hj} x_{hij}$ is called the fixed part of the model. The second part $u_{0j} + \sum_{h=1}^{q} u_{hj} x_{hj}$ is called the random part.

The intercept-only model does not explain any variance of the dependent variable. It only decomposes the variance into two independent components: σ_ε^2, which is the variance of the lowest level (household-level) errors ε_{ij}, and τ_{00}, which is the variance of the highest-level (region level) errors u_{0j}. Using this model, we can define the intraclass correlation ρ by the equation:

$$\rho = \frac{\tau_{00}}{\tau_{00} + \sigma_\varepsilon^2} \quad (9)$$

The intraclass correlation indicates the proportion of the variance explained by the grouping structure in the population.

Multilevel Model Selection Criteria

The AIC and the BIC are two common measures for comparing maximum likelihood models. Given two models fit on the same data, the model with the smaller value of the information criterion is considered to be better (Akaike, 1974 and Schwarz, 1978). In this paper these two model selection criteria were used to suggest the best model.

3. Results and Discussion

3.1 Descriptive Statistics Results

As it can be seen from Table 1, out of the total household heads, 31.5% were female headed and the remaining 68.5% were male headed. With respect to poverty status, 77.5% female headed households were categorized under poor and the remaining 22.5% female headed households were belonging to non-poor category. The study also illustrates that 12.84% of urban and 52.95 of rural household heads were below the poverty line, and thus categorized as poor. The proportion of poor rural households were higher than urban.

In terms of education, about 94.2% of the household heads in Ethiopia were literate with different level of schooling, the largest part of the sample population being in primary school. Based on literacy status, non-poor household heads did much better than poor household heads. In each level of schooling, most of the poor households were tend to be lower in number as compared to non-poor households. Similar to the non-poor household heads, most of the poor household heads concentrate in primary school while the number of heads with school levels higher than secondary school was very small.

It can be viewed from Table 1 that the majority of household head respondents (73.10% and 26.90%) were self-employed for both non-poor and poor categories, respectively. Households who owned agricultural land comprises 19.95 % of the poor and 80.89% of the non-poor. Regionally, the distribution of poverty was highest in Afar region (47.9%) followed by Somali region (46.48%) and lowest in Addis Ababa City administration (14.27%).

Table 1. Descriptive results for categorical variables disaggregated by poverty status.

Variable	Categories	Non-poor Count	Non-poor Percent	Poor Count	Poor Percent	Total	χ^2 value
Sex	Male	13334	69.89	5744	30.11	19078	
	Female	6786	77.49	1971	22.51	8757	173.051*
Place of residence	Urban	15264	87.16	2249	12.84	17513	
	Rural	4856	47.05	5466	52.95	10322	5215.804*
Educational level	Illiterate	578	62.02	354	37.98	932	
	Primary School	5699	70.29	2409	29.71	8108	
	Secondary School	2820	81.53	639	18.47	3459	79.857*
	College & above	2904	82.90	599	17.10	3503	
Employment status	Self	11744	73.10	4321	26.90	16065	
	Formal	4721	70.11	2013	29.89	6734	29.187*
	Informal	543	77.02	162	22.98	705	
Landholding	Yes	10680	80.09	2655	19.91	13335	779.152*
	No	9438	65.10	5060	34.90	14498	
Region	Tigray	1597	69.74	693	30.26	2290	
	Afar	697	52.05	642	47.95	1339	
	Amhara	4071	80.42	991	19.58	5062	
	Oromiya	4556	79.23	1194	20.77	5750	
	Somali	920	53.52	799	46.48	1719	
	Benishangul-Gumuz	742	55.83	587	44.17	1329	111.02*
	SNNP	2767	70.50	1158	29.50	3925	
	Gambela	719	53.54	624	46.46	1343	
	Harari	470	70.25	199	29.75	669	
	Addis Ababa	3207	85.73	534	14.27	3741	
	Dire Dawa	373	56.01	293	43.99	666	

** = Significant at 0.05*

The chi-square test result presented in Table 1 was also used to test whether or not there is a significant association between poverty status of household and each predictor variables independently. These tests revealed that all predictor variables showed a significant ($P \leq 0.05$) association with poverty status.

According to the results computed from the data (Table 2), the average age of the poor household heads (44.92 year) was significantly ($P \leq 0.05$) greater than that of the non-poor (40.46 year). However, standard deviation for poor households was relatively higher showing relatively higher dispersion from the mean age. The mean family size of the sample respondent, was found to be 4.74 persons per household. The average family sizes of the sampled poor and non-poor households were 5.77 and 3.71 persons, respectively. It shows that the mean household size of the poor category was greater than the non-poor category. The average dependency ratio for the sample data was computed to be about 81, which indicates that every 100 persons of economically productive age group were responsible to take care of themselves as well as additional 81 persons (children and aged population) based on the survey. The mean dependency ratios for poor and non-poor households were estimated to be 127% and 63.4%, respectively. The survey has also indicated high variation in dependency ratio for poor households than the non-poor (0.994 vs 0.761).

Table 2. Continuous variables disaggregated by poverty status.

Variable	Poverty Status				z/t value
	Non-poor		Poor		
	Mean	St. Dev.	Mean	St. Dev.	
Age	40.46	14.54	44.92	15.94	-71.09*
Family size	3.71	2.200	5.770	2.158	-22.26*
Dependency ratio	0.634	0.761	1.270	0.994	-51.44*

** = Significant at 0.05*

Moreover, the z/t-test was used to know the mean variations between the poor and non-poor in terms of continuous explanatory variables. The analysis of z/t-test also showed that there was a significant ($P \leq 0.05$) statistical difference between poor and non-poor in terms of three variables.

3.2. Poverty Indices

The estimated poverty indices for Ethiopia using HICE survey (2010/2011) were presented in Figure 1. Based on total poverty line, absolute headcount index stood at about 28%, which indicates the percentage of the sampled population who was unable to meet the required minimum amount of 2, 200 kcal per person per day. In other words, this proportion of households could not attain the minimum amount of consumption (ETB 3781) to satisfy the minimum calorie requirement per adult equivalent per year.

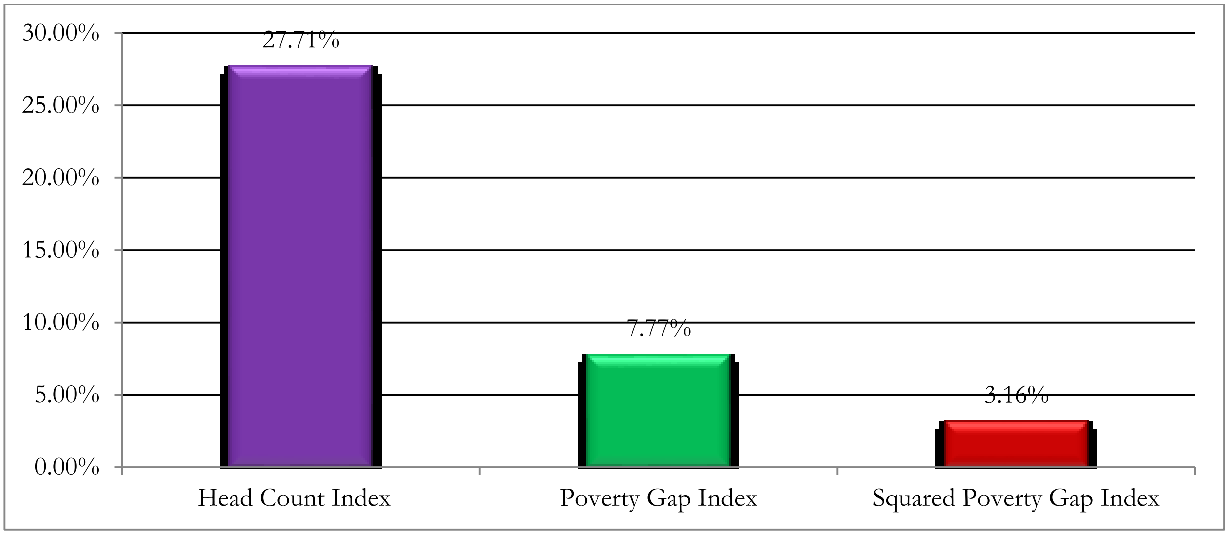

Figure 1: Absolute Poverty Indices in Ethiopia.

The poverty gap index $(\alpha = 1)$ which captures the average proportional shortfall (i.e., the difference between per capita consumption and total poverty line and then divided by the total poverty line) is 7.77%. This means average consumption needed to bring the poor above the poverty line or the minimum level of living is 7.77% of the poverty line. It indicates the percentage of consumption expenditure deficit the poor faces so as to uplift the poor from the poverty line. If one simply adds up the difference between the expenditure measure and poverty line for all those who were below, one would obtain the total cost required to eliminate poverty. Similarly, the squared poverty gap index $(\alpha = 2)$ in consumption expenditure, was 3.16%, which could indicate the severity of poverty by assigning more weight to the poor.

