Land Use/Cover Changes between 1966 and 1996 in Chirokella Micro-watershed, Southeastern Ethiopia

Mohammed Assen* and Tassew Nigussie

Wollo University, P O Box 1271, Dessie, Ethiopia
Haramaya University, P O Box 138, Dire Dawa, Ethiopia

Abstract: Two periods of panchromatic aerial photographs taken in 1966 and 1996 were analyzed to determine spatial and temporal land cover changes occurring in Chirokella micro-watershed, Southeastern Ethiopia. The results of the analysis were digitized with Arc View GIS 3.3 software to produce land use/cover maps for 1966 and 1996. Five land use/cover categories, namely dense forest, moderately disturbed forest, bush, degraded and cultivated and settlement were identified. The result indicated an increase in an area of cultivated and settlement, bush and degraded and a decline in forest land cover categories over the 30 year period. The dense forest land cover decreased by over 80%, giving an average decreasing rate of 32 ha (-2.9%) per year. The moderately disturbed forest land was completely transformed to other land cover systems between 1966 and 1996. Cultivated and settlement land increased by 62.8%, giving an annual average expansion rate of 33.3 ha (+2.1%) over the analysis period. Bush and degraded land cover categories showed increasing patterns of 49.9% and 100%, respectively. Transformation of forest land cover to others could explain an increasing demand for more arable and settlement land and timber resources associated with a population increase and a decline in land productivity due to degradation. This expansion largely took place onto steeper and upper slope positions, which resulted in increasing the area prone to land degradation, and further implicates adapting of more forest to cultivated and settlement land use/cover categories. Thus, it seems that, in the micro-watershed land, cover changes resulted from combinations of physical (e.g. land degradation) and socioeconomic (e.g. demand for more land resources) factors.

Keywords: Land Cover; Dynamic; Expansion; Exposed Land; Reduction

1. Introduction

In order to meet their demands, human beings engage in transformation of land cover systems. The form of transformation mainly involves a conversion of forest to agricultural and settlement land (FAO 2001). The pattern and magnitude of these transformations can be studied from an analysis of historical aerial photographs and satellite images (Solomon, 1994; Amare, 1996; Gete, 2000; Kebrom and Headlund, 2000; Muluneh, 2003; Selamyihun and Tekalign, 2003; Woldeamlak, 2003; Mohammed, 2006). This approach can help to inter about the past, and present as well as to predict future status of land (e.g. forest, soil and water) resources. It is used to evaluate potential land degradation, such as soil erosion occurring in response to land use/cover changes (Morgan, 1986).

With the help of satellite images organized by FAO-UNDP, Daniel (1980) indicates that, before 1950s, natural forests covered nearly 40% of the highlands of Ethiopia. However, according to EFAP (1984), this extensive natural forest cover was reduced to 3% in the early 1980s. This estimate of forest cover was slightly raised to 4.5% in 1990s and 4.2% in 2000 (FAO, 2001). The presence of differences in forest coverage of Ethiopia may partly suggest lack of accurate quantified data, at least at national levels. The slight increase in forest coverage of Ethiopia after 1980s may also partly imply the existence of some forest plantation activities in those periods. Irrespective of the presence of such differences and possible explanations, the historical decrease in forest cover could be attributed to the demand for additional space for cultivation, grazing, settlement and timber resources (EFAP, 1994; Gete, 2000; Kebrom and Headlund, 2000; FAO, 2001) and to a decrease in land productivity (Solomon, 1994). As indicated in some studies (Hurni, 1983; FAO, 1984), this situation has led to severe land degradation (e.g. soil erosion) in the country.

Local physical and socioeconomic characteristics of each locality determine land use/cover changes and its associated impacts. For instance, in the Metu area of Western Ethiopia, land cover changes involving cultivation following vegetation regeneration induces soil fertility decline (Solomon, 1994). In the south central highlands of Ethiopia, cultivated land expanded mainly onto steeper marginal parts by about 25% at the expense of forest land between 1957 and 1994 (Muluneh, 2003). In the Simen Mountains (Ethiopia), expansion of 12% to 41% of cultivated land onto high altitude forests was observed between 1975 and 1994 (Amare, 1996). In the Ginchi watershed of central west Ethiopia, cultivated land expanded by 118% and forest land decreased by 53% between 1957 and 1994 (Selamyihun and Tekalign, 2003). Whereas forest land decreased by 80%, cultivated land increased by 55% in the Jelo micro-catchment of the Chercher highlands of Ethiopia between 1966 and 1996 (Mohammed, 2006). In parts of the north western highlands of Ethiopia, 98.9% of the forest land became cultivated land over 27 years (Gete, 2000). But in the other parts of north western highlands of Ethiopia, forest land increased by about 50% between 1957 and 1998 due to mass reforestation programmes (Woldeamlak, 2003). Thus, analysis of land cover changes and patterns at local levels shows existence of spatial variability in effects, degree and extent of the problem. As a consequence, extent and degree of the problems need to be assessed within each of the micro-watershed conditions. As there

*Corresponding author. E-mail: Moh_assen@yahoo.com

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is a link between upper and lower slope positions within a given watershed (e.g. in water flow, sediment and solutes movements), watersheds represent basis for understanding the state of land resources and form the basis of resource management unit. Therefore, management methods have to be designed to suit local conditions (Young, 1998).

For this reason, the objectives of this study are to assess the spatial-temporal patterns of land cover changes, quantify the rate and direction of these changes and indicate their significance to land degradation in the Chirokella micro-watershed. The study will create awareness among policy makers and extension workers in understanding the severity and extent of land cover changes and help to develop a natural resources management system in Chirokella micro-watershed as well as in the other parts of southeastern Ethiopia. The study watershed was selected partly because the area is one of the severely degraded parts of Ethiopia requiring involvement for proper land use plan and partly due to available aerial photographs at required scale for analysis. The authors assume that proper land use planning is necessary in the watershed and elsewhere in southeastern highlands, for which spatio-temporal information is required an a local scale.

Description of the study area

Chirokella micro-watershed is located between 08°59'50.3" - 09°03'59.4"N and 40°50'54.4" - 40°54'45.2"E. It is found 4 km southeast of Asebe Teferi town, about 325 km east of Addis Ababa (Figure 1). It forms part of northern Chercher highlands, which are a part of the extensive highlands of Southeastern Ethiopia. Altitude of the micro-watershed ranges from 1800 meters above sea level (m asl) to 3000 m asl. Slope degree ranges from less than 1 to over 50% and generally increases in a north-south direction. Based on data from Asebe Teferi, mean annual rainfall is 813 mm and the mean annual temperature is 20° C.

The upper slopes mainly comprise mountains and hills and are covered with tertiary basaltic rocks, whereas the lower pediment slopes consist of colluvium-alluvium deposits. The watershed overlooks the Ethiopian Rift Valley system. The stream Chirokella (on which the study area is named) forms part of the Rift Valley drainage system of Ethiopia.

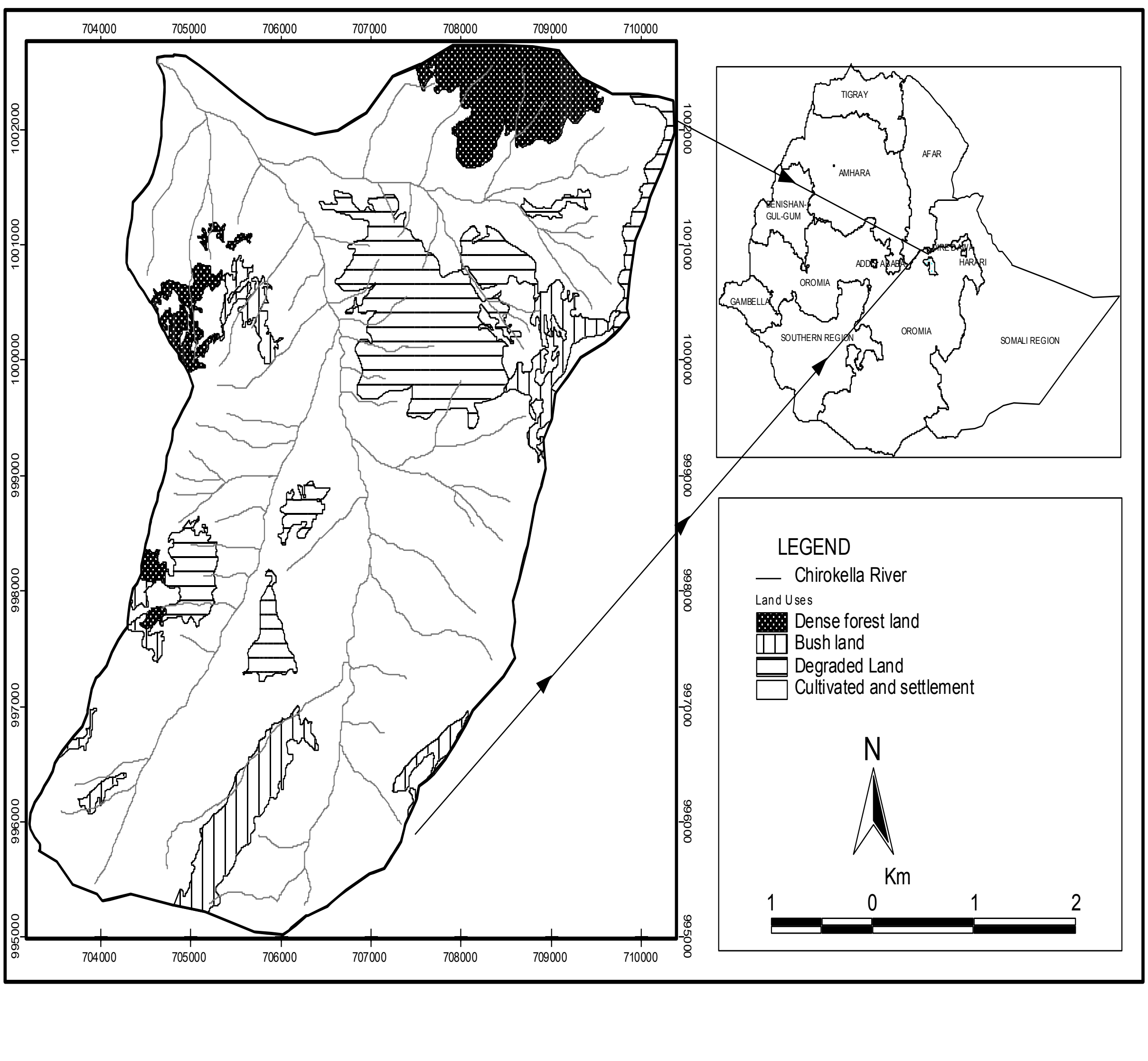

Figure 1. Chirokella micro-watershed, south eastern Ethiopia.

The natural vegetation is dominated by *Podocarpus fulcatus* and *Juniperus procera*. These are found in the steeper and upper slope positions and in isolated stands in valleys. Sorghum (*Sorghum bicolor* (L.)) interspersed with maize (*Zea mays*) are the predominant cultivated food crops. Other minor cultivated food crops include potato (*Solanum tuberosum*), sweet potato (*Ipomea batatas*) and barley (*Hordeum vulgare*). *Chat* (*Catha edulis*) is the principal cash crop.

2. Data Source and Analysis

The required data for the study was acquired from interpretation of 1:50000 panchromatic aerial photographs taken in 1966 and 1996 obtained from EMA. As it was not possible to obtain other aerial photographs and satellite images are expensive, it was not possible to include other remote sensing data sources in the study. The available satellite images via World Wide Web were unsuitable for this study mainly for quality reasons

The boundary of the micro-watershed was delineated on a 1:50000 topographic map (EMA 1999) and then on the respective aerial photographs using mirror stereoscope. In the processing, interpretation, analysis and presentation of the results, computer assisted image interpretation software was used.

Aerial photographs used for the study were scanned with a resolution of 1200 dots per inch and stored in Tag Image File Format. To geo-reference the aerial photographs, a topographic map of the study area was scanned and registered with Universal Transfer Mercator 1983 metric projection. Important landmarks such as rivers, roads and the boundary used as a ground control point were digitized. Then, aerial photographs were geo-referenced using different ground control points taken from topographic map with the help of the image analysis software. To have the required level of accuracy, geo-referenced aerial photographs were further divided into four equal grid cells and geo-referenced again. This helps to reduce distortion and displacement which could exist primarily at the margin of aerial photographs. Then, the scanned watershed delineated on the aerial photographs was clipped on the delineated watershed of 1:50000 topomap. The recognized land use categories of the watershed on the aerial photographs were digitized in Arc View GIS 3.3. Analysis of transformations of one form of land use/ cover to others was made through overlaying the two sets of maps in the Arc View GIS 3.3 software environment.

Prior to analysis of the panchromatic aerial photographs, preliminary land use/cover categories were set and, in the course of interpretation, some classes were omitted whereas others were included. The accuracy of land cover classification was verified under field conditions in 2006. As it was difficult to separately delineate and map scattered rural settlement, this was included in the cultivated land. This seems to be logical as scattered homestead farms are planted in field crops. The land cover categories used in the final interpretation are given in Table 1.

Table 1. Description of categories of land cover in Chirokella micro-watershed, eastern Ethiopia.

Land cover category	Description
Dense forest land	Formed a portion of uncultivated land containing natural forest with nearly closed canopy and undergrowth.
Moderately disturbed forest land	Uncultivated land containing scattered natural trees and secondary undergrowth. It contained some isolated big local trees.
Bush land	Uncultivated land covered with open stand of trees and shrubs forming degraded part of forest land due to selective cutting of trees. It consisted of poor specimens of *Podocarpus fulcatus*.
Degraded land	This almost consisted of scattered scrubs and exposed bed rocks. Sporadically remnant big trees were found only in gullies of this category.
Cultivated and settlement land	Land covered with annual and perennial crops and occupied by rural dwellings. Trees found around homesteads is also included in this category.

3. Results and Discussion

3.1. Land Use/Cover Changes

3.1.1. Dense Forest Land

Land cover under dense forest showed a considerable decline over the analysis period. In the study area, much of the forest cover was found on the steeper and upper slope positions of the landscape. In 1966, dense forest cover was 34% (1117.3 ha.) of the area of the watershed, which was reduced to 5% (162.8 ha.) in 1996 (Table 2; Figures 2 and 3). Between 1966 and 1996, dense forest cover decreased by 85.4%. The average decrease was 32 ha. per year, giving an average annual deforestation rate of 2.9%. This is an indicator of considerable transformation of dense forest land to other land cover categories. As a result, out of the 1966 dense forest land about 72.5% (809.7 ha) was changed to cultivated and settlement, 8.5% (94.4 ha) to bush and 6.1% (67.8 ha) to degraded land categories. Thus, only 13.0% (145.4 ha) of the 1966 dense forest land remained unchanged. This reveals that in Chirokella micro-watershed, forest removal for cultivation and settlement forms the major reason for its destruction. However, little transformation was made from other land covers to dense forest land category (Table 3). As a result, only about 17.4 ha of dense forest land was gained which, together with 145.4 ha retained from 1966, made a total of 162.8 ha. in 1996.

3.1.2. Moderately Disturbed Forest

The moderately disturbed forest land covered 14.1% (463.7 ha) in 1966, and was completely transformed to other land cover categories in 1996. It was transformed to degraded (51.5%), cultivated and settlement (45.1%) and bush (2.1%) land cover categories. The relatively high percentage of transformation to degraded land reveals that, in 1966, much of moderately disturbed forest cover system was on the verge of destruction. The 45.1% transformation to cultivated and settlement land reconfirms the importance of clearing of uncultivated land for cultivation and settlement. It is also an indication of the presence of little rehabilitation and reforestation attempts in recovering forests during the 30 year analysis period.

Table 2. Land cover dynamics between 1966 and 1996 in Chirokella micro-watershed, eastern Ethiopia.

Land over class	Year				% change between 1966 and 1996
	1966		1996		
	(ha)	%	(ha)	%	
Dense forest land	1117.3	34	162.8	5.0	-85.4
Moderately disturbed forest land	463.7	14.1	-	-	-100
Bush land	118.7	3.6	177.9	5.4	+49.9
Degraded land	-	-	359.0	10.9	+100
Cultivated and Settlement land	1592.3	48.3	2592.3	78.7	+62.8
Total	3292.02	100	3292.02	100	-

Table 3 Extent of land converted from each category to other land cover categories in Chirokella micro-watershed, eastern Ethiopia.

Changed from	Changed to	Area (ha)	(%)
Dense forest land	cultivated	809.7	72.5
	bush	94.4	8.5
	Degraded	67.8	6.1
	unchanged	145.4	13.01
Moderately disturbed forest	cultivated	209	45.1
	bush	9.7	2.1
	Degraded	239	51.5
	Dense forest	6.2	1.3
	unchanged	0	0
Bush land	cultivated	73.4	61.8
	Degraded	2.5	2.1
	Dense forest	1.1	0.9
	unchanged	41.7	35.1
Cultivated and settlement	bush	32.2	2.0
	Degraded	49.8	3.2
	forest	10.2	0.6
	unchanged	1500.2	94.2

3.1.3. Bush Land

The bush land category showed a slight increase from 3.6% (118.7 ha.) in 1966 to 5.4% (177.9 ha.) in 1996 of the area of the watershed. This reveals an increase in bush land category by 49.9% over the 30 year analysis period. The increase is gained from dense forest, moderately disturbed forest and cultivated and settlement land cover categories (Table 3). Much of the gain was from dense forest land, suggesting an existence of forest quality degradation in the micro-watershed. Bush land also transformed to cultivated and settlement (61.8%), degraded (2.1%) and dense forest (0.9%) land cover categories. Hence, the high percentages of transformation to cultivated and settlement category reconfirms that, in a subsistence agricultural society, clearance of uncultivated land for cultivation and settlement represented the major reason for land cover changes.

3.1.4. Degraded Land

There was no identified degraded land category in 1966 following the employed classification criteria. But, on the 1996 aerial photographs, 10.9% (359.0 ha) of the micro-watershed was classified in the degraded land cover category. This shows a 100% increase in the degraded land category from 1966 to 1996. This was due to transformation of a part of other land cover categories to this land cover category (Table 3). Transformation to degraded land occurred from dense forest (6.1%), moderately disturbed forest (51.5%), bush ((2.1%) and cultivated and settlement (3.2%) land use/cover categories. The high percentage of transformation of moderately disturbed forest to degraded land may be an indication of its intensive exploitation by the local community for construction and firewood purposes, suggesting that these may be some of the other reasons in (forest) land degradation in the micro-watershed. It also implicates that moderately disturbed forest category might have been at a critical stage of degradation on the 1966 aerial photographs and probably an absence of rehabilitation activities in the study area caused its degradation. A gain from forest land is also an indicator of the existence of severe degradation of dense forest land within the analysis period. The existence of isolated trees in gullies of degraded land (Table 1) means it was transformed from forest land via processes of deforestation.

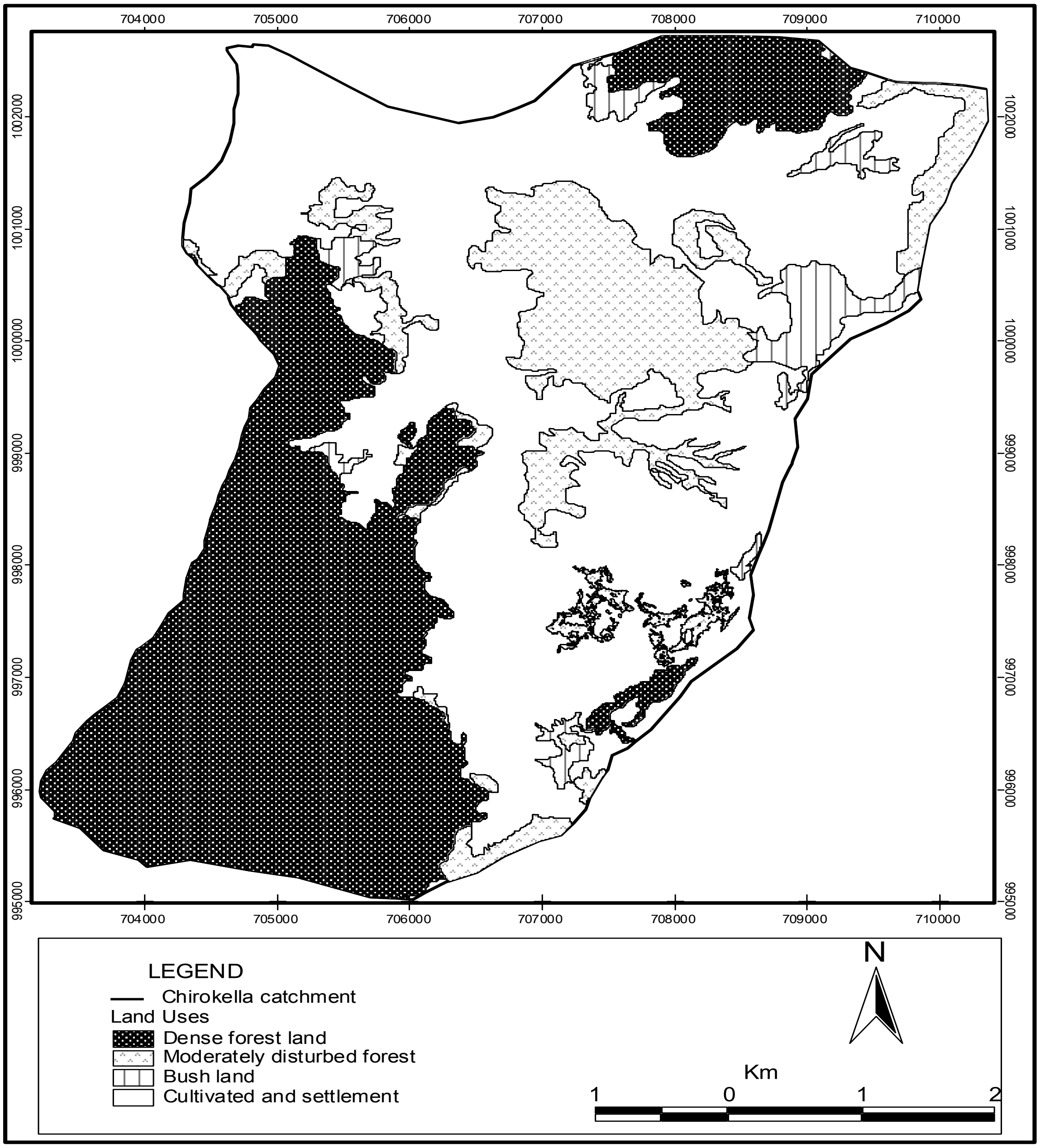

Figure 2. Land cover map of Chirokella Micro-watershed eastern Ethiopia in 1966.

3.1.5. Cultivated and Settlement Land

Considerable expansion of cultivated and settlement land was observed from 1966 to 1996. During the analysis period, this land cover category contained the largest portion of the study area. It contained 48.3% (1592.3 ha.) in 1966 and 78.7% (2592.3 ha.) in 1996 of the area of the micro-watershed. This showed a total increase of 62.8% between 1966 and 1996. The increase averaged to 33.3 ha/year, giving a rate of expansion of +2.1% per year. Also, on the 1996 aerial photographs, isolated big remnants of local trees existed in some cultivated plots, suggesting recent transformation of forest to cultivated land category in parts of those plots. This was verified in 2006 under field conditions. This expansion in cultivated and settlement land probably suggests that, in the micro-watershed, food crop supply was achieved through farm land expansion rather than intensification. It may also implicate an existence of high population pressure with an increasing demand for more arable, settlement and timber resources. As discussed above, cultivated and settlement land encroached all non-cultivated land cover categories (Table 3). This land cover category also showed a slight transformation to degraded (3.2%), bush (2.0%) and forest (0.6%) land cover categories. Thus, much of the transformation is to degraded land and the least is to forest land. This reconfirms that, in the micro-watershed, little effort has been made to rehabilitate the degraded land through reforestation programmes. Therefore, this study generally indicates a presence of a sequential change of forest to cultivated/settlement and, finally, to degraded land cover category.

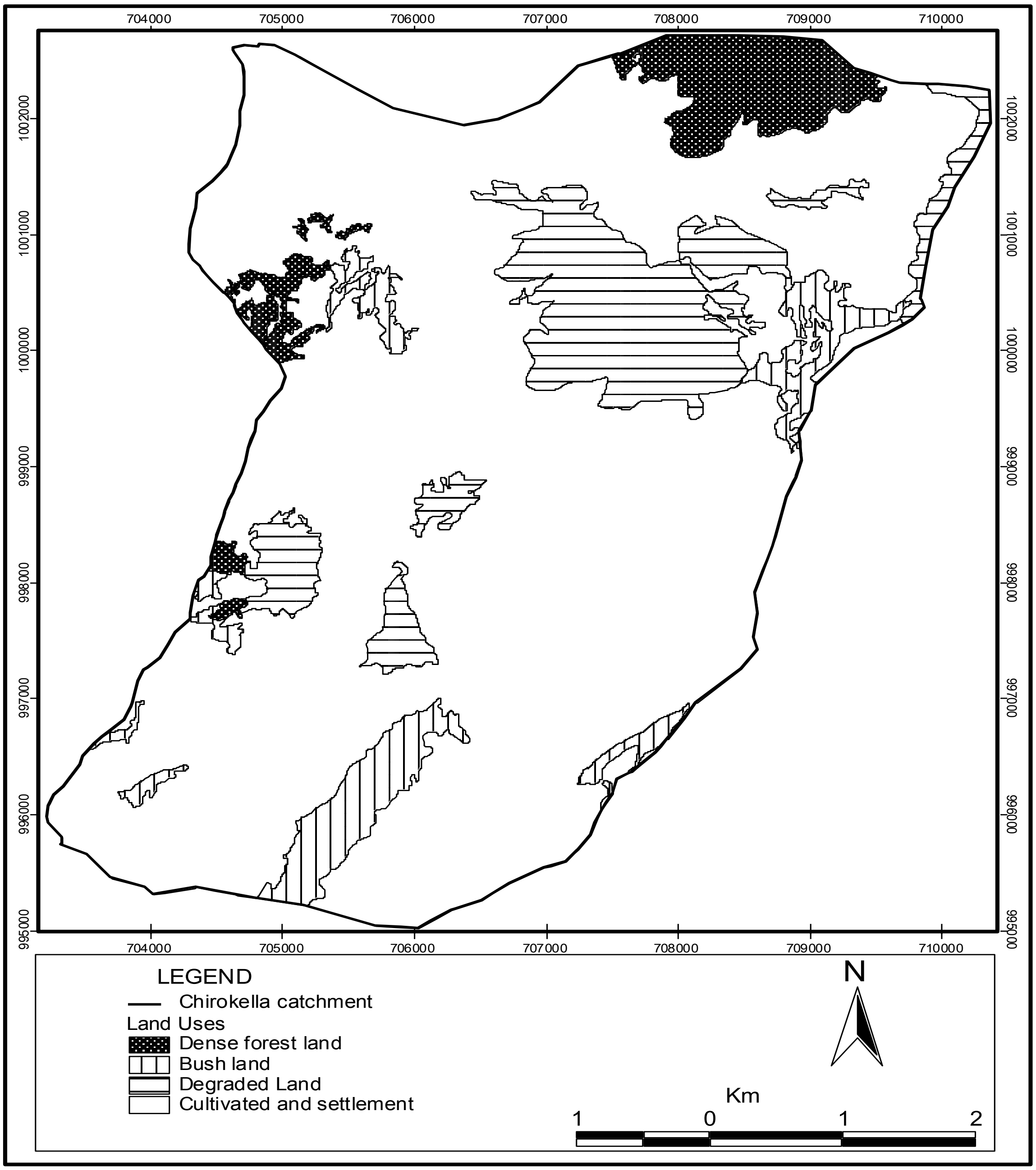

Figure 3. Land cover map of Chirokella Micro-watershed eastern Ethiopia in 1996.

3.2. Implications of Land Cover Changes to Land Degradation

The removal of natural vegetation cover for various reasons as explained above could lead to land degradation, such as deforestation and soil erosion through land exposure to the impacts of raindrops. This process accelerates detachment and removal of soil particles and its associated consequences (Morgan, 1986). The problem becomes worse where steeper land is cultivated under intense seasonal rainfall (and high erosivity) in the absence of effective soil conservation measures (Belay, 1992), as in the Chirokella micro-watershed. In Chercher highlands, among other factors, patterns of land cover and types of conservation measures form major determinants of rate of soil erosion (Thomas, 1998). As elsewhere in other parts of Ethiopia (Hurni, 1983; Barber, 1984; Constable, 1984), water erosion could form the dominant form of land degradation in Chirokella micro-watershed.

Considering the land cover status of the micro-watershed, the degraded and cultivated and settlement land cover categories could be more vulnerable to processes of land degradation, such as soil erosion. As a consequence, the potential proportion of land prone to soil erosion increased from 48.3% in 1966 to 89.6% in 1996 of the total area of the micro-watershed. Therefore, on average, about 45.3 ha (2.9%) of the 1966 degraded and cultivated and settlement land categories or 1.4% of the total area of the watershed was potentially exposed to soil erosion per year. This implicates that, in the study area, cultivated and degraded land cover systems would potentially form major sources of soil erosion. Therefore, the existence of spatial-temporal variability of potential environmental hazards (e.g. deforestation and soil erosion) in the Chirokella micro-watershed verifies the need for designing and implementation of land use planning and management methods suited to local site conditions.

4. Conclusion

Analysis of available panchromatic aerial photographs indicated that considerable land cover changes occurred in Chirokella micro-watershed between 1966 and 1996. The changes decreased the proportion of forest and increased the proportion of cultivated and settlement, bush and degraded land cover categories. Dense and moderately disturbed forest land categories decreased by over 85%, whereas the other identified land cover systems increased from 50 to 100% over the 30 year period. Thus, a gain in the other land cover patterns is due to a loss in any form of forest cover. Over time, this could make the area prone to soil erosion as the land will lose its protective natural vegetation cover due to its removal for cultivation, settlement and other related purposes. The need for more land could explain the expansion in cultivated and settlement. It may also explain expansion of degraded land covers, as a result of forest resources consumption probably related to a growth in population size and/or a decline in land productivity in the micro-watershed. It appears that, through selective cutting of trees, dense forest land was sequentially changed to moderately disturbed forest land and then to bush land. Finally, it might have been converted to cultivated and/or settlement land, which may end up in degraded land. Thus, an interaction of physical (e.g. soil erosion) and socioeconomic characteristics (e.g. demand for more cultivated and settlement lands) has influenced to a great extent the patterns of land cover changes of the Chirokella micro-watershed. Therefore, a sound watershed management plan is required in Chirokella micro-watershed as well as elsewhere in the Southeastern highlands. This could include reforestation of the degraded parts of the watershed, protecting and enhancing the existing forest land cover. Effective soil and water conservation and management methods that sustain improvement in productivity of the cultivated land could help in preventing expansion of forest to cultivation and marginal land cover patterns.

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Soil Properties under Selected Homestead Grown Indigenous Tree and Shrub Species in the Highland Areas of Central Ethiopia

Kindu Mekonnen[1*], Gerhard Glatzel[2], Monika Sieghardt[2] and Ottner Franz[3]

[1]Holetta Agricultural Research Center, P O Box 2003, Addis Ababa, Ethiopia
[2]Institute of Forest Ecology, UNI BOKU, Peter-JordanStrasse 82, A-1190, Vienna, Austria
[3]Institute of Applied Geology, UNI BOKU, Peter-Jordan Strasse 70, A-1190, Vienna, Austria

Abstract: A study was conducted in Galessa-Jeldu areas to evaluate soil pH, organic C, total N, available P and exchangeable bases under four indigenous and one exotic tree species, and to examine the correlation between the different soil properties. The tree and shrub species included in the study were *Senecio gigas* Vatke, *Hagenia abyssinica* (Bruce) J.F. Gmel., *Dombeya torrida* (J.F. Gmel.) P. Bamps, *Buddleja polystachya* Fres. and *Chamaecytisus palmensis* (Christ) Bisby and K. The first four are indigenous, while the last one is an exotic N-fixing species. The soil pH values under *H. abyssinica* and *S. gigas* were above 6.34 as compared to the soil pH values under *C. palmensis, D. torrid* and *B. polystachya.* Total N was slightly higher under *H. abyssinica* although not statistically different with the N content under other species. Organic C was higher under *H. abyssinica* than under *B. polystachya.* The variation for exchangeable K was more at 0-15 cm soil depth than at the 15-30 and 30-50 cm soil depths. The correlation between soil pH and total N as well as pH and organic C was positive in almost all the horizontal positions. *Hagenia abyssinica, S. gigas and C. palmensis* are some of the potential species that can be evaluated in different land-use systems of the high altitude areas to protect the loss of plant nutrients.

Keywords: High Altitude; Total N; Organic C; Exchangeable Bases; Soil Fertility; Nutrient Cycling

1. Introduction

High human and livestock population, a decline of forest resources and soil fertility depletion are some of the features of the highlands of central Ethiopia (ICRAF, 1990; German *et al*., 2005; Amare *et al*., 2006). The natural forests in the highlands of Ethiopia in general are heavily exploited to fulfill the cash and wood demand of the growing population. Similarly, the areas previously covered by forests have declined as a result of the expansion of farming with annual crops. Homesteads are one of the most important niches in which farmers feel confident to plant and maintain tree and shrub species.