3.3. Intercept Only Model

Is there significant variation in poverty status at household and region level? To answer this question, the intercept-only model was estimated. Table 3 shows the parameter estimate of the average log odds (grand mean log odds) and the variance component. As one can see, the variance component (τ_{00}) is statistically significant suggesting that there was significant variance in poverty status of households at region level. This indicates the multilevel character of household data should not be ignored.

With the existence of hierarchically structured data, applying traditional regression models violates the assumption of independence of observations and increases Type-I error (Kreft & De Leew, 1998). Another way to examine clustered data is to compute intraclass correlation, which is a measure of the degree of dependence of households belonging to the same region. The intraclass correlation can also be interpreted as the fraction of total variability that is due to the region level (Kreft & DeLeew, 1998). When the logistic model is applied, the level-one residuals are assumed to follow the standard logistic distribution, which has a mean of 0 and a variance of $\pi^2 / 3 = 3.26$ (Snijders & Bosker, 1999). Using $\rho = \frac{\tau_{00}}{\tau_{00} + 3.26}$, the intraclass correlation coefficient is 0.146. Where τ_{00} is between region variance and $\sigma_\varepsilon^2 = 3.26$ is within region variance. Thus, about 14.6% of the total variance in poverty status of households is attributed to differences between regions in the country.

Table 3. Intercept Only Model.

Fixed Effect	Coefficient	S.E.
Intercept (γ_{00})	-0.122*	0.007
Random Effect	Var. Comp.	S.E.
Region-level (τ_{00})	0.556*	0.126

** = Significant at 0.05*

3.4 The Random Intercept and Fixed Slope Model

The results of the intercept only model indicate very clearly that there was significant variation in poverty status of household at two levels of analysis. Now we return to the question of whether the model specified in equation (6) can account for this variance. Table 4 below gives the parameter estimates of the fixed effects and the variance component of this multilevel model. From the model estimates $\gamma_{00} = 0.361$ is the expected log-odds of poverty status for an average household. Introducing eight level-1 variables decreased the intraclass correlation to 0.043.

Table 4. The Random Intercept and Fixed Slope Model.

Fixed Effects	Estimate	S.e.	OR
Intercept (γ_{00})	0.361*	0.008	.
Dependency ratio	0.450*	0.034	1.568
Family size	0.376*	0.014	1.456
Age	-0.035*	0.002	0.965
Female	0.471*	0.063	1.601
Rural	0.239*	0.065	1.269
Landholding	-0.990*	0.056	0.372
Primary school complete	-0.588**	0.270	0.555
Secondary school complete	-0.372*	0.094	0.689
College & above	-0.554*	0.070	0.575
Employed in formal sector	-0.295*	0.061	0.744
Self-employee	-0.702*	0.170	0.496
Random Effects	**Random Component**	**S.E.**	
Region level (τ_{00})	0.145*	0.004	

** = Significant at 0.01; ** = Significant at 0.05; S.e = Standard error; OR = Odds ratio*

The variance of random effect of the intercept and fixed slope model (0.145) decreased compared to random effect of the intercept only model (0.556). The reduction of the random effects of the intercept variance is due to the inclusion of fixed explanatory variables. That is, taking into account the fixed independent variables can provide extra predictive value on poverty status in each region. The random intercept $\tau_{00} = 0.145$ (P $\leq$ 0.01) indicates that poverty status differs from region to region in terms of measured covariates (Table 4). This implies that there is still unexplained variation on poverty status across regions.

The fixed part of the model presented in Table 4 reveals that covariates family size, dependency ratio, landholding of household, age, sex (female), type of place of residence (rural), educational attainment and employment status of household head were statistically significant at 5% level of significance. This implies that all variables were correlated with the probability of being poor at household level (level-1) in Ethiopia. For example, the coefficient of family size (0.376) indicates that log of being poor increase by an average of about 0.456 for each increase in household member fixing other covariates. Looking at the results of multilevel logistic regression estimated above (Table 4), the sign for sex (female) of the head was positive and statistically significant at 5% level of significance. The average odd of being poor for female headed households were 1.602 times that for male headed households. Education was grouped into four categories ranging from illiterates to those who have attended higher education (college and above). The odds of being poor with education level of elementary school, secondary school and college and above was found to be 0.555, 0.689 and 0.575 times that of the illiterates (reference category), respectively.

The random intercept and fixed slope multilevel logistic regression model also helps to compare poverty status across regions. The results of this model in Table 5 show the estimated regional random effects of intercept in eleven regions of Ethiopia. Among these regions, the random effect of intercept for poverty status in Afar, Somali, SNNP, Benishangul-Gumuz, Gambela, Harari and Addis Ababa were statistically significant at 5% level of significance. The estimated random regional effects revealed the average poverty status in a particular region.

Table 5. Estimated random effects of intercepts for each region in explaining poverty status.

Effect	Subject	Estimate	S.e.	Z value	P-value	OR
Intercept	Region Tigray	0.306	0.256	1.190	0.2320	1.36
Intercept	Region Afar	0.885	0.212	4.170	0.000*	2.42
Intercept	Region Amhara	-0.204	0.129	-1.580	0.1130	0.82
Intercept	Region Oromiya	-0.007	0.071	0.011	0.9180	0.99
Intercept	Region Somali	0.288	0.067	4.280	0.000*	1.33
Intercept	Region Ben-Gumuz	0.210	0.100	2.040	0.041*	1.23
Intercept	Region SNNP	0.544	0.286	1.990	0.028*	1.72
Intercept	Region Gambela	0.225	0.116	1.935	0.027*	1.25
Intercept	Region Harari	-0.202	0.044	21.59	0.001*	0.82
Intercept	Region Addis Ababa	-0.041	0.003	162.24	0.000*	0.96
Intercept	Region Dire Dawa	-0.047	0.038	1.559	0.2110	0.95

*** = Significant at 0.05; S.e = Standard error; OR = Odds ratio*

The result also depicts that the average poverty status in Afar and SNNP was very high compared to the average of all regions. On the contrary, Harari and Addis Ababa regions had better performance in the average reduction of household poverty compared to the average of all regions as the odds ratio were less than one (Table 5).

3.5. The Random Coefficient Model

So far, we have allowed the probability of being poor to vary across regions, but we have assumed that the effects of the explanatory variables are the same for each region. We will now modify this assumption by allowing the difference between urban and rural areas within a region to vary across regions. To allow for this effect, we will need to introduce a random coefficient for place of residence as one can see in Table 6 below. One can also test the significance of the added parameters, τ_{55} (variance in the slopes of place of residence) and τ_{05} (covariance between region and place of residence), using a Wald test. The test statistic is 39.136, which is approximately Chi-Square distributed with 2 degree of freedom ($P \leq 0.001$).

Table 6. The Random Coefficient Model.

Fixed Effects	Estimate	S.E.
Intercept (γ_{00})	0.361*	0.008
Intercept (γ_{50})	0.240*	0.065
Dependency ratio	0.459*	0.035
Family size	0.369*	0.014
Age	-0.035*	0.002
Female	0.487*	0.063
Landholding	-0.972*	0.057
Primary school complete	-0.476*	0.091
Secondary school complete	-0.611*	0.104
College & above	-0.516*	0.110
Employed in formal sector	-0.302*	0.063
Self-employee	-0.708*	0.174
Random Effects	**Var. Comp.**	**S.E.**
τ_{00} (var. in intercept)	0.0718	0.0046
τ_{55} (var. in area slopes)	0.4731	0 .1135
$\tau_{05} = \tau_{50}$ (covariance)	-0.125	0.0220

** = Significant at 0.05*

At the 5% level of significance, both parameters are non-zero (γ_{00} and γ_{50}), which implies that the effect of place of residence does indeed vary across regions. On average (after adjusting for the other explanatory variables), the log odd of being poor was 0.240 higher for rural areas than for urban areas. Depending on the value of u_{5j}, the difference in a given region can be larger or smaller than 0.240. That means, the average effect of rural is $\gamma_{50} = 0.240$, but the effect for region *j* is $\beta_{5j} = \gamma_{50} + u_{5j} = 0.240 + u_{5j}$, where

$$\begin{bmatrix} u_{0j} \\ u_{5j} \end{bmatrix} \sim N(0, \Omega_u): \ \Omega_u = \begin{bmatrix} \tau_{00} & \tau_{05} \\ \tau_{50} & \tau_{55} \end{bmatrix} = \begin{bmatrix} 0.0718 & -0.125 \\ -0.125 & 0.4731 \end{bmatrix}.$$