Homesteads in the high altitude (> 2900 m.a.s.l) areas of central Ethiopia have a better tree and shrub species composition than farmlands (Kindu *et al*., 2006a). The proportion and area coverage of indigenous species around the homesteads is also considerable as compared to exotic species. The increased proportion of indigenous species over the exotics is due to their adaptability to the local environmental conditions, resistance to pests and diseases, availability as sources of planting material and familiarity to the local farmers. Farmers grow tree and shrub species around homesteads to obtain various products (wood, food and feed) and services (live fence, shade and soil fertility improvement) (Berhane *et al*., 2006).

Farmers in the high altitude areas highly recognize *Hagenia abyssinica*, *Dombeya torrida* and *Senecio gigas* as important indigenous soil improving tree and shrub species (Kindu *et al*., 2006a). The contribution of some other indigenous tree species for soil fertility improvement in farmlands has been investigated in the intermediate altitude (1500-2400 m.a.s.l) areas of Ethiopia by Abebe *et al.* (2001); Yeshanew *et al.* (1999); Hailu *et al.* (2000); Poschen (1986) and Gindaba *et al.* (2005). Assessments of the soil properties under and away from the tree canopies were the focus of all of the studies. The report from most of the previous studies show a higher soil organic matter, total N and other soil attributes under the tree canopies than in open areas.

Studies on soil properties under farmers' recognized indigenous tree and shrub species around homesteads are limited in the high altitude areas. Cognizant to the research gap, a study was conducted from 2004 to 2006 (a) to evaluate soil pH, organic C, total N, available P, exchangeable bases under four indigenous and an exotic tree species; and (b) to examine correlations between the different soil properties.

2. Materials and Method

2.1. Study Site

The study was conducted from 2004 to 2006 in the upper plateaus of Galessa-Jeldu areas, Dendi and Jeldu districts, central Ethiopia (9° 02' 47" to 9° 15' 00" N and 38° 05' 00" to 38° 12' 16" E). The altitude ranges from 2900 to 3200 m.a.s.l. The rainfall pattern is bimodal. The main rainy season is from June to September and the short rainy season from March to April with a mean annual rainfall of 1399 mm. Barley is the most dominant crop followed by potato and enset (*Ensete ventricosum*). The most common land-use systems in the study areas are crop, pasture and forest. Trees and shrubs are concentrated around the homestead and the nearby Chilmo state forest. The original vegetation in the area was mainly *H. abyssinica* and *Juniperus procera.* The exotic tree and shrub species introduced in the area include *C. palmensis* and *Acacia decurrens.* Cattle, sheep and horses are dominant livestock in the study area. The soil is characterized as Haplic Luvisols. The physical and chemical properties of the soil are presented in Table 1.

2.2. Selection of the Tree and Shrub Species

A total of 150 households were interviewed to find out indigenous tree and shrub species that are traditionally considered by farmers as important soil fertilizers. Subsequently the farmers were asked to describe the type of tree and shrub species that they consider important. The most important tree and shrub species for the farmers were species that regularly shed their leaves, have fast decomposing leaves, grow fast, propagate easily, produce high biomass, and protect soil erosion. Finally, farmers selected *Senecio gigas* Vatke, *Hagenia abyssinica*

*Corresponding author. E-mail: kindumeko@yahoo.com

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(Bruce) J.F. Gmel, *Dombeya torrida* (J.F. Gmel.) P. Bamps and *Buddleja polystachya* Fres (Kindu *et al.*, 2006a). Three villages that had all the required indigenous species were identified. Tree and shrub species free from addition of farm weeded material; manure or house wastes and inorganic fertilizers were selected and demarcated in each village. The three villages were considered as replications. Most tree and shrub species in the village exist in hedges. A total of three trees per indigenous and exotic species (*Chamaecytisus palmensis* (Christ) Bisby and K. Nicholls) were included in the present study. The exotic tree species was used for comparison purposes. Detailed description of the species is presented in Table 2.

Table 1. Some physical and chemical properties of the soil in the Galessa-Jeldu area.

Depth (cm)	pH (H_2O)	OC (mg g^{-1})	Tot. N (mg g^{-1})	Av. P (mg g^{-1})	Sand (%)	Silt (%)	Clay (%)
0-18	6.28	48.280	4.796	0.083	12	47	41
18-60	6.19	15.290	1.316	0.018	11	37	52
60-125	5.66	4.356	0.459	0.021	4	34	62
125-160	5.97	2.027	0.198	0.022	28	33	39

Tot. N - total N, OC - organic C, Av. P - available P

Table 2. Description of the tree and shrub species considered for the study.

Species	Familly name	Estimated age (year)	Propagation	Height (m)	Average crown diameter (m)
Hagenia abyssinica	Rosaceae	5-8	Seed	4.0-4.6	2.5
Dombeya torrida	Sterculiaceae	6-8	Seed	4.3-5.0	2.3
Buddleja polystachya	Loganiaceae	5-9	Seed, cutting	3.1-4.6	2.2
Chamaecytisus palmensis	Fabaceae	4-5	Seed	4.5-4.9	2.4
Senecio gigas	Asteraceae	5-8	cutting	2.7-3.5	1.8

2.3. Soil Sampling and Analysis

A radial pattern of soil sampling was used. Sampling locations were 75 cm (hereafter referred to as closest), 150 cm (hereafter referred to as midst), and 225 cm (hereafter referred to as distant) positions at both sides from the base of each marked tree (Hailu *et al.*, 2000; Wezel, 2000; Power *et al.*, 2003). Sampling depths were 0-15, 15-30 and 30-50 cm (Kindu *et al.*, 1997). Soil samples collected under each species and village from similar depths and positions were thoroughly mixed to obtain composite samples. The total number of composite samples was 135 (Soil improving tree and shrub species (5) * depths of sampling (3) * distances of sampling from the base of the tree (3) * replications (3)).

The soil pH was determined in 1:2.5 soil suspensions in deionised water for active acidity using potentiometric pH-Meter (ÖNORM L1083, 2005). Organic carbon was determined by C/S-Element Analyzer LECO S/C 444 using oven-dry samples. Dry combustion at 1400 ^oC in pure O_2 atmosphere and infrared detection of evolved CO_2 was applied (ÖNORM L1080, 2005). Total nitrogen was determined by semi-micro-Kjeldahl procedure using the air-dry samples. Wet combustion of air-dry soil samples was carried out with H_2SO_4 (98%) and a catalyst containing K_2SO_4 and $CuSO_4$ at 400 ^oC. Automatic vapour distillation with saturated NaOH and titration of evolved NH_3 using a Kjeltec Auto 2300, (TECATOR) with automatic calculation device was used (ÖNORM L1082, 2005).

Available P was determined by Olsen method (Olsen and Sommers, 1982). Exchangeable element contents (K^+, Ca^{2+}, Mg^{2+}, Mn^{2+} and Al^{3+}) were determined by extraction of air-dried samples with 0.1M NH_4OAc at pH 7.0. Determination of the exchangeable elements was carried out using a simultaneous ICP-OES (Inductively Coupled Plasma – Optical Emission Spectroscopy) with an axial plasma (Perkin Elmer, OPTIMA 3000 XL). The determinations were made after calibration with matrix-adapted standard solutions (ÖNORM L1085, 2004). Cation Exchange Capacity (CEC) and % base saturation (BS) were calculated as follows:

CEC (mmol$_c$ / 100 g) = K (ppm)/390 + Mg (ppm)/120 + Ca (ppm)/200 + Na (ppm)/230 + H (buffer pH) -- (1)

BS = (Base (meq/100g)/CEC) *100 --------------------- (2)

2.4. Statistical Analysis

A one-way analysis of variance (ANOVA) was conducted on soil pH, OC, N and exchangeable bases. The effect of depths and positions, and their interactions on soil properties was conducted following the procedures of liner models ANOVA. Both analysis were run using SAS (SAS institute, 1999). The significance between means was tested using the least significance difference (LSD). The following model was considered while running the ANOVA:

$Y_{ij} = \mu + a_i + \beta_j + e_{ij}$, -- (3)

where μ is the overall mean, a_i the i th treatment (tree species) effect, β_j the j th block (site) effect and e_{ij} is the random error associated with Y_{ij}.

Correlation analysis was performed to understand the relation between OC vs N; pH vs OC, N, Al, Mn, BS and CEC. Levels of $P < 0.05$, $P < 0.01$ and $P < 0.001$ were chosen to test significance differences.

3. Results

3.1. Soil pH, Organic C, Total N and Available P

Soil pH at the depth of 0-15 cm varied horizontally from 6.01 to 6.8, 5.9 to 6.7 and 5.85 to 6.95 in the closest, midst and distant positions, respectively (Table 3). The soil pH values under *H. abyssinica* and *S. gigas* were above 6.34 as compared to the soil pH values under *C. palmensis, D. torrid* and *B. polystachya*. The pH values under the five tree and shrub species varied significantly among the soil depths (Table 3 and 4). Higher pH values were found at the topsoil than that of lower depths. Similarly, the soil pH varied along the three horizontal positions. Higher pH values were noticed in the closest position than in the midst and the distant positions.

The soil OC and N content under *H. abyssinica*, S. *gigas*, *C. palmensis* and *D. torrida* were comparable in the top 0-15 cm depth (Table 3). On the other hand, the soil OC content under *H. abyssinica* was higher by 23.25, 24.53 and 21.03 mg g^{-1} than under *B. polystachya* in the closest, midst and distant positions, respectively. Total N was slightly higher under *H. abyssinica* although not statistically different with the N content under other species. The content of soil P had the following sequence in the top 0-15 cm soil depth of the closest and midst horizontal positions: *H. abyssinica* > *S. gigas* > *C. palmensis* > *D. torrida* > *B. polystachya* (Figure 1). Organic C, N and P showed significant differences among the soil depths, as well as the horizontal positions (Table 4). The content of OC, N and P depicts a decreasing pattern from the 0-15 to the 30-50 cm soil depths and from the closest to the midst and distant positions.

3.2. Exchangeable Bases

The variation for exchangeable K and Ca was high at 0-15 cm soil depth than at the 15-30 and 30-50 cm soil depths (Table 5). The soil under *H. abyssinica, S. gigas* and *C. palmensis* had a high content of soil K and Ca as compared to the soil under *B. polystachya* and *D. torrida*. The Mg content under *H. abyssinica* and *S. gigas* was high as compared to the Mg content under other species in all the soil depths and horizontal positions. The content of K, Ca and Mg varied at the three soil depths of the closest, midst and distant horizontal positions, i.e. it decreased from the top to the lower soil depths and from the closest to the midst and distant positions.

3.3. Cation Exchange Capacity

The CEC values under *H. abyssinica* and *S. gigas* were higher at the three soil depths of all the horizontal positions (Figure 2). The soil under *C. palmensis* had higher CEC values than under *B. polystachya* and *D. torrida*. The lowest CEC values were recorded under *B. polystachya* at the 0-15 and 15-30 cm soil depths of all the three horizontal positions.

3.4. Correlation between Soil Properties

The correlation between OC and N was positive and statistically significant at all the soil depths of the three horizontal positions (Table 6). Soil pH was positively and significantly correlated with CEC and BS, and negatively and significantly correlated with Mn. The correlation between soil pH and N as well as pH and OC was positive in almost all the cases. No significant correlation was found between pH and Al; pH and OC; pH and N, except at the 0-15 cm soil depth and in the closest position of the five tree species.

Table 3. Total N, organic C and pH at different depths and positions from five tree and shrub species.

Species	Depth (cm)	pH (H_2O)			Organic C (mg g^{-1})			Total N (mg g^{-1})		
		75 cm position	150 cm position	225 cm position	75 cm position	150 cm position	225 cm position	75 cm position	150 cm position	225 cm position
B. polystachya	15	6.07^{b}	5.90^{c}	5.86^{b}	51.31^{b}	40.33^{b}	39.73^{b}	4.75^{a}	3.99^{b}	3.83^{b}
C. palmensis		6.01^{b}	5.97^{bc}	6.09^{b}	61.37^{ba}	58.63^{ba}	56.36^{ba}	5.92^{a}	5.74^{ba}	5.19^{ba}
D. torrida		6.14^{ba}	5.92^{bc}	5.85^{b}	63.50^{ba}	59.86^{ba}	57.59^{a}	4.92^{a}	5.36^{ba}	5.36^{ba}
H. abyssinica		6.80^{a}	6.70^{a}	6.95^{a}	74.56^{a}	64.86^{a}	60.76^{a}	6.60^{a}	6.26^{a}	5.66^{a}
S. gigas		6.59^{ba}	6.47^{ba}	6.47^{ba}	58.93^{ba}	55.11^{ba}	53.00^{ba}	5.36^{a}	5.15^{ba}	5.04^{ba}
SEM		0.121	0.111	0.139	3.302	3.372	2.899	0.335	0.333	0.274
B. polystachya	30	5.77^{b}	5.77^{b}	5.76^{b}	38.00^{a}	32.52^{a}	33.01^{a}	3.64^{a}	2.66^{a}	3.03^{a}
C. palmensis		5.89^{b}	5.83^{b}	6.11^{b}	50.84^{a}	44.82^{a}	39.34^{a}	4.94^{a}	3.98^{a}	3.82^{a}
D. torrida		5.77^{b}	5.74^{b}	5.73^{b}	44.04^{a}	37.70^{a}	38.63^{a}	4.22^{a}	3.68^{a}	3.68^{a}
H. abyssinica		6.72^{a}	6.59^{a}	6.86^{a}	56.29^{a}	43.92^{a}	44.42^{a}	5.21^{a}	4.13^{a}	4.14^{a}
S. gigas		6.39^{ba}	6.42^{a}	6.36^{ba}	43.76^{a}	36.95^{a}	33.84^{a}	4.07^{a}	3.28^{a}	2.89^{a}
SEM		0.128	0.118	0.141	3.199	2.654	2.279	0.280	0.284	0.227
B. polystachya	50	5.71^{b}	5.74^{b}	5.77^{b}	32.41^{a}	24.96^{a}	21.12^{b}	2.92^{a}	2.14^{a}	1.96^{b}
C. palmensis		5.77^{b}	5.79^{b}	5.85^{b}	29.12^{a}	26.50^{a}	28.18^{ba}	2.67^{a}	2.45^{a}	2.51^{ba}
D. torrida		5.67^{b}	5.64^{b}	5.71^{b}	31.25^{a}	28.24^{a}	28.49^{ba}	2.91^{a}	2.60^{a}	2.28^{ba}
H. abyssinica		6.50^{a}	6.52^{a}	6.75^{a}	38.37^{a}	35.37^{a}	36.30^{a}	3.36^{a}	3.19^{a}	3.19^{a}
S. gigas		6.40^{a}	6.44^{a}	6.35^{a}	39.37^{a}	22.57^{a}	21.48^{b}	3.46^{a}	1.93^{a}	1.91^{b}
SEM		0.111	0.112	0.121	2.120	1.992	2.099	0.200	0.213	0.183

Means with different letters within a column at similar depth and position are significantly different ($p < 0.05$).
SEM - Standard error of the means ($n = 15$).

Table 4. the effect of five tree and shrub species on soil properties at three depths and three horizontal positions.

	Effect		
Soil attributes	Depth	Position	Depth x Position
pH (H_2O)	0.000	0.002	0.007
OC (mg g^{-1})	0.000	0.000	0.821
Tot. N (mg g^{-1})	0.000	0.000	0.040
Av. P (mg g^{-1})	0.000	0.000	0.043
Exch. K (μg g^{-1})	0.000	0.000	0.000
Exch. Ca (μg g^{-1})	0.000	0.003	0.757
Exch. Mg (μg g^{-1})	0.000	0.002	0.107
CEC (mmolc kg^{-1})	0.000	0.000	0.014

Figures under the depth, position, and depth x position are P-values.

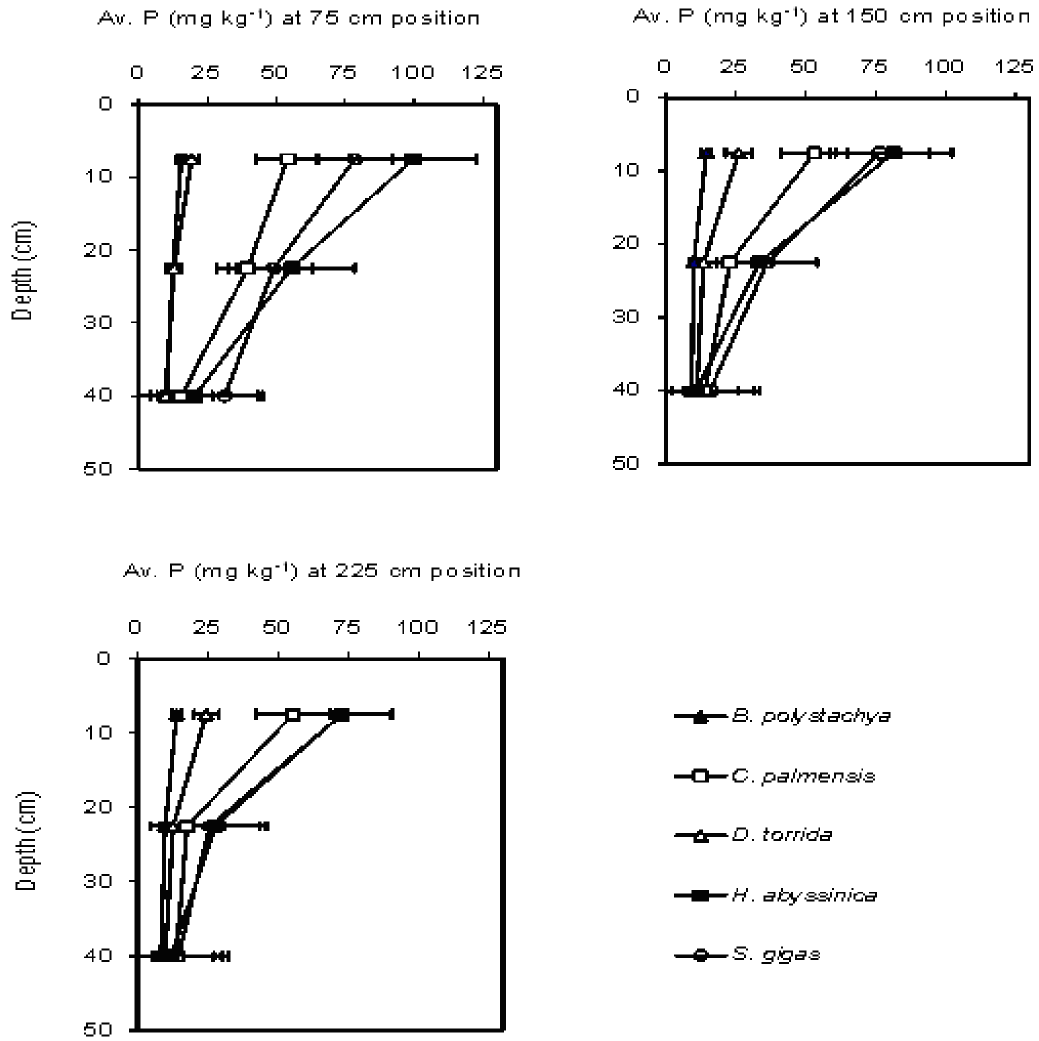

Figure 1. Trends of available P under five tree and shrub species at different soil depths and horizontal positions. Horizontal bars show standard errors of the mean.

Table 5. Excangeable cations at different depths and positions from five tree and shrub species.

Species	Depth (cm)	K ($\mu g\ g^{-1}$)			Ca ($\mu g\ g^{-1}$)			Mg ($\mu g\ g^{-1}$)		
		75 cm position	150 cm position	225 cm position	75 cm position	150 cm position	225 cm position	75 cm position	150 cm position	225 cm position
B. polystachya	15	826^{b}	568^{a}	455^{c}	845^{b}	736^{b}	707^{b}	169^{b}	155^{b}	146^{b}
C. palmensis		1428^{ba}	1409^{a}	1291^{bac}	1106^{ba}	1056^{ba}	1100^{ba}	189^{b}	181^{b}	211^{ba}
D. torrida		927^{b}	771^{a}	639^{bc}	982^{ba}	853^{b}	782^{b}	203^{b}	183^{b}	143^{b}
H. abyssinica		1929^{ba}	1592^{a}	1642^{a}	1637^{a}	1476^{a}	1869^{a}	369^{a}	339^{a}	327^{a}
S. gigas		2306^{a}	1518^{a}	1507^{ba}	1580^{a}	1529^{a}	1527^{ba}	305^{ba}	251^{ba}	251^{ba}
SEM		215.11	175.62	167.27	120.27	110.68	160.04	27.47	25.14	24.72
B. polystachya	30	489^{a}	444^{a}	424^{a}	686^{a}	592^{c}	621^{c}	145^{a}	147^{a}	147^{ba}
C. palmensis		1171^{a}	1154^{a}	1389^{a}	994^{a}	747^{bc}	783^{bc}	181^{a}	139^{a}	157^{ba}
D. torrida		539^{a}	531^{a}	482^{a}	738^{a}	682^{bc}	689^{c}	136^{a}	133^{a}	125^{b}
H. abyssinica		1483^{a}	1205^{a}	1324^{a}	1364^{a}	1110^{ba}	1266^{a}	268^{a}	249^{a}	272^{a}
S. gigas		1544^{a}	1259^{a}	1222^{a}	1368^{a}	1277^{a}	1201^{ba}	242^{a}	242^{a}	235^{ba}
SEM		183.33	178.74	183.44	115.19	89.44	88.80	23.18	20.26	22.53
B. polystachya	50	339^{a}	480^{a}	470^{a}	640^{b}	556^{a}	666^{a}	148^{ba}	130^{b}	148^{b}
C. palmensis		840^{a}	876^{a}	915^{a}	631^{b}	622^{a}	652^{a}	127^{b}	121^{b}	137^{b}
D. torrida		343^{a}	325^{a}	344^{a}	667^{b}	596^{a}	659^{a}	136^{ba}	131^{b}	137^{b}
H. abyssinica		1048^{a}	938^{a}	1141^{a}	982^{ba}	1024^{a}	1138^{a}	228^{ba}	195^{ba}	200^{ba}
S. gigas		1372^{a}	1232^{a}	1197^{a}	1363^{a}	1055^{a}	991^{a}	268^{a}	265^{a}	277^{a}
SEM		166.41	158.13	157.64	89.72	85.50	82.91	22.49	21.31	18.50

Means with different letters within a column at similar depth and position are significantly different ($p < 0.05$).
SEM - Standard error of the means ($n = 15$).

Table 6. Correlations between selected soil attributes for the five tree and shrub species.

Depths and positions (cm)	Tot. N vs OC	pH vs Tot. N	pH vs OC	pH vs Exch. Al	pH vs Exch. Mn	pH vs BS	pH vs CEC
0 to15 and 75	0.841***	0.640**	0.630**	-0.510*	-0.768***	0.918***	0.944***
0 to 15 and 150	0.954***	0.512*	0.449	-0.450	-0.706***	0.897***	0.929***
0 to 15 and 225	0.974***	0.410	0.407	-0.468	-0.8089***	0.897***	0.964***
15 to 30 and 75	0.984***	0.357	0.447	-0.415	-0.706***	0.880***	0.921***
15 to 30 and 150	0.937***	0.031	0.043	-0.243	-0.726***	0.888***	0.924***
15 to 30 and 225	0.968***	-0.032	0.002	-0.313	-0.703***	0.838***	0.921***
30 to 50 and 75	0.972***	0.256	0.315	-0.185	-0.607*	0.811***	0.883***
30 to 50 and 150	0.969***	0.067	0.072	-0.212	-0.654***	0.848***	0.907***
30 to 50 and 225	0.940***	0.322	0.252	-0.229	-0.695***	0.815***	0.925***

Tot. N - total N, OC - organic C, Exch. Al - exchangeable Al, Exch. Mn - exchangeable Mn,
BS - base saturation, CEC - cation exchange capacity
$^{*}P<0.05$, $^{**}P<0.01$ *and* $^{***}P<0.001$ *(level of significances)*

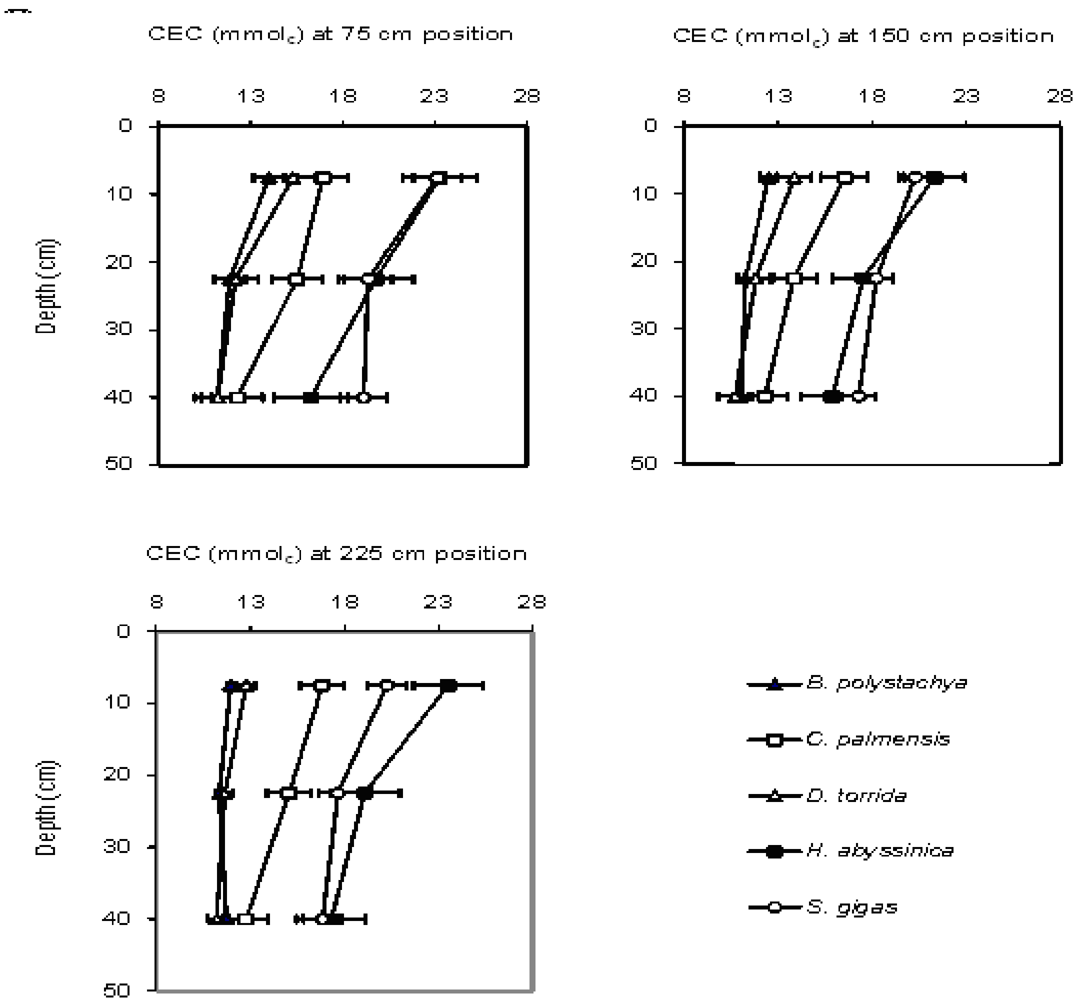

Figure 2. Trends of CEC of the soil under five tree and shrub species at different soil depths and horizontal positions. Horizontal bars show standard errors of the mean.

4. Discussion

Tree and shrub species can differ in their effect on soil properties through various mechanisms, including rates of nutrient inputs, outputs, and cycling. The high content of OC and N under *H. abyssinica* as compared to *B. polystachya* could be due to the addition of higher organic resources of the former than the later. *Hagenia abyssinica* constantly sheds high amount of leaves and provides mulch and green manure to the soil within its vicinity. Kindu *et al.* (2006b) reported the presence of high amount of litter deposition under 64 months old *H. abyssinica* and *Grevillea robusta* on Nitisols of central Ethiopia. *Dombeya torrida, S. gigas* and *C. palmensis* shed substantial amount of leaves even though their leaf shedding pattern is not as regular as that of *H. abyssinica*.

Farmers in the highlands of central Ethiopia rake the excess foliage litter under *H. abyssinica*, *D. torrida* and *S. gigas* trees and use them as organic fertilizer source for the nearby crop fields. However, *H. abyssinica*, *D. torida* and *S. gigas* as non N-fixing tree species only cycling the N present in the soil, not adding N inputs to the system, as happens through biological nitrogen fixation (BNF) in *C. palmensis*. Non N-fixing tree and shrubs species in general obtain their N and other nutrients through effective retrieval from the soil (Jama *et al.*, 2000).

The contents of P, K, Ca and Mg in the soil under *H. abyssinica*, *S. gigas* and *C. palmensis* were relatively high as compared to the other species considered for the present study (Table 5 and Figure 2). Enrichment of these nutrients under the three species could be associated to the rooting system and efficient nutrient cycling power of the trees. Deep-rooted trees and shrubs often act as ‘nutrient pumps’, taking nutrients from deep subsoil horizons into their root systems, translocating it to their leaves, and recycling it back to the surface of the soil via leaf fall and leaching (Kindu *et al.*, 1997, 1999; Berger *et al.*, 2006). Hence, the cycling of essential nutrients maintains an abundant supply of nutrients for incorporation into new biomass while at the same time limiting nutrient losses from the soil profile.

The soil under *B. polystachya* had the lowest nutrient content as compared to all other indigenous and exotic species included in the present study. The low soil nutrient content under *B. polystachya* can be related to the very low leaf shedding characteristics of the species. As a result of low leaf shedding, the nutrient gain of the soil system under *B. polystachya* through litter fall can be inadequate. It is likely to notice the positive impact of the *B. polystachya* through chopping and incorporating the green biomass of the tree into the soil system. *Buddleja polystachya* readily coppice and provide substantial amount of green biomass.

Organic C, N, P, K, Ca and Mg progressively declined with depth and horizontal distance from the base of the tree and shrub species. The presence of the tree and shrub species and associated soil enrichment would therefore seem to be restricted to the near surface layers. The effect of the trees on the bulk of the soil in the lower depths was very minimal (Table 3, 5 and Figure 2). The minimal effect for the five tree and shrub species on the soil properties in lower as compared to topsoil depths could be related to young age of the trees. The age of the tree and shrub species included in the present study was between four and nine years (Table 2). Trees can positively influence soil properties in lower soil depths during many years of their below and aboveground growth (Pandey *et al.*, 2000; Chang *et al.*, 2002). Improvement of soil nutrients in the upper soil depths and close to the tree stems has been reported to various tree and shrub species (Yeshanew *et al.*, 1999; Tadesse *et al.*, 2000; Abebe *et al.*, 2001; Gindaba *et al.*, 2005).

The soil pH under *H. abyssinica* and *S. gigas* was high as compared to the soil pH under other species (Table 3). The elevated soil pH under the two species could be a result from increased base cation cycling and subsequent enrichment of the base status of the underneath soil. The presences of higher level of exchangeable base forming cations contribute to the amelioration of soil acidity (Brady, 1990). Our findings on the levels of K, Ca, Mg and Na under *H. abyssinica* and *S. gigas* are in accordance with the investigation of Sae-Lee *et al.* (1992) and Tadesse *et al.* (2000).

The level of CEC under the five species was slightly higher in the top 0-15 cm soil depth than in the lower 15-30 and 30-50 cm soil depths (Figure 3). Likewise, the soil under *H. abyssinica* and *S. gigas* depicted relatively more CEC than under other species. Like the contents of base cations, higher level of CEC under the two species could be due to greater amount of litter deposition. The level of CEC varies with changes in soil pH, organic matter, and clay content. Cation exchange capacity provides a reservoir of nutrients to replenish nutrients that can be removed from the soil water by plant uptake and leaching (Camberato, 2001).

Total soil N was positively and strongly correlated with OC under the five tree and shrub species. Such a correlation of N with OC was expected as the amount of the former parallels with soil organic matter (Schlesinger, 1997; Brady and Weil, 2002). Similarly, soil pH was positively related with BS and CEC while negatively related with Al and Mn. Soil pH drops as acidic H and Al cation in the exchange sites increases and basic Ca, Mg and K cation decreases (Brady and Weil, 2002).

5. Conclusions

The soil under *H. abysinica, S. gigas* and *C. palmensis* retained a substantial amount of plant nutrients. This is an indication of the species potential to protect the loss of nutrients and thereby contribute to long-term ecosystem sustainability. Hence, the planting efforts of *H. abyssinica, S. gigas and C. palmensis* should be strengthened in different land-use systems of the high altitude areas.