For the model specified in Table 6, the residual variance between regions is a function of rural.

$$\mathrm{var}(u_{0j} + \mathrm{rural}\, u_{5j}) = \mathrm{var}(u_{0j}) + 2\, \mathrm{rural}\, \mathrm{cov}(u_{0j}, u_{5j}) + \mathrm{rural}^2 \mathrm{var}(u_{5j})$$

$$= \tau_{00} + 2\, \mathrm{rural}\tau_{05} + \mathrm{rural}^2 \tau_{55}$$

Because rural is a (0, 1) variable, $\mathrm{rural}^2 = \mathrm{rural}$. Thus, the above equation becomes:

$$\mathrm{var}(u_{0j} + \mathrm{rural}\, u_{5j}) = \tau_{00} + (2\,\tau_{05} + \tau_{55})\mathrm{rural}$$

The equation can be more simplified for rural and urban separately. For rural areas (rural = 1).

$$\mathrm{var}(u_{0j} + \mathrm{rural}\, u_{5j}) = \tau_{00} + 2\,\tau_{05} + \tau_{55}$$

$$= 0.0718 + 2(-0.125) + 0.4731 = 0.2949$$

For urban areas (rural = 0), which leads to $\mathrm{var}(u_{0j} + \mathrm{rural}\, u_{5j}) = \tau_{00} = 0.0718$.

Hence, there was greater region level variation in the probability of being poor in rural areas than in urban areas in the country.

Besides, Table 7 shows the cases for the empty model, random intercept and fixed slope model and random coefficient model. Each model had its own AIC and BIC.

Table 7. Model Selection Criteria.

Model	AIC	BIC
Empty Model	20819.56	20836.03
Fixed Slope Model	6083.665	6181.622
Random Coefficient Model	5844.545	5912.723

The AIC and BIC reported were measures of model misfit; when we add explanatory variables to the model, AIC and BIC are expected to go down. After examining each model, the random coefficient model had the lowest value of both criterion (AIC and BIC) since lower values of these statistics indicate a better fitting model by adjusting for the number of explanatory variables. This indicates that the random coefficient model was found to give a better fit as compared to the empty and random intercept and fixed slope model to predict poverty status of household in Ethiopia.

4. Conclusion

Estimates and policy recommendations based on a model without considering the nature and structure of data can be seriously biased. This study attempted to identify the most reliable model among the three multilevel logistic models (the random intercept only, the random intercept and fixed slope and the random coefficient) to analyze poverty when the data contain hierarchical structures. Using data from Ethiopia, the random coefficient model was found to be more appropriate than others to predict poverty status at households' level. This suggests that researchers should consider the nature of hierarchically structured datasets when modeling poverty at household level. Moreover, multivariate analyses techniques which considers the hierarchical nature of the data can be routinely incorporated to obtain better estimates of parameters for policy inputs at various level. Failure to account the hierarchical nature of the data may lead to biased estimate and wrong conclusions.

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Short Communication

Effects of *Leucaena* [*Leucaena leucocephala* (Lam.) de Wit] Leaf Biomass and NP Fertilizer Application on Soil Fertility, *Striga* [*Striga hermonthica* (*Del.*) Benth] Management and Sorghum [*Sorghum bicolor* (L.) Moench] Growth and Yield in Pawe District, Northwestern Ethiopia

Dargo Kebede[1*], Abdu Abdelkadir[2], Zebene Asfaw[2] and Zewge Teklehaimanot[3]

[1]School of Natural Resource Management and Environmental Sciences, Haramaya University, Ethiopia
[2]Wondo Genet College of Forestry and Natural Resources, Shashemene, Ethiopia
[3]School of the Environment and Natural Resources, Bangor University

Abstract: Sorghum production in Pawe District is often constrained by low soil fertility resulting from continuous cropping with minimum or no input which in turn encourages *Striga* infestation. Field experiment was conducted during the 2010 cropping season to investigate the effects of *Leucaena* leaf biomass incorporation and NP fertilizer application on sorghum growth and *Striga* control. Two levels of *Leucaena* leaf biomass (2.5 and 5 t ha^{-1}) were applied with 50% recommended dose of urea (RDU) with or without 50% recommended dose of diammonium phosphate (DAP). The experiment included a standard treatment of 100% recommended dose of fertilizer (RDF i.e. 100 kg urea + 100 kg DAP) and farmers' practice of growing sorghum without any input as a control. The experiment was laid out in a randomized complete block design (RCBD) with three replications. Plots treated with 5 t ha^{-1} *Leucaena* + 50% RDF and 5 t ha^{-1} *Leucaena* + 50% RDU gave significantly higher soil organic carbon (OC), cation exchange capacity (CEC), total N and leaf N content whereas significantly higher available P and plant tissue P content were recorded in the 5 t ha^{-1} *Leucaena* + 50% RDF-treated plots, respectively, over the control plots. Grain yield and aboveground biomass of sorghum were increased by 133 and 123%, and 368 and 385% in the 5 t ha^{-1} *Leucaena* + 50% RDF and 5 t ha^{-1} *Leucaena* + 50% RDU-treated plots, respectively, over the control plots. The number of *Striga* plants at 65 days after sowing (DAS) of sorghum was also reduced by 82.33% and 96.33% in the 5 t ha^{-1} *Leucaena* + 50% RDF and 5 t ha^{-1} *Leucaena* + 50% RDU-treated plots, respectively, over the control plots. Aboveground biomass of *Striga* at 95 DAS decreased by 41.6 and 39.32% in the 5 t ha^{-1} *Leucaena* + 50% RDF and 100% RDF treated plots, respectively, over the control plots. Plots treated with 2.5 t ha^{-1} *Leucaen*a + 50% RDF recorded comparable grain yield (2.160 t ha^{-1}) and even slightly greater sorghum above ground biomass (23.23 t ha^{-1}) than the 100% RDF-treated plots which recorded 2.22 t ha^{-1} of grain yield and 22.66 t ha^{-1} of aboveground biomass, respectively . It is, therefore, concluded that 5 t ha^{-1} *Leucaena* + 50% RDU can be used to improve sorghum productivity and manage *Striga* in the study area. Further research should be conducted across different locations for at least two seasons to substantiate this conclusion considering the cost benefit analysis of the practice.

Keywords: Aboveground Biomass; Grain Yield; Leuceana Leaf Biomass; Striga Infestation

1. Introduction

In Ethiopia**,** sorghum is one of the most widely grown staple cereal crops on which the lives of millions of poor Ethiopians depend. It is one of the leading traditional food crops ranking third in the country following *teff* and maize and second to *teff* for its *injera* (national pancake or bread) making quality (Tewdros *et al*., 2005).

Despite its importance in the livelihood of Ethiopians, sorghum production is constrained by different biotic and abiotic factors. The major sorghum production constraints include low soil fertility, weeds particularly *Striga*, insect mainly stalk borer (*Busseola fusca* and *Chilo partellus*) and birds. The increased land use pressure associated with rapid population growth and continuous cropping with minimum or no inputs is resulting in declining soil fertility. The decline in soil fertility and erratic rainfall favor increased *Striga* [*Striga hermonthica* (Del.) Benth] infestation. *Striga* species are semi-parasitic plants that parasitize the root systems of their hosts; and all *Striga* species except *Striga angustifolia* [Don.] Saldanha are dependent on a host to establish themselves, which makes them obligate parasites (Van Mourik, 2007). *Striga hermonthica* (Del.) Benth is a green erect herb with bright pink flowers and a height of around 30-40 cm at flowering (Van Mourik, 2007). It is thought to have co-evolved with wild relatives of sorghum during domestication in the Sudano-Ethiopian region of Africa (Mohamed *et al*., 1998). It has colonized over 86,000 hectare (h) of Ethiopian cropland resulting in maize yield losses of 76,395 tons (t) per year that is valued at almost $15.8 million per year (Woomer and Savala, 2008).

The presence of this parasitic weed has been assumed by farmers as an indicator of reduced soil fertility conditions (Avav *et al.,* 2009). *Striga* is the second most important sorghum production constraint resulting in yield loss of 560,000 metric tons per year (Wortmann *et al.,* 2006). Therefore, it is becoming a major concern

*Corresponding author. E-mail: dargokebede@gmail.com

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threatening sorghum production in many parts of the country.

Growing of preferred cereals, such as maize and sorghum, without the application of chemical fertilizer is often being abandoned because of severe *Striga* infestation. It is widely accepted that applying nitrogen (N) in a form of fertilizer reduces crop losses attributed to *Striga* (Kim *et al*., 1997). However, in Ethiopia in general and the study area in particular, few farmers have the resource to afford the present escalating price of fertilizer. Applying farmyard manure is also difficult, if not possible, for most resource-poor farmers who own only few or no farm animals. Leguminous trees' leaf biomass is capable of releasing considerable amounts of N that can sustain crop growth and yield (Makumba *et al.,* 2007). The use of N rich tree pruning as a substitute to inorganic fertilizers has proven to be a viable alternative source of soil fertility replenishment in low input smallholder subsistence farming systems where N deficient soils are the major limitation to crop production (Makumba *et al.,* 2007). Esilaba *et al.* (2000) at Sirinka, Ethiopia found that the combined application of manure and N at 40 kg N ha^{-1} and 30 t ha^{-1} for sorghum and 80 kg N ha^{-1} and 30 t ha^{-1} manure for maize increased crop yields during the second season. Moreover, and the combined application of 40 kg N ha^{-1} and 30 t ha^{-1} manure significantly reduced *Striga* emergence on maize. But, resource-poor subsistence farmers in Ethiopia cannot afford applying this much chemical fertilizer and farmyard manure. On the other hand, as indicated by Sharma and Behera, (2010) fast-growing leguminous trees and shrubs such as *Leucaena* are grown in non-agricultural lands or in alley cropping systems for multiple uses including nutrient cycling from the pruned biomass i.e. biomass transfer.

Therefore, in response to the sorghum production challenges highlighted above, there is a need to identify soil management systems which can maintain adequate level of soil fertility, increase crop yield and most importantly reduce the *Striga* seed bank in the soil. Hence, the specific objectives of this study were to: (1) investigate the effect of *Leucaena* leaf biomass and inorganic fertilizer application on soil fertility, and (2) investigate the effect of *Leucaena* leaf biomass and fertilizer application on sorghum growth and yield and *Striga* management.

2. Materials and Methods

2.1. Description of the Study Area

The study was conducted at farmer's crop field near Pawe Agricultural Research Center, northwestern part of Ethiopia during the 2010 cropping season. Pawe Agricultural Research Center is located in Metekel Zone of Benishangul Gumuz National Regional State, at about 580 km north-west of Addis Ababa at 11^{o} 12' N latitude and and 36^{o} 25' E longitude.

The agroecological zone of the study area is characterized by hot humid condition with annual rainfall ranging from 1500 to 1800 mm, the average annual rainfall being 1659 mm concentrated in one season, i.e. from May to October (sometimes extending to November). The mean annual maximum temperature is 32 ^{o}C and monthly values range between 27 and 37 ^{o}C. The mean annual minimum temperature is 16 ^{o}C, and monthly values range between 12 and 19 ^{o}C. The meteorological data for the 2010 cropping season of the study area is given in Table 1.

The soils of the study area are broadly categorized as Vertisols (black clay soils) accounting for 40 to 45% of the area; Nitosols (red or redish-brown laterite soils) accounts for 25 to 30% and Luvisols (intermediate soils of blakish-brown color) accounts for 25 to 30% of the the area (Abayneh, 2003). The pH of the soil at the study area ranges from 5.5 to 6.9 (Abayneh, 2003) (Table 2). The major crops grown in the area include maize, sorghum, finger millet, rice, groundnut and sesame.

Table 1. Monthly rain fall and temperature data of the study area (Pawe District) for the 2010 cropping season (May to December).

		Temperature (^{0}C)	
Month	Rainfall (mm)	Mean minimum.	Mean maximum
May	68.7	21.0	39.2
June	270.3	18.9	30.52
July	440.1	18.5	28.35
August	438.1	18.6	28.1
September	242.4	18.1	28.47
October	185.9	18.3	31.7
November	6.4	15.0	32.23
December	0.0	10.8	33.0
Total	1651.9	-	-
Mean	206.50	17.40	31.45

Table 2. Some soil characteristics of the experimental field in Pawe District before treatment application.

Soil characteristics	Values for each block			
	Block 1	Block 2	Block 3	Mean
Sand (%)	26.04	25.08	13.60	21.57
Silt (%)	22.35	29.44	17.85	23.21
Clay (%)	51.60	45.48	68.55	55.21
Textural class	Clay	Clay	Clay	Clay
pH	6.20	6.57	6.12	6.30
Soil organic carbon (OC) (%)	2.17	1.85	1.86	1.96
Total N (%)	0.175	0.181	0.185	0.18
Cation exchange capacity (CEC) (cmolkg^{-1})	40.00	39.00	45.00	41.33
Available P (mg kg^{-1})	22.00	15.00	16.00	17.67
Exchangeable K (cmolkg^{-1})	1.81	1.56	1.65	1.67
Exchangeable Ca (cmolkg^{-1})	22.00	24.00	22.00	22.67
Exchangeable Mg (cmolkg^{-1})	12.00	9.00	10.00	10.33

2.2. Experimental Design and Procedures

The field experiment was conducted during the 2010 cropping season (from May to December). Six treatments were laid out in a randomized complete block design (RCBD) with three replications. The treatments included: (1) 100% RDF: 100% recomonded dose of fertilizer (100 kg urea with 100 kg of DAP); (2) 2.5 t ha^{-1} + 50% RDF: 2.5 tons of *Leucaena* leaf biomass per hectare with 50% recomonded dose of fertilizer (50 kg of urea and 50 kg of DAP); (3) 2.5 t ha^{-1} + 50% RDU 2.5 tons of *Leucaena* leaf biomass per hectare with 50 % recommended dose of urea ; (4) 5 t ha^{-1} + 50% RDF: 5 tons of *Leucaena* leaf biomass per hectare with 50% recomonded dose of fertilizer (50 kg urea with 50 kg of DAP); and (5) 5 t ha^{-1} *Leucaena* + 50% RDU: 5 tons of *Leucaena* leaf biomass per hectare with 50% recomonded dose of urea, and (6) Control: farmers' practice i.e. production of sorghum without fertilizer and *Leucaena* leaf biomass application.

Fresh leaves of *Leucaen*a were collected from locally grown trees (trees around homesteads) and transferred to the experimental plots. The applied fresh *Leucaena* leaf biomass had 4.5% N, 1.04% phosphorus, 0.95% potassium, 1.91% calcium, 0.52% magnesium and C: N ratio of 16.45. The leaf biomass was applied in splits i.e. one half one month before planting the crop and the remaining half does at planting as suggested by Kurdali and Al-Shamma'a (2010), and it was incorporated in to the soil using hand hoe. The leaf biomass was evenly applied so to avoid biasness.

Each experimental plot was 4 m x 4 m (16 m^2) in size and there was 1 m space between plots. There was a 2 m disatnce between blocks. A land race sorghum variety locally known as "Nech Bove" was used as test crop. The variety was selected due to its sensitiveness to *Striga* infestation, and is widely grown in the district due to its high grain yielding potential relative to other varieties. The crop was planted on 15th June, 2010 spaced 0.75 m apart with 0.25 m spacing between plants within each row. There were five rows of sorghum per plot. Data on sorghum leaf nutrient content, growth parameters, grain yield and aboveground biomass, striga counts and above ground biomass were taken from the middle three rows or the net plot area of 2.5 m x 2.5 m (6.25 m^2). All weedy species except *Striga* were removed regularly once a week so as to avoid the effect of other weeds on sorghum growth.

2.3. Soil Sampling and Analysis

The soil and plant tissue analyses were conducted at Water Works Design and Supervision Enterprise in Addis Ababa, Ethiopia. Soil samples were taken from the upper (0-30 cm) soil depth at five spots spots in an X design in each block using auger prior to the application of *Leucaena* leaf biomas mulch to get a composite sample that could represent the block. More over, soil samples were taken using the same method as indicated above from each treatment plot in the block after the crop was harvested and mixed to make composite samples for each treatment. The samples were then air-dried at room temperature, crushed and sieved through a 2 mm mesh for analysis.

Soil texture was determined by Bouyocous hydrometer method (Ryan *et al.*, 2001) and soil pH by pH meter in a 1:2.5 soil suspension (W/V). Soil OC (%) was determined using a Walkley-Black Method as described in (Nelson and Sommers, 1982) and sodium acetate for extraction and CEC was determined using flame photometer as described by van Reeuwijk (2002). Total N was determined using Kjeldhal method as stated in Baker and Thompson (1992) and available phosphorus was determined using Olsen method as described by Ryan *et al.* (2001). The amount of available K was determined using flame photometer; whereas exchangeable bases (Ca and Mg) in the NH_4OAc extract were determined using atomic absorption spectrophotometer as stated by van Reeuwijk (2002).