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Biomass and Nutrient Accumulation of Green Manuring Legumes Terminated at Different Growth Stages

Tamiru Hirpa[1*], Heluf Gebrekidan[2], Kindie Tesfaye[2] and Asfaw Hailemariam[3]

[1]Benishangule Gumuze Regional State Bureau of Agriculture, P O Box 30, Assosa, Ethiopia
[2]Department of Plant Sciences, Haramaya University, P O Box 138, Dire Dawa, Ethiopia
[3]National Soil Testing Center, P O Box 141, Addis Ababa, Ethiopia

Abstract: A field study was conducted at the experimental site of the Assosa Research Center, western Ethiopia, with the objective of generating information about the biomass and nutrient accumulation of four green manuring (GM) legume crops at different growth stages. Accordingly, factorial combinations of four legume crops [cowpea (*Vigna unguiculata*), soybean (*Glycine max*), and two common bean verities (Black Dessie and Awash Melka) (*Phaseolus vulgaris*)] and three growth stages of termination (mid-vegetative, mid-flowering and pod-setting) treatments laid in a randomized complete block design were used. Significant species by growth stage treatment interaction ($P \leq 0.01$) were observed in dry matter (DM) concentration, and an increase in cowpea and a decrease in Awash Melka variety were observed with a delay in termination times. In addition to the species variability in total DM production, highly significant effect of growth stage at termination was also observed, and a rise in overall DM production was recorded with the development of GM crops. Cowpea recorded the highest per plant number (5.8) and fresh mass of total (0.4 gm) and effective (0.21 gm) nodules compared to the rest, particularly at the mid-flowering stage of growth. According to the results of this study, nutrient (particularly N and K) concentrations of shoot tissue showed a declining trend with increasing plant age. After considering the species and growth stage effects on the nutritional input or contribution of GM, it was discovered that cowpea and mid-flowering stage of growth outweighed the rest.

Keywords: Concentration; Nodules; Dry Matter; Input

1. Introduction

Unlike natural systems, in which biomass production is in equilibrium with nutrient reserves, the subsistence type of agricultural system found most often in the rainfed areas of Ethiopia is typified by continual loss and net removal of soil nutrients which could cause a serious threat to the overall agricultural productivity and destabilize the natural resource base (Nair, 1996). The sustainability of such agricultural systems depends to a great extent on optimizing the balance between inflows and outflows of the nutrients. The use of inorganic fertilizers in achieving this balance for successful crop production, as well as its high costs and unreliable availability for resource poor farmers, is currently causing global concern due to environmental costs in agriculture. (Bohlool *et al*., 2004). Beyond sustainability considerations, increasing demand for and promising returns from organic products currently have made legume green manuring (GM) an important agronomic approach to combat soil fertility problems (Horst *et al*., 2001; Bohlool *et al*., 2004). Organic inputs from GM legumes could increase crop yield through improved nutrient supply/availability and improved soil-water holding capacity. Some researchers have found N-substitution values for GM in excess of actual green manure N accumulation, suggesting that GM N is sometimes taken up more efficiently than chemical fertilizer N or that GM modifies the soil environment, crop growth, or both such that greater crop N uptake is possible (Yadav *et al*., 2000). Therefore, cropping systems which include legumes as green manure could be the most efficient.

Residues of GM legume, unlike fertilizer N sources, have different effects that vary according to crop species and development stage. The chemical composition of the organic materials added into the soil as green manure has a great effect on the net N release from material or immobilization of soil mineral N. Utilization of green manure N may thus be enhanced through measures that deliberately affect the chemical composition of the materials incorporated into the soil. The chemical composition of plant material is highly affected by the developmental stage of the plant (Dahlin *et al*., 2005). In the case of green manure, management options which influence the developmental stage, such as cutting, could be used to adjust the quality of the plant material at the time of incorporation so that better synchrony between GM-N release and subsequent crop demand could be achieved (Cline and Silvernail, 2001; Cherr *et al*., 2006). In legume crops, however, cutting practices also have a range of effects on other features, such as N_2-fixation activity and abortion of nodules and roots (Wivstad, 1996). Thus, green manure crops could be chosen and managed with the aim of manipulating their quality.

According to Tandojam (2002) the selection of suitable legume species and age at termination determines the amount of biomass, N accumulation and the rate of liberation of nutrients in available forms. Termination or the soil incorporation date of GM crops could affect the fraction of plant biomass (leaf, stem, reproductive, or senesced tissue) and N if the GM responds to late-season changes in weather conditions (Cherr *et al*., 2006). According to Cline and Silvernail (2001) and Sainju and Singh (2001), increasing the length of the GM growing season, may or may not increase GM biomass and N content. Kong *et al*. (1993), however, have reported that the amount of biomass and N provided by the GM crops varies according to the growth stage at the time of soil

*Corresponding author. E-mail: thirpa2002@yahoo.com

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incorporation. Cavigelli and Thien (2003), on the other hand, suggested that plant type seems more important than residue application rate in affecting soil P availability, whereas others have reported that residue application rate is more important than plant type (Bumaya and Naylor, 1988; Li *et al*., 1990). Ratilla and Escalada (2006), however, did not observe any significant effect of species and timing of field legume incorporation.

The efficiency of GM crops in improving soil conditions could generally be increased through correct selection of the GM crops with higher capacity and by identifying the growth stage at which maximum top-growth and N_2-fixation could be achieved (Cline and Silvernail, 2001). Knowledge of GM crop DM yield and nutrient accumulation dynamics during the growth period could, therefore, provide farmers with management options aimed at maximizing the DM production for green manure and N for a subsequent crop. Such manipulation of residue quality could facilitate better synchrony between GM-N release and demand by a subsequent crop, thereby conserving N within the agricultural ecosystem (Odhiambo and Bomke, 2001). With regard to changes in biomass production and nutrient composition dynamics, most reported studies so far have been based on values of GM biomass and N content at a certain growth stage (Isse *et al*., 1999; Somado and Sahrawat, 2007). Sampling of different green manure crops at their varied phenological stages, however, could provide much more meaningful information for selection of appropriate GM crop and development of residue management strategies. In this context, it is important to study the relationships between residual attributes of different legumes and their different phonological stages. This study was, therefore, initiated to generate information about GM biomass yield and the nutrient accumulation of four legume species terminated at their different phenological stages in the soil and climatic conditions of areas around Assosa.

2. Materials and Methods

2.1. Description of the Study Area

The study was carried out in 2007 at the experimental site of the Assosa Research Center, western Ethiopia. According to the classification of EARO (1999), the agro-climate of the area falls under sub-humid lowland with a mono-modal rainfall pattern. The area receives an annual rainfall of 1275 mm. The annual mean maximum temperature reaches 28 ^{0}C while the mean minimum temperature is 15 ^{0}C. Rainfall and weather data during the growing season are presented in Table 1. The dominant soil at and around the Research Center is reddish brown, Nitosols, which, according to pre-sowing soil test results, is low in fertility especially in N, P and organic matter (Table 2).

Table 1. Mean monthly weather data for Assosa in the 2007 cropping season.

Month	Rainfall (mm)	Mean temperature (^oC)		Relative humidity (%)	Evapo-transpiration (mm day^{-1})	Sunshine hours day^{-1}
		Max	Min			
April	47.9	30.4	17.4	48.62	11.4	7.48
May	82.6	28	17.3	50.68	8.9	5.4
June	178.9	24.1	16.4	80.46	2.94	4.4
July	178.9	23.2	15.9	85.56	2.35	3.32
August	NA	NA	NA	NA	NA	NA
September	224	24.1	15.6	NA	NA	NA
October	147.5	26.7	13.2	64.62	3.7	6
November	16.1	27.3	12.5	62.32	5.9	7.9

NA = Data not available
Source: Assosa Metrological Service Branch Office.

2.2. Experimental Treatments and Procedures

A factorial combination of four legume species [cowpea, (*Vigna unguiculata*), soybean (*Glycine max*) and two common bean varieties (Black Dessie and Awash Melka) (*Phaseolus vulgaris*)] and three growth stages of termination viz., mid-vegetative, mid-flowering and pod-setting (Table 3), resulting in a total of 12 treatments, were applied on plots of 4.5 m by 6 m. The experiment was laid out in two factors randomized complete block design (RCBD) and was replicated three times. Before the sowing of each crop, the land was plowed to prepare a suitable seed bed and then seeds of the GM legume crops were sown by hand drilling at spacing of 40 by 10 cm.

Table 2. Properties of the soil as analyzed before legume planting.

Parameters	Soil test values
pH (H_2O)	5.9
Organic C (g C kg^{-1})	19.7
Total N (g kg^{-1})	1.4
Avilable P (mg kg^{-1})	1.84
EC (dS/m)	0.14
CEC (Cmol(+)/kg)	25
K (mg kg^{-1})	37.14
Ca (Cmol(+)/kg)	6.34
Mg (Cmol(+)/kg)	3.67
Na (Cmol(+)/kg)	0.16
Base Sa. (%)	40.6

Table 3. Description of experimental treatments.

Legume species	Growth stage at termination	Description of growth stage
Cowpea	Mid-vegetative	8 weeks after emergence (WAE)
	Mid-flowering	11 WAE
	Pod-setting	14 WAE
Common bean[1]	Mid-vegetative	5 WAE
	Mid-flowering	8 WAE
	Pod-setting	11 WAE
Common bean[2]	Mid-vegetative	5 WAE
	Mid-flowering	8 WAE
	Pod-setting	11 WAE
Soybean	Mid-vegetative	8 WAE
	Mid-flowering	11 WAE
	Pod-setting	14 WAE

[1]Black Dessie Variety, [2]Awas Melka Variety

2.3. Sampling, Data Collection and Analysis

2.3.1. Data Collection

From legume crops grown in a uniform inter- and intra-row spacing of 40 cm by 10 cm, the biomass yield was estimated by mowing the foliage from 1 m x 1 m quadrate of each plot at the respective termination stage. The fresh and dry foliage weights were taken immediately and after oven drying (at 105 ^{o}C for 48 hrs), and were later extrapolated to t ha^{-1}. To determine the per plant production of total and effective nodulation, nodules which developed a pink-brown internal color after slice opening of the nodules (Gwata *et al.*, 2003); number and the fresh weight of each nodule were recorded after careful uprooting of 5 randomly taken plants from each plot at the respective stage of termination.

2.3.2. Tissue Sampling and Analysis

Shoot materials of GM legumes sampled from each plot at respective growth stages were analyzed for N, P, K and Ca concentrations. Nitrogen concentration in dry matter (DM) was determined using the Micro-Kheldahl method (AOAC, 1994). To determine the P in plant tissue, colorimetric measurement was taken, while K and Ca were determined by flame photometry and atomic absorption spectrometry respectively (Rhoades, 1982). Total GM N, P, K and Ca inputs were calculated by multiplying the concentration with the respective total DM yield.

2.3.3. Statistical Analysis

Analysis of variance was carried out using MSTATC statistical software followed by mean separation using the least significant difference (LSD) test and correlation test both at 1 and 5% probability levels.

3. Results and Discussion

3.1. Species and Growth Stage Effects on Biomass Production

Total fresh biomass production was observed to vary significantly ($P \leq 0.01$) among the GM legumes (Table 4). Cowpea produced the highest biomass (6.85 t ha^{-1}) when averaged across growth stages. The biomass yield of cowpea is as high as more than double that of Black Dessie and Awash Melkas common bean varieties (Table 5). Growth stage at termination in the present study, however, did not affect ($P>0.05$) the fresh biomass weight. In this study, highly significant species by termination time treatment interaction was observed in DM content, and an increase in cowpea and a decrease in Awash Melkas were recorded with a delay in termination times (Figure 1). In this case, cowpea contained the lowest DM content, which may be attributable to dilution of the material because of large biomass production (Teasdale *et al.*, 2004).

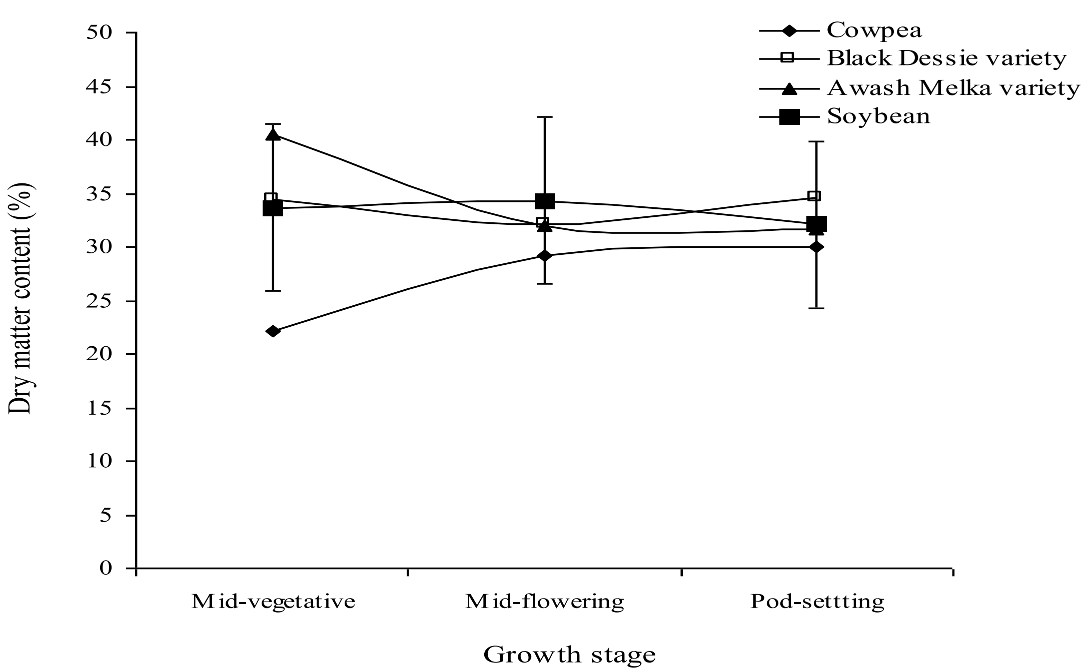

Figure 1. Interaction effect of species and growth stage on dry matter content (%) Vertical bars represent LSD values for interaction effect at 1% probability level.

After considering total DM inputs of GM crops, the highest amount ($P \leq 0.01$) was recorded by cowpea (1.86 t ha^{-1}) followed by soybean (1.42 t ha^{-1}) when averaged across green manure termination stages (Table 5). A significant ($P \leq 0.05$) effect of growth stage at termination of GM legumes was also observed with regard to total DM input (Table 4), although a marked difference in the pattern of change in DM yield of legumes may be attributable to species variability. In this study, DM yield increased significantly as termination was delayed from mid-vegetative to flowering stages of growth. Similarly, Brandt (1996) found the average biomass of black lentil doubled from early bud to full-bloom stages. Martin *et al.* (1976), however, reported that the DM yield of crotalaria reached its peak at early-flowering period, similar to the case in cowpea in this study.

Table 4. Mean square estimates for biomass yield, nodules per plant and nutrient concentrations and inputs of legume species as analyzed for two factors randomized complete block design.

Parameters studied	Mean squares for source of variation†			
	Legume crop (3)	Sampling stage (2)	LS X SS (6)	Error (22)
Fresh biomass	36.74**	52.97	1.52	1.46
% DM content	108.56**	2.23	47.69**	11.59
Total dry matter yield	1.96**	0.42*	0.11	0.10
Nodules/plant	19.58**	1.18	2.57*	1.03
Wt. fresh nodules/plant	0.05**	0.03**	0.01	0.004
Effective nodules/plant	5.14**	0.88	0.92*	0.33
Wt. effective nodules/plant	0.05**	0.02**	0.008*	0.003
% N concentration	1.29**	0.20*	0.33**	0.05
%P concentration	0.03**	0.009*	0.006*	0.003
%K concentration	0.32	1.16*	1.16	0.29
%Ca concentration	6.72**	2.13	1.26	1.04
Total N input	1642.40**	333.52*	215.11	101.08
Total P input	16.19**	2.31	2.34	2.15
Total K input	397.79*	73.01	79.56	101.76
Total Ca input	5953.38**	2006.86**	501.97	237.84

*[1]Black Dessie Variety, [2]Awas Melka Variety, †Figures in parenthesis = degrees of freedom; * = Significant at P = 0.05; ** = Significant at P = 0.01.*

Table 5. Effects of sampling stages on fresh biomass and total dry matter production of the legume species.

Legume species (LS)	Growth stage (GS)			Mean*
	Mid-vegetative	Mid-flowering	Pod-setting	
Fresh biomass (FB) production (t ha^{-1})				
Cowpea	7.31	6.87	6.37	6.85a
Common bean[1]	1.77	2.42	3.58	2.59c
Common bean[2]	1.74	2.90	3.04	2.56c
Soybean	3.64	3.89	5.44	4.32b
Mean	3.62	4.02	4.61	
Total dry matter (DM) production (t ha^{-1})				
Cowpea	1.60	2.10	1.90	1.86a
Common bean[1]	0.61	0.78	1.24	0.87c
Common bean[2]	0.90	0.93	0.94	0.92c
Soybean	1.21	1.33	1.74	1.42b
Mean*	1.08b	1.28ab	1.42a	
LSD	LS (FB)	GS (FB)	LS (DM)	GS (DM)
(0.01)	1.60	NS	0.43	NS
(0.05)	-	NS	-	0.27

*[1]Black Dessie Variety, [2]Awas Melka Variety, *Fresh biomass (FB) or dry matter (DM) means within a row or column followed by the same letter are not significantly different at the specified probability levels.*
NS=non-significant; LS X Gs=treatment interaction.

3.2. Nodulation Pattern of Legumes at Different Phonological Stages

Nodulation of legumes has been used by many workers as an indirect measurement (indicator) of N_2-fixation (Johnson and Hume, 1983; Wolyn *et al.*, 1989). In this study, significant ($P \leq 0.05$) species by growth stage treatment combined effect was observed in the total number of root nodules whereby cowpea at mid-flowering stage of growth recorded the top amount, and declining trends were observed for the remaining species in the subsequent samplings (Table 6), ascribable to genetic variation and to N_2-fixing ability involving both legume species and rhizobium components of the symbiotic association (Sanginga *et al.*, 2000). A trend similar to the total number of nodules was also observed in nodule fresh mass while considering the effects of species variability and growth stage (Figure 2). Similar results were reported by Elahi *et al.* (2004) who observed a decline in number and fresh weight of nodules after the flowering stage of growth in mungbean cultivars.

Significant ($P \leq 0.05$) interaction effects of species and growth stage treatments were also observed in this study both in the number and weight of effective nodules (Table 4), where cowpea and soybean recorded their maximum number and mass of effective nodules at the mid-flowering stage of growth and both common bean varieties recorded their maximum at the mid-vegetative stage of growth (Table 7). The number and weight of effective nodules in this study are found to be highly correlated with the number and weight of total nodules (r = 0.91 and r = 0.75, respectively) (Table 9). Generally declining values of indirect measures of N_2-fixation (nodulation pattern) after the flowering stage of growth have been documented extensively (Swaraj and Garay, 1977; Johnson and Hume, 1983; Wolyn *et al.*, 1989). The Number and mass of total and effective nodules were found to correlate more to the total phytomass N input than to change in DM yield with plant development (Table 8), attributable to sink strength (*e.g.*, nodules versus pods) (Maschner, 1995).

Table 6. Interaction effects of species and growth stage on number of total nodules per plant.

Legume species (LS)	Growth stage (GS)			Mean
	Mid-vegetative	Mid-flowering	Pod-setting	
Cowpea	3.2cd	5.8a	5.2ab	4.7
Common bean[1]	2.3cde	1.9de	1.4e	1.9
Common bean[2]	2.2cde	1.1e	1.1e	1.5
Soybean	3.5cd	3.9c	3.4cde	3.3
Mean	2.8	3.2	2.5	
LSD	LS X GS			
(0.01)	NS			
(0.05)	1.72			

Values followed by the same letter are non-significant at 5% probability level.
[1]Black Dessie Variety, [2]Awas Melka Variety, NS=non-significant; LSXGS=treatment interaction

Table 7. Interaction effects of species and growth stage on number and fresh weight (g) of effective nodules per plant.

Legume species (LS)	Growth stage (GS)			Mean
	Mid-vegetative	Mid-flowering	Pod-setting	
Nodule number (NN)/plant				
Cowpea	1.2bcd	2.2a	1.9ab	1.8
Common bean[1]	0.9cde	0.0e	0.0e	0.3
Common bean[2]	0.9cde	0.0e	0.0e	0.3
Soybean	1.7abc	1.9abc	0.7de	1.4
Mean	1.2	1.0	0.6	
Fresh weight (FW) of nodules (g/plant)				
Cowpea	0.13abc	0.21a	0.16ab	0.17
Common bean[1]	0.10bc	0.00d	0.00d	0.03
Common bean[2]	0.10bc	0.00d	0.00d	0.03
Soybean	0.22a	0.18ab	0.07cd	0.15
Mean	0.14	0.10	0.06	
LSD	NN (LSX GS)	FW (LSX GS)		
(0.01)	NS	NS		
(0.05)	0.97	0.09		

Means within a row or column followed by the same letter are not significantly different at the specified probability levels.
[1]Black Dessie Variety, [2]Awas Melka Variety

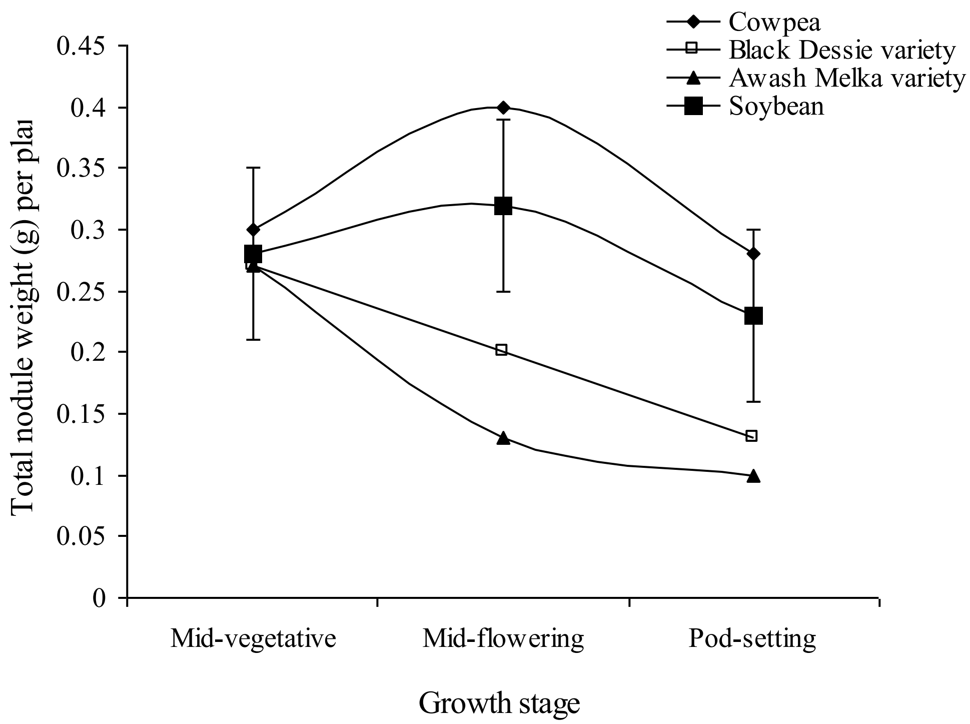

Figure 2. Effect of growth stage of legumes on fresh weight (g) of total nodules per plant Vertical bars represent LSD values for growth stage effect at 1% probability level.

3.3. Effect of Legume Growth Stage on Nutrient Composition and Input

3.3.1. Nitrogen Content and Total Input

In this study, a species by termination stage interaction effect ($P \leq 05$) on shoot tissue N concentration was observed. Both common bean varieties recorded a peak in N content at the vegetative growth stage after which it nearly stabilized with a further delay in termination (Figure 3). Soybean also followed a trend similar to the former crops in its N concentration, but was found to be the lowest throughout the growing season. The N concentration of cowpea, which was the lowest at the early growth phase, rose at the mid-flowering stage and declined thereafter, corresponding to nodulation pattern, which most likely is an expression of sink competition for photosynthates between the developing pods and the N_2-fixing root nodules (Marschner, 1995). The findings of this study, however, contradicted the observations made by Sainju *et al.* (2001) who observed on kill date effect on N concentration of hairy vetch and winter weeds.

The total N input or contribution, the product of tissue N concentration and total DM yield from GM legumes showed a marked difference ($P \leq 0.01$) between legume species grown (Table 4), corresponding to the differential biomass production (Table 5 and 8). In this regard, maximum DM production in cowpea contributed to a great extent to the rise in its total N input compared to its tissue N content; and in comparison with black haricot bean which yielded the lowest levels of DM and total N. Similar contributions of biomass production to the total N inputs were observed by Wagger (1989) and Teasdale *et al.* (2004) in hairy vetch. The difference in the tissue N concentration and total N inputs between the species could, therefore, be attributable to differential potential biomass productivity and N_2-fixation ability of the species (Odhiambo and Bomke, 2001; Njunie *et al.*, 2004). Moreover, in plants grown on low-N field soils, like that of this study (Table 1), the total plant or biomass N contribution could be attributable to N derived from the N_2-fixation (Wolyn *et al.*, 1989).

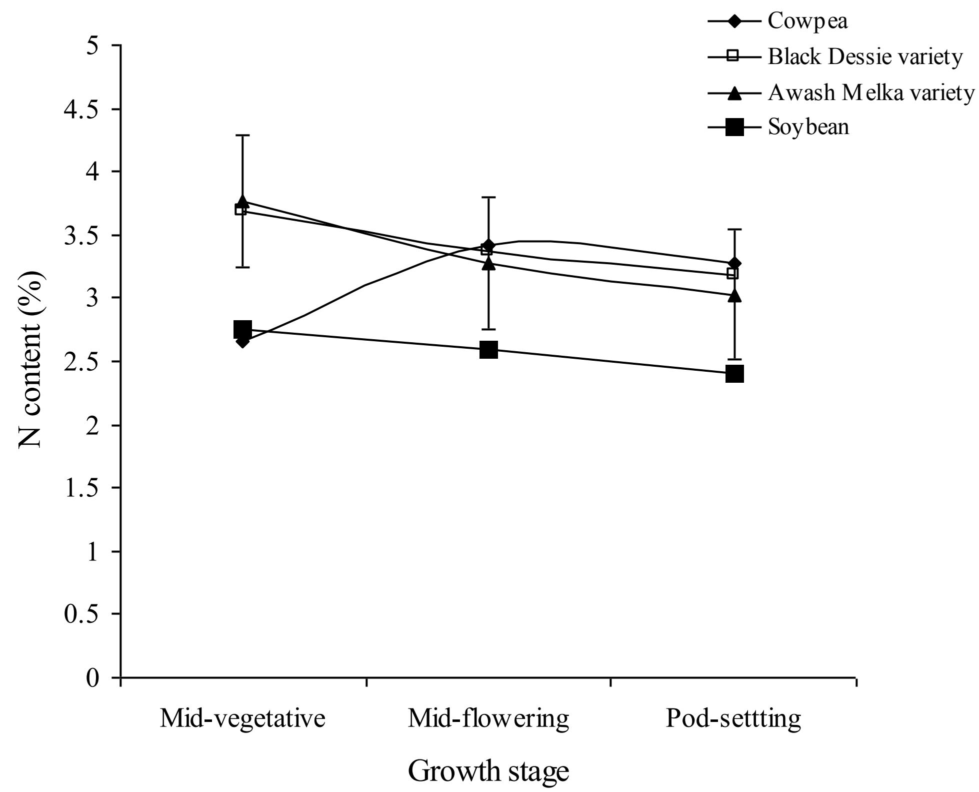

Figure 3. Interaction effect of species and growth stage on shoot tissue N content (%) Vertical bars represent LSD values for interaction effect at 1% probability level.

Growth stage of the GM legumes at termination was also found to significantly ($P \leq 0.01$) affect the total N input following the pattern similar to its effect on total DM production, as indicated by a highly significant correlation between them ($r = 0.93$). The maximum N input (43.17 kg ha^{-1}) was recorded during the latter stage of termination (pod-setting) at which DM yield attained its peak (1.42 t ha^{-1}) (Table 5 and 8). Kong *et al.* (1993) reported similar observations, stating that the amount of N provided by the GM crops varied according to the growth stage at the time of incorporation, corresponding to the biomass production. Ranells and Wagger (1992) in North Carolina, however, reported an opposing trend in crimson clover, where the N input declined as DM production increased with the maturity of crimson clover from the late vegetative to early seed set growth stages.

Since the N accumulation is a major determinant of the ability of organic residues to supply nutrients, though there are other modifying factors (Myers *et al.*, 1994), cowpea at the mid-flowering stage of growth could be considered a superior GM crop to provide GM-N. This result corroborates the results reported by Odhiambo and Bomke (2001), who observed peak N inputs at the flowering stage of growth while examining the potential of crimson clover (*Trifolium incarnatum* L.) and narrow leaf vetch (*Vicia angustifolia* L.) as legume green manure.

Table 8. Species and growth stage effects on estimated total nitrogen input (kg ha^{-1}).

	Growth stage (GS)			
Legume species (LS)	Mid-vegetative	Mid-flowering	Pod-setting	Mean
Cowpea	42.67	71.23	62.49	58.80a
Common bean[1]	22.59	26.34	39.59	29.81b
Common bean[2]	33.99	31.53	28.43	31.32b
Soybean	33.14	34.20	42.19	36.51b
Mean	33.10b	40.83ab	43.17a	
LSD	LS	GS		
(0.01)	13.4	NS		
(0.05)	-	8.53		

Means within a row or column followed by the same letter are not significantly different at the specified probability levels.
[1]Black Dessie Variety, [2]Awas Melka Variety.

Table 9. Correlation coefficients between growth parameters of green manuring legume crops.

Parameters	NTN	WTN	NEN	WEN	TDM	TNI
NTN	1	0.85**	0.91**	0.79**	0.37*	0.44**
WTN		1	0.80**	0.75**	0.34*	0.49**
NEN			1	0.90**	0.40*	0.49**
WEN				1	0.39*	0.48**
TDM					1	0.93**
TNI						1

[1]* = *Significant at P = 0.05; ** = Significant at P = 0.01; NTN = Number of total nodules; WTN = Weight of total nodules; NEN =Number of effective nodules; WEN = Weight of effective nodules; TDM = Total dry matter; TNI = Total N input*

3.3.2. Phosphorus and Potassium Compositions and Inputs

In this study significant interaction (P≤0.05) of the species according to growth stage treatments was observed in tissue P concentration (Table 4), where Awash Melka variety showed an increase followed by a decrease at and after the mid-flowering stage of growth. Tissue P concentration in soybean, however, showed a marginal and linear decrease as termination was delayed (Figure 4). After considering the total P input of green manure, a significant difference (P≤0.01) between species was observed, where cowpea contributed the highest amount (6.84 kg P ha^{-1}) (Table 10). The total P input, however, was not found to vary (P>0.05) due to growth stage effect.

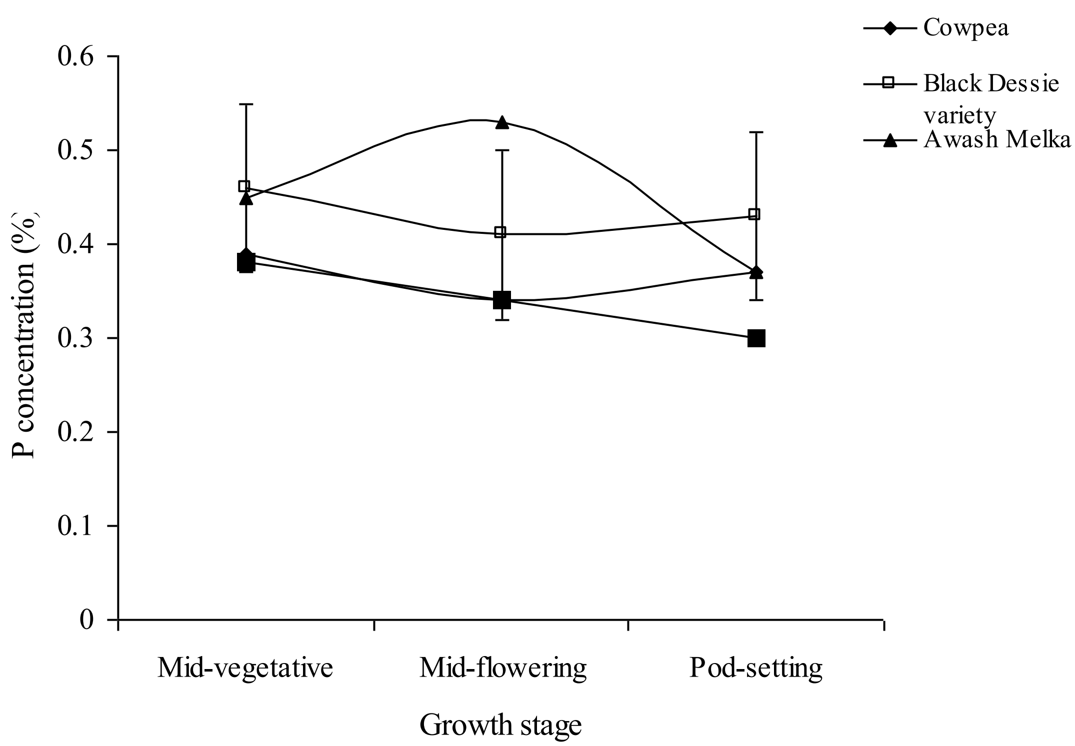

Figure 4. Interaction effect of species and growth stage on shoot P concentration (%) Vertical bars represent LSD values for interaction effect at 5% probability level.