2.4 Leaf Tissue Sampling and Analysis

Leucaena leaf sub-samples were collected for nutrient content determination before the leaf biomass was soil-incorporated. Sorghum leaf tissue samples were collected at random from the second top leaf of the plant at heading stage as recommended by Jones *et al.* (1991) and Reuter and Robinson (1986). The leaf tissue samples were washed with distilled water to remove any adhering particles and dried in oven at 65 ^oC for 48 hours. The samples were then finely ground and made ready for analysis using wet ashing with concentrated H_2SO_4 and H_2O_2 for N while dry ashing was used for P, K, Ca and Mg using hydrochloric acid as stated by Nathan and Sun (2006).

The leaf N content was determined using Kjeldahl method as stated in Baker and Thompson (1992), P content was determined using colorimetry as stated by Moore (1992), K was determined using flame photometer; while atomic absorption spectrophotometry was used for the determination of Ca and Mg as stated by Nathan and Sun (2006).

2.5 Sorghum Growth Parameters

The parameters measured as sorghum growth components included: plant height (m), stalk diameter (cm) and number of effective tillers. All measurements on the above mentioned parameters were made on the same five randomly selected plants from the net plot area of each treatment. Grain was harvested from all plants in the net plot of 2.5 * 2.5 (6.25 m^2). The collected air-dried heads were threshed, cleaned and weighed for grain weight analysis. The aboveground biomass (t ha^{-1}) was estimated based on air-dried sub-sample plant biomass in each net plot. The percenatage (%) relative yield and aboveground biomass increament (%) over the control (check) ware then determined.

2.6 Parameters for *Striga*

Number of *Striga* shoots that emerged per net plot was recorded at 65 DAS (vegetative stage) and 95 DAS (heading stages) of sorghum. The first *Striga* count was taken at 65 DAS of sorghum where the maximum number of *Striga* emergence could be observed at 60-70 DAS (Kim, 1994). The secound count was made at 95 DAS of sorghum to see the trend of *Striga* infesstation. Similarly, the above-ground biomass of *Striga* was determined from the same net plot area. The *Striga* shoots collected from the net plot area at 95 DAS were sun dried in the field for four days until constant weight was attained and the dry weight was converted to hectare basis.

2.7 Data Analysis

To reduce variation in the results of effective number of sorghum tillers and *Striga* count; and make data analysis valid, the data were transformed using square root transformation ($\sqrt{x+0.5}$).

All data collected were subjected to analysis of variance (ANOVA) to assess treatment effects (Gomez and Gomez, 1984) and the significant differences between means were determined by LSD at 5% probability level using SAS version 9.

3. Results and Discussion

3.1. Soil Fertility Status of the Experimental Plots after Sorghum Harvest

Soil organic carbon (%), total N (%), CEC (cmol kg^{-1}), and exchangeable Mg (cmol kg^{-1}) showed increments in the plots treated with 5 t ha^{-1} *Leucaena* leaf biomass either with 50% RDF or with 50% RDU as compared to the control (Table 3). Significantly higher OC (2.87 and 2.75%), CEC (52.85 and 51.29 cmol kg^{-1}) and total N (0.214 and 0.209%) were recorded in the plots treated with 5 t ha^{-1} + 50% RDF and 5 t ha^{-1} + 50% RDU, respectively. Relative to the control plots, the 5 t ha^{-1} *Leucaena* + 50% RDF and 5 t ha^{-1} *Leucaena* + 50% RDU-treated plots increased OC by 52.66 and 46.28% and total N by 50%, respectively.

Hossain *et al.* (2007) also found highest OC (%) and total N (%) in the 5 t ha^{-1} *Leucaena* leaf green manure treated plots 105 days after incorporation as compared to green manure from *Erythrina orientalis, Acacia auriculiformis, Dalbergia sissoo* and the control (no green manure) plot. The results of this study also support the conclusion made by Kang *et al.* (1985) that large amounts of N could be obtained from *Leucaena* pruning. This was due to the high N content of the applied *Leucaena* leaf biomass.

CEC, that is the ability of the soil to adsorb (hold) cations, and which is an indication of the soils potential fertility, was significantly ($P < 0.05$) higher in plots treated with 2.5 t ha^{-1} *Leucaena* + 50% RDF, 5 t ha^{-1} *Leucaena* + 50% RDF or 5 t ha^{-1} *Leucaena* + 50% RDU than both the 100% RDF-treated and the control plots. Significantly higher ($P < 0.05$) exchangeable Mg (17.05 cmol kg^{-1}) was recorded in the 5 t ha^{-1} *Leucaena* + 50% RDU-treated plots. But, there was no significant difference in available K (mg K Kg^{-1}) and exchangeable Ca (cmol kg^{-1}) among treatment means.

There was very high variation in available P among treatments. Available P (30.86 mg P Kg^{-1}) recorded in the 5 t ha^{-1} *Leucaena* + 50% RDF-treated plots was considerably greater by 901.95% than the available P (3.08 mg P Kg^{-1}) recorded in the the control plot. The result of the present study was in line with Larbi *et al.* (1993) who reported that available P tended to increase with increasing proportion of prunning applied as mulch. However, the current finding contracdts with the finding reported by Atta-Krah (1990) and Haggar (1994) who indicated that lower soil P was recorded in plots treated with *Leucaena* leaf mulch than the conventional cropping system. This may be due to the released P was fixed by clay colloids.

3.2. Sorghum Leaf Nutrient Content

The highest leaf N content (3.35%) was recorded in 5 t ha^{-1} *Leucaena* + 50% RDU-treated plots and the lowest (2.44%) was in the control plots (Table 4). There was an increment by 37.29% in leaf N content in the 5 t ha^{-1} *Leucaena* + 50% RDU-treated plots over the control plots. The results of the present study were in agreement with the findings reported by Cox and Unruh (2000). According to Cox and Unruh (2000), leaf N content recorded in the plots treated with 100% RDF, 2.5 t ha^{-1} *Leucaena* + 50% RDF and 5 t ha^{-1} *Leucaena* + 50% RDU falls in the sufficient range (2.5-4.0) at flowering (heading stage) of sorghum, whereas leaf N content at this growth stage in the control plots was in the deficient range (2.4%).

The highest (1.55%) leaf P content was recorded in the plots treated with 5 t ha^{-1} *Leucaena* + 50% RDF, while the lowest leaf P content (0.76%) was recorded in the control plots. This shows that plots treated with 5 t ha^{-1} *Leucaena* + 50% RDF increased leaf P content by 103.95% over the control plots. Despite the significant difference (P < 0.05) among treatments in leaf P content at flowering of sorghum, the values recorded in all treatments were in the high range (> 0.5%) (Cox and Unruh, 2000).

Table 3. Soil fertility status of experimental plots as influenced by *Leucaena* leaf biomass and fertilizer application in Pawe in 2010.

Treatment	OC (%)	CEC(cmolkg^{-1})	Total N (%)	A.P (mg P Kg^{-1})	A.K (mg K Kg^{-1})	Ex.Ca (cmolkg^{-1})	Ex.Mg (cmolkg^{-1})
1) 100%RDF	2.06^{bc}	43.26^{bc}	0.16^{bc}	21.77^{ba}	259.5^{a}	18.89^{a}	10.04^{bc}
2) 2.5 t ha^{-1} + 50% RDF	2.64^{ba}	50.59^{a}	0.18^{ba}	14.56^{ba}	253^{a}	19.91^{a}	13.67^{ba}
3) 2.5 t ha^{-1} + 50% RDU	2.56^{ba}	47.37^{ba}	0.18^{ba}	5.17b^{a}	110.8^{a}	20.51^{a}	14.02^{ba}
4) 5 t ha^{-1}+ 50% RDF	2.75^{a}	52.85^{a}	0.214^{a}	30.86^{a}	253.6^{a}	21.28^{a}	15.53^{a}
5) 5 t ha^{-1}+ 50% RDU	2.87^{a}	51.29^{a}	0.219^{a}	18.80^{ba}	125.1^{a}	21.73^{a}	17.05^{a}
6) Control	1.88^{c}	38.67^{c}	0.140^{c}	3.08^{b}	97.8^{a}	19.56^{a}	8.39^{c}
CV(%)	13.31	11.83	7.36	13.23	15.65	9.48	18.48
LSD (0.05)	0.59	6.34	0.04	26.13	NS	NS	NS

Values along column followed by the same letter (s) are not significantly different (P < 0.05); OC = Soil organic carbon; A.P = Available P; A.K= Available K; Ex.Ca = Exchangeable; Ca; Ex. Mg = Exchangeable Mg,

Table 4. Leaf nutrient content (%) of sorghum at 95 DAS (heading stage) as influenced by *Leucaena* leaf biomass and fertilizer application in Pawe in 2010.