Even though the shoot K concentration of GM crops in this study was found to be non-significant (P>0.05), growth stage at termination was observed to significantly affect (P≤0.05) the tissue K concentration (Table 4). Declining trends of shoot K composition in the subsequent samplings of GM legumes right after the initial termination observed in this study (Figure 5) were found to be in agreement with the findings of Franchini *et al.* (2003) and Njunie *et al.* (2004) who reported higher K contents from foliage of legume crops during earlier stages of growth. In spite of the non-significant species difference in tissue K concentration observed in this study, significant differences (P≤0.05) between the legume crops were, however, recorded in total K input, where cowpea contributed the highest amount (24.02 kg K ha^{-1}) (Table 10). Growth stage of green manure crops at soil incorporation did not cause significant differences (P>0.05) in total K input.

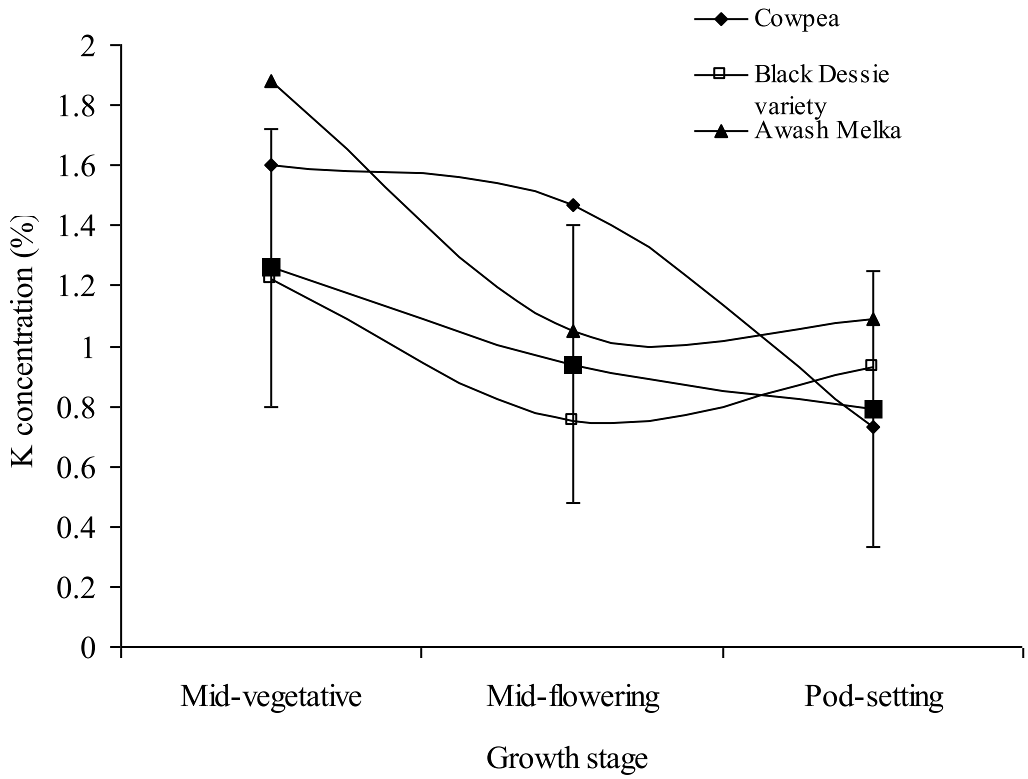

Figure 5. Effect of growth stage of legumes at incorporation on tissue K concentration (%) Vertical bars represent LSD value for growth stage effect at 5% probability level.

3.3.3. Effect on Calcium Composition and Input

In comparison to other plant nutrients considered in this study, the widest range of concentration in legume shoot materials were recorded for Ca. Tissue Ca concentration was observed to vary between the GM crops which ranged between 2.79 and 4.37% where soybean and cowpea recorded the lowest and the highest values, respectively (Table 11). At varying stages of plant growth, however, the Ca concentration in the tissue was not found ($P>0.05$) to vary statistically. Maschner (1995) on the other hand, has reported that the Ca content of plants varies at between 0.1 and >0.5% of tissue dry weight depending on the growing condition, plant species and plant organ. While determining the total Ca input of the GM legumes in this study, significant difference ($P\leq0.01$) was also observed between GM crops, where cowpea contributed the highest amount (79.38 kg Ca ha^{-1}). Difference in total Ca input was also observed due to the effect of growth stage at termination, where an increase in the overall Ca input was observed as termination was delayed (Table 11).

Table 10. Species effect on estimated total phosphorus and potassium inputs (kg ha^{-1}).

Legume species (LS)	Growth stage (GS) Mid-vegetative	Mid-flowering	Pod-setting	Mean
Phosphorus (P)				
Cowpea	6.24	7.19	7.13	6.84a
Common bean[1]	2.86	3.19	5.34	3.86b
Common bean[2]	4.04	4.97	3.47	4.16b
Soybean	4.16	4.47	5.25	4.76b
Mean	4.45	4.95	5.32	
Potassium (K)				
Cowpea	29.28	28.95	13.84	24.02a
Black Dessie	7.69	5.84	11.74	8.42b
Awash Melka	16.74	9.91	10.21	12.29b
Soybean	15.51	12.67	13.85	14.01ab
Mean	17.31	14.34	12.42	
LSD	LS (P)	GS(P)	LS (K)	GS (K)
(0.01)	1.19	NS	10.24	NS
(0.05)	-	NS	-	NS

Means within a column followed by the same letter are not significantly different at the specified probability levels.
[1]Black Dessie Variety, [2]Awas Melka Variety.

Table 11. Species and growth stage effects on tissue Ca concentration and total input (kg ha^{-1}).

Legume species (LS)	Growth stage (GS) Mid-vegetative	Mid-flowering	Pod-setting	Mean
% Ca concentration (CC)				
Cowpea	2.21	4.30	5.61	4.37a
Common bean[1]	2.58	1.91	2.62	2.37b
Common bean[2]	2.86	3.49	3.04	3.13ab
Soybean	2.20	3.23	2.93	2.79b
Mean	2.72	3.23	3.55	
Total Ca (TC) input (kg ha^{-1})				
Cowpea	46.86	85.58	105.69	79.38a
Common bean[1]	16.08	14.72	32.69	21.16b
Common bean[2]	26.19	34.03	28.67	29.61b
Soybean	26.84	43.38	51.75	40.66b
Mean	28.99b	44.43a	54.68a	
LSD	LS (CC)	GS(CC)	LS(TC)	GS(TC)
(0.01)	1.35	NS	20.49	NS
(0.05)	-	NS	-	13.06

Means within a row or column followed by the same letter are not significantly different at the specified probability levels.
[1]Black Dessie Variety, [2]Awas Melka Variety.

4. Conclusion

The nutrient contents of shoot tissues, mainly N, P and K varied according to GM crops which generally decreased with increasing plant age, confirming that the nutritional inputs of green manuring crops depend on the species and age at termination. The total N input of the GM legumes was found to be significantly affected by growth stage at termination, where termination at early (mid-vegetative) stage of growth contributed the lowest total N, whereas the latest stage of termination contributed the maximum. From the results of this study, it could, therefore, be concluded that cowpea used as green manure if incorporated into soil at its flowering stage of growth may generally be promising in the nutrient cycling potential of crops as it could make available the largest amount of plant nutrients, namely organic matter, N, P, K and Ca, compared to the rest, owing to deep rooting characteristics and biomass production. In this regard, further delay in the termination of cowpea beyond the flowering stage of growth could result in no additional benefit with respect to total N input from the phytomass.

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Supplementation of Graded Levels of Wheat Bran to Intact and Castrated Afar Sheep Fed Urea Treated Tef Straw: Effects on Feed Intake, Digestibility, Body Weight and Carcass Characteristics

Awet Estifanos[1] and Solomon Melaku[2*]

[1]Axum Agricultural Research Station, Axum, Ethiopia
[2]Department of Animal Science, Haramaya University, P O Box 138, Dire Dawa, Ethiopia

Abstract: A feeding and digestibility trial was conducted to evaluate the effect of wheat bran (WB) supplementation on feed utilization and carcass characteristics in urea treated tef (*Eragrostis tef*) straw (UTTS) based feeding of Afar sheep. Sixteen intact and sixteen castrated Afar sheep with initial body weight (BW) of 15.75 ± 1.57 kg (mean ± SD) were used in a randomized complete block design with 2 sex (intact, T1-T4 and castrated, T5-T8) x 4 levels (0, control; 150 g, low; 250 g, medium; 350 g, high) of WB supplementation on a dry matter (DM) basis. Supplementation promoted higher total DM, crude protein (CP) ($P<0.001$), OM ($P<0.01$) intake, final BW, daily BW gain, feed conversion efficiency (FCE), rib-eye muscle area ($P<0.001$), and dressing percentage ($P<0.01$). Supplementation at medium and high levels compared to the low level resulted in higher ($P<0.05$) DM and CP intake. High and medium levels of supplementation resulted in higher ($P<0.05$) apparent digestibility of DM compared to feeding solely on UTTS. The results of the study showed that UTTS could promote a reasonable level of feed intake and animal performance. Moreover, it was found that the level of supplementation is more important regarding the performance of Afar sheep in feed intake, BW and carcass parameters than castration or maintaining them intact in small-scale fattening schemes. Failure to observe differences in BW, FCE and carcass characteristics between intact and castrated Afar sheep could be attributed to the age of the sheep used in the study.

Keywords: Afar Sheep; Carcass; Digestibility; Feed Intake; Urea Treated Tef Straw; wheat bran

1. Introduction

Sheep rearing in the mixed crop livestock production system in the highlands of Ethiopia is the most important form of investment and cash income, and provides food security during years of crop failure (Getachew, 1988). Moreover, it is a common traditional practice followed by Ethiopian farmers to castrate and fatten sheep intended for the lucrative religious holiday markets. The major reason for castration of sheep is to promote fat deposition in the carcass, although it is associated with low feed conversion efficiency (FCE) and daily body weight (BW) gain (MacDonald *et al.,* 2002). Nevertheless, the degree at which castration promotes fat deposition and compromises FCE and daily BW gain has not been studied in depth and documented for most indigenous sheep types subsisting on locally available feed resources such as crop residues in Ethiopia. McDonald *et al.* (2002) reported that crop residues such as straws and related by-products are extremely fibrous, most have a high content of lignin, low content of crude protein (CP) and, thus, are of low nutritive value. Their high fiber and low CP contents restrict the availability and use of nutrients contained in them by domestic animals such as sheep. Urea treatment of straws could improve the poor nutritive value of fibrous feeds by increasing their nitrogen content (ILRI, 1999) and by also making their cell wall fibers more amenable for microbial fermentation. On the other hand, supplementation with energy source agro-industrial by-products, such as wheat bran (WB), supply the energy required by rumen microorganisms to capture the ammonia released from urea treated straw and incorporate it into their cell proteins. Thus, this could be a group opportunity to use agro-industrial by-products such as WB as supplementary feeds, particularly in smallholder sheep fattening schemes which are being promoted by the livestock extension services in Ethiopia. Moreover, WB is currently being produced by a number of flour milling factories in different parts of Ethiopia, which makes it more accessible to farmers in most parts of the country. Policy shift also demands the intensification of livestock production in Ethiopia. Therefore, this study was conducted to evaluate the effect of the level of WB supplementation on feed intake, digestibility, BW change and carcass characteristics of castrated and intact Afar sheep offered a basal feed of urea treated tef (*Eragrostis tef*) straw (UTTS).

2. Materials and Methods

2.1. Experimental Site

The experiment was conducted at Wukro Saint-Mary ATVET College, located at 13° 47' N latitude and 39° 35' E longitude, and at an altitude of 1900 masl. It receives mean annual precipitation of 502 mm and has mean minimum and maximum temperatures of 17 °C and 23 °C, respectively (BoANR, 2004).

2.2. Experimental Design and Treatments

Thirty-two yearling Afar sheep with initial BW of 15.75 ± 1.57 kg (mean ± SD) were used in a study which lasted for 90 days of feeding and 10 days of digestibility trials. The Afar sheep are hardy and adapted to drought prone arid and semi-arid areas. They are fat, tailed, hairy sheep with an adult BW of 28.3 kg and 35 kg for females and males, respectively (DAGRIS, 2007). Sixteen of the thirty-two sheep were castrated 30 days before the beginning of the feeding trial. A randomised complete block design in a 2

*Corresponding author. E-mail: solmelay@yahoo.com
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(intact vs. castrated) x 4 (levels of supplementation) factorial arrangement was used in the study. The sheep were blocked based on initial BW within sex group. Each dietary treatment was randomly assigned to each sheep in a block resulting in four replications per treatment. The treatments included feeding of solely on UTTS (T1, control) and daily supplementation of 150 (T2, low), 250 (T3, medium) and 350 (T4, high) g WB on a dry matter (DM) basis to intact Afar sheep, and feeding solely on UTTS (T5, control) and daily supplementation of 150 (T6, low), 250 (T7, medium) and 350 (T8, high) g WB on a DM basis to the castrated Afar sheep. The experimental sheep were weighed every ten days after overnight fasting to determine weight change during the experimental period. The daily BW gain was calculated as the difference between the final and initial BW divided by the number of feeding days. The FCE was calculated as the daily BW gain divided by the daily feed intake.

2.3. Feed Preparation and Feeding Management

A solution of 4 kg of urea in 80 liters of water was prepared and applied to 100 kg of tef straw DM (Ibrahim and Schiere, 1989) in a trench with a dimension of 2 m x 2 polythene m x 2 m. The trench was covered with a polyethylene sheet on the floor and the four sides. The urea solution was sprayed thoroughly onto layers of tef straw, rubbed by hand to ensure proper penetration and trampled on by foot to ensure proper packing. After filling the trench with urea treated straw, it was covered with plastic sheeting, and loaded with soil to create a hermetic sealing and left to incubate for 21 days. The UTTS was fed to the experimental sheep *ad libitum* after overnight aeration. The experimental sheep had *ad libitum* access to water and common salt licks. With the exception of sheep in the control treatments, those in the other treatments were supplemented with the respective level of WB at 0800 and 1600 h in two equal portions. Daily feed offer and refusals were recorded for each sheep to calculate daily feed intake. Samples of feed offers were taken on batches of feed and refusals were sampled per animal and pooled for each treatment. Representative samples of UTTS offer and refusals were kept in a deep freezer to minimize loss of ammonia.

2.4. Feces Collection

Twenty four sheep were fitted with fecal collection bags for three adaptation days, which was followed by total collection of feces for seven consecutive days. Daily fecal excretions per animal were collected and weighed every morning. Twenty percent of the total collected feces were sampled daily and kept in air-tight plastic containers for each animal until the end of the collection period, during which time they were thoroughly mixed for each animal and sub- sampled for chemical analysis.

2.5. Carcass Characteristics

At the end of the experiment, 24 sheep were fasted overnight and slaughtered. Blood, skin, the gastrointestinal contents and all the internal organs were weighed separately. The rib-eye muscle area was determined by tracing its cross-section between the 11th and 12th rib on transparent paper and then measured using a planimeter. The empty BW, total edible offal components (TEOC) and total non-edible offal components (TNEOC) were determined by summation of the different carcass components. Dressing percent was calculated as the proportion of hot carcass weight to slaughter weight and empty BW.

2.6. Laboratory Analysis

Samples of feed offer, refusals and feces were ground to pass through a 1 mm sieve screen and analyzed for contents of DM, CP, ash (AOAC 1990), neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) (Van Soest and Robertson, 1985). The apparent DM and nutrient digestibility coefficients were determined as:

$$\text{Apparent digestibility} = \frac{\text{Nutrient intake - Fecal nutrient output}}{\text{Nutrient intake}}$$

2.7. Statistical Analysis

The experimental data were subjected to the analysis of variance using MSTAT-C computer software. Treatment means were separated using Duncan's multiple range test. The model used for analysis of data collected in the experiment was:

$Y_{ijk} = \mu + r_i + a_j + b_k + ab_{ik} + e_{ijk},$

Y_{ijk} = response variable; μ =overall mean; r_i =ith replication effect; a_j =jth effect of castration; b_k =kth effect of level of WB; ab_{ik} =ikth interaction effect of castration and supplement level; e_{ijk} =error component for interaction.

3. Results and Discussion

3.1. Chemical Composition of Experimental Feeds

The partial DM and the laboratory DM of the UTTS used in this study were 43.3% and 92.5%, respectively (Table 1) and are closely comparable with the values of 45% and 93% reported by Rehrahie and Ledin (2001) for UTTS used in their study. The CP content of UTTS used in this study was 8.4% and less than that reported by Rehrahie and Ledin (2001). Differences in CP content of urea treated straws have also been reported in other studies (Sundstøl and Coxworth, 1984; Chenost, 1995) and attributed to the evaporative loss of up to two-thirds of the ammonia generated into the environment in the course of straw treatment with urea and until fed to animals. It has also been stated that large increases in CP do not necessarily indicate better urea treatment, but may imply the existence of residual urea subjected to partial ureolysis which, in turn, results from the limited hydrolyzation of urea to ammonia gas. The CP content of the UTTS in the current study showed an increase by 158%, 55.4%, 121%, 86.4% and 174.2% compared with the CP content of untreated tef straw reported by Abule (1994), Bonsi *et al.* (1995), Rehrahie and Ledin (2001), Solomon *et al.* (2004), and Zemicael (2007), respectively. The major component of the DM of UTTS offer was NDF (76%), which was higher than 55%, the level above which NDF content has a limiting effect on voluntary feed intake (Van Soest, 1965). The UTTS refusals contained lower CP and higher ADL than the UTTS offer in all treatments, indicating the selective feeding behavior of sheep on portions of feeds with better nutritive value. The CP content (16.4%) of WB in this study was lower than 17% (Devendra and McLeroy, 1982), 17.19% (Tesfaye *et al.*, 2001) and 17.5% (Lonsdale, 1989). However, similar CP content (16.3%) as in this study was obtained by Getnet (1998) and Solomon *et al.*

(2004). Higher cell wall constituents (50%) and inorganic components (7%) of WB were also reported by Lonsdale (1989). The variation might be attributed to the effect of processing in flour milling industries and the quality of the original wheat grain used for milling.

Table 1. Chemical composition of the urea treated tef straws experimental feeds.

Nutrient	WB	UTTS offer	UTTS Refusal							
			Intact				Castrated			
			T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8
DM (%)	87.4	92.5	92.2	92.2	92.2	91.9	92.3	92.0	92.0	92.3
Ash (%DM)	4.0	9.2	17.4	11.0	9.5	10.6	11.5	13.2	9.1	11.2
OM (%DM)	96.0	90.8	82.6	89.0	90.5	89.4	88.5	86.8	90.9	88.9
CP (%DM)	16.4	8.4	6.8	8.0	7.1	7.8	8.1	8.0	7.4	7.8
NDF (%DM)	35.2	76.0	65.0	71.0	72.8	71.2	71.3	69.5	75.3	71.9
ADF (%DM)	8.3	42.1	37.3	42.6	43.0	42.2	41.2	43.6	48.5	44.7
ADL (%DM)	2.2	3.8	5.0	4.5	4.2	4.4	4.1	5.0	5.5	5.3
Cellulose	26.9	33.9	27.7	28.4	29.8	29.0	30.1	25.9	26.8	27.2
Hemicellulose	6.1	38.3	32.3	38.1	38.6	37.8	37.1	38.6	43.0	39.4

ADF= acid detergent fiber; ADL= acid detergent lignin; CP= crude protein; DM= dry matter; NDF= neutral detergent *fiber; OM= organic matter; T1= intact sole UTTS; T2= intact UTTS + 150 g DM WB; T3= intact UTTS + 250 g DM WB; T4= intact UTTS + 350 g DM WB; T5= castrated sole UTTS; T6= castrated UTTS + 150 g DM WB; T7= castrated UTTS + 250 g DM WB; T8= castrated UTTS + 350 g DM WB; UTTS= urea treated tef straw;*
WB= wheat bran.

3.2. Feed Intake

Daily UTTS DM intake was higher (P<0.05) for the castrated compared to the intact sheep (Table 2). However, total DM intake was similar between both sexes. The daily total DM, organic matter (OM) and CP intake were higher (P<0.001) for sheep supplemented with WB than those fed only on UTTS. This could be attributed to the similar quantity of UTTS DMI consumed by sheep on the control treatment and those supplemented with the different levels of WB, where the latter contributed to the observed high total DM intake which increased with the level of supplementation. Sheep on the medium and high levels of WB supplementation had higher (P<0.001) total DM and CP intake compared to the low level of supplementation. This is contrary to the reports of Tesfaye *et al.* (2001) in which medium level compared to low and high levels of WB supplementation improved total DM intake in tef straw based feeding of zebu oxen. The similarity in daily total DM intake for UTTS out of all the supplemented treatments indicates absence of substitution of the basal diet with the supplement. The ADF intake was higher (P<0.05) for the non- supplemented sheep and those supplemented with the low level compared to the high level of WB. The higher ADF intake in the non-supplemented sheep and those supplemented with the low level of WB could be attributed to the high ADF containing UTTS contributing to a higher proportion of their daily DM intake. Moreover, urea treatment was also reported to increase the ADF content of straws (Zaman and Own, 1995).

Table 2. Daily feed intake of intact and castrated Afar sheep fed urea treated tef straw supplemented with graded levels of wheat bran.

Factor	UTTS DMI (g)	Total DMI (g)	OMI (g)	CPI (g)	NDFI (g)	ADFI (g)
A (Sex)						
Intact	735.3^{a}	806.5	776.6	86.1	569.8	292.8
Castrated	799.2^{b}	870.7	787.8	86.9	577.4	296.4
SL	*	ns	ns	ns	ns	ns
SEM	26.41	23.64	22.28	2.08	18.70	10.18
B (WB level)						
0 g	738.0	738.0^{c}	674.1^{b}	62.6^{c}	566.7	312.4^{a}
150 g	677.4	826.4^{b}	804.8^{a}	85.7^{b}	608.7	317.0^{a}
250 g	638.4	883.8^{a}	815.5^{a}	94.8^{a}	571.6	286.1^{ab}
350 g	623.9	963.7^{a}	834.4^{a}	102.9^{a}	547.4	262.7^{b}
SL	ns	***	**	***	ns	*
SEM	37.35	33.43	31.51	2.94	26.45	14.40
AxB (Interaction)						
SL	ns	ns	ns	ns	ns	ns

^{abc} = Means within a column not bearing a common superscript differ significantly; *= P< 0.05; **= P< 0.01; ***= P< 0.001; *ADFI= acid detergent fiber intake; CPI= crude protein intake; DMI= dry matter intake; NDFI= neutral detergent fiber intake; ns= non significant; OMI= organic matter intake; SEM= standard error of mean; SL= significance level; UTTS= urea treated tef straw; WB= wheat bran.*

3.3. Feed Digestibility

Supplementation with the medium and high levels of WB resulted in higher ($P<0.05$) apparent digestibility of DM compared to non- supplemented sheep, whereas only the high level of WB supplementation resulted in higher ($P<0.05$) apparent digestibility of OM compared to in the non- supplemented sheep (Table 3). The control treatment had lower ($P<0.001$) apparent CP digestibility compared to the low, medium and high levels of WB supplemented treatments. Moreover, the sheep on the low level of WB supplementation had lower ($P<0.001$) apparent digestibility of CP than those on the high level of supplementation. The result of this study agrees with a similar study (Ponnampalam *et al*., 2004) which reported a significant increase in hay DM digestibility in lambs supplemented with oat, and a further increase in DM digestibility with barley supplementation. Nuwanykpa and Butterworth (1987) also reported lower apparent digestibility of nitrogen in sheep fed solely on tef straw supplemented with molasses compared to those supplemented with urea or fed tef straw alone. Based on their results, the same authors argued that nitrogen deficiency may be a greater cause of poor performance than energy deficiency in sheep fed solely on cereal crop residues. The NDF digestibility was similar in all treatments, which agrees with the results of Nuwanykpa and Butterworth (1987) in Ethiopian Highland sheep fed on a basal diet of tef straw supplemented with noug seed cake.

Table 3. Apparent digestibility coefficient of feed nutrients in intact and castrated Afar sheep fed urea treated tef straw supplemented with graded levels of wheat bran.

	Apparent digestibility				
Factor	DM (%)	OM (%)	CP (%)	NDF (%)	ADF (%)
A (Sex)					
Intact	0.76	0.78	0.72	0.80	0.78
Castrated	0.78	0.80	0.75	0.81	0.80
SL	ns	ns	ns	ns	ns
SEM	1.08	0.91	1.31	1.17	1.16
B (WB level)					
0 g	0.73^{b}	0.76^{b}	0.62^{c}	0.82	0.82
150 g	0.77^{ab}	0.80^{ab}	0.74^{b}	0.81	0.80
250 g	0.78^{a}	0.80^{ab}	0.77^{ab}	0.79	0.77
350 g	0.81^{a}	0.82^{a}	0.80^{a}	0.81	0.79
SL	*	*	***	ns	ns
SEM	1.53	1.29	1.85	1.66	1.64
A x B (Interaction)					
SL	ns	ns	ns	ns	ns
SEM	2.16	1.82	2.61	2.34	2.32

*[abc]= Means within a column not bearing a common superscript differ significantly; *= P< 0.05; **= P< 0.01; ***= P< 0.001; ADF= acid detergent fiber; DM= dry matter; CP= crude protein; ns= not significant; NDF= neutral detergent fiber; OM= organic matter; SEM= standard error of means; SL= significance level; WB= wheat bran.*

3.4. Body Weight Change

The daily BW gain was higher ($P<0.001$) in the order of high > medium > low > zero (control) level of supplementation (Table 4). Final BW and FCE were higher ($P<0.001$) in sheep supplemented with WB compared to those fed only UTTS. Out of all the supplemented sheep, those on the high level of WB supplementation had higher ($P<0.001$) final BW and FCE compared to those on the low level of WB supplementation (Table 4). In agreement with this study, supplementation of WB in rice straw based feeding of entire bulls (Chowdhury, 1996), and supplementation of WB in mixture with groundnut cake to pregnant does (Getnet *et al*., 1998) resulted in substantial BW gain. However, supplementation with mixtures of multi-purpose trees resulted in higher BW gain and final BW compared to supplementation with WB in tef straw based feeding of Menz sheep (Solomon *et al*., 2004). The absence of BW loss in Afar sheep fed sole UTTS is similar to the results of Trach (2004) which reported BW gain in steers fed on urea treated rice straw. This could be attributed to higher straw DM intake which, in turn, could have stemmed from the increased digestibility of the UTTS. Moreover, the CP content of the UTTS accounted for more than the minimum requirement of 7% and 8% to limit microbial fermentation in the rumen and feed intake in the host animal, respectively (Van Soest, 1994). Contrary to the results of this study, Sibanda *et al.* (1989) reported that FCE was not affected by the level of protein supplementation. However, in agreement with the current study, Merkel *et al.* (1999) reported lower FCE in control lambs compared to lambs fed tree leaves at 50% dietary CP intake. Abule (1994) also reported FCE increasing linearly with the level of supplementation. Higher nitrogen utilization efficiency at higher than lower levels of CP supplementation was also reported by Tegene *et al.* (2001).

Muhikambele *et al.* (1996) reported that castrated goats were less efficient in utilizing barley based concentrate and lucerne pellets than intact ones. Field (1971), Price and Yeats (1971) also indicated that entire males utilized feed better than castrated ones. However, the results of this study did not show differences between castrated and intact Afar sheep in FCE, daily BW gain and final BW achieved.

Table 4. Body weight change and feed conversion efficiency of Afar sheep fed urea treated tef straw supplemented with graded levels of wheat bran.

Factor	Initial BW (kg)	Daily BW gain (g/d)	Final BW (kg)	FCE
A ("Sex")				
Intact	15.7	65.6	21.6	0.07
Castrated	15.8	68.8	22.0	0.07
SL	ns	ns	ns	ns
SEM	0.11	4.00	0.33	0. 004
B (WB level)				
0 g	15.9	40.3[d]	19.5[c]	0.05[c]
150 g	15.7	64.6[c]	21.5[b]	0.07[b]
250 g	15.8	75.7[b]	22.6[ab]	0.09[ab]
350 g	15.7	88.2[a]	23.6[a]	0.09[a]
SL	ns	***	***	***
SEM	0.16	1.00	0.47	0.006
AxB (Interaction)				
SL	ns	ns	ns	ns
SEM	0.23	1.00	0.66	0.82

*[abcd]=means within a column not bearing a common superscript differ significantly; *= P< 0.05; ** P< 0.01; *** P< 0.001; BW= body weight; FCE= feed conversion efficiency; ns= not significant; SEM= standard error of mean; SL= significance level; WB= wheat bran.*

3.5. Carcass Characteristics

Supplementation with the high level of WB resulted in heavier empty BW (P<0.01), hot carcass weight (P<0.01) and rib eye area (P<0.001) compared to the other treatments (Table 5). Moreover, the medium level of WB supplementation resulted in heavier (P<0.01) hot carcass weight compared to the non- supplemented sheep, and both the medium and low level of WB supplementation resulted in higher (P<0.001) rib eye muscle area compared to in the non- supplemented sheep. This agrees with the results of Asnakew (2005) which reported heavier empty BW for Hararghe Highland goats supplemented with concentrates. Rib-eye muscle area is mostly used as a tool to indicate the proportion of carcass lean or an expression of carcass desirability (Wolf *et al*., 1980) and, in this regard, supplementation appeared to impart better carcass quality characteristics. The interaction between sex and level of WB supplementation was significant (P<0.01) for rib-eye muscle area, indicating that supplementation could disfavor carcass leanness in castrated Afar sheep, whereas the contrary is true for the non-castrated ones. Dressing percent on slaughter weight base was higher (P<0.01) for the WB supplemented sheep compared to those fed only UTTS. The dressing percent observed in this study agrees with the results of similar studies (Asnakew, 2005; Simret, 2005). According to Devendra and Burns (1983), dressing percent helps to assess the meat production capacity of animals. Therefore, it can be inferred that supplementation of UTTS with WB has contributed to increased meat production of Afar sheep. Castrated sheep had higher (P<0.05) omental fat than the intact sheep, (table 6) and this could be attributed to the fact that castrated animals tend to deposit more fat in their body compared to intact ones. Sheep supplemented with the high level of WB had heavier intestinal fat (P<0.05), omental fat, TEOC, skin and TUP (P<0.01) compared to sheep fed solely on UTTS. According to Kirton *et al*. (1972), nutritional dietary status of the animal and BW affect the production efficiency of offals. In agreement with the current study, Solomon *et al*. (1991) reported lower omental fat deposition for non- supplemented compared to maize, noug cake and alfalfa supplemented Afar goats.

The lack of differences in dressing percent and rib-eye muscle area between intact and castrated Afar sheep in this study agrees with other studies (Solomon *et al*., 1991; Yibrah *et al*.,1991; Demissie *et al*., 1989) in Afar goats and Horro sheep maintained at a high level of nutrition. Osman *et al*. (1970) also reported no effect of castration on hot carcass weight and dressing percent in 14 month-old Sudan Desert sheep. Unlike the findings of Mahgoub *et al*. (1997), this present study showed that yearling intact and castrated Afar sheep are equally suitable for meat production since they attained similar slaughter weight without reduced FCE and the risk of becoming excessively fat.

Table 5. Carcass characteristics of castrated and intact Afar sheep fed on urea treated tef straw and supplemented with graded levels of wheat bran.

Factor	SW (kg)	EBW (kg)	HCW (kg)	Rib-eye area (cm^2)	Dressing percentage	
					SW base	EBW base
A (Sex)						
Intact	20.8	16.2	8.5	5.4	42.0	52.4
Castrated	20.2	15.1	8.3	5.3	43.1	54.9
SL	ns	ns	ns	ns	ns	ns
SEM	0.55	0.48	0.25	0.15	0.93	1.32
B (WB level)						
0 g	19.4	13.8^{b}	7.2	4.3	38.3^{b}	51.8
150 g	19.8	15.3^{b}	8.2^{c}	5.1^{b}	42.3^{a}	53.1
250 g	20.6	15.6^{b}	8.6	5.2^{b}	44.1^{a}	54.1
350 g	22.2	17.9^{a}	9.7^{a}	6.6^{a}	45.6^{a}	55.5
SL	ns	**	**	***	**	ns
SEM	0.78	0.68	0.35	0.21	1.31	1.87
AxB						
1	18.8	13.3	6.7	3.71^{e}	37.0	50.1
2	19.8	15.9	8.3	4.96^{cd}	44.3	52.5
3	21.9	16.6	9.0	6.09^{ab}	43.2	52.7
4	22.8	19.1	10.0	6.67^{a}	43.7	55.6
5	19.2	14.3	7.7	4.19^{de}	39.5	51.0
6	19.9	15.3	8.8	4.81^{cd}	46.8	53.7
7	19.2	14.1	7.3	5.40^{bc}	41.5	54.3
8	21.6	16.7	9.3	6.61^{a}	44.5	58.6
SL	ns	ns	ns	**	ns	ns
SEM	1.37	0.96	0.50	0.29	1.86	2.60

^{abc}= *Means within a column not bearing a common superscript differ significantly; *=P<0.05; **= P<0.01; ***= P<0.001; EBW= empty body weight; HCW= hot carcass weight; ns= not significant; SEM= standard error of means; SL= significance level; SW= slaughter weight; T1= intact sole UTTS; T2= intact UTTS + 150 g DM WB; T3= intact UTTS + 250 g DM WB; T4= intact UTTS + 350 g DM WB; T5= castrated sole UTTS; T6= castrated UTTS + 150 g DM WB; T7= castrated UTTS + 250 g DM WB; T8= castrated UTTS + 350 g DM WB; UTTS = urea treated tef straw;WB = wheat bran.*

Table 6. Carcass offal characteristics of castrated and intact Afar sheep fed on urea treated tef straw and supplemented with graded levels of wheat bran.

Factor	Empty gut (kg)	Omental fat (g)	Intestinal fat (g)	Tail (g)	TEOC (kg)	Skin (kg)	Genital organ (g)	Gut fill (kg)	TNEOC (kg)	TUP (kg)
A (Sex)										
Intact	1.15	66.94^{b}	104.0	621.4^{b}	11.7	2.5	209.3^{a}	5.1^{a}	3.7^{a}	14.2^{a}
Castrated	1.22	87.03^{a}	122.0	848.8^{a}	11.2	2.2	95.4^{b}	5.2^{a}	2.6^{a}	13.4^{a}
SL	ns	*	ns	**	ns	ns	***	ns	ns	ns
SEM	0.04	6.68	7.84	60.00	0.38	0.01	11.67	0.02	0.50	0.47
B (WB level)										
0 g	1.1	50.8^{c}	88.4^{b}	565.9	9.9^{b}	1.9^{c}	94.5^{b}	4.4^{b}	2.7	11.9^{b}
150 g	1.2	65.0^{bc}	110.3^{ab}	686.7	11.4^{ab}	2.1^{bc}	152.7^{a}	5.0^{ab}	2.8	13.5^{b}
250 g	1.2	80.7^{b}	114.1^{ab}	797.5	11.5^{ab}	2.5^{ab}	165.4^{a}	5.3^{ab}	3.3	13.9^{ab}
350 g	1.3	111.5^{a}	139.2^{a}	890.2	12.9^{a}	2.9^{a}	196.8^{a}	6.1^{a}	3.7	15.8^{a}
SL	ns	**	*	ns	**	**	**	*	ns	**
SEM	0.06	9.44	11.10	113.1	0.53	0.01	16.50	0.03	0.70	0.67
AxB										
1	1.0	47.6	85.4^{a}	515.0^{b}	9.2^{c}	1.8	179.5^{bc}	3.9	2.7	10.9^{c}
2	1.1	49.1	100.0^{a}	560.0^{b}	11.0^{bc}	2.2	125.9^{cd}	5.3	2.9	13.2^{bc}
3	1.2	74.6	113.7^{a}	575.0^{b}	12.3^{ab}	2.7	239.9^{ab}	5.6	3.1	15.0^{ab}
4	1.4	96.4	117.0^{a}	1020.0^{ab}	14.3^{a}	3.2	309.3^{a}	5.8	4.0	17.5^{a}
5	1.1	54.0	91.5^{a}	480.4^{b}	10.6^{bc}	2.0	80.3^{d}	4.7	2.3	12.8^{bc}
6	1.2	80.9	103.6^{a}	616.7^{b}	10.7^{bc}	2.1	84.4^{d}	4.9	2.5	12.8^{bc}
7	1.3	86.7	164.8^{a}	813.3^{ab}	11.5^{bc}	2.2	90.8^{d}	5.1	2.6	13.9^{bc}
8	1.2	126.6	128.06^{a}	1300.0^{a}	11.9^{b}	2.5	108.7^{cd}	6.4	4.9	14.1^{bc}
SL	ns	ns	ns	*	*	ns	**	ns	ns	*
SEM	0.09	13.35	15.68	160.00	0.75	0.02	23.34	0.05	1.00	0.94

^{abcd} *means in the same row with different superscripts differ significantly; *** =(P<0.001); ** =(P<0.01); * =(P<0.05); ns =not significant; SEM =standard error of mean; SL =significance level; T1=intact sole UTTS; T2 =intact UTTS + 150 g DM WB; T3 =intact UTTS + 250 g DM WB; T4 =intact UTTS + 350 g DM WB; T5 =castrated sole UTTS; T6 =castrated UTTS + 150 g DM WB; T7 =castrated UTTS + 250 g DM WB; T8 =castrated UTTS + 350 g DM WB; TEOC =total edible offal component; TNEOC =total non edible offal components; TUP =total usable product; UTTS =urea treated tef straw; WB =wheat bran.*

4. Conclusions

The results of the study showed that UTTS could support a reasonable level of feed intake and animal performance. Moreover, it was found that level of supplementation is more significant regarding the performance of Afar sheep in feed intake, BW and carcass parameters than castration or maintaining them intact during small scale fattening schemes. Failure to observe differences in BW, FCE and carcass characteristics between intact and castrated Afar sheep could be attributed to the age of the sheep used in the study.

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Intake, Digestibility, Body Weight and Carcass Characteristics of Tigray Sheep Fed Tef Straw Supplemented with Sesame Seed Meal or Wheat Bran and their Mixtures

Zemicael Gebreslassie[1] and Solomon Melaku[2*]

[1]Enda Selassie ATVET College, P O Box 07, Shire, Tigray, Ethiopia
[2] Department of Animal Science, Haramaya University, P O Box 138, Dire Dawa, Ethiopia

Abstract: The study was conducted over 90 days feeding and 7 days digestibility trials at Enda Selassie ATVET College to assess the effect of supplementation on feed utilization and carcass characteristics in tef (*Eragrostis tef*) straw based feeding of Tigray rams. The rams were arranged in a randomized complete block design divided into five blocks based on initial BW. The treatments comprised of *ad libitum* tef straw (control, T1) and daily supplementation with 300 g dry matter (DM) sole sesame (*Sesame indicum*) seed meal (SSM, T2), 0.65SSM:0.35 wheat bran (WB, T3), 0.35SSM:0.65WB (T4) and sole WB (T5). Tef straw used in the study contained low (30.6 g kg $^{-1}$ DM) crude protein (CP) and high (825.8 g kg $^{-1}$ DM) neutral detergent fiber (NDF) contrary to the supplement feeds. Total daily DM intake and DM intake as a percentage of BW were higher ($P < 0.001$) for the supplemented rams (701.4-725 g day^{-1} and 2.57-2.63%) than those fed solely on tef straw (403.1 g day^{-1} and 1.8%). The CP intake increased ($P < 0.001$) in the order T2 > T3 > T4 > T5 > T1. Daily BW gain was negative and lower ($P < 0.001$) in rams fed solely on tef straw (-22 g g day^{-1}) compared to the supplemented ones (50-71.1 g day^{-1}). Out of all supplemented treatments, T5 was lower ($P < 0.001$) in apparent digestibility of CP and daily BW gain compared to T2, T3 and T4. Hot carcass weight and empty BW were higher ($P < 0.001$) for T2, T3, T4 compared to T1. Dressing percent on slaughter weight base was higher ($P< 0.001$) for supplemented (39.5-43.4%) compared to the control treatment (32.9%). Out of all supplements, SSM and its mixtures with WB resulted in better performance of the sheep compared to supplementation with sole WB.

Keywords: Tigray Sheep; Body Weight; Carcass; Intake; Sesame Seed Meal; Tef Straw; Wheat Bran

1. Introduction

Small ruminants are valuable sources of meat, milk and fiber globally. The economic importance of small ruminants is far-reaching in countries with developing economies such as Ethiopia since they are immediate sources of cash income, serve as a saving account, ensure household food security, and are used as a means to build assets and alleviate poverty among the poorest sections of society. Moreover, meat from small ruminants is ideal for family consumption without deteriorating in quality owing to their comparatively small carcass size, particularly in rural communities which lack effective cooling systems for meat preservation (Devendra, 2001).

Although Ethiopia has a large population of sheep that are widely distributed across all agro-ecological zones of the country, their productivity is very low, mainly due to inadequate production inputs such as animal feeds. Most of the sheep in Ethiopia which are owned by smallholder farmers and pastoralists depend entirely on natural grasslands and crop aftermaths as sources of feeds. These feed resources contain less than 7% crude protein (CP) and more than 75% neutral detergent fiber (NDF) (Seyoum and Zinash, 1995), which compromise feed intake and digestibility, resulting in inadequate nutrient supply to satisfy the maintenance requirement of sheep, and thus cause severe weight losses, particularly in the non-forage growing season.

Therefore, it is imperative to improve the utilization of poor quality feed resources such as crop residues by correcting their nutrient deficiencies. One alternative in this regard is the use of agro-industrial by–products as supplements in straw-based feeding of livestock (Reverdin and Sauvant, 1991). Such a strategy could enable the high nutrient requirements for growing livestock to be met in order to attain desired degree of finish for the market. Out of all the agro-industrial by-products available in Ethiopia, sesame seed meal (SSM) and wheat bran (WB) could be used as feed supplements in crop residue based feeding of sheep.

However, these by-products are not effectively utilized by smallholder farmers in their area of production, mainly due to lack of information about their potential as feed supplements as well as the optimum ratio at which they can be mixed in supplementary rations for sheep. Therefore, this experiment was conducted with the objective of studying the effect of supplementing SSM, WB and their mixtures at 0.65 SSM:0.35WB and 0.35SSM:0.65WB on feed intake, digestibility, body weight (BW) change and carcass parameters in tef (*Eragrostis tef*) straw based feeding of Tigray rams.

2. Materials and Methods

2.1. Description of the Study Area

The experiment was conducted at Enda Selassie Agricultural Technical Vocational, Education and Training (ATVET) College located at 14° 06' N, 38° 17' E and at an altitude of 1860 masl in the Northwestern Zone of Tigray Regional State, Ethiopia. The mean annual rainfall is 700-900 mm, mean annual minimum and maximum temperature is 10 °C and 27 °C, respectively (Zemichael, 2007).

2.2. Animals, Experimental Design and Treatments

Twenty-five yearling Tigray rams with mean initial BW of 23.1 ± 0.81 kg (mean ± SD) were used in the experiment that lasted for 90 days of feeding and 7 days of digestibility trials. The animals were quarantined for three weeks during which time they were dewormed and

*Corresponding author. E-mail: solmelay@yahoo.com

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sprayed against internal and external parasites, respectively, as well as vaccinated against pasteurellosis. The rams were blocked based on initial BW into five blocks of five animals in a randomized complete block design. The five dietary treatments (Table 1) were randomly assigned to each animal in a block giving five animals per treatment.

Table 1. Experimental treatments.

Treatment	Tef straw	Supplement	Quantity
Treatment 1(control)	*Ad libitum*	0	
Treatment 2	*Ad libitum*	SSM	300 g DM day $^{-1}$
Treatment 3	*Ad libitum*	0.65SSM: 0.35WB	300 g DM day $^{-1}$
Treatment 4	*Ad libitum*	0.35SSM: 0.65WB	300 g DM day $^{-1}$
Treatment 5	*Ad libitum*	WB	300 g DM day $^{-1}$

DM = dry matter; SSM = sesame seed meal; WB = wheat bran;

2.3. Feeds and Feeding Management

Tef straw, common salt block and water were offered *ad libitum*. The supplement feeds, consisting of sole SSM, sole WB or mixtures of both at 0.65SSM:0.35WB and 0.35SSM:0.65WB were offered at the rate of 300 g DM/ day in two equal portions at 08:00 h and 16:00 h daily. The SSM and WB were thoroughly mixed at the given proportions after grinding the sesame seed cake into a meal. The tef straw and the supplement feeds were offered in separate troughs per experimental sheep. Daily supplement and basal feed offers and refusals were weighed and recorded for each sheep to calculate daily feed intake. Samples of feed offer were taken per batch of feed and refusals were collected per animal over the experimental period, pooled on treatment basis and sub-sampled for laboratory analysis.

2.4. Digestibility Trial

The digestibility trial was conducted at the end of the feeding trial using a completely randomized design. Four sheep from each treatment were adapted to the carrying of fecal bags for three days. This was followed by total collection of feces for seven days per animal. Feces collected in the fecal bags over 24 hours were weighed every morning for each sheep. Twenty percent of the voided feces were sampled and pooled for each animal over the collection period. The fecal samples were stored at -20 ^{o}C. At the end of the feces collection, the fecal samples were dried in a forced air oven at 55 ^{o}C for 48 hours and ground to pass through a 1 mm sieve. The ground samples were stored in airtight plastic containers until required for analysis. The sheep were weighed at the beginning and the end of the digestibility trial. The digestibility coefficient of nutrients was determined as the proportion of nutrients consumed but not recovered in feces.

2.5. Body Weight and Carcass Parameters

Body weight of each animal was measured at the beginning of the experiment and every 10 days after overnight fasting to account for the confounding effect of gut fill on BW. Daily BW gain was calculated as the difference between the final and initial BW divided by the number of feeding days. The feed conversion ratio (FCR) was calculated as a proportion of daily DM intake to the daily BW gain. At the end of the feeding and digestibility trial, twenty sheep, four from each treatment were slaughtered after overnight fasting. Blood, skin with legs below the fetlock joints, head (with horn, tongue, and ear), reproductive organs (testis and penis), organs in the peritoneal sac (lung, heart and trachea) and organs in the abdominal sac (empty gut, liver, gall bladder, kidney, spleen and pancreas, kidney), omental and channel fat as well as hot carcass weights were weighed. Dressing percent was calculated as a proportion of carcass weight to slaughter weight or empty BW. The cross section of the rib-eye muscle was traced on transparent plastic foil between the 11th and 12th ribs on both sides. The traced rib eye muscle area was placed on a square paper which had a grid area of 1x1 mm and the numbers of squares within the traced grid were counted to calculate the rib eye muscle area. Squares with more than 50% of their area in the grid were accounted for as full squares, whereas those with less than 50% of their area in the grid were not counted. Half squares in the traced area were accounted for their actual size.

2.6. Chemical Composition

Ash, DM and CP were determined according to AOAC (1990). The NDF, acid detergent fiber (ADF) and acid detergent lignin (ADL) were analyzed according to Van Soest and Robertson (1985).

2.7. Statistical Analysis

The experimental data were subjected to the analyses of variance using the general linear model procedure of SAS (1998). Treatment means were separated by least significant difference test. The statistical model used for analyzing data on feed intake and BW was:

$Y_{ij} = \mu + T_i + B_j + E_{ij}$ where,

Y_{ij}= the response variable; μ= the overall mean; T_i= the treatment effect; B_j= the block effect; E_{ij}= the random error.

Data collected on digestibility and carcass parameters were analyzed using the model;

$Y_{ij} = \mu + T_i + E_{ij}$ where,

Y_{ij}= the response variable; μ= the overall mean; T_i= the treatment effect; E_{ij}= the random error.

3. Results and Discussion

3.1. Chemical Composition of Treatment Feeds

The CP content of SSM in this study (Table 2) was higher than the CP content of 30.93% (Solomon, 1992) and 38% (Enseminger, 2002). The differences in the composition of SSM used in this study and that reported in the other studies may be due to the differences in the methods and efficiencies of extracting oil from the sesame seed as well as differences in the varieties of sesame seed (Solomon, 1992; Enseminger, 2002). The CP NDF, ADF, ADL contents of WB used in this study were comparable to the results reported by Solomon *et al*., 2004. Tef straw contained low CP, but high NDF and ADF fractions, contrary to the content of the constituents in the supplement feeds which justify the use of the supplements in tef straw-based feeding of sheep.

Table 2. The chemical compositions of treatment feeds.

Composition	Tef straw	SSM	0.65SSM: 0.35WB	0.35SSM: 0.65WB	WB
DM (g kg^{-1})	881.4	812.4	829.5	844.1	861.2
OM (g kg^{-1} DM)	947.5	941.8	946.5	950.5	955.2
CP (g kg^{-1} DM)	30.6	437.5	342.7	261.4	166.6
NDF (g kg^{-1} DM)	825.8	183.7	283.1	368.4	467.8
ADF (g kg^{-1} DM)	491.7	103.4	113.0	121.2	130.8
ADL (g kg^{-1} DM)	53.2	15.0	21.4	26.9	33.3
Hemicellulose (g kg^{-1} DM)	334.1	80.3	170.1	247.2	337.0
Cellulose (g kg^{-1} DM)	438.5	88.4	91.6	94.3	97.5

ADF= acid detergent fiber; ADL= acid detergent lignin; DM= dry matter; CP= crude protein; NDF= neutral detergent fiber; OM= organic matter; SSM= sesame seed meal; WB= wheat bran.

3.2. Feed Intake

Supplementation did not affect ($P > 0.05$) tef straw DMI (Table 3), although Preston and Leng (1984) suggested that supplements can substitute fibrous feeds if the levels of supplementation exceed 20% of total DM intake. This result agrees with that of Nsahlai *et al.* (1999), where supplementation of sheep fed tef straw basal feed with oilseed cake and tanniferous feeds (pods of *Acacia albida* and *Sesbania sesban* leaves) had no effect on the intake of tef straw. Supplemented sheep had higher ($P<0.001$) total DM intake than unsupplemented ones, which is similar to the results of other studies (Swanson *et al.,* 2000; Kabir *et al.*, 2004). The increase in total DM intake in the supplemented sheep might be due to better contents of CP in the supplement feeds. This provided adequate CP for the rumen micro-organisms to speed up fermentation of feed which, in turn, might have reduced feed retention time in the rumen, leading to more total DM intake. Moreover, supplementation might have improved the supply of escape protein at tissue level which covered amino acids in which microbial protein was deficient, thus improving the balance of absorbed nutrients which, consequently, could have promoted total DM intake. Indeed, Swanson *et al.* (2000) suggested that the supply of amino acids at tissue level improved DM intake. In contrast to the above result, Shahjalal *et al.* (2000) reported similar DM intake in goats supplemented with high protein and energy sources and those maintained otherwise. Kabir *et al.* (2004) also showed similarity in DM intake in grazing goats supplemented with high protein or low protein diets. The higher ($P<0.001$) CP intake observed in supplemented treatments compared to the control was expected, since the tef straw was deficient in CP content. Out of all supplemented sheep, the difference ($P<0.001$) in CP intake was in the order of T2 > T3 > T4 > T5, and this could be attributed to the differences in CP content of the treatment diets, which is a reflection of higher CP content in sole SSM or in its mixture with WB.

3.3. Apparent Digestibility

The apparent digestibility of CP was higher ($P < 0.001$) for the supplemented compared to the non-supplemented sheep (Table 4) which is indeed a function of the higher CP supplied by the supplements. Ash and Norton (1987) also showed that supplementation with protein rich diets in goats significantly improved nitrogen digestibility compared to low protein diets. Among the supplemented sheep, SSM resulted in higher ($P < 0.001$) apparent digestibility of CP than WB. The difference in digestibility of CP between SSM and WB fed sheep in this study may be due to the low content of CP and higher proportion of cell wall fiber in WB which might have reduced the apparent digestibility of CP in the latter.

Table 3. Daily feed intake of Tigray sheep fed tef straw supplemented with sesame seed cake, wheat bran and their mixtures at different proportions.

Feed intake	T1	T2	T3	T4	T5	SL	SEM
Tef straw DMI (g d^{-1})	403.1	423.0	413.5	415.6	401.3	ns	14.4
Supplement DMI (g d^{-1})	-	300.0	300.0	300.0	300.0	ns	0.00
Total DMI (g d^{-1})	403.1^{b}	723.0^{a}	713.5^{a}	715.6^{a}	701.4^{a}	***	14.4
Tef straw DMI (% BW)	1.80	1.53	1.48	1.49	1.50	ns	0.08
Supplement DMI (% BW)	-	1.09	1.08	1.08	1.13	ns	0.03
Total DMI (% BW)	1.80^{b}	2.62^{a}	2.61^{a}	2.57^{a}	2.63^{a}	***	0.09
Substitution rate	-	0.09	0.12	0.12	0.12	ns	0.27
Total CP intake (g d^{-1})	12.3^{e}	144.2^{a}	115.5^{b}	91.14^{c}	62.3^{d}	***	0.44
Total NDF intake (g d^{-1})	332.9^{c}	404.5^{b}	437.5^{ab}	453.7^{ab}	471.8^{a}	***	11.9
Total ADF intake (g d^{-1})	198.2^{b}	239^{a}	243.8^{a}	240.7^{a}	236^{ab}	**	7.06

*[abc] Means with different superscripts in a row are significantly different; ***= P<0.001; ADFI= acid detergent fiber intake; CPI= crude protein intake; DMI= dry matter intake; NDFI= neutral detergent fiber intake; ns= non- significant; SEM= standard error of mean; SL= significance level; SSM= sesame seed meal; T1= tef straw; T2= T1+ SSM; T3= T1+ 0.65 SSM: 0.35 WB; T4 = T1+ 0.35 SSM: 0.65 WB; T5= T1+ WB; WB= wheat bran.*

Table 4. Apparent digestibility of nutrient in Tigray sheep fed tef straw supplemented with sesame seed cake, wheat bran and their mixtures at different proportions.

Treatments	Digestibility coefficient				
	DM	OM	CP	NDF	ADF
T1	0.52	0.58	-0.12[c]	0.57	0.63
T2	0.61	0.63	0.81[a]	0.50	0.55
T3	0.55	0.59	0.74[ab]	0.44	0.51
T4	0.61	0.65	0.72[ab]	0.53	0.59
T5	0.59	0.63	0.60[b]	0.50	0.56
SL	ns	ns	***	ns	ns
SEM	.023	.024	.026	.077	.022

[abc] *Means with different superscripts in column are significantly different at***= P<0.001; ADF= acid detergent fiber; CP= crude protein; DM= dry matter; NDF= neutral detergent fiber; ns: non-significant; OM= organic matter; SEM= standard error of mean; SL= significance level; SSM= sesame seed meal; T1= tef straw; T2= tef straw + SSM; T3= T1+ 0.65 SSM: 0.35 WB; T4= T1+ 0.35 SSM: 0.65 WB; T5= T1+ WB; WB= wheat bran.*

3.4. Body Weight and Carcass Parameters

The supplemented sheep excelled (P < 0.001) compared to the non- supplemented ones in final BW, BW change during the experimental period, and daily BW gain (Table 5), which was in agreement with other studies (Bonsi *et al*., 1994; Nsahlai *et al*., 1999; Solomon *et al*., 2004) which reported increased BW gain in small ruminants as a result of supplementation with high energy or protein sources or both in an attempt to bridge the gap between dry and wet season feed availability or for fattening purposes. The BW change and daily BW gain were higher (P < 0.001) for sheep supplemented with SSM compared to those supplemented with WB and this could be attributed to higher intake and better apparent digestibility of CP in the former. This was indeed in agreement with Owens and Zinn (1988) who, after reviewing a large body of data, reported that added dietary protein resulted in increased rate of BW gain in over 85% of the feeding trials due due to meeting the energy and protein requirements of the animals for tissue accretion.

The sheep on the control diet continuously lost BW. Similar results were recorded by Abule (1994) in calves fed sole tef straw, which lost BW at the rate of -75.76 g d^{-1}. Loss of BW at the rate of -17.5 g d^{-1} (Kaitho, 1997) and -24.4 g d^{-1} (Kaitho, 1998) was also reported for sheep fed solely on tef straw. This could be due to the high cell wall fiber content in tef straw resulting in low rumen fermentation, digestibility and voluntary feed intake, thereby limiting BW gain in the sheep. The Higher level of daily BW loss in the current study compared with the aforementioned studies could be attributed to the poor nutrient content of the tef straw used in this study. Sheep supplemented with sole WB had lower (P< 0.001) daily BW gain compared to sheep supplemented with sole SSM or the higher proportion of SSM with WB, indicating that sole or higher proportion of SSM in the supplement was more effective in promoting daily BW gain due to better chemical composition. Similar results were reported by Getnet (1998) in which kids from lactating does supplemented with a higher proportion of groundnut cake in a mixture with wheat bran had a higher BW gain. Lema (1993) compared supplementation with leguminous hay and oil seed cakes to growing sheep fed tef straw as a basal diet and concluded that different sources of CP even at equal intakes may result in different BW gains. Similarly, supplementation with mixtures of multi-purpose trees resulted in higher BW gain and final BW compared to supplementation with wheat bran or sole multi-purpose trees (Solomon *et al*., 2004). This could be attributed to the nature of the protein sources, where protein sources which are slowly degradable in the rumen resulted in the better BW gain. Indeed, Solomon (1992) indicated that mechanically pressed SSM had intermediate rumen degradability and high energy content. Therefore, the higher daily BW gain observed in this study in sheep supplemented with a high proportion of SSM or with sole SSM compared to sole WB- supplemented sheep could be attributed to the intermediate rumen degradability of SSM (Solomon, 1992) allowing more absorption of escape protein at intestinal level as well as also supplying adequate rumen degradable protein to the rumen microbes. The lack of differences between sheep supplemented solely with SSM or its higher mixture with WB in daily BW gain might be attributed to the similar quality of protein available in the small intestine, even accounting for differences in CP intake between sheep in both treatments. The hypothesis for explaining the observed similarity in BW gain could be that a higher proportion of the dietary protein in sheep fed on the highest CP intake might have been wasted by degradation in the rumen resulting in excess ammonia than could be utilized by the rumen microorganisms. Excess CP beyond the requirements of rumen microbes is either recycled or excreted in urine (McDonald *et al*., 2002) and the latter may be the reason for obtaining the observed similar BW gain in both treatments. Thus, the feed offer should account for the quantity of CP which is effectively utilized by sheep. Comparable BW gains to the results of this study were reported by Shahjalal (2000). The low BW gain in sheep supplemented with sole WB may be due to lower CP and high NDF, ADF and ADL content in WB that could have reduced nutrient utilization in experimental sheep in this treatment. Similar results were reported by Getnet (1998) and Solomon *et al.* (2004).

Feed conversion ratio was lower (P<0.001) for the supplemented compared to the non-supplemented sheep. Feed conversion ratio increased with a decrease in the proportion of SSM, indicating that the sheep used SSM with better efficiency for BW gain. The higher feed conversion ratio for WB supplemented and tef straw consuming sheep compared to SSM supplemented sheep in this experiment might be due to the result of low energy and CP intake, type of CP and the high fiber content of the former diets which resulted in reduced digestibility of nutrients and efficiency of utilization of metaboliziable energy. Supplemented sheep had higher dressing percent (P<0.001) on slaughter weight basis than the non-supplemented ones (Table 5). In this study, the observed dressing percent on slaughter weight base ranged between 32.9-43.4%, and this result was comparable to the report of Beniam *et al.* (1983) for Somali and Afar sheep (36 - 43.8%) as well as with the dressing percent reported by Devendra and Burns (1983) which ranged between 35-60%. A relatively higher dressing percent compared to in the present study was reported by Galal *et al.* (1979) for Ethiopian Highland sheep (41.2%) and Horro lambs (47.7%). The rib eye muscle area was higher (P<0.05) for sole SSM supplemented sheep compared to those offered only tef straw. Comparable results were reported by Galal and Kasahun (1981) for Afar sheep in Ethiopia.

Table 5. Body weight and carcass parameters of Tigray sheep fed tef straw supplemented with sesame seed cake, wheat bran and their mixtures at different proportions.

Parameters	T1	T2	T3	T4	T5	SL	SEM
Initial BW (kg)	23.2	23.2	23.3	23.1	22.7	ns	0.42
Final BW (kg)	21.2^{b}	29.6^{a}	29.5^{a}	29.0^{a}	27.2^{a}	***	0.49
BW change (kg)	-1.98^{c}	6.4^{a}	6.38^{a}	5.94^{ab}	4.5^{b}	***	0.27
Daily BW gain (g)	-22.0^{c}	71.1^{a}	70.9^{a}	66.0^{ab}	50.0^{b}	***	2.99
FCR	-19.1^{b}	10.3^{a}	10.2^{a}	10.8^{a}	14.2^{a}	***	1.06
Hot carcass weight (kg)	6.9^{b}	12.1^{a}	11.8^{a}	12.3^{a}	10.8^{ab}	***	0.7
Empty BW (kg)	14.6^{b}	24.1^{a}	22.6^{a}	23.3^{a}	19.1^{ab}	**	1.27
Dressing percent (% SW)	32.9^{b}	41.5^{a}	41.9^{a}	43.4^{a}	39.5^{a}	***	0.83
Dressing percent (% EBW)	47.2^{b}	50.2^{ab}	52.2^{ab}	53.1^{a}	51.2^{ab}	*	1.33
Rib – eye muscle area	7.5^{b}	12.7^{a}	11.5^{ab}	11.7^{ab}	11.0^{ab}	*	1.1

*^{abc} Means with different superscripts in the same row are significantly different at ***= P<0.001; BW= body weight; EBW= empty BW; FCE= feed conversion efficiency; ns= not significant; SEM= standard error of mean; SL= significance level; SSM= sesame seed meal; SW= slaughter weight; T1= tef straw; T2= T1 + SSM; T3= T1 + 0.65 SSM: 0.35 WB; T4= T1+ 0.35 SS: 0.65 WB; T5= T1+ WB; WB= wheat bran.*

4. Conclusions

Supplementation with SSM, WB and their mixtures maintained tef straw intake and improved total DM intake which, subsequently, resulted in better BW gain and final BW. The results showed that supplementation with sole SSM or its mixture with WB (0.65SSM: 0.35WB) required less feed for a unit of BW gain compared to supplementation solely with WB.

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Effects of Different Cultivation Practices and Postharvest Treatments on Tomato Quality

Meaza Melkamu, Tilahun Seyoum* and Kebede Woldetsadik

Haramaya University, College of Agriculture, P O Box 138, Dira Dawa, Ethiopia

Abstract: The present investigation was aimed at evaluating the combined effect of pre- and postharvest treatments on the quality of tomato (*Lycopersicon esculentum* Mill). The preharvest treatments used were ComCat®, manure, NP and the combinations of ComCat® with the two forms of fertilizers and a control. These preharvest treatments were combined with three disinfection and two storage treatments. The tomatoes were periodically analyzed for weight loss, total soluble solids, pH, titratable acidity, ascorbic acid and marketability. Preharvest ComCat® and ComCat® + manure treatments improved the quality of tomato during storage. During the storage period, ComCat® reduced weight loss, better maintained the chemical compositions and marketability of the tomatoes. Manure treated tomatoes had higher ascorbic acid content during the storage period. Tomatoes stored using evaporative cooling system remained marketable up to the 28 days compered to a maximum of 16 days of ambient storage conditions. Storage at ambient conditions resulted in higher weight loss and rapid change in chemical composition that resulted in quality deterioration of tomatoes. Disinfecting treatments had significant ($P < 0.01$) effects on weight loss of tomatoes during storage. Two-way interactions between preharvest and storage conditions were significant ($P < 0.05$) in terms of the various physiological and chemical parameters of tomatoes. In general, the benefits of the combined effect of preharvest treatments and evaporatively cooled storage on tomatoes included reduction in the weight loss and total soluble solids, maintenance of higher titratable acidity, ascorbic acid and marketabilityof tomatoes.

Keywords: Biocatalyst; Disinfection; Evaporative Cooling; Fertilizer; Quality; Tomato

1. Introduction

Postharvest physiological, microbiological and chemical qualities of tomatoes partly depend up on preharvest factors such as genetic, environmental conditions and management (Hobson, 1964). Cultural practices such as nutrient and water supply and harvesting methods are also claimed to be factors influencing tomato quality after harvest (Watkins and Pritts, 2001). Application of mineral fertilizers, especially of nitrogen, affects the chemical composition of vegetables including tomato (Watkins and Pritts, 2001). Similarly, application of organic fertilizer makes it possible to obtain high and good quality yields of vegetables and replenish soil fertility degeradation (Fichter, 1986). Recent research findings suggested the possibility of natural plants species, in which their bio-stimulatory activity (Schenabel *et al.*, 2000; Seyoum, 2002). As a result, ComCat® was one of the plant procuct developed as a natural product with its plant strengthening properties and the ability to improve growth and yield in different agricultural crops including tomato. The treatment consists of biocatalysts of plant origin and induces resistance via activating plant defence mechanisms against pathogens, and biotical and abiotical stress factors (Schenabel *et al.*, 2000). It is is an alternative to chemical treatments and can fit into future research trends to have a balance between yield and ecologisation. Many postharvest losses are influenced by factors before harvest (Booth, 1978). For example, fruit and vegetables that are infected with pests and diseases, inappropriately irrigated and fertilized, or management can never be improved by postharvest treatments (Harvey, 1978). Very often, the rate of commodity loss is faster if the quality at harvest is below standard. Unlike the other preharvest chemical treatments ComCat® is that it is both environmentally and ecologically friendly. However, at present there is no information on the postharvest quality aspects of ComCat® treated vegetables. The following questions arise: how do these complex plant growth regulators and natural metabolites affect the quality of tomatoes at harvest?