	Leaf nutrient content (%)				
Treatment	N	P	K	Ca	Mg
1) 100% RDF	2.73^{bc}	1.28^{b}	0.78^{a}	1.80^{a}	0.56^{a}
2) 2.5 t ha^{-1} + 50% RDF	2.81^{bc}	1.22^{bc}	0.75^{a}	1.63^{a}	0.58^{a}
3) 2.5 t ha^{-1} + 50% RDU	2.73^{bc}	1.01^{dc}	0.62^{a}	1.57^{a}	0.47^{a}
4) 5 t ha^{-1} + 50% RDF	3.01^{ab}	1.55^{a}	0.62^{a}	1.45^{a}	0.61^{a}
5) 5 t ha^{-1} + 50% RDU	3.35^{a}	1.25^{bc}	0.85^{a}	1.45^{a}	0.52^{a}
6) Control	2.44^{c}	0.76^{d}	1.21^{a}	1.85^{a}	0.47^{a}
CV(%)	9.35	33.63	23.08	23.12	18.94
LSD (0.05)	0.484	0.26	NS	NS	NS

Note:Values along column followed by the same letter (s) are not significantly different (P < 0.05.

However, no significant difference was recorded between treatments in leaf K, Ca and Mg (%) content of sorghum among treatments. The recorded leaf K content was at the deficient level (< 1.4%) according to Cox and Unruh (2000) in all treatments with slight difference among means whereas sorghum leaf Ca content was in the high range (> 0.6%) in all treatments. Leaf Mg content recorded in the plots treated with 2.5 t ha^{-1} *Leucaena* + 50% RDU and the control plots was in the sufficient range (0.2 to 0.5 %) where as it was in the high range (> 0.5%) in the 100% RDF, 2.5 t ha^{-1} *Leucaena* + 50% RDF, 5 t ha^{-1} *Leucaena* + 50% RDF and 5 t ha^{-1} *Leucaena* + 50% RDU-treated plots (Cox and Unruh, 2000).

3.3. Growth Parameters of Sorghum

The data on plant height, stalk diameter and number of effective tillers per plant showed significant differences (P ≤ 0.05) among treatments (Table 5). Plant height and stalk diameter increased with increase in *Leucaena* leaf biomass level. The tallest plant height of 3.58 and 3.54 m were recorded in plots treated with 5 t ha^{-1} *Leucaena* + 50% RDF and 5 t ha^{-1} *Leucaena* + 50%

RDU, respectively, as compared to 3.15 m in the 100% RDF-treated plots and 2.10 m in the control plots.

Though the difference was not significant among the treatments except the control, the thickest stalk diameter was recorded in plots treated with 5 t ha^{-1} *Leucaena* + 50% RDU (2.89 cm) and 5 t ha^{-1} *Leucaena* + 50% RDF (2.88 cm). However, there was significant difference (P < 0.05) in number of effective tillers per plant among treatments. Plots treated with 5 t ha^{-1} *Leucaena* + 50% RDF and 5 t ha^{-1} *Leucaena* + 50% RDU produced significantly higher average number of effective tillers of 1.33 and 1.56, respectively, than the control plots (0.71).

Table 5. Plant height, stalk diameter and number of effective tillers as influenced by *Leucaena* leaf biomass and fertilizer application.

Treatment	Height (m)	Stalk diameter (cm)	No. of effective tillers/plant
1) 100% RDF	3.15^{cd}	2.66^{a}	$0.88(0.33)^{cd}$
2) 2.5 t ha^{-1} + 50% RDF	3.34^{bc}	2.76^{a}	$1.16\ (0.89)^{b}$
3) 2.5 t ha^{-1} + 50% RDU	3.11^{d}	2.70^{a}	$0.99(0.56)^{cb}$
4) 5 t ha^{-1} + 50% RDF	3.58^{a}	2.88^{a}	$1.332(1.333)^{a}$
5) 5 t ha^{-1} + 50% RDU	3.54^{ab}	2.89^{a}	$1.4(1.56)^{a}$
6) Control	2.10^{e}	1.80^{b}	$0.71(0)^{d}$
CV(%)	6.89	10.05	25.5
LSD (0.05)	0.15	0.25	0.16

Values along column followed by the same letter (s) are not significantly different (P < 0.05); Numbers in the parenthesis are original data (data before square root transformatio

Hossain *et al.* (2007) also found tallest rice plant height and the greatest number of effective tillers per hill from plots treated with *Leucaena* leaf green manure compared to plots treated with green manure from *Erythrina orientalis, Acacia auriculiformis, Dalbergia sissoo* and the control (no green manure). Similarly, Latt *et al.* (2009) found significantly higher plant height and tiller number of rice in green manure treatments than those in the urea and no application treatments. The vigorous growth of sorghum in the 5 t ha^{-1} *Leucaena* + 50% RDF and 5 t ha^{-1} + 50% RDU-treated plots which resulted in the tallest plants, thickest stalk diameter and highest average number effective tillers might be attributable to the highest OC and total N content (Hossain *et al.,* 2007; Latt *et al.,* 2009).

3.4. Sorghum Grain Yield and Aboveground Biomass

Grain yield differed significantly (P < 0.05) with treatment difference (Table 6). Applications of 5t ha^{-1} *Leucaena* + 50% RDU and 5 t ha^{-1} *Leucaena* + 50% RDF gave significantly higher (P < 0.05) grain yield of 2.65 t ha^{-1} and 2.54 t ha^{-1}, respectively, than the control (1.12 t ha^{-1}) and 100% RDF-treated plots (2.22 t ha^{-1}). The pronounced response of sorghum grain yield and aboveground biomass to the application of 5 t ha^{-1} *Leucaena* + 50% RDF and 5 t ha^{-1} *Leucaena* + 50% RDU; and the comparable grain yield and aboveground biomass obtained from plots treated with 2.5 t ha^{-1} *Leucaena* + 50% RDF with the 100% RDF contradicts the investigation of Nyathi and Campbell (1995) who elucidated that *Leucaena* which is reach in N but low in P, resulted in largest yield reduction, assuming that this material resulted in P immobilization.

However, the current finding is in line with the findings reported by Hossain *et al.* (2007). The authors reported that application of tree litter of different species had a significantly positive effect on the yield parameters of rice. They concluded that it is worthy to note that addition of tree litter to inorganic fertilizer produced significantly higher yield than inorganic fertilizers solely. From their experiment grain yield of plots treated with *Leucaena* resulted in yield increment over the control plots (plots treated with recommended dose of inorganic fertilizer) by 39.6%. This indicates that there is a possibility of replacing the expensive commercial fertilizers by the locally produced fertility enhancing green manure sources to improve productivity and gain yields from maize-based cropping systems. Nahar *et al.* (1996) also found higher rice grain yield from *Leucaena* leaf green manure-treated plots than plots applied solely with chemical fertilizer. Furthermore, Sharama and Behera (2010) found near maximum wheat grain yield when equal amounts of N were substituted through use of *Leucaena* and urea.

In a similar trend to the grain yield, aboveground biomass of sorghum also showed high variation among treatments (Table 6). Application of 5 t ha^{-1} *Leucaena* + 50% RDU and 5 t ha^{-1} *Leucaena* + 50% RDF, which yielded 42.81 and 41.45 t ha^{-1}, respectively, also resulted in a 385.3 and 368.94% increment, respectively, over the control plots (Figure 1). Plots treated with 5 t ha^{-1} *Leucaena* + 50% RDU and 5 t ha^{-1} *Leucaena* + 50% RDF produced significantly (P < 0.05) higher aboveground biomass even than the 100% RDF-treated plots. Aboveground biomass of sorghum increased by 385.3% in the 5 t ha^{-1} *Leucaena* + 50% RDU-treated plots followed by a 368.94% increment in the 5 t ha^{-1} *Leucaena* + 50% RDU-treated plots over the control plots (Figure 1). This could be attributed to the improvement in plant height, stem diameter and number of effective tillers due to the beneficial effect of *Leucaena* leaf biomass addition as also reported by Latt *et al.* (2009). The increment in grain yield and above-ground biomass of sorghum seemed to benefit from *Leucaena* leaf biomass addition that has contributed significantly to the N and P nutrition of the crop.

Table 6. Effect of *Leucaena* leaf biomass and fertilizer application on sorghum grain yield and aboveground biomass.

Treatment	Grain yield (t ha^{-1})	Aboveground biomass (t ha^{-1})
1) 100% RDF	2.22^{b}	22.66^{b}
2) 2.5 t ha^{-1} + 50% RDF	2.16^{b}	23.23^{b}
3) 2.5 t ha^{-1} + 50% RDU	2.01^{c}	17.93^{c}
4) 5 t ha^{-1} + 50% RDF	2.54^{a}	30.95^{a}
5) 5 t ha^{-1} + 50% RDU	2.65^{a}	32.03^{a}
6) Control	1.12^{d}	6.60d
CV (%)	7.26	11.29
LSD (0.05)	1.4	4.03

Values along column followed by the same letter(s) are not significantly different (P < 0.05).