The microbial load associated with tomatoes during storage plays an important role on quality deterioration (Brackett, 1990). Chlorine treatments were found to be effective in reducing the occurrence of post harvest decay by pathogens (Prusky *et al.,* 2001) and hot water washing was also found to be very efficient to control postharvest decay in fruit and vegetables (Fallik *et al.,* 1999). Regarding extended shelf life, literature pointed out low storage temperature and high relative humidity is preferable for best results (Seyoum and Woldetsadik, 2004). A cooling chamber that works on the principle of evaporative cooling was developed to alleviate postharvest loss of fruit and vegetables. Generally, quality and duration of shelf life of fruit and vegetables are affected by the combined effect of preharvest and postharvest treatments. Therefore, the increase in yield of tomato due to some of the prehatvest treatments needs to be necessarily accompanied by the use of appropriate techniques that minimize postharvest loss. Thus, in this paper the effect of preharvest ComCat®, manure, NP, combinations of ComCat® with the two forms of fertilizers and postharvest treatments such as dipping in chlorinated water, dipping in hot water, storage under evaporatively cooled storage and ambient conditions on

*Corresponding author. E-mail: Tilahun_Seyoum@yahoo.com

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weight loss, total soluble solid, pH, titratable acidity, ascorbic acid and marketability of tomato are reported.

2. Materials and Methods

2.1. Site Description

The field experiment was conducted at the farm of Haramaya University in Dire Dawa during the period from September to January, 2004/2005. The Farm is located at an altitude of 1197 m above sea level and lies at 9° 6' N latitude and 41° 8' E longitude in the eastern part of Ethiopia. The station lies in the semi-arid belt of the eastern rift valley escarpment with a long-term average rainfall of 612 mm. The mean annual rainfall is 520 mm and mean maximum and minimum temperatures range from 28.1°C to 34.6°C and 14.5°C to 21.6°C, respectively (Belay, 2002). The soil is classified as Eutric Regosol with a gentle slop (3-8%) (Tesfaye, 2004). The texture and structure of the topsoil (0-30 cm) are sandy loam and sub angular blocky, respectively. The soil has an average pH (H_2O 1:2.5) of 8.54 and organic matter content of 1.94% (0-15 cm) and 1.84% (15-30 cm) (Tesfaye, 2004).

2.2. Sample Production

Fresh tomato variety, Marglobe, was raised in glass house at Haramaya University campus for about two weeks from July 30 to August 16, 2004 and were pricked for another two weeks in the field from August 17 to September, 2004. The plots prepared consisted of six rows 0.75 m apart, spaced 0.5 m apart in the row with 90 plants per plot. The net area of the experimental field was 875.75 m^2.

The experiment was conducted in a randomized complete block design with three replications per treatment. The inorganic fertilizer, diammonium phosphate (DAP) and urea were applied to each plot at the rate of 200 kg ha^{-1} and 150 kg ha^{-1} respectively. The rate of organic fertilizer (manure) was 20 tons per hectare. Organic fertilizer (manure), DAP and half of the nitrogen fertilizer were incorporated to the experimental plots before planting while the rest was applied two weeks after the establishment of seedlings. ComCat® was applied at 100 g ha^{-1} in 350 L and sprayed twice during the growth period. First spray was just prior to transplanting of seedlings while the second was carried out before flowering as recommended by Huster (2001). Other agronomic practices were applied as needed during the growth season uniformly to all plots. Plots were irrigated every other day for the first two weeks and then at weekly interval.

2.3. Sample Preparation

Green mature tomato fruit were harvested from each plot that was subjected to different preharvest treatments. Harvesting was carried out manually with care to minimize mechanical injury. Data on quality parameters were recorded from the central four rows of randomly selected plants. Uniform unblemished fruit having similar size and color were selected and hand washed with tap water.

To determine quality of fresh market tomato at harvest (0 day storage) six green mature tomatoes were randomly selected from each plot and were analyzed for six chemical parameters after disinfection treatments. For analysis during storage, washed fruit were subdivided into three groups of 288 kg each, in preparation for dipping treatments. Plastic containers were washed and rinsed with distilled water prior to use for the dipping treatments. The disinfection treatments consisted of chlorinated water, hot water at 52°C and tap water (23°C) dipping as control.

For the chlorinated water dipping treatment, tap water was adjusted to 100 □ g ml^{-1} total chlorine with standard grade sodium hypochlorite (5% NaOCl) and tomato was dipped for 20 minute (Seyoum *et al.,* 2003). The free chlorine was determined using a test kit from Hach (Model CN-66; USA). The temperature was maintained at 4°C during the measurements of total chlorine. A 20 minute dipping time in 100 μg ml^{-1} chlorine supplemented water solutions was selected, as this was reported to be the optimum effective concentration and dipping time without significant effect on the overall quality of fruit and vegetables (Nunes and Emond, 1999). The hot water dipping treatment included dipping tomatoes in hot water at 52°C for five minutes. Dipping tomato fruit in tap water (24.2°C) for 20 minute was used as control treatment. After the disinfecting treatment, the disinfected fruit were again subdivided and stored in evaporatively cooled storage (432 kg) and at ambient conditions (432 kg) in three replications in a 1 kg unit. A total amount of 864 kg tomatoes were used in the study.

2.4. Experimental Design

A factorial combination of six preharvest, three disinfecting and two storage treatments with 3 replications were used in the study. The treatments were arranged in a randomized complete block design. On each sampling date, a sample of tomatoes was randomly taken from each treatment for quality analysis. On each sampling date, a sample of 5 tomato fruit from evaporatively cooled and ambient storage in each treatment was randomly taken for assessment. Data were recorded on 0, 4, 8, 12, 16, 20, 24 and 28 days after storage.

2.5. Evaporative Cooling System

The evaporative cooling system developed by Seyoum and Woldetsadik (2004) was used as storage chamber in this study. The evaporative cooling chamber maintained lower temperature (14.3-19.3°C) and higher relative humidity (70.2-82.4%). On the other hand, the ambient temperature and relative humidity ranging from 25.2-32.1°C and 32.2-50.6%, respectively, were recorded during the storage.

2.6. Chemical Analysis

Weight loss was determined using the methods described by Waskar *et al.* (1999). The physiological weight loss was calculated for each interval and converted into percentage of initial weight. The cumulative weight loss was expressed in percentage with respect to different treatments. Total soluble olids (TSS) were determined following the procedures described by Waskar *et al.* (1999). An aliquot of juice was extracted using a juice extractor (Type 6001x, USA), according to Nunes and Emond (1999). An Atago N, hand refractometer with a range of 0 to 32°Brix and resolutions of 0.2°Brix was used to determine TSS by placing 2-3 drops of clear juice on the prism. The ascorbic acid content of the fruit was determined by the 2, 6-dichlorophenol indophenols method (AOAC 1970). The aliquot of 10 ml tomato juice was diluted to 50 ml with 3 percent metaphosphoric acid in a 50 ml volumetric flask. The aliquot was titrated with the standard dye to a pink end point (persisting for 15 second). The ascorbic acid (AA) content was calculated from the titration value, dye factor and volume of the sample. The pH value of the tomato juice was measured with a pH meter. The titratable acidity (TA) of tomato was measured according to the methods described by Maul *et al.* (2000). An aliquot of tomato juice was extracted from the sampled tomato with the juice extractor (6001x model No. 31JE35 6x.00777) and filtered through cheese cloth. Decanted clear juice was used for the analysis. The TA, expressed as percentage citric acid, was obtained by titrating 10 ml of tomato juice with 0.1N NaOH to pH 8.2.

2.7. Subjective Quality Analysis

The marketable quality of tomato fruit was subjectively assessed according to Mohammed *et al.* (1999). The descriptive quality attributes were determined by observing the level of visible mould growth, decay, shriveling or dehydration, colour and the surface appearance characteristics such as smoothness and shine of the fruit.

2.8. Statistical Analysis

All the data were analysed according to Gomez and Gomez (1984). ANOVA was carried out with an MSTAT-C soft ware package (MSTAT, USA). Comparisons of the treatment means were done using Duncan's Multiple Range Test (Duncan 1955).

3. Results and Discussion

3.1. Weight Loss

Preharvest treatment, storage temperature and their interaction had significant ($P < 0.01$) effect on the weight loss of tomatoes (Table 1). However, disinfection treatments showed nonsignificant ($P > 0.05$) effect till the end of day 12. ComCat® treatment significantly ($P < 0.01$) lowered WL than all the other preharvest treatments (see day 28 data in Table 1). The control tomatoes had the highest WL on the 28th days of storage. The preharvest ComCat® + manure and ComCat® + NP treatments also resulted in significantly ($P < 0.01$) lower WL than manure, NP and control treatments from day 12 onwards. Tomatoes subjected to preharvest manure, NP and control treatments had higher ($P < 0.01$) WL towards the end of storage periods. Literature has shown that excessive fertilization resulted in increased weight loss in sweet potato during storage (Mark *et al.* 2003), which seems to agree with the results in this study. The combination of ComCat® with the two forms of fertilizers reduced WL but not as ComCat® did alone. On day 28, WL significantly ($P < 0.01$) reduced by 12.7%, 8.5% and 6.68% in ComCat®, ComCat® + manure and ComCat® + NP treated tomatoes when compared to control tomatoes, respectively.

Weight loss was not significantely ($P > 0.05$) affected by the disinfection treatments up to day 12; however, disinfection had significant ($P < 0.01$) effect on WL thereafter. The tomato fruit dipped in chlorinated water had significantly ($P < 0.01$) higher WL starting from day 16 until day 24 of the storage period when compared to tomato fruit dipped in hot and tap water. The relatively higher WL associated with tomato fruit dipped in chlorinated water compared to hot water treated fruit could be attributed to the itching effect of chlorine solution on the skin of the fruit and surface tissues which is in agreement with the finding of Seyoum et al. (2003). Storage environment had significant ($P < 0.001$) effect on the weight loss of tomato fruit during storage as shown in Table 1. WL slowly increased in tomatoes stored using the evaporative cooling system comered to a rapid rate of increase in tomatoes stored at ambient conditions. Tomatoes stored at ambient conditions suffered about two times more weight loss than those stored at cool storage. High temperature increases the vapour pressure difference between the fruit and the surrounding, which is the driving potential for faster moisture transfer from the tomato fruit to the surrounding air (Kader 1985 and Salunkhe *et al.*, 1991). The reduction in WL of tomato at EC storage in the present work agrees with previous reports for mango fruit (Waskar *et al.,* 1991; Pal and Roy 1991). The two-way interaction between preharvest and storage treatments significantly ($P < 0.001$) affected WL during the storage. Similarly, the three-way interaction showed significant ($P < 0.01$) effect on WL after 16 days of storage. This data clearly demonstrated the importance of integerated agro-technology on the shelf life improvement of tomatoes.

3.2. Total Soluble Solids

The total soluble solid (TSS) values varied between 4.07 and 5.60 °Brix. At harvest, the green mature ComCat® treated tomatoes contained significantly ($P < 0.01$) higher TSS when compared with NP, ComCat® + NP and ComCat® + manure treated tomato fruit. However, it did not show significant difference ($p > 0.01$) when it is compared with control and manure treated tomatoes.

At harvest, manure treated tomatoes had higher TSS when compared to tomatoes subjected to NP treatment. This increase in the TSS content of manure treated tomatoes might be due to the higher photosynthetic efficiency by the relatively larger and broader leaves and increase of fruit sink strength in manure treated tomatoes. Raupp (1996) reported the positive effect of manure on TSS content of vegetables whereas Mccollum *et al.* (2004) found little difference in soluble solids between conventional grown and organically grown fruit. Among the preharvest treatments, only ComCat® + NP treatment significantly ($p < 0.01$) decreased the TSS content of tomato at harvest compared with control, which agrees with the findings of Hegde and Srinivas (1990) and Karaman (1996).

During storage, the preharvest treatments significantly ($P < 0.01$) affected the TSS content of tomatoes. A pick increase in TSS was observed on day 12 for tomatoes subjected to NP, manure and control treatments whereas four days later in the preharvest ComCat®, ComCat® + manure and ComCat® + NP treatments. In addition, the TSS content started to decline on day 16 for the preharvest treatment of NP, manure and control tomatoes whereas the tomatoes subjected to preharvest ComCat®, ComCat® + manure and ComCat® + NP treatments showed a sharp decline on day 20 of the storage. The rapid decline in TSS content of tomato subjected to preharvest application of manure, NP fertilizer and control tomatoes might be due to higher rate of respiration associated with those tomatoes leading to faster ripening processes (Davies and Hobson, 1971). Disinfecting treatments significantly ($P < 0.05$) affected the TSS content of tomatoes during storage period. The increase in TSS of tomatoes during storage is an indication of quality deterioration (Pal and Roy, 1991; Wasker *et al.*, 1999). Hot water treatment showed significantly ($P < 0.05$) lower TSS during the storage periods except on day 16. Generally, tomatoes dipped in chlorinated and tap water contained more TSS during most of the storage periods. After 28 days of storage, increase in TSS content of tomato was shown by 3.98% and 2.68% in chlorinated and tap water dipped tomatoes than in hot water dipped tomatoes. The effect of storage conditions on the TSS of tomato fruit was ($P < 0.001$) during the storage period. The TSS content of tomato fruit was maintained at lower levels in the evaporatively cooled storage than in the ambient storage. The slow changes in TSS of tomato fruit stored in the evaporative cooler compared to those stored at ambient conditions is in agreement with the finding of Pal and Roy (1991). Similarly, Kader (1985) reported increase in TSS content with the progression of storage and duration and storage temperature. Higher rates of increase in TSS of tomato samples stored at ambient temperature were reported to be caused by excessive moisture loss and the hydrolysis of carbohydrates to soluble sugars (Wasker *et al.*, 1999). Changes in TSS occurred at substantially faster rates in tomatoes stored at room temperature than in tomatoes stored at cool storage conditions. The two-way interaction between preharvest and storage temperature showed highly significant ($p < 0.05$) effect on the TSS of tomato fruit during storage.

3.3. pH Values

The quality characteristic of tomato is influenced by the pH of fruit at harvest. There was an increase in the pH value of tomato fruit from 3.8 at harvest to 5.0 at the full ripe stage (Table 2). The pH of tomato is generally known to increase with an increasing ripeness (Mohamed *et al.*, 1999).

Preharvest treatment significantly ($P < 0.01$) affected the pH value of tomato fruit at harvest and throughout the storage period except on day 24. Immidiately after harvest, the pH of ComCat® treated tomato was significantly ($p < 0.01$) lower except in tomatoes treated with ComCat® + manure. During the first four days of storage, significantly ($P < 0.01$) higher pH value was observed in the untreated control tomato fruit showing difference in rate of metabolism. During the first 16 days, ComCat®, ComCat® + NP and ComCat® + manure treated tomatoes had significantly ($P < 0.01$) lower pH values than the control tomatoes with the lowest pH value was being observed for tomatoes subjected to ComCat® + manure treatment. The pH value of control tomato was lower than the pH values of tomatoes subjected to preharvest ComCat®, manure, ComCat® + NP and ComCat® + manure treatment on day 20. On day 24, only manure treatment tomatoes showed significantly ($P < 0.05$) higher pH compared to control. Towards the end of the storage period, ComCat® treated tomato had shown significantly ($P < 0.01$) lower pH when compared to the other treatments, except ComCat® + manure. Similarly, ComCat® + manure treated tomatoes showed significantly ($P < 0.01$) lower pH than manure and control tomatoes. In general, those tomatoes that received ComCat® either alone or in combination with the two forms of fertilizer showed lower pH, especially in ComCat® + manure treated tomatoes, during the 16 days of storage. However, these treatments showed higher pH value from 16 days onwards.

Disinfection treatments had brought significant ($P < 0.01$) effect on the pH values of tomato fruit from day 8 onwards. On day 8, tomato fruit dipped in chlorinated water had significantly ($P < 0.05$) higher pH value than hot water dipped tomatoes. On day 12, chlorinated water treatments significantly ($P < 0.01$) increased the pH value when compared to tap water treatment. However, the effect of chlorinated and hot water treatment showed no variation on the pH value on days 12, 16 and 24. On day

16, tomatoes subjected to both chlorinated and hot water treatments showed significantly ($P < 0.01$) higher pH value than the pH values dipped in tap water. On day 20, hot water treatment significantly ($P < 0.01$) increased pH than both chlorinated and tap water treatments. At the end of storage period, fruit dipped in chlorinated water had significantly ($P < 0.01$) higher pH value when compared to the pH values of tomatoes subjected to tap and hot water dipping treatments. Tomato fruit dipped in tap water showed significantly lower pH value during most part of the storage period ($P < 0.01$).

Storage conditions significantly ($P < 0.001$) affected the pH value of tomato fruit. The pH increased faster for tomatoes stored at ambient temperature than evaporative cooler. Lowering the storage temperature, to reduce respiration and delay senescence while high temperature storage resulted in faster ripening process. The increase in the pH values of tomato at ambient conditions with increase storage time was in agreement with the pervious findings (Mohammed *et al.,* 1999). Others reported that the tendency of increasing pH value and reduced acidity is observed with longer storage time since the fruit with proceeding of the ripening process is going to diminish its predominant malic acid (Medlicoot *et al.* 1985). According to Mizrach *et al.* (1997) during postharvest ripening, carbohydrate and acid metabolism are closely connected. The two-way interaction between preharvest and storage conditions was significant ($P < 0.01$) on the pH values of tomatoes during the 16 days of storage period. Similarly, the interaction between disinfection and storage temperature had significant ($p < 0.01$) effect on pH value from 12 days onwards.

3.4. Titiratable Acidity

The predominant acid of ripe tomato fruit is citric and malic acid (Davies and Hobson 1971). In this study, titratable acidity (TA) decreased dramatically during ripening from the green mature to the full mature stage from around 1.36% to as low as 0.20% which agrees with the previous reports (Davies and Hobson, 1981; Salunkhe *et al.*, 1991).

Preharvest treatments significantly ($P < 0.01$) affected the TA of tomato fruit at harvest and during storage period (Table 2). At harvest, significantly ($p < 0.01$) higher TA content of tomato fruit was found in NP, manure and ComCat® treated tomato fruit compared to ComCat® combined with the fertilizers and control tomatoes. The increase in TA of tomato treated with manure and NP fertilizer is in accordance with the result reported earlier (Hegde and Srinivas, 1990) that acidity increased with increasing fertilizer. ComCat® + NP treated tomato also showed significantly ($p < 0.01$) higher TA than the controls. However, ComCat® + manure treated tomato had statistically comparable TA content with that of ComCat® + NP and the control.

TA of tomato fruit grown using NP fertilizer was higher on day 8 and 12 of storage period when compared to the rest of the preharvest treatments applied. Hegde and Srinivas (1990) and Winsor and Adams (1976) also reported an increase in acidity of tomato with nitrogen application. The preharvest manure fertilized tomato fruit had higher TA when compared to ComCat® + manure, ComCat® + NP and control tomato fruit during the first 8 days of storage. On day 16, the preharvest ComCat® and NP treated tomato fruit had significantly ($P < 0.01$) higher TA content than the other treatments. Similarly, ComCat® + manure and manure treated tomatoes had significantly ($P < 0.01$) higher TA than ComCat® + NP treated and control tomatoes. At the end of the storage periods, the preharvest ComCat® treated tomato fruit still had higher TA when compared to all of the other treatments.

The disinfection treatments had significant ($P < 0.05$) effect on the level of TA only on day 12. The TA of tomato fruit dipped in chlorinated water was higher when compared to hot water dipped tomato fruit between 8 and 12 days of storage.

Storage temperature had highly significant ($P < 0.001$) effect on the changes in TA of tomato fruit. During the 20 days of storage, the TA was found to be higher in tomato fruit stored using evaporatively cooled storage compared to those stored at ambient conditions. The relatively higher ambient temperature leads to higher rate of reduction in the TA as described in Koksal (1989). This could be associated with the higher rate of respiration using substrate for catabolic process for rapid ripening at higher temperature (Medicott *et al.*, 1986). It is known that evaporatively cooled storage reduces respiratory activity, thereby delaying the ripening process and consequently increasing fruit shelf life (Seyoum, 2002; Seyoum and Woldetsadik, 2004). The two-way interaction between Preharvest treatments and storage environment had highly significant ($P < 0.01$) effect on the changes in TA of tomato fruit.

Table 1. Interaction effects of pre- and postharvest treatments on changes in the weight loss and total soluble solids content of tomato fruit over a storage period of 28 days.

Treatment	Physiological weight loss (%) Storage period (day)							Total soluble solids (°Brix) Storage period (day)							
	4	8	12	16	20	24	28	0	4	8	12	16	20	24	28
Preharvest (A)															
CC	2.66^{b}	4.75^{c}	5.69^{c}	10.06^{c}	12.18^{d}	13.14^{d}	14.36^{c}	4.87^{a}	4.51^{b}	4.88^{a}	5.03^{ab}	5.07^{a}	4.46^{ab}	4.59^{a}	4.20^{a}
M	3.55^{a}	6.05^{b}	6.98^{a}	11.49^{a}	14.02^{b}	14.06^{a}	15.35^{b}	4.53^{ab}	4.58^{b}	4.92^{a}	5.04^{a}	4.87^{a}	4.56^{a}	4.27^{b}	4.18^{a}
NP	3.59^{a}	6.52^{a}	6.91^{a}	10.83^{b}	14.01^{b}	13.49^{b}	16.31^{a}	4.33^{bc}	4.73^{a}	4.94^{a}	5.01^{ab}	4.57^{b}	4.34^{bc}	4.37^{ab}	4.02^{a}
CC+ M	2.69^{b}	4.89^{c}	6.33^{b}	10.82^{b}	13.16^{c}	13.26^{c}	15.52^{b}	4.33^{bc}	4.54^{b}	4.81^{a}	4.80^{c}	4.88^{a}	4.26^{c}	4.12^{b}	4.11^{a}
CC+NP	3.56^{a}	6.06^{b}	6.30^{b}	10.82^{b}	13.15^{c}	13.11^{d}	15.10^{b}	4.07^{c}	4.50^{b}	4.86^{a}	4.85^{bc}	4.84^{a}	4.28^{bc}	4.19^{b}	4.13^{a}
Control	3.56^{a}	6.51^{a}	6.98^{a}	11.54^{a}	14.40^{a}	14.04^{a}	16.45^{a}	4.67^{ab}	4.58^{b}	4.96^{a}	4.99^{ab}	4.83^{a}	4.32^{bc}	4.19^{b}	4.04^{a}
LSD	**	**	**	**	**	**	**	**	*	*	*	**	**	*	ns
SE±	0.05	0.06	0.05	0.02	0.02	0.03	0.15	0.06	0.06	0.07	0.06	0.06	0.06	0.10	0.08
Disinfection (B)															
NaOCL	3.27^{a}	5.79^{a}	6.53^{a}	11.08^{a}	13.76^{a}	13.65^{a}	15.71^{a}	4.34^{a}	4.54^{b}	4.83^{b}	5.09^{a}	4.99^{a}	4.49^{a}	4.36^{a}	4.19^{a}
H_2O, 52°C	3.26^{a}	5.80^{a}	6.53^{a}	10.84^{b}	13.33^{b}	13.41^{b}	15.32^{bc}	4.46^{a}	4.51^{b}	4.81^{b}	4.80^{b}	4.65^{a}	4.21^{b}	4.11^{b}	4.02^{b}
H_2O, 24.2°C	3.27^{a}	5.80^{a}	6.53^{a}	10.86^{b}	13.35^{b}	13.49^{b}	15.51^{b}	4.44^{a}	4.67^{a}	5.04^{a}	4.98^{a}	4.89^{a}	4.40^{a}	4.39^{a}	4.13^{ab}
LSD	ns	ns	ns	**	**	**	**	ns	*	*	**	ns	**	*	*
SE±	0.04	0.04	0.04	0.01	0.01	0.02	0.11	0.06	0.04	0.05	0.04	0.04	0.04	0.07	0.05
Storage condition (C)															
EC	2.20^{b}	3.88^{b}	4.92^{b}	7.40^{b}	10.73^{b}	-	-	-	4.26^{b}	4.56^{b}	4.78^{b}	4.49^{b}	4.58^{a}	-	-
AM	4.34^{a}	7.69^{a}	8.15^{a}	14.45^{a}	16.24^{a}	-	-	-	4.88^{a}	5.23^{a}	5.14^{a}	5.19^{a}	4.15^{b}	-	-
LSD	***	***	***	***	***	-	-		***	***	***	***	***	-	-
SE±	0.03	0.034	0.03	0.01	0.01	-	-		0.04	0.04	0.03	0.03	0.03	-	-
Significance															
AXB	ns	ns	ns	*	**	**	ns	ns	ns	ns	ns	ns	ns	ns	ns
AXC	***	***	***	***	***	-	-	-	***	***	*	**	*	-	-
BXC	ns	Ns	ns	ns	**	-	-	-	ns	ns	ns	ns	ns	-	-
AXBXC	ns	Ns	ns	***	**	-	-	-	ns	ns	ns	ns	ns	-	-

*Weight loss calculated as percentage of initial weight (0 day) and the weight loss and TSS data for day 24 and 28 are mean values for evaporatively cooled storage. Means within the same column followed by a common letter are not significantly different at P < 0.01 by DMRT where NS, *, **, *** indicate nonsignificant or significant difference at p < 0.05, 0.01 or 0.001,.respectively; A = Preharvest; B = disinfection; C = storage; CC = ComCat®; M = manure; NP = nitrogen & phosphorus; C+M = ComCat® + manure; C = control; CC + NP = ComCat® + nitrogen & phosphorus; EC = evaporative cooling; AM = ambient storage*

Table 2. Interaction effects of pre- and postharvest treatments on changes in ihe pH and titratable acidity of tomato fruit over a storage period of 28 days.

Treatment	pH values Storage period (day)								Total titratable acidity (%) Storage period (day)							
	0	4	8	12	16	20	24	28	0	4	8	12	16	20	24	28
Preharvest (A)																
CC	3.84^{c}	4.12^{b}	4.27^{b}	4.65^{b}	4.73^{b}	4.80^{a}	4.85^{ab}	4.75^{c}	1.25^{a}	0.61^{b}	0.56^{b}	0.53^{b}	0.459^{a}	0.449^{a}	0.44^{a}	0.37^{a}
M	3.98^{b}	4.17^{b}	4.32^{ab}	4.63^{b}	4.71^{b}	4.76^{a}	4.89^{a}	4.91^{a}	1.209^{a}	0.79^{a}	0.55^{b}	0.47^{c}	0.378^{b}	0.36^{b}	0.36^{b}	0.24^{b}
NP	4.02^{b}	4.18^{b}	4.35^{ab}	4.58^{b}	4.66^{b}	4.74^{ab}	4.77^{b}	4.88^{ab}	1.376^{a}	0.585^{bc}	0.858^{a}	0.57^{a}	0.468^{a}	0.46^{a}	0.29^{c}	0.28^{b}
CC+ M	3.93^{bc}	3.84^{c}	4.09^{c}	4.22^{c}	4.50^{c}	4.80^{a}	4.82^{ab}	4.78^{bc}	0.45^{bc}	0.53^{d}	0.427^{d}	0.41^{d}	0.40^{b}	0.31^{c}	0.32^{c}	0.27^{b}
CC+NP	4.04^{b}	4.15^{b}	4.29^{b}	4.52^{b}	4.71^{b}	4.76^{a}	4.75^{b}	4.86^{ab}	0.59^{b}	0.56^{cd}	0.42^{d}	0.45^{c}	0.33^{c}	0.29^{cd}	0.28^{c}	0.25^{b}
Control	4.21^{a}	4.64^{a}	4.44^{a}	4.74^{a}	4.81^{a}	4.67^{b}	4.76^{b}	4.90^{a}	0.37^{c}	0.45^{e}	0.50^{c}	0.458^{c}	0.32^{c}	0.28^{d}	0.23^{d}	0.23^{b}
LSD	**	**	**	**	**	*	Ns	*	**	**	**	**	**	**	**	**
SE±	0.01	0.04	0.03	0.02	0.02	0.03	0.04	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Disinfection (B)																
NaOCL	4.00^{a}	4.23^{a}	4.38^{a}	4.61^{a}	4.74^{a}	4.75^{b}	4.79^{a}	4.89^{b}	0.87^{a}	0.59^{a}	0.57^{a}	0.49^{a}	0.39^{a}	0.36^{a}	0.33^{a}	0.29^{a}
H_2O, 52°C	3.99^{a}	4.16^{a}	4.31^{b}	4.57^{ab}	4.69^{a}	4.81^{a}	4.84^{a}	4.83^{a}	0.85^{a}	0.59^{a}	0.54^{b}	0.47^{b}	0.39^{a}	0.36^{a}	0.31^{a}	0.27^{a}
H_2O, 24.2°C	4.00^{a}	4.16^{a}	4.41^{ab}	4.53^{b}	4.63^{b}	4.71^{b}	4.79^{a}	4.83^{b}	0.88^{a}	0.59^{a}	0.56^{ab}	0.48^{ab}	0.40^{a}	0.36^{a}	0.32^{a}	0.27^{a}
LSD	NS	NS	*	**	**	**	NS	*	Ns	Ns	Ns	*	Ns	Ns	Ns	Ns
SE±	0.01	0.03	0.02	0.04	0.01	0.02	0.03	0.02	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Storage (C)																
EC	-	4.10^{b}	4.24^{b}	4.48^{b}	4.60^{b}	4.72^{b}	-	-	-	0.68^{a}	0.64^{a}	0.55^{b}	0.47^{a}	0.42^{b}	-	-
AM	-	4.26^{a}	4.39^{a}	4.66^{a}	4.77^{a}	4.79^{a}	-	-	-	0.50^{b}	0.47^{b}	0.41^{a}	0.32^{b}	0.29^{a}	-	-
LSD		***	***	***	***	***				***	***	***	***	***	-	-
SE±		0.03	0.02	0.01	0.01	0.02			-	0.01	0.01	0.004	0.004	0.004	-	-
Significance																
AXB	ns	ns	ns	ns	ns	Ns	ns	ns	-	ns	ns	ns	ns	ns	ns	ns
AXC	-	*	*	***	***	Ns	-	-	-	***	***	***	***	***	-	-
BXC	-	ns	ns	**	***	*	-	-	-	ns	ns	ns	ns	ns	-	-
AXBXC	-	ns	ns	ns	ns	Ns	-	-	-	ns	ns	ns	ns	ns	-	-

*pH and titratable acidity data for 20 days of storage and the data of day 24 and 28 are mean values for EC only. Means within the same column followed by a common letter are not significantly different at $p < 0.01$ by DMRT where ns, *, **, *** indicate nonsignificant or significant difference at $P < 0.05$, 0.01or 0.001, respectively. A = Preharvest; B = disinfection; C = storage; CC = ComCat®; M = manure; NP = nitrogen phosphorus; C = control; C+M = ComCat® + manure; CC+NP = ComCat® + nitrogen & phosphorus; EC = evaporative cooling; AM = ambient storage*

3.5. Ascorbic Acid

Several investigators reported an increase in ascorbic acid content with ripening with either a continuing rise or a slight fall (Dalal *et al*., 1965) during the final stages of ripening. Watada *et al.* (1976) also reported AA content of mature green tomato fruit to be essentially the same as in fully ripened ones. In the present study the increase in AA content, followed by a fall during the full ripening stage, was observed (Table 3).

At harvest, the application of manure had a positive effect on the accumulation of AA content in tomatoes. Raupp (1996) draws attention to the positive effect of manure on the content of AA in vegetables. Cacek and Lagner (1986) also confirmed the positive effect of organic fertilizer on the AA content of vegetable. ComCat® + NP treatment significantly ($p < 0.01$) lowered AA content of tomato fruit compared to the control. The lower AA content in the preharvest NP and ComCat® + NP treatments could be due to the effect of N fertilization. Likewise, Augustin (1975) and Lisiewska and Kmiecik (1996) reported a decrease in AA content of fruit and vegetables with increasing amounts of nitrogen fertilizer. One possible explanation for the lower AA content in the preharvest NP and ComCat® + NP treatments could be due to the vegetative growth that impairs the reproductive development and this may probably decreased the sink strength, as a result decreases AA.

The preharvest treatment had also shown significant ($P < 0.01$) effect on the AA content of tomato fruit during the storage period. The preharvest manure fertilized tomato fruit maintained higher AA contents up to 12 days of storage compared to the other preharvest treatments. Towards the end of the storage period, ComCat® maintained higher amount of AA than the other treatments. The preharvest ComCat® + manure and ComCat® + NP treated tomatoes also had significantly higher AA content during the first 12 days of storage compared to control tomatoes. However, ComCat® + manure had significantly higher AA content than ComCat® + NP treated tomatoes. Those tomatoes subjected to preharvest ComCat® and manure treatments had longer and wider leaves during the preharvest condition and this might have contributed to an increase in AA since light plays an important role in AA accumulation in tomato fruit (Davies and Hobson, 1971).

After 20 days of storage at ambient conditions, the preharvest manure and ComCat® treated tomato fruit had higher AA, followed by ComCat® + NP treated tomato fruit while the preharvest NP and ComCat® + NP treated tomato fruit contained higher AA when compared to the control tomatoes. Davies and Hobson (1971) reported that additional soil nitrogen application decreased the ascorbic acid. It appears from this that the growth of foliage in NP and ComCat®+ NP treated tomatoes might have affected the AA. It is probable that the individual fruit were shaded to some extent in NP and ComCat® + NP treated plots. Thus, exposure of the fruit to light may have been a factor since light plays an important role in ascorbic acid accumulation in tomato fruit (Davies and Hobson, 1971).

Disinfecting treatments showed significant ($P < 0.05$) effect on the AA content of tomato except on day 0 and 28. The AA content of tomato fruit dipped in hot water were higher than the AA content of chlorine dipped and control tomato fruit in most storage periods. McDonald et al. (1979) reported that some heat treatments could delay or inhibit ripening in certain tomato varieties. This is attributed to the fact that blanching reduced the metabolic rate and hence limits the chemical and biochemical changes during storage due to inactivation of enzymes.

AA content of tomato fruit increased with ripening during 20 days at cooled storage while it rapidly increased during the first 8 days of ripening at ambient conditions and showed a decline after full ripening. This trend was in agreement with the previous data that AA content increased with ripeness (Mohammed *et al*., 1999; Seyoum, 2002). After 12 days, significantly ($P < 0.01$) higher AA content of tomatoes stored at evaporatively cooled storage condition was observed than storage at ambient conditions. High temperature is known to increase enzymatic catalysis and lead to biochemical breakdown of compounds in fruit and vegetables (Yeshida *et al*., 1994). At relatively low storage temperature slow ripening of tomatoes would be associated with slow chemical and biochemical processes.

The two-way interaction between disinfection and storage environment showed nonsignificant ($P > 0.01$) variation expect on days 12 and 16. The interaction between the preharvest treatments and storage environment had highly significant ($P < 0.01$) effect on AA content of tomatoes.

Table 3. Effect of different preharvest, disinfection and storage treatments on ascorbic acid content and percent marketability of tomatoes over a storage period of 28 days.

Treatment	Ascorbic Acid, mg 100g^{-1} Storage period (day)								Marketability (%) Storage period (day)					
	0	4	8	12	16	20	24	28	8	12	16	20	24	28
Preharvest (A)														
CC	11.72^{bc}	14.17^{b}	15.04^{c}	15.85^{b}	15.78^{a}	14.41^{a}	14.86^{a}	13.53^{a}	92.77^{a}	74.60^{a}	64.68^{a}	50.62^{a}	40.80^{a}	28.64^{a}
M	14.92^{a}	16.02^{a}	19.75^{a}	16.12^{a}	15.86^{a}	14.53^{a}	13.12^{b}	11.56^{b}	90.30^{a}	76.14^{a}	55.06^{b}	33.54^{bc}	20.48^{c}	18.84^{bc}
NP	12.97^{b}	13.82^{c}	15.10^{c}	12.98^{e}	12.17^{c}	12.12^{c}	11.94^{b}	11.50^{b}	86.49^{b}	69.81^{b}	55.15^{b}	36.33^{b}	19.64^{c}	17.12^{c}
CC+ M	12.36^{b}	14.22^{b}	16.546^{b}	14.35^{c}	12.60^{b}	12.33^{b}	12.54^{b}	11.21^{b}	91.67^{a}	69.72^{b}	50.64^{b}	31.19^{c}	26.83^{b}	20.78^{b}
CC+NP	10.88^{c}	12.56^{d}	14.68^{d}	14.02^{d}	12.03^{c}	11.99^{c}	12.19^{b}	11.64^{b}	86.16^{b}	67.48^{b}	53.67^{b}	26.65^{d}	18.55^{c}	15.22^{c}
Control	13.00^{b}	11.89^{e}	12.966^{e}	12.07^{f}	11.76^{d}	11.62^{d}	12.39^{b}	11.40^{b}	86.47^{b}	69.72^{b}	44.96^{c}	26.74^{d}	19.35^{c}	16.19^{c}
LSD	**	**	**	**	**	**	**	**	**	**	**	**	**	**
SE$\pm$	0.561	0.07	0.05	0.05	0.051	0.040	0.38	0.31	0.68	1.01	1.198	1.05	0.84	0.95
Disinfection (B)														
NaOCL	12.64^{a}	13.70^{b}	15.57^{b}	14.17^{b}	13.44^{a}	12.75^{b}	13.13^{a}	11.91^{a}	88.88^{a}	72.81^{b}	56.70^{a}	39.32^{a}	29.27^{a}	24.05^{a}
H_2O, 52°C	12.63^{a}	13.89^{a}	15.88^{a}	14.23^{ab}	13.26^{b}	13.05^{a}	13.18^{a}	11.90^{a}	89.09^{a}	75.80^{a}	59.56^{a}	35.29^{b}	23.89^{b}	19.51^{b}
H_2O, 24.2°C	12.63^{a}	13.74^{ab}	15.59^{b}	14.29^{a}	13.40^{a}	12.69^{b}	12.22^{b}	11.61^{a}	88.96^{a}	65.12^{c}	45.82^{b}	27.92^{c}	19.66^{c}	14.84^{c}
LSD	ns	*	**	*	**	**	**	Ns	Ns	**	**	**	**	**
SE$\pm$	0.06	0.054	0.04	0.04	0.036	0.028	0.27	0.22	0.48	0.714	0.847	0.74	0.60	0.67
Storage conditions(C)														
EC	-	13.13^{b}	13.87^{b}	14.62^{a}	15.34^{a}	15.90^{a}	-	-	100.00^{a}	82.75^{a}	65.15^{a}	45.09^{a}	-	-
AM	-	14.43^{a}	17.50^{a}	13.85^{b}	11.40^{b}	9.77^{b}	-	-	77.95^{b}	59.74^{b}	42.90^{b}	23.27^{b}	-	-
LSD		**	**	**	**	**			**	**	**	**	-	-
SE$\pm$	-	0.044	0.03	0.031	0.03	0.023	-	-	0.39	0.58	0.69	0.60	-	-
Significance														
AXB	ns	ns	ns	ns	ns	**	*	ns	ns	ns	ns	ns	*	ns
AXC	-	***	***	***	***	***	-	-	***	*	ns	***	-	-
BXC	-	ns	ns	***	**	Ns	-	-	ns	***	***	ns	-	-
AXBXC	-	ns	ns	ns	ns	**	-	-	ns	ns	ns	ns	-	-

*Ascorbic acid content and percentage marketability of tomato from day 20 onwards is mean valves for the EC only. A = Preharvest; B = Disinfection; C = Storage. ns, *, **, *** indicate nonsignificant or significant difference at P < 0.05, 0.01or 0.001, respectively; means within the same column followed by a common letter are not significantly different at p< 0.01 & 0.01 (DMRT). C = ComCat®; M = manure; NP = nitrogen & phosphorus; C = control; C+M = ComCat® + manure; C+NP = ComCat® + nitrogen & phosphorus; EC = evaporative cooling; AM = ambient storage*

3.6. Percentage Marketability

On day 8, the preharvest ComCat®, manure and ComCat® + manure treatments significantly ($P < 0.01$) increased percent marketability of tomato when compared to the other treatments. On day 12 ComCat® and manure treatments kept on significantly ($P < 0.01$) higher percentage marketability of fruit over the others treatments. From day 16 onwards, the preharvest ComCat® treatment significantly ($P < 0.01$) increased the percent marketability when compared to the rest of the preharvest treatments. On day 16, ComCat® + manure, ComCat® + NP, manure and NP treatments had higher percent marketable fruit than control tomatoes.

On day 20, lower percent marketability of tomato fruit was observed in the preharvest treatments of ComCat® + NP and control tomatoes. During the last two storage interval days, ComCat® and control treatments showed significant ($P < 0.01$) variations in percent marketable tomatoes where on day 28 the preharvest ComCat®, ComCat® + manure, manure and NP treatment had 43.4%, 22.0%, 14.0%, and 5.4%, respectively, more marketable fruit over the control treatment. However, ComCat® + NP treated tomatoes showed reduction of percent marketability by 6.3% when compared to the control. The preharvest ComCat® + manure and manure treated tomatoes also had improved percent marketable tomatoes.

Disinfecting did not show significant effect on the percentage marketability of tomato fruit for the first 8 days of the storage periods but there after it showed significant ($P < 0.01$) effect until the end of the storage period. On day 12, hot water dipping treatment improved percent marketability by 3.9% over chlorinated water dipping treatment and by 14% over the tap water dipping control treatment.

On day 16, no difference was observed due to both chlorinated and hot water dipping treatment on percent marketability but both treatments significantly ($P < 0.01$) improved the percent marketability when compared to tap water dipping treatment. During the last three sampling intervals, chlorinated water dipping treatment significantly improved percent marketability than hot and tap water dipping treatments. However, hot water dipping treatment resulted in a good and attractive colored fruit while chlorine dipping left a taint on the surface of some samples of tomato during those days of storage. The higher percent marketability in chlorinated water treatment could be due to the action of chlorine as disinfecting agent and control of microorganisms, which is responsible for decay. Water washed tomato fruit (control) had lower percentage of marketable tomato fruit throughout the storage periods when compared to chlorine and hot water treatments.

The percentage marketability of tomato fruit stored in the evaporative cooling chamber was higher than those stored at ambient conditions. In this experiment, mature green tomato fruit could be stored for a period of 32 days in evaporatively cooled storage against 16 days under ambient temperature conditions. Tomato fruit stored at cool storage remained fresh, firm, shiny and had attractive color for a reasonable period of time. The termination of shelf life of tomatoes, on day 20, at ambient conditions was determined by shriveling, which produced plainly visible wrinkling and discoloration, making the fruit unacceptable for market. The percentage marketable fruit were lower ($P < 0.01$) by 48% for tomatoes stored at AM than those stored at evaporatively cooled storage at the end of the storage day. In addition, over-ripening and soft rot were the most serious problems associated with tomatoes stored at ambient temperature and humidity. Similar observations were reported by Pal and Roy (1991) and Seyoum (2002). The interaction effect between preharvest and storage condition was highly significantly ($P < 0.01$) except on day 16. Similarly, the interaction between disinfecting and storage treatment had shown significant effect on percent marketable tomato fruit on day 12 and 16.

4. Conclusion

Quality management starts in the field and continues until produce reaches the end user. The response of fruit and vegetables during storage to postharvest factors in part depends on preharvest practices. Understanding and managing the various roles that preharvest factors play in postharvest quality is very important in order to achieve maximum harvest and postharvest quality. The preharvest treatments had influenced the quality of tomatoes at harvest. The preharvest treatments had also influenced the postharvest quality parameters during storage. Foliar application of ComCat® displayed better maintenance of total soluble solids and ascorbic acid. ComCat® treatment when combined with manure and NP fertilizers had shown lower pH, total soluble solids, titratable acidity and ascorbic acid. Manure treated tomato fruit had higher total total soluble solids, titratable acidity and ascorbic acid. NP fertilizer application resulted in higher titratable acidity. ComCat® + manure and manure maintained ascorbic acid better during storage. ComCat®, ComCat® + manure and ComCat® + NP treatments had shown positive effect in keeping weight loss and thus improving the shelf life of tomatoes. Disinfection treatments significantly ($P < 0.05$) improved marketability of tomatoes during storage. Evaporative cooling positively affected chemical and physiological parameters in tomato fruit and was shown to improve the shelf life of the tomatoes compared to the storage at ambient conditions. This study reveald that integerated agro-technology, combining proper pre- and postharvest treatments, assist in improving the shelf life and maintain chemical quality of tomatoes.

5. Aknowledement

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Correlation and Path Analysis in Shallot *(Allium cepa* var. *ascalonicum* Baker.*)* Genotypes

Fasika Sendek [1], Hailu Tefera [2] and Kebede W/Tsadik [3*]

[1]Sirinka Agricultural Research center, P O Box 74, Weldia, Welo, Ethiopia
[2]Debre Zeit Agricultural Research Center, P O Box 32, D/Zeit, Ethiopia
[3] Haramaya University , P O Box 138, Dire Dawa, Ethiopia

Abstract: Field experiments were conducted on forty nine shallot genotypes to study the nature of correlations between bulb yield and other related characters at Sirinka and Girana in northeastern Ethiopia. Observations were made on ten plant samples for data analysis. At Girana, total bulb yield per plant showed high and positive phenotypic and genotypic correlations with plant height, leaf number, leaf diameter, bulb splits, marketable yield, biological yield and bulb dry weight. At Sirinka, the same trend was observed at genotypic level while, at phenotypic level, bulb yield correlated positively and significantly with plant height, lateral branches, bulb splits, bulb diameter marketable yield, biological yield and bulb dry weight. At both locations, biological yield, harvest index, marketable yield, bulb splits, pungency, laterals branches, bulb dry weight and bulb diameter exerted a positive direct effect on bulb yield at phenotypic level. At genotypic level, biological yield, bulb splits, harvest index, plant height, leaf diameter, marketable yield and pungency showed a positive direct effect on bulb yield per plant at Grana. The same trend at genotypic level was observed at Sirinka. The correlation of leaf number, plant height and leaf diameter with bulb yield and their positive indirect effects on bulb yield via their contribution to biological yield indicated that they could be considered as useful traits for selection in a breeding program of shallot for bulb yield.

Keywords: Shallot; Phenotypic Correlation; Genotypic Correlation; Direct Effect; Indirect Effect; Bulb Yield

1. Introduction

Shallot *(Allium cepa* var. *ascalonicum* Baker*)* is ranks among the very important vegetable crops used as a vegetable and condiment in most Ethiopian cuisine. It is widely cultivated as a cash crop mainly by subsistence farmers in the mid and high altitude areas of the country. Local shallot germplasm collections are reported to vary in shape, color, pungency, storability and several other characters (Getachew and Asfaw, 2000). Farmers grow different shallot lines and name them after major production belts. However, as shallot is propagated mainly by asexual method, it is unclear whether these variabilities reflect environmental or genetic background for possible use in breeding programs.

Association of characters among yield, its components, and other economic traits are important for making selection and for combining several desirable attributes in a breeding program. To facilitate selection in a breeding program for high yield, it is logical to examine various components and to give more attention to those having the greatest influence on yield. In correlation studies, it is customary to emphasize large number of plant characters examined in a large number of genotypes and use the correlation to establish an index in deciding the direction of selection (Dudley and Moll, 1969).

Genotypic correlation coefficient provides a measure of genetic association between traits in order to identify the important character to be considered in a breeding program (Pandey and Gritton, 1975). Different researchers have reported associations between different traits in *Allium cepa*. Dowker *et al.* (1976), for example, reported a positive correlation between bulb yield and leaf length. Patil and Kale (1985) reported positive association between neck thickness and bulb diameter in onion. As is true for any crop, selection based on any single plant attribute is unlikely to lead to dramatic improvements in the yield potential of *Allium spp*. Thus, it is suggested that alternative selection criteria are used, based on physiological or morphological characters which contribute to improvement of yield potential (Moot and McNeil, 1995).

Furthermore, path coefficient analysis technique, which involves partitioning of the correlation coefficient into direct and indirect effects *via* alternative characters or pathways is used to determine which characters affect bulb yield directly or indirectly (Dewey and Lu, 1959; Kalloo *et al., 1982;* Pal and Singh, 1988*)*. Bulb yield, being a complex outcome of various characters, is considered as the resultant characteristic in onion while the rest of the characters are the causal ones (Kalloo *et al., 1982*). Therefore, this research intended to study the nature and magnitude of correlation of different traits with bulb yield and how they affect the bulb yield in shallot.

2. Materials and Methods

The study was conducted at Sirinka and Girana trial sites of Sirinka Agricultural Research Center, northeastern Ethiopia, during the main growing season (July to November) in 2003. Sirinka Station is located at latitude 11°83' N and longitude 39°68' E with an altitude of 1850 m .a.s.l. The mean annual rainfall is 950 mm with a mean maximum and minimum temperature of 26°C and 13°C, respectively (SARC, 2000). The soil type is eutric Vertisol (Samuel, 2001)**.** Girana research site is located about 50 kilometers south of Sirinka Agricultural Research Centre. It is situated at an altitude of 1450 m .a.s.l. and the soil type is clay with pH of 7.6 (SARC, 2000).

Forty nine shallot genotypes obtained from collections of the National Shallot Improvement Program, including one local and one standard check, were evaluated in a simple lattice design with two replications. The experimental plot size was 2 m long and 2 m wide, consisting of 50 plants in rows. Bulbs were planted at a spacing of 40 cm x 20 cm between rows and plants, respectively. A distance of 1m was maintained between plots. The plants in the middle three rows of each plot were used for data collection. The data were subjected to analysis of variance using MSTATC computer program. Path analysis was carried out using Statistical Package for Agricultural Research (SPAR).

2.1. Correlation Analysis

Phenotypic correlation of characters refers to both genotypic and environmental effects, while genotypic correlation refers to the inherent association between two

*Corresponding author. E-mail:

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characters. Both correlations were estimated based on the procedures of Miller *et al.* (1958) as follows:

$$\text{Phenotypic correlation (rp)} = \frac{P\operatorname{cov} X.Y}{\sqrt{(\sigma 2px * \sigma 2py)}}$$

$$\text{Genotypic correlation (rg)} = \frac{G\operatorname{cov} X.Y}{\sqrt{(\sigma 2gx * \sigma 2gy)}}$$

Where: **r**p = phenotypic correlation coefficient.

Pcov X.Y = Phenotypic covariance between characters X and Y

$\sigma 2px$ = Phenotypic variance for character x

$\sigma 2py$ = Phenotypic variance for character y

rg = genotypic correlation coefficient

Gcov X. Y = genotypic covariance between characters X and Y

$\sigma^2 gx$ = genotypic variance for character x

σ^{2gy} = genotypic variance for character y

2.2. Path Coefficient Analyses

The path coefficient analyses were estimated with the simultaneous solution of the following general formula suggested by Dewey and Lu (1959).

$$rij = Pij + \sum rikPkj,$$

Where, rij = mutual association between the independent character (i) and dependent character (j) as measured by the genotypic correlation coefficient

Pij = components of direct effect on the independent character (i) on the dependent character (j) as measured by the genotypic path coefficient

$\sum rikPkj$ = Summation of components of indirect effects of a given independent character (i) on the given dependent character (j) via all other independent characters (k). To determine Pij values, square matrices of the correlation coefficients between independent characters in all possible pairs inverted and then multiplied by the correlation coefficients between the independent and dependent characters. The residual effects were estimated using the formula:

$\sqrt{1} - R^2$ where, $R^2 = \sum Pijrij$

3. Result and Discussion

3.1. Correlation Analysis

3.1.1. Correlation of Bulb Yield per Plant with Its Components

The estimates of phenotypic and genotypic correlation coefficients both at Girana and at Sirinka (Tables 1 and 2) revealed that the genotypic correlations were of higher magnitude than the corresponding phenotypic ones for the majority of the characters studied, thereby establishing a strong inherent relationship among the attributes studied.

At Girana the interrelationship of total bulb yield per plant was significantly positive with plant height, leaf number, leaf diameter, bulb splits, marketable yield, biological yield and bulb dry weight both at phenotypic and genotypic levels (Table 1). Total bulb yield per plant also had positive and significant genotypic correlation with lateral, bulb splits, bulb diameter and days to maturity.

Total bulb yield at Sirinka correlated positively and significantly with plant height, lateral branches, bulb splits, bulb diameter, marketable yield and biological yield at phenotypic level. Similarly, at genotypic level, total bulb yield correlated positively and significantly with plant height, number of leaves, leaf diameter, bulb diameter, biological yield, marketable yield, and bulb dry weight (Table 2).

The correlation of bulb yield with the vegetative growth suggests that improvement of these characters would improve the photosynthetic capacity of the crop to mobilize and translocate photosynthate to the organ of economic value. This result is in agreement to the work of (Patil and Kale, 1985), Abayneh (2001) and Mohanty (2001) in onion. The positive correlation of bulb yield with bulb splits suggests that genotypes producing a large number of lateral branches could produce a large number of bulb splits per plant, thereby increasing bulb yield per plant although size of individual bulb splits could decrease. On the other hand, the result indicated that shallot genotypes producing a relatively large bulb size could increase bulb yield per plant. Therefore, since most shallot genotypes produce small sized bulbs, improving bulb size would increase bulb yield of marketable size.

Bulb yield per plant exhibited low and positive genotypic correlations with harvest index and total soluble solids, indicating that improving these traits could increase bulb yield per plant to a certain extent. The negative and low magnitudes of genotypic and phenotypic correlations recorded between pungency and bulb yield per plant indicated that increase of bulb yield per plant had no significant impact on pungency of shallot genotypes.

3.1.2. Correlation among Other Characters

Marketable yield per plant had positive and high phenotypic and genotypic correlation with plant height, number of leaf per plant, leaf diameter, bulb diameter and bulb dry weight, which indicated that increasing these traits would increase bulb size and marketable yield of shallot (Tables 1 and 2). Plant height showed positive and significant correlation with number of leaves per plant and bulb diameter. This result suggested that increasing plant height could result in an increase of leaf number per plant which, in turn, could lead to higher photosynthetic capacity of the genotypes for better bulb yield with high bulb dry matter content. The observation is in concordance with the reports of Sadhu and Korla (1976), Patil and Kale (1985), Abayneh (2001) and Mohanty (2001) in onion.

Bulb dry weight correlated positively and highly with the vegetative growth, both at the phenotypic and genotypic levels. This showed that an increase in these characters facilitate increased production of dry matter in shallot, which is an important quality factor in onion bulbs. Harvest index per plant was also positively and significantly associated with leaf diameter and bulb dry weight, indicating that an increase in these characters increases bulb yield per plant. However, its association with plant height, number of leaf per plant and pungency was negative and high, implying that an increase in these traits would increase biomass at the expense of bulb yield and quality. Similarly, the total soluble solids showed negative and high correlation with plant height, number of leaf per plant and bulb diameter. Mc Collum (1968) also reported negative genetic correlation between total soluble solids and bulb diameter in onion.

Days to maturity was correlated positively and highly with leaves per plant, lateral branches and bulb splits per plant. This probably indicates that medium phenological period could result in large biomass accumulation with minimum contribution to bulb yield, due to less efficiency in dry matter partitioning. Plant height showed positive and high correlation with number of leaves per plant, leaf diameter and bulb diameter. This result is in agreement with the reports of Mittal and Srivastava (1965) and Abayneh (2001) in onion.

Table 1. Correlation coefficients at genotypic (above diagonal) and phenotypic (below diagonal) levels of various characters in shallot genotypes at Girana.

Character	PH	LPP	LD	LBPP	BSPP	BD	TYPP	MYPP	BYPP	HI	BDW	DTM	TSS	PCY
PH		0.295	0.264	-0.347	0.070	0.702	0.496	0.410	0.579	-0.713	0.241	0.639	-0.373	0.541
LPP	0.392**		-0.489	0.441	0.833	0.025	0.313	0.087	0.415	-0.672	0.140	0.609	-0.450	0.090
LD	0.142	0.219		-0.613	0.116	-0.206	0.985	0.885	0.762	0.733	1.096	1.885	0.237	0.112
LBPP	0.235	0.510**	0.098		0.937	-0.245	0.586	0.172	0.488	0.229	0.476	-0.279	0.125	-0.053
BSPP	0.433**	0.008	0.579**	0.162		0.006	0.306	0.044	0.261	-0.160	0.133	-0.123	-0.016	-0.241
BD	0.034	-0.105	0.105	-0.002	0.319*		0.887	1.009	0.892	0.114	0.868	0.416	-0.316	0.106
TYPP	0.467**	0.485**	0.320*	0.194	0.380**	0.255		0.955	0.978	0.222	1.091	0.499	0.160	-0.142
MYPP	0.915**	0.473**	0.322*	0.203	0.229	0.295*	0.296*		0.936	0.219	0.926	0.558	0.192	-0.087
BYPP	0.891**	0.965**	0.439**	0.472**	0.338*	0.197	0.463**	0.388**		0.025	1.039	0.564	0.077	-0.069
HI	0.074	0.267	0.287*	0.276	0.026	-0.030	0.056	-0.188	-0.427**		0.353	-0.049	0.227	-0.400
BDW	-0.228	0.673**	0.635**	0.693**	0.374**	0.270	0.319*	0.268	0.271	0.230		0.557	0.060	0.042
DTM	0.279	-0.188	0.248	0.203	0.218	0.166	-0.023	-0.176	0.037	-0.056	0.156		0.077	0.231
TSS	0.074	0.190	0.056	0.181	0.218	0.232	0.046	0.136	0.132	0.142	-0.019	-0.084		-0.388
PCY	-0.183	0.028	0.049	-0.138	-0.049	-0.089	-0.083	-0.171	0.061	-0.054	0.075	0.082	0.263	

PH= plant height, LPP= leaves per plant, LD= leaf diameter, LBPP= lateral branches per plant, BSPP= bulb splits per plant, BD=bulb diameter, TYPP= total yield per plant, MYPP= marketable yield per plant, BYPP= biological yield per plant, HI= harvest index, BDW= bulb dry weight, DTM= days to maturity, TSS= total soluble solids, and PCY= pungency.
**, ** indicate significant difference at 5% and 1% probability levels respectively.*
The phenotypic correlation coefficients must exceed 0.288 and 0.372 to be significant at 5% and 1% probability levels, respectively.

Table 2. Correlation coefficients at genotypic (above diagonal) and phenotypic (below diagonal) levels of various characters in shallot genotypes at Sirinka.

Characters	PH	LPP	LD	LBPP	BSPP	BD	TYPP	MYPP	BYPP	HI	BDW	DTM	(TSS)	PCY
PH		0.475	0.731	0.071	-0.148	1.007	0.751	0.773	0.771	-0.156	0.519	-0.681	-0.052	0.417
LPP	0.335*		0.278	1.174	0.409	-0.109	0.347	0.330	0.464	-0.783	0.051	0.344	-0.510	0.187
LD	0.295*	0.500**		-0.218	-0.600	0.335	0.452	0.533	0.510	-0.238	0.292	0.056	-0.260	0.138
LBPP	0.095	0.612**	0.016		0.942	-0.431	0.239	0.091	0.347	-0.765	0.295	0.559	-0.661	0.246
BSPP	0.613**	-0.264	0.465**	-0.009		-0.137	0.070	-0.072	0.058	-0.036	0.106	0.303	0.006	-0.044
BD	-0.092	-0.256	0.229	-0.015	0.354*		0.619	0.670	0.564	0.359	0.677	-0.517	0.043	0.096
TYPP	0.402**	0.263	0.158	0.420**	0.375**	0.559**		0.993	0.988	0.139	0.936	0.069	0.178	0.104
MYPP	0.970**	0.450**	0.109	0.062	0.469**	0.319*	0.579**		0.992	0.070	0.912	0.029	0.153	0.079
BYPP	0.958**	0.982**	0.376**	0.254	0.187	0.446**	0.464**	0.560**		-0.008	0.864	0.136	0.130	0.068
HI	-0.045	0.110	0.134	0.128	0.002	-0.165	-0.072	-0.445	-0.001		0.548	-0.548	0.427	0.170
BDW	0.277	0.478**	0.556**	0.531**	0.403**	0.029	0.130	0.088	0.126	0.209		0.400	0.180	-0.035
DTM	0.071	0.130	0.124	0.140	0.143	-0.126	0.098	0.158	0.128	0.227	-0.023		-0.869	-0.350
TSS	-0.096	0.124	0.279	0.079	0.164	0.130	0.066	-0.105	-0.250	-0.097	-.324*	0.103		-0.096
PCY	-0.019	-0.185	0.015	0.128	0.070	0.092	0.103	0.093	-0.016	0.116	0.157	0.130	0.227	

PH= plant height, LPP= leaves per plant, LD= leaf diameter, LBPP= lateral branches per plant, BSPP= bulb splits per plant, BD=bulb diameter, TYPP= total yield per plant, MYPP= marketable yield per plant, BYPP= biological yield per plant, HI= harvest index, BDW= bulb dry weight, DTM= days to maturity, TSS= total soluble solids, and PCY= pungency.
**, ** indicate significant difference at 5% and 1% probability levels, respectively.*
The phenotypic correlation coefficients must exceed 0.288 and 0.372 to be significant at 5% and 1% probability levels respectively.

3.2. Path Analysis

3.2.1. Phenotypic Direct and Indirect Effects of Characters on Bulb Yield

At Girana, biological yield (0.847) and harvest index (0.169) had positive direct effects on bulb yield (Table 3). Other characters which showed positive direct effects on bulb yield were marketable yield, bulb splits, pungency, bulb dry weight, number of lateral branches per plant and bulb diameter. Plant height showed negative direct effect on bulb yield per plant, indicating that its negative direct effect was counterbalanced by its positive indirect effect *via* biological yield, bulb splits per plant and marketable yield per plant. These characters could be considered as main components of selection in a breeding program for obtaining higher bulb yield. This finding is supported by the work of Abayneh (2001) and Singh (1981) who reported that biological yield and harvest index contributed direct effects in onion bulb yield.

At Sirinka, biological yield (0.930) and harvest index (0.152) also directly affected bulb yield per plant (Table 4). Low magnitudes of negative direct effects were observed on bulb yield per plant via leaves per plant, leaf diameter and total soluble solids. In addition to its direct positive effect on bulb yield per plant, harvest index also exhibited positive indirect effects via bulb diameter, bulb dry weight, days to maturity, total soluble solids and pungency. Negative indirect effects of harvest index were observed through traits such as leaf per plant, leaf diameter, marketable yield and biological yield per plant. This result is in agreement with the work of Abayneh (2001) who reported that harvest index had a negative indirect effect on biological yield per plant in onion. Bulb dry weight demonstrated a favorable positive indirect effect through bulb diameter, marketable yield, biological yield and harvest index. In addition, a near absence effect was observed via the other characters.

Table 3. Phenotypic direct (bold face) and indirect effects of various characters on bulb yield per plant of shallot genotypes at Girana.

Character	PH	LPP	LD	LB	BSPP	BD	MY	BYPP	HI	BDW	DTM	TSS	PCY
PH	-0.0.35	-0.022	0.000	0.001	0.013	0.001	0.032	0.329	-0.072	0.003	0.000	0.001	0.004
LPP	-0.014	-0.057	0.000	0.006	0.046	0.000	0.032	0.392	-0.032	0.004	0.000	0.000	0.001
LD	-0.008	-0.008	0.002	0.003	0.001	0.000	0.025	0.167	0.009	0.004	0.000	-0.001	0.001
LBPP	-0.003	-0.029	0.000	0.013	0.035	0.000	0.022	0.286	-0.005	0.005	0.000	-0.001	-0.001
BSPP	-0.006	-0.033	0.000	0.005	0.080	0.000	0.34	0.399	0.004	0.004	0.000	-0.001	-0.003
BD	-0.011	0.000	0.000	-0.001	0.003	0.002	0.051	0.371	0.047	0.005	0.000	0.000	0.001
TYPP	-0.010	-0.017	0.000	0.003	0.026	0.001	0.107	0.755	0.045	0.009	0.000	-0.002	-0.001
MYPP	-0.014	-0.026	0.000	0.004	0.038	0.001	0.096	0.847	0.013	0.010	0.000	-0.002	-0.001
BYPP	0.015	0.011	0.000	0.000	0.002	0.001	0.029	0.063	0.169	0.003	0.000	-0.003	-0.002
HI	-0.008	-0.015	0.000	0.004	0.022	0.001	0.068	0.0570	0.038	0.015	0.000	-0.001	0.000
BDW	-0.005	0.003	0.000	-0.002	-0.002	0.000	0.022	0.210	-0.011	0.004	-0.001	-0.001	0.000
DTM	0.003	0.001	0.000	0.002	0.011	0.000	0.023	0.153	0.048	0.003	0.000	-0.009	-0.003
TSS	-0.009	-0.005	0.000	-0.001	-0.014	0.000	-0.010	-0.041	-0.023	0.001	0.000	0.002	0.016

PH= plant height, LPP= leaves per plant, LD= leaf diameter, LBPP= lateral branches per plant, BSPP= bulb splits per plant, BD=bulb diameter, TYPP= total yield per plant, MYPP= marketable yield per plant, BYPP= biological yield per plant, HI= harvest index, BDW= bulb dry weight, DTM= days to maturity, TSS= total soluble solids, and PCY= pungency.

Residual effect=0.0161

Table 4. Phenotypic direct (bold face) and indirect effects of various characters on bulb yield per plant of shallot genotypes at Sirinka.