3.5. Number and Aboveground Biomass of Striga

Striga number per plot showed significant differences (P < 0.05) among treatments (Table 7). The number of Striga per plot was highest in the control (9/plot) and lowest in the 2.5 t ha^{-1} *Leucaena* + 50% RDU, 5t ha^{-1} *Leucaena* + 50% RDF and 5 t ha^{-1} *Leucaena* + 50% RDU- treated plots each producing one per plot at 65 DAS (vegetative stage). This agrees with the findings reported by Avav *et al.* (2009) that the highest numbers of Striga stands emerged in plots that had neither mucuna leaf biomass nor fertilizer. The highest number of Striga in the control plots at 65 DAS agrees with the discussion made by Gurney *et al.* (1999) that early infestation by Striga had more negative effect on the host plant than late infestation. Gacheru and Rao (2001) also found lowest Striga infestation when 120 kg N was applied with or without P using fresh foliage of 5 t (dry weight) ha^{-1}.

However, at the later growth stages of sorghum (heading stage) the number of *Striga* significantly (P < 0.05) increased in the 5 t ha^{-1} *Leucaena* +50% RDF and 5 t ha^{-1} *Leucaena* +50% RDU-treated plots even were greater than in the control plots (Table 7). Esilaba *et al.* (2000) also found that addition of fertilizer N increased the mean *Striga* emergence on sorghum. They suggested that the later increase in *Striga* emergence may be related to production of a more extensive sorghum root system which increased the root surface area and thus stimulated emergence of the parasitic weed population. The vigorous growth of sorghum in the 5 t ha^{-1} *Leucaena* + 50% RDF and 5 t ha^{-1} *Leucaena* + 50% RDU-treated plots in this study also implies an extensive root growth and increased root surface area of sorghum attributed to improved OC, total N and available P. Despite the highest number in the later growth stages, the growth of *Striga* at these plots was highly suppressed by the shade created by the vigorous growth of sorghum. This agrees with the findings reported by Kureh *et al.* (2003) that N-fertilizer delayed *Striga* emergence, promoted maize growth and shoot dry matter production and reduced *Striga* damage.

Dry weight of *Striga* was also significantly (P < 0.05) influenced by the different treatments. Plots treated with 5 t ha^{-1} *Leucaena* +50% RDF gave the lowest *Striga* dry weight (1.99 t ha^{-1}), followed by plots treated with 100% RDF (2.062 t ha^{-1}) (Table7). Significantly higher (P < 0.05) *Striga* dry weight was recorded in the control plots. The reduction (by 41.72%) in *Striga* infestation level in aboveground biomass was recorded in the plots treated with 5 t ha^{-1} *Leucaena* + 50% RDF, followed by a 38.72 and 37.54% reduction in the plots treated with 100% RDF and 5 t ha^{-1} *Leucaena* + 50% RDU-treated plots, respectively (Table 7). This indicates that application of *Leucaena* leaf biomass and fertilizer had resulted in the impediment of *Striga* germination during the vegetative growth (early growth) stage of sorghum. This could be attributed to the N released from the applied *Leucaena* leaf biomass and fertilizer during the active growth stage of sorghum which enabled the crop to uptake nutrients for its robust growth. This, in turn, implies that much of the nutrient released from the added *Leucaena* leaf biomass and fertilizer was utilized by the crop in its active (vegetative) growth stage.

Table 7. Effect of *Leucaena* leaf biomass and fertilizer application on *Striga* infestation in number at 65 and 95 DAS of sorghum and aboveground biomass at 95 DAS.

Treatment	Number of *Striga* per plot (6.25 m^2)		*Striga* above ground biomass (t ha^{-1})
	At 65 DAS (vegetative stage)	At 95 DAS (heading stage)	
1) 100% RDF	$1.39(1.78)^{b}$	$6.74(49.67)^{d}$	2.06^{bc}
2) 2.5 t ha^{-1} + 50% RDF	$1.44(3.44)^{b}$	$7.32(61.55)^{dc}$	2.24^{bc}
3) 2.5 t ha^{-1} + 50% RDU	$0.98(0.67)^{b}$	$7.55(64)^{bdc}$	2.40^{b}
4) 5 t ha^{-1} + 50% RDF	$0.88(0.33)^{b}$	$8.99(91.44)^{a}$	1.99^{c}
5) 5 t ha^{-1} + 50% RDU	$0.88(0.33)^{b}$	$8.90(90.55)^{ba}$	2.13^{bc}
6) Control	$3.25(9.22)^{a}$	$8.12(70.78)^{bac}$	3.41a
CV (%)	24.74	17.80	19.06
LSD(0.05)	0.67	1.38	0.34

Values along column followed by the same letter (s) are not significantly different ($P < 0.05$); Numbers in the parenthesis are original data (data before square root transformation).

4. Conclusions

The findings revealed that application of 5 tons of *Leucaena* leaf biomass either with 50% RDF or with 50% RDU resulted in significantly ($P < 0.05$) higher % OC, total N content and CEC than both the 100% RDF and control plots. Available P was highest in the 5 t ha^{-1} *Leucaena* + 50% RDF-treated plots, followed by the 100% RDF-treated plots as compared to any other plots. The improvement in these soil fertility parameters resulted in significantly ($P < 0.05$) taller plant height, higher stalk diameter, maximum average number of effective tillers and, which in turn, ultimately resulted in significantly ($P < 0.05$) higher grain yield and above ground biomass of sorghum than in the control plots. Similarly, application of *Leucaena* leaf biomass and fertilizer could delay *Striga* germination.

Therefore, we can conclude that application of *Leucaena* leaf biomass at 2.5 t ha^{-1} with 50% RDF and 5 t ha^{-1} either with 50% RDF or with 50% RDU can substitute the 100% RDF to improve sorghum productivity and manage *Striga*.

Hence, it is recommended that (1) application of *Leucaena* leaf biomass with fertilizer should be considered as one option to improve soil fertility, increase sorghum productivity and manage *Striga* in Pawe District; (2) since this study was conducted for a single cropping season, further research should be done for more cropping seasons to substantiate these findings; and (3) further investigation should also be done to determine the long term effect of applying *Leucaena* leaf biomass in terms of soil fertility improvement, crop productivity and soil *Striga* seed bank and *Striga* management considering cost-benefit analysis over the chemical fertilizer in the study area.

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Registrations of *Korme* and *Katta* Soybean [*Glycine max* (L.) Merr.] Varieties

Abeya Temesgen*, Chemeda Daba, Tadesse Birhanu, Dagnachew Lule, Teshome Bogale and Kebede Desslgne

Bako Agricultural Research Center, P O Box 03, Bako, Ethiopia

Abstract: *Korme* and *Katta* soybean [*Glycine max* (L.) Merr.] varieties are with pedigree of AGS-129-2 and PR-145-2, respectively. These varieties were tested and released by the Bako Agricultural Research Center for Western Ethiopia and similar agro-ecological zones. *Korme* and *Katta* were evaluated for seed yield, agronomic characters and disease reaction at Bako, Boshe and Gute experimental sites between the years 2007/2008 and 2009/2010. The oil and protein contents of the two varieties were also tested. *Korme* and *Katta* soybean varieties were released because of their better seed yields as well as oil and protein contents compared to the commercial soybean variety of the same maturity group i.e. medium set. *Korme* and *Katta* were resistant to bacterial blight and bacterial pustule. The result of multi-environment yield trials showed that *Korme* and *Katta* have outperformed the commercial variety, Ethio-yogozlavia by 15 and 14% at on station and by 20 and 14% at on-farm in seed yield, respectively. The stability analysis showed that *Korme* and *Katta* were more ideal and stable in grain yield performance than Ethio-yogozlavia.

Keywords: Commercial Variety; Soybean; Stability; Pedigree

1. Introduction

Korme and *Katta* are common names for soybean [*Glycine max* (L.) Merr.] **v**arieties. These varieties were tested across multi environments (locations and years). Results from multi-location yield trials revealed that *Korme* and *Katta* were found to be superior and stable in seed yield and quality traits than the commercial variety viz., Ethio-yogozlavia. In addition, *Korme* and *Katta* varieties are resistant to bacterial blight and bacterial pustule. Hence, *Korme* and *Katta* varieties were released by the Bako Agricultural Research Center for Western Ethiopia and similar agro-ecological zones.

2. Origin and Pedigree

Korme and *Katta* soybean varieties are with pedigree of AGS-129-2 and PR-145-2, respectively. The genotypes were introduced from the International Institute for Tropical Agriculture (IITA).