Character	PH	LPP	LD	LB	BSPP	BD	MY	BYPP	HI	BDW	DTM	TSS	PCY
PH	0.014	-0.010	-0.004	0.000	0.000	0.002	0.034	0.521	0.000	0.000	0.000	0.000	0.004
LPP	0.005	-0.031	-0.002	0.004	0.013	0.000	0.018	0.432	-0.068	0.000	0.002	0.001	0.002
LD	0.007	-0.009	-0.008	0.001	-0.007	0.002	0.027	0.415	-0.011	0.000	0.001	0.000	0.002
LBPP	0.000	-0.019	-0.001	0.007	0.017	-0.002	0.004	0.174	-0.025	0.000	0.001	0.001	0.002
BSPP	0.000	-0.014	0.002	0.004	0.027	-0.001	0.006	0.237	0.000	0.000	0.001	0.000	0.000
BD	0.005	0.000	-0.002	-0.002	-0.003	0.007	0.026	0.350	0.019	0.001	-0.001	-0.001	0.001
TYPP	0.008	-0.010	-0.004	0.000	0.003	0.003	0.058	0.891	-0.017	0.001	0.001	-0.001	0.001
MYPP	0.008	-0.014	-0.004	0.001	0.007	0.003	0.056	0.930	-0.007	0.001	0.001	0.000	0.001
BYPP	0.000	0.014	0.001	-.0.001	0.000	0.001	0.006	-0.042	0.152	0.001	0.001	-0.001	0.002
HI	0.003	0.004	-0.001	-0.001	0.001	0.003	0.032	0.445	0.042	0.002	0.001	0.000	0.000
BDW	0.000	-0.007	-0.001	0.001	0.003	-0.001	0.008	0.115	0.020	0.000	0.008	0.000	-0.003
DTM	0.001	0.010	0.001	-0.002	-0.003	0.000	0.009	0.074	0.042	0.000	-0.001	-0.003	0.000
TSS	0.003	-0.004	-0.001	0.001	0.000	0.001	0.005	0.065	0.019	0.000	-0.001	0.000	0.016

PH= plant height, LPP= leaves per plant, LD= leaf diameter, LBPP= lateral branches per plant, BSPP= bulb splits per plant, BD=bulb diameter, TYPP= total yield per plant, MYPP= marketable yield per plant, BYPP= biological yield per plant, HI= harvest index, BDW= bulb dry weight, DTM= days to maturity, TSS= total soluble solids, and PCY= pungency.

Residual effect=0.0025

3.2.2. Genotypic Direct and Indirect Effects of Characters on Bulb Yield

At Girana, genotypic direct effect on bulb yield per plant was exerted by biological yield (0.987), bulb splits per plant (0.237) and harvest index (0.115). Low magnitude and positive direct effects were also exhibited by plant height, leaf diameter, marketable yield per plant, and pungency (Table 5). Number of leaves per plant, however, exhibited a negative direct effect on bulb yield per plant. Bulb dry weight also affected bulb yield per plant unfavorably. Bulb splits per plant showed a positive direct effect on bulb yield per plant through the indirect positive influence on plant height, leaf diameter, lateral branches, marketable yield per plant, biological yield per plant, days to maturity and total soluble solids per plant. The findings showed that the influence of bulb dry weight was counterbalanced by the positive indirect effects of biological yield per plant, harvest index, bulb splits per plant, marketable yield per plant, leaf diameter, plant height and pungency.

At Sirinka, biological yield per plant showed maximum positive direct effect (0.846) followed by harvest index, marketable yield per plant, bulb dry weight, pungency, bulb diameter, bulb splits, days to maturity and total soluble solids (Table 6). Biological yield also showed a favorable indirect influence on bulb yield via leaves per plant, bulbs splits per plant, bulb diameter, marketable yield, bulb dry weight per plant, total soluble solids and pungency. In addition to the positive direct effect on bulb yield per plant, marketable yield exerted a favorable indirect influence on bulb yield via leaves per plant, bulb diameter, biological yield, harvest index, bulb dry weight per plant, total soluble solids and pungency. The overall finding is in conformity with Kalloo *et al.* (1982) and Abayneh (2001) who reported that biological yield, leaf diameter, harvest index and plant height exerted a positive direct effect on bulb yield of onion. Pal and Singh (1988) reported that selection based on weight and diameter of bulb was useful for onion. Similarly, Mohanty (2001) suggested that leaf number per plant be envisaged independently or in combination with other vegetative characters to circumvent the bulb yield of onion.

Generally, each of the characters considered in this study has influenced bulb yield directly and indirectly. At both locations the residual effects were not significantly high, which demonstrated that the traits considered were enough to explain the direct and indirect effects on bulb yield per plant. The estimates of the direct and indirect effects were more pronounced in genotypic path than the phenotypic path, particularly at Girana site rather than at Sirinka, indicating better genetic expression of the traits and their contribution towards bulb yield as a tool for selection of shallot genotypes under Girana condition.

Table 5. Genotypic direct (bold face) and indirect effects of various characters on bulb yield per plant of shallot genotypes at Girana.

Character	PH	LPP	LD	LB	BSPP	BD	MY	BYPP	HI	BDW	DTM	TSS	PCY
PH	0.034	-0.058	0.015	0.003	0.017	-0.032	0.029	0.571	-0.082	-0.013	-0.017	-0.015	0.014
LPP	0.010	-0.196	-0.027	-0.004	0.197	-0.001	0.006	0.409	-0.077	-0.008	-0.016	-0.017	0.002
LD	0.009	0.096	0.056	0.006	0.027	0.009	0.63	0.751	0.084	-0.060	-0.050	0.009	0.003
LBPP	-0.012	-0.087	-0.034	-0.009	0.222	0.011	0.012	0.481	0.026	-0.026	0.007	-0.005	-0.001
BSPP	0.002	-0.164	0.007	-0.008	0.237	0.000	0.003	0.258	-0.018	-0.007	0.003	0.001	-0.006
BD	0.024	-0.005	-0.012	0.002	0.001	-0.045	0.072	0.880	0.013	-0.047	-0.011	0.012	0.003
TYPP	0.014	-0.017	0.050	-0.002	0.010	-0.045	0.071	0.924	0.025	-0.050	-0.015	-0.007	-0.002
MYPP	0.020	-0.081	0.043	-0.004	0.062	-0.040	0.067	0.987	0.003	-0.057	-0.015	-0.003	-0.002
BYPP	-0.024	0.132	0.041	-0.002	-0.038	-0.005	0.016	0.025	0.115	-0.019	0.001	.-0.009	-0.011
HI	0.008	-0.028	0.062	-0.004	0.031	-0.039	0.066	1.025	0.041	-0.054	-0.015	-0.002	0.001
BDW	0.022	-0.119	0.106	0.003	-0.029	-0.019	0.040	0.556	-0.006	-0.030	-0.027	-0.003	0.006
DTM	-0.013	0.088	0.013	-0.001	-0.004	0.014	0.014	0.076	0.026	-0.003	-0.002	-0.039	-0.010
TSS	0.018	-0.018	0.006	0.000	0.057	-0.005	-0.006	-0.068	-0.046	-0.002	-0.006	0.015	0.027

PH= plant height, LPP= leaves per plant, LD= leaf diameter, LBPP= lateral branches per plant, BSPP= bulb splits per plant, BD=bulb diameter, TYPP= total yield per plant, MYPP= marketable yield per plant, BYPP= biological yield per plant, HI= harvest index, BDW= bulb dry weight, DTM= days to maturity, TSS= total soluble solids, and PCY= pungency.

Residual effect=-0.0137

Table 6. Genotypic direct (bold face) and indirect effects of various characters on bulb yield per plant of shallot genotypes at Sirinka.

Character	PH	LPP	LD	LB	BSPP	BD	MY	BY	HI	BDW	DTM	TSS	PCY
PH	-0.012	0.012	-0.019	-0.001	-0.002	0.031	0.074	0.652	-0.016	0.025	-0.006	0.000	0.0 13
LPP	-0.006	0.025	-0.007	-0.015	0.006	-0.003	0.032	0.392	-0.079	-0.002	-0.003	-0.004	0.006
LD	-0.009	0.007	-0.026	0.003	-0.008	0.010	0.051	0.431	-0.024	0.014	0.000	-0.002	0.004
LBPP	-0.001	0.029	0.006	-0.012	0.013	-0.013	0.009	0.294	0.077	-0.014	-0.005	-0.005	0.008
BSPP	0.002	0.010	0.015	-0.012	0.014	-0.004	-0.007	0.049	-0.004	0.005	0.003	0.000	-0.001
BD	-0.013	-0.003	-0.009	0.005	-0.002	0.031	0.064	0.477	0.036	0.032	-0.005	0.000	0.003
TYPP	-0.010	0.008	-0.014	-0.001	-0.001	0.021	0.096	0.839	0.007	0.044	0.000	0.001	0.002
MYPP	-0.010	0.011	-0.013	-0.004	0.001	0.017	0.095	0.846	-0.001	0.041	-0.001	0.001	0.002
BYPP	0.002	-0.019	0.006	0.010	0.000	0.011	0.007	-0.007	0.101	0.026	-0.005	0.003	0.005
HI	-0.006	-0.001	-0.007	0.004	0.001	0.021	0.087	0.731	0.055	0.048	0.003	0.001	-0.001
BDW	0.008	0.008	-0.001	-0.007	0.004	-0.016	0.003	0.115	-0.055	0.019	0.009	-0.007	0.011
DTM	0.001	-0.013	0.007	0.008	0.000	0.001	0.015	0.110	0.043	0.009	-0.008	0.008	-0.003
TSS	-0.005	0.005	-0.004	-0.003	-0.001	0.003	0.008	0.058	0.017	-0.002	-0.003	-0.001	0.031

PH= plant height, LPP= leaves per plant, LD= leaf diameter, LBPP= lateral branches per plant, BSPP= bulb splits per plant, BD=bulb diameter, TYPP= total yield per plant, *MYPP= marketable yield per plant, BYPP= biological yield per plant, HI= harvest index, BDW= bulb dry weight, DTM= days to maturity, TSS= total soluble solids, and PCY= pungency.*

Residual effect=0.0007

4. Conclusion

Total bulb yield per plant in shallot was found to be associated positively and significantly with plant height, bulb splits, biological yield and marketable yield per plant at phenotypic level at Girana and Sirinka study sites. Similarly, at genotypic level, bulb yield per plant correlated positively and significantly with plant height, number of leaves, leaf diameter, bulb diameter, biological yield and marketable yield in both locations. The findings indicated that most of the characters considered in this study had positive and high intercharacter correlation at phenotypic and genotypic levels, which indicated the possibility of correlated response to selection and that, with an increase in one, there is a possibility of increment in the other.

In path coefficient analysis at phenotypic level, biological yield, harvest index, marketable yield, bulb splits, lateral branches, bulb diameter and pungency showed a positive direct effect on bulb yield per plant. At genotypic level, biological yield, bulb splits, harvest index, marketable yield and pungency showed a positive direct effect on bulb yield. At both locations, the residual values were low, which indicated the traits considered have explained the path analysis pattern.

Both at Girana and Sirinka, genotypic correlations were found to be higher in magnitude than that of phenotypic for the majority of the characters studied. This indicated that genetic factors played a major role in these associations among the characters. Vegetative traits such as plant height, leaf number, leaf diameter and bulb diameter, which showed positive correlation with bulb yield and also positively affected bulb yield via their contribution to biological yield, appear to be useful traits to be considered in the selection of shallot for bulb yield.

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Variability and Association of Quantitative Traits in *Plectranthus edulis* (Vatke) Agnew

Weyessa Garedew[1], Admasu Tsegaye[2], Bezuayehu Tesfaye[2] and Hussein Mohammed[2]

[1]Jimma University, College of Agriculture and Veterinary Medicine, P O Box 1492, Jimma, Ethiopia
[2] Hawassa University, P O Box 5, Hwassa, Ethiopia

Abstract: Thirty six accessions of *Plectranthus edulis* were evaluated to estimate the nature and magnitude of variability and associations among tuber yield and related characteristics. Analysis of variance for each characters indicated highly significant ($p<0.01$) variation among the accessions for all characters except tuber length. Relatively high phenotypic (43.17, 37.85, and 24.25 %) and genotypic coefficients of variation (42.42, 36.47 and 18.40%) were observed for tuber weight per hill, number of tuber per hill and stem number per hill in the order of magnitudes. High heritability (96.50 and 92.84%) coupled with high genetic advance as percent of mean (86.85 and 72.38%) were recorded for tuber weight per hill and number of tubers per hill respectively. Analysis of phenotypic correlation indicated that tuber yield per hill was significantly and positively associated with number of branches ($r = 0.366$), tuber diameter ($r = 0.435$), and number of tuber per hill ($r = 0.567$). Path coefficient analysis at genotypic level also revealed that number of tubers per hill ($p=0.982$) exerted a high magnitude of positive direct effect on tuber weight per hill. Nevertheless, the need for confirmation of genotypic-environment interaction and widening of the genetic base for *P. edulis* improvements are suggested.

Keywords: Correlation Analysis; Genetic Variability; Path Analysis; *Plectranthus edulis*

1. Introduction

Plectranthus edulis is an indigenous annual tuber crop grown widely in the central, southern, western, northwestern and southwestern parts of Ethiopia (Uphof, 1968; Westphal, 1975; Zeven and Zhukovsky, 1975; PGRC/E, 1986; Edward, 1991; Edossa, 1996; Abdissa, 2000; GRIN, 2005). It is a dicotyledonous plant and belongs to the family Lamiaceae/Labiatae; subfamily Nepetoideae and tribe Ocimeae (GRIN, 2005).

In the various growing areas of Ethiopia, different vernacular names are used for *Plectranthus edulis*. Among these are '*Dinicha Oromo*' in Oromia, meaning "potato of the Oromo people" (Abdissa, 2000), '*Wolaita Dinich*' (potato of the Wolayita people) around Wolaita (Endale, 1997), '*Agew Dinch'* (potato of the Agew people) in the northwest and '*Gurage Dinich'* (potato of the Gurage people) around Gurage zone (Westphal, 1975). For generations, farmers in different parts of the country have been cultivating *Plectranthus edulis,* primarily for its edible tuber. The leaves are also eaten as a green vegetable in some regions (Abebe, 1988). Moreover, the edible tubers are good for people with asthma (IAR, 1980) and, because of its abundant nectar, the plant is a good source of honey (Reinhard and Admasu, 1994).

Despite its importance for food security as well as its medicinal value, only limited research has been conducted on the crop (Abebe, 1988). On the other hand, changes in agricultural practices and environmental degradation are causing genetic loss in the local gene pool of this crop (Amsalu and Tesfaye, 2004). In response to these problems and the expressed need for making useful germplasm readily available for crop improvement programs, some collection and conservation work has been started. However, the collected accessions have not been properly characterized and evaluated, their attributes remaining unknown to breeders. Admasu (2002) indicated that lack of knowledge about the genetic diversity of the enset crop complicated the conservation, improvement and utilization by farmers, conservationists and breeders. He also noted that knowledge about clonal diversity allows the selection of clones prioritized for conservation, by removing duplication and optimizing genetic diversity and hence optimizing cost benefit ratio in maintaining the crop germplasm.

Therefore, the value of the conserved germplasm depends greatly upon the information available on each accession. Furthermore, the effectiveness of selection also depends upon the amount of variability existing in the material, the extent to which the character is heritable and the association/correlation between traits. This study, therefore, was undertaken to characterize the accessions in the collection and identify the nature and magnitude of variability of traits and their association with each other, with the ultimate goal of providing a basis for conservation and utilization in a breeding program.

2. Material and Methods

The study was carried out at Jimma Agricultural Research Centre. The site is located at $7^0 46'$ N and 36^0 E with an altitude of 1753 meters above sea level. The soil type of the experimental area is Eutric Nitosol (reddish brown) with a pH of around 5.2. The area receives mean annual rainfall of 1536 mm with a mean annual maximum and minimum temperatures of 25.9 °C and 11.2 °C, respectively (IAR, 1997).

A total of 36 *Plectranthus edulis* accessions collected from six different regions of the country by Jimma Agricultural Research Centre and Institute of Biodiversity Conservation were grown in single row plots during the 2005 main cropping season (April-October) in 6 x 6 simple lattice design. Each row was 3.5 m long with a space of 1 m between rows. Plants were spaced 50 cm apart within the row. Tubers which had just started sprouting were used as planting material. Planting was done at the beginning of the rainy season (April) in well-drained, loose soil on flat ground. Three kg/plot of

*Corresponding author. E-mail: weyessa2001@yahoo.com
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farmyard manure (8.571 t/ha) was applied along the rows. One month later, when the crop was well established, earthing up with loose soil was undertaken. Hand weeding was conducted as required to keep plots weed-free.

A total of 16 quantitative traits were recorded on plant basis on five selected plants. The average of five plants was used for statistical analysis. Days to flower initiation and days to 50 percent flowering were recorded on plot basis. The collected traits included : Plant height (cm): the height measured from the mounding to the tip of the plant at crop maturity (the longest height); Stem girth (cm): the diameter (girth) of the main stem measured at the fourth internode from the mound at 50 % flowering; Number of tubers per hill: the actual count of the number of tubers at harvest; Tuber length (cm): the average length of five tubers per hill measured at harvest; Tuber diameter (cm): the average diameter of five tubers measured per hill at harvest using vernier calliper; Number of nodes: the number of nodes on the main stem counted at 50% flowering; Internodes length (cm): the length of nodes on the main stem measured at 50% flowering; Tuber weight per hill (kg): the total weight of tubers per hill (tuber yield per hill or plant);Tuber dry matter content (%): estimated by drying 500 g tuber in a forced air circulation oven at 70^{0}C for about 72 hours and expressed in percentage of the total tuber weight and Number of stems per hill: the number of stems at crop maturity per hill.

Days to initiation of flowering: number of days from planting until the appearance of the first open flower in any of the sampled plants; Days to flowering: number of days from planting to the stage when 50% of the sampled plants have begun to flower; Number of primary branches: number of primary branches on the main stem counted at crop maturity; Leaf length (cm): length of the leaf on the main stem originating at the fourth node below the main stem inflorescence; Leaf width (cm): width of the leaf on the main stem originating at the fourth node below the main stem inflorescence and Flower length (cm): length of flowers measured at 50% flowering.

Since the relative efficiency of simple lattice design over randomized complete block design was low, mean values of the characters were subjected to RCBD ANOVA to derive variance components as setout below.

Phenotypic σ^2_p and genotypic σ^2_g variances and coefficient of variations PCV and GCV were calculated according to the method suggested by Burton and Devane (1953) considering genotypes as random effects using SAS Statistical Package (SAS, 2001).

Genotypic variance component

$$(\sigma^2 g) = \frac{MS_g - MS_e}{r}$$

Where MS_g is genotypic mean square, MS_e is Error mean square and r is replication

Environmental variance component (on genotype mean basis) $(\sigma^2 e) = \frac{MS_e}{r}$

Phenotypic variance component

$$(\sigma^2 p) = \sigma^2 g + \sigma^2 e$$

The phenotypic and genotypic coefficients of variation were calculated according to the method suggested by Burton and Devane (1953) as:

Genotypic Coefficient of Variation

$$(GCV) = \frac{\sqrt{\sigma^2 g}}{\overline{X}} * 100$$

Phenotypic Coefficient of Variation

$$(PCV) = \frac{\sqrt{\sigma^2 p}}{\overline{X}} * 100$$

Where $\overline{X}$ is the grand mean value of the trait

Broad sense heritability (h^2) in percents was estimated for each character using variance components as described by Allard (1960).

$$h^2 = \frac{\sigma^2 g}{\sigma^2 p} * 100$$

The expected gain or genetic advance (GA) with one cycle of selection, assuming the selection intensity (k) of 5%, was predicted as suggested by Poehlman and Sleeper (1995).

$$GA = h^2 \kappa \sigma p$$

Expected genetic advance (GA) in percent of the mean $= \frac{GA}{\overline{X}} * 100$

Covariance analysis was carried out in the same way as that of analysis of variance, and the mean cross products were equated with the expected mean square product to calculate the covariance component used to compute the correlation coefficients.

Genotypic covariance of traits x and y

$$(\sigma gxy) = \frac{MSCP_{gxy} - MSCP_{exy}}{r}$$

Where, MSCPgxy is the genotypic mean cross product of traits x and y

MSCPexy is the error mean cross product of traits x and y

Phenotypic covariance

$$(\sigma_{pxy}) = \sigma_{gxy} + \frac{\sigma_{exy}}{r}$$

Genotypic and phenotypic correlation coefficients for tuber yield and its components were estimated by calculating the variance and covariance at phenotypic and genotypic levels by using the formula suggested by Singh and Chaudhury (1985).

Phenotypic correlation, the observable correlation between two variables, which includes both genotypic and environmental components between two variables, was estimated using the formula suggested by Miller *et al.* (1958) as: $r_{pxy} = \frac{\sigma_{pxy}}{\sqrt{(\sigma^2{}_{px})(\sigma^2{}_{py})}}$

Genotypic correlation between traits x and y was computed as: $r_{gxy} = \frac{\sigma_{pxy}}{\sqrt{(\sigma^2 gx)(\sigma^2 gy)}}$

Where, σ^2_{gx} and σ2px are genotypic and phenotypic variance components of trait x.

The coefficients of correlation at phenotypic level were tested for their significances using the t – test as

$$t = \frac{r_{pxy}\sqrt{g-2}}{\sqrt{1-r^2{}_{pxy}}}$$

The calculated 't' value was compared with the tabulated 't' at g-2 degree of freedom, where g is the number of genotypes.

The correlation coefficients at genotypic level were tested with the following formula suggested by Robertson (1959).

$$t = \frac{r_{gxy}}{SEr_{gxy}}$$

Where r_{gxy} is the genotypic correlation coefficient, SEr_{gxy} is the standard error of genotypic correlation coefficient and

$$SEr_{gxy} = \sqrt{\frac{(1-r^2 gxy)^2}{2h^2 x h^2 y}}$$

Where, h^2_x and h^2_y are broad sense heritability for characters x and y respectively. The calculated t value for each genotypic correlation coefficient was tested against tabulated 't' at (g-2) degrees of freedom.

In path coefficient analysis which indicates causal relationship, tuber weight per hill was considered as the dependent variable while the rest of the variables were used as independent variables.

Path coefficient analysis was calculated using the formula suggested by Dewey and Lu (1959) to assess direct and indirect effects of different variables on tuber yield as:

$$r_{ij} = p_{ij} + \sum r_{ik}p_{kj}$$

Where r_{ij} is mutual association between the independent traits (i) (tuber weight/hill) and any independent variable j as measured by the correlation coefficient, p_{ij} is component of direct effect of the independent trait (j) on the dependent variable (i); and $\sum r_{ik}p_{kj}$ is summation of components of indirect effect of a given independent trait (j) via all other independent traits (k). The residual effect (U), or the unexplained variation of the dependent variable that is not accounted for by path coefficients, was calculated as: $U = \sqrt{1-R^2}$, where $R^2 = \sum r_{ik}p_{kj}$

3. Result and Discussion

3.1. Analysis of Variance

The analysis of variance for each character revealed highly significant ($P < 0.01$) difference among the accessions for all the characters examined except tuber length (Table 1), which was omitted from further analysis, indicating the presence of considerable amount of variability for the characters. Amsalu (2003) and Baye *et al.* (2005) also reported similar results for the majority of the characters in potato and cassava, respectively.

The wide range, not only for tuber yield (0.37 to 3.15 kg/hill), but for almost all the other quantitative traits studied is an indication that Ethiopian farmers have maintained the genetic variability of this crop. The yield of this crop is comparable to that of other root and tuber crops. For example, Baye *et al.* (2005) reported a yield range of 536.9 to 1008.9 gram/plant for potato. The breeder has the raw material in which selection in any direction (early or late, tall or dwarf, high yielding or low yielding, etc) can be successful (Table 1)

The average dry matter content of *P. edulis* is 20.75%, which is similar to that of Irish potato (20%), but less than that of sweet potato (30%), cassava (40%), taro (30%) and yam (27%) (Admasu, 2002).

Table 1. Mean performance values for 16 characters of 36 *P. edulis* germplasm accessions evaluated at Jimma in 2005.

ACC	PH	SG	NN	NS	NB	FL	LW	DFI	DF	IL	LL	TL	TD	TW	NT	TDM
028/02	112.33	2.06	20.83	2.28	17.58	14.13	5.13	137.0	151.0	4.81	15.68	16.44	1.98	2.02	141.60	23.36
076/03	115.42	1.65	18.55	1.90	15.93	21.50	4.67	143.0	147.0	5.46	14.91	16.90	1.97	1.50	134.70	21.48
106/03	117.00	1.63	20.30	1.50	17.03	20.88	5.00	143.0	151.0	5.34	17.16	15.34	2.09	1.76	141.05	21.62
073/02	130.85	1.91	23.00	2.80	13.10	15.77	4.54	140.0	154.5	5.29	14.07	16.06	1.86	1.69	113.60	21.36
066/02	101.85	1.58	21.90	1.80	18.80	14.98	4.16	158.0	168.0	4.51	13.07	16.86	1.64	0.84	97.90	23.57
102/03	117.25	1.44	19.40	2.20	18.30	18.53	4.44	132.0	140.0	5.26	14.82	16.02	2.05	2.69	196.80	20.96
107/03	117.00	1.67	24.00	2.50	14.70	16.58	3.72	135.0	163.0	4.44	11.65	14.58	1.55	1.52	181.50	22.45
082/02	107.25	1.92	20.80	1.80	13.90	20.28	3.84	97.0	143.0	4.34	12.83	17.00	1.74	1.43	136.08	20.81
010/02	106.50	2.02	17.10	1.90	17.50	17.17	4.66	143.0	154.5	5.45	14.81	18.76	2.25	2.07	138.90	20.74
018/02	100.10	1.63	15.40	1.90	22.20	18.15	4.66	110.0	124.0	5.08	12.05	19.28	2.01	1.48	141.10	19.81
049/02	103.75	1.57	16.70	1.88	18.60	17.50	3.50	109.0	154.0	4.66	13.09	16.72	1.67	1.69	184.45	21.97
067/02	102.25	1.50	19.60	2.30	15.30	16.40	4.08	159.5	171.0	4.66	13.20	20.60	1.72	2.20	219.33	21.80
022/02	90.50	1.89	21.10	1.40	20.70	16.77	4.31	151.0	164.5	4.12	13.16	19.20	2.15	2.46	126.00	18.14
099/03	113.50	1.58	22.60	2.20	18.50	16.80	3.00	162.0	166.0	4.95	12.29	16.56	1.88	1.20	98.00	22.51
052/02	110.75	1.84	20.80	2.60	19.70	18.73	4.86	149.0	163.0	5.03	14.28	18.90	2.22	1.87	82.90	18.47
235969	121.50	1.69	19.10	2.30	19.80	23.88	4.49	143.0	143.0	5.96	13.93	19.94	1.99	2.37	121.80	18.86
044/03	146.75	1.66	27.00	4.10	12.40	12.82	3.58	159.5	168.0	5.10	11.75	15.64	1.56	1.53	167.20	22.50
003/02	113.85	1.75	22.30	3.00	17.60	16.60	4.43	148.5	158.0	4.68	13.28	22.02	1.95	3.15	118.00	17.83
063/02	97.00	1.48	20.03	2.40	14.18	15.23	4.06	151.0	164.5	4.28	13.17	19.38	1.52	1.67	190.50	23.33
079/02	90.38	1.49	17.78	2.10	15.20	18.83	4.08	114.5	143.0	4.52	12.67	17.46	1.74	1.34	85.10	19.70
064/02	104.25	1.83	20.93	2.60	16.80	19.57	4.72	84.5	154.5	4.53	13.78	19.70	2.06	2.28	122.10	19.10
011/02	91.75	1.73	18.35	1.93	15.60	17.23	4.05	135.0	158.0	3.89	12.71	17.68	2.44	1.46	75.40	16.93
235976	108.50	1.25	17.33	2.10	16.00	25.50	4.73	110.0	124.0	4.97	15.34	19.14	2.01	0.57	49.50	20.76
046/02	92.25	1.44	21.00	1.70	15.00	15.10	4.05	158.5	169.5	4.02	12.62	14.46	1.71	0.81	125.20	23.17
014/03	109.25	1.56	25.80	2.70	12.50	14.48	3.48	153.5	164.5	4.40	11.28	13.24	1.59	0.97	93.00	21.22
242494	89.00	1.01	15.10	1.80	15.30	20.42	4.42	144.5	147.0	4.25	14.20	15.08	1.81	0.74	64.10	20.53
071/02	104.25	1.86	19.43	3.10	15.80	18.12	4.58	144.5	144.5	4.93	13.65	16.92	1.83	1.39	119.30	21.30
004/02	93.25	1.42	18.50	2.33	14.58	15.17	4.22	158.0	171.5	4.51	14.86	15.86	1.51	0.59	84.68	20.86
242493	89.69	1.36	15.63	1.73	17.68	18.83	4.86	109.0	139.0	4.38	14.42	16.36	1.66	0.37	37.77	20.23
Lu-bo	87.50	1.70	20.40	2.50	15.80	16.92	4.30	151.0	158.0	3.92	12.76	18.18	2.09	1.42	83.00	20.61
113/03	96.35	1.65	20.33	3.10	16.30	17.45	4.42	148.5	154.5	4.22	12.88	17.02	2.02	1.60	70.60	19.17
045/02	89.75	1.78	19.20	1.90	15.90	18.12	4.23	143.0	151.0	4.17	13.20	15.60	1.85	1.17	113.80	22.06
041/02	107.00	1.71	18.55	1.80	14.30	24.47	4.80	124.0	143.0	5.68	15.66	18.94	1.96	1.58	74.80	18.31
235975	93.75	1.39	20.38	2.92	15.13	15.92	3.61	147.0	151.0	4.30	11.77	15.12	1.43	1.18	141.96	21.71
235978	102.25	1.43	20.00	1.80	15.80	22.10	4.63	129.0	143.0	4.75	15.39	14.28	1.85	0.48	42.10	19.91
242491	91.25	1.58	18.90	2.50	13.20	13.15	3.50	147.0	150.5	4.47	11.53	13.13	1.72	0.72	92.43	19.84
LSD(5%)	24.36	0.38	3.27	1.02	4.08	4.36	0.73	16.58	17.49	0.96	1.67	NS	0.35	0.35	33.94	2.09
CV (%)	11.48	11.35	8.07	22.33	12.34	11.99	8.43	5.91	5.62	10.07	6.07	15.10	9.13	11.35	14.32	4.96

Acc= accession number; PH= Plant height(cm); SG=Stem girth (cm); NN=Number of nodes(n); NS=Number of stem per hill(n); NB=number of branches(n); FL= Flower length(cm); LW=Leaf width(cm); DFI=Days to flower initiation; DF=Days to 50% flowering; IL=Internodes length(cm); LL=Leaf length(cm); TL=Tuber length(cm); TD=Tuber diameter(cm)); TW=Tuber weight per hill(kg); NT=Number of tubers per hill and TDM=Tuber dry matter (%)

3.2. Range and Mean Performance

The mean values of the accessions for the various characters showed differences among the accessions (Table 2). A wide range of variation in the characters studied was observed. The highest value (25.50 cm and 2.06 cm) was almost twice of the minimum value (12.82 cm and 1.01 cm) for flower length and stem girth, three fold for number of stems per hill (4.1 and 1.4), sixfold for number of tubers per hill (219.33 and 37.77) and eight fold for tuber weight per hill (3.15 and 0.37 kg) respectively.

3.3. Phenotypic and Genotypic Variation

Phenotypic coefficients of variation (PCV) ranged from 7.76 for days to 50 percent flowering to 43.17 percent for tuber weight per hill, whereas genotypic coefficients of variation (GCV) ranged from 6.67 for days to 50 percent flowering to 42.42 percent for tuber weight per hill (Table 2). This indicates that tuber weight per hill, on average, had the largest PCV and GCV; and days to 50 percent flowering had the lowest PCV and GCV. Number of tubers per hill had also PCV and GCV values of 37.85% and 36.47%, respectively, suggesting the existence of high genetic variability among the accessions for effective selection. These high PCV and GCV values for tuber weight per hill and number of tubers per hill could be evidence for the existence of a wide range of variation for such characters. This view is in agreement with the observation of Baye *et al.* (2005) on potato with respect to number of tubers per hill, and Ruth and Ramaswamy (2002) who also found high PCV and GCV for yield per plant in cassava. On the other hand, genetic variability for days to 50 percent flowering, tuber dry matter content, internode length, leaf length, plant height and leaf width were lower (Table 2), suggesting a need to search for diverse accessions in order to ensure effective selection.

Moreover, a narrow range of difference between PCV and GCV was recorded for days to flower initiation, tuber weight per hill, tuber dry matter content and leaf length (Table 2) indicating less environmental influence on the phenotypic expression of these characters and that they are mostly governed by genetic factors .Hence, selection based on phenotypic values may be effective for these traits. This is in agreement with Baye *et al.* (2005) who found narrow range between PCV and GCV for tuber dry matter content and days to maturity in potato. On the contrary, a wide difference between PCV and GCV were observed for number of stems per hill, number of branches, and plant height and internodes length (Table 2) indicating the high influence of the environment on these characters. Thus, selection on a phenotypic basis may not be effective for the genetic improvement of such traits.

3.4. Estimates of Heritability and Expected Genetic Advance

Heritability estimates ranged from 56.73 for internode length to 96.5 % for tuber weight per hill (Table 2). Maximum heritability was obtained for tuber weight per hill, followed by number of tubers per hill, days to flower initiation, leaf length, tuber dry matter content and number of nodes