3. Morphological Description

Korme and *Katta* are similar in seed shape (round), seed coat color (yellow) and seed coat luster (dull). Both are indeterminate and have erected growth habit, which enable them to prevent from pod rot during heavy rain fall. *Korme* and *Katta* have large seed size compared to the commercial variety, Ethio-yogozlavia (Table 1). Their leaf size is large and more uniform. Both are suitable for intercropping with high yielding erected leaf type maize hybrids such as BH661 and BH543.

4. Phenological Description

On three locations (Bako, Boshe and Gute) and two years (2008/2009 and 2009/2010) mean basis, *Korme* and *Katta* flowered in 64 days and matured in 137 and 138 days, respectively.

5. Agronomic Description

Korme and *Katta* were heavier than the standard check, Ethio-yogozlavia, in terms of seed weight (Table 1). *Katta* has better pod load than *Korme*. The average seeds per plant for both *Korme* and *Katta* are comparable (Table 1).

6. Yield Performance

Korme and *Katta* soybean varieties were evaluated with standard check, in multi-locations yield trials. *Korme* gave a seed yield ranging from 1.2 to 3.8 t ha^{-1} on research stations and 1.2 to 3.2 t ha^{-1} on farmers' fields (Table 1). Similarly *Katta* gave a seed yield ranging from 1.4 to 3.2 t ha^{-1} on research stations and 1.3 to 2.8 t ha^{-1} on farmers' fields (Table 1). *Korme* and *Katta* have outperformed *Ethio-yogozlavia* by 15 and 14% on station and by 20 and 14% on-farm in seed yield, respectively.

*Corresponding author. Email: abeya.tefera@uqconnect.edu.au

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Table 1. Summary of mean grain yield and other data of *Korme* (AGR-129-2), *Katta* (PR-145-2) and commercial variety (*Ethio-yogozlavia*) across years and locations.

Characteristics	*Korme* (AGS-129-2)	*Katta* (PR-145-2)	*Ehio-yogozlavia*
Adaptation area			
Altitude (masl)	1200-1900	1200-1900	1200-1900
Rainfall (mm)	1000-1200	1000-1200	1000-1200
Fertilizer rate			
P_2O_5 (kg ha^{-1})	46	46	46
N (kg ha^{-1})	18	18	18
Fertilizer application time	At sowing	At sowing	At sowing
Fertilizer application method	Side dressing, avoid seed contact	Side dressing, avoid seed contact	Side dressing, avoid seed contact
Planting and Seeding:			
Planting date	Early June	Early June	Early June
Seed rate (kg ha^{-1}):	60-75	60-75	60-75
Row spacing (cm)	60	5	5
Plant spacing (cm)	60	5	5
Weeding frequency	3-4	3-4	3-4
Days to flowering	64	64	63
Days to maturity	137	138	138
Number of pods per plant	29	33	33
Number of seeds per plant	49	53	52
Leaf size	Large	Large	Large
Growth habit	Indeterminate	Indeterminate	Indeterminate
Seed coat color	Yellow	Yellow	Yellow
Seed coat luster	Dull	Dull	Dull
Helium color	White	White	Black
Seed shape	Round	Round	Round
300 seed weight (g)	45	46	38
Oil content	20.53	18.82	17
Protein content	39.33	38.73	36
Crop pest reaction (1-9 scale)			
Bacterial blight	3	3	3
Bacterial pustule	2.5	2.1	2.5
Yield (ton ha^{-1}):			
Research field (t ha^{-1})	1.23 - 3.76	1.40 – 3.20	0.94-3.30
Farmer field (t ha^{-1})	1.20 - 3.20	1.30 – 2.80	0.91-2.90
Mean (t ha^{-1})	2.13	2.10	1.84
Year of release	2011	2011	2007

7. Oil and Protein Content

Seed oil and protein contents of *Korme, Katta* and Ethio-yogozlzvia soybean varieties were analyzed. The result showed that *Korme* had slightly higher oil content (21%) than *Katta* (19%). However, seed of both varieties had the same protein content (39%). *Korme* and *Katta* varieties had better oil and protein contents than Ethio-yogozlavia (Table 1).

8. Stability Performance

Yield stability comparisons for nine soybean genotypes including *Korme*, *Katta* and Ethio-yogozlzvia for two years and three locations were illustrated based on meta-analysis (GGE Biplot) method (Yan and Tinker, 2005). Genotype x environments interaction was partitioned into principal component axes and the first IPCA (65.11%) and the second IPCA (17.97%) explained the largest proportion (83.08%) of the interactions. The result of the study revealed that *Katta* (PR-145-2) and *Korme* (AGS-129-2) are ideal and stable varieties compared to the commercial variety, Ethio-yogozlavia (Figure 1). *Katta* was found to be a more stable soybean variety than Korme.

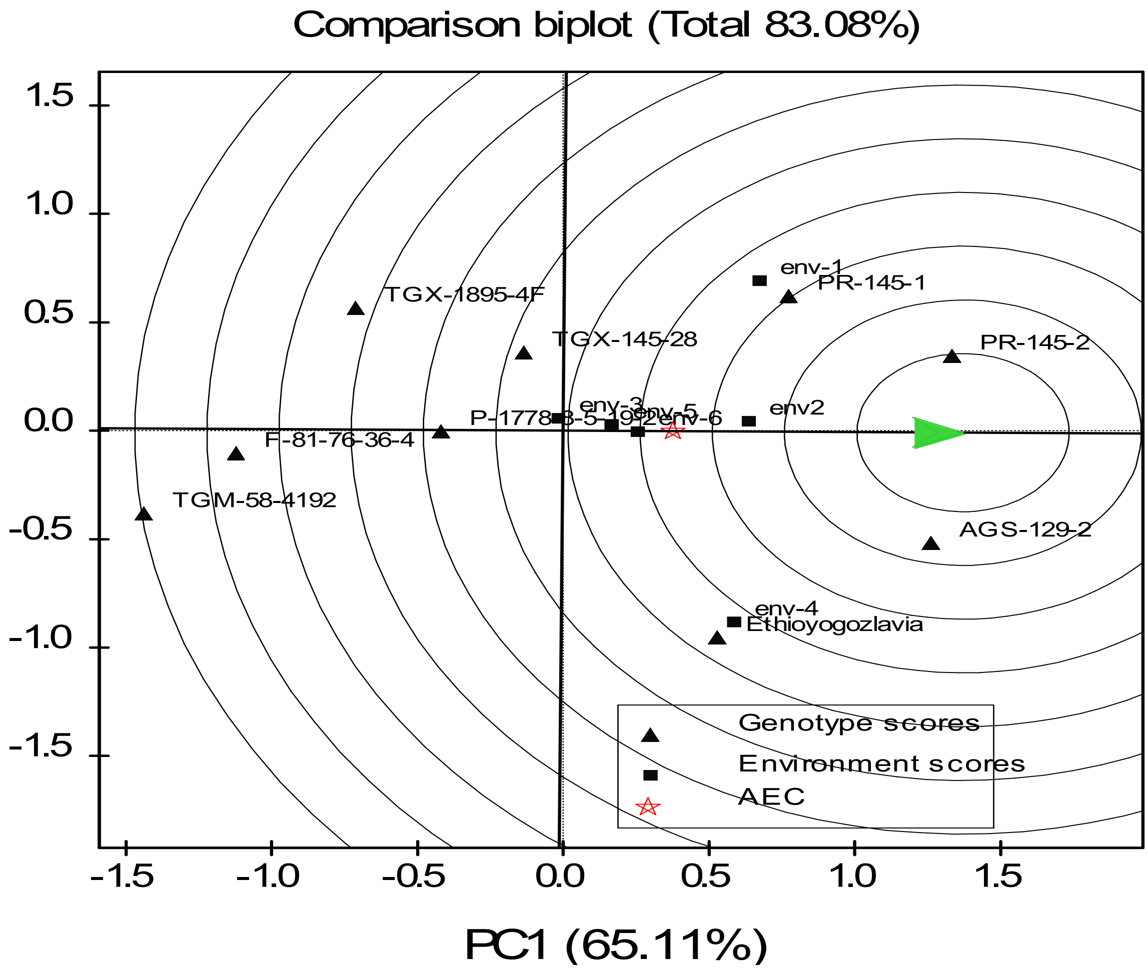

Figure 1. Ranking genotypes relative to the ideal genotype.

9. Disease Reaction

Korme and *Katta* were resistant (n < 3 where n = 1-9 scores) to the common soybean diseases viz., bacterial blight and bacterial pustule (Table 1).

10. Conclusion

The soybean varieties, *Korme* and *Katta* had higher seed yields and better stability performances than the commercial variety. The seeds of the new varieties have also higher contents of oil and protein compared to the seed of the commercial variety, *Ethio-yogozlavia*. These varieties were also resistant to common soybean diseases viz., bacterial blight and bacterial pustule and hence, have been released for Western Ethiopia and similar agro ecologies.

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12. Reference

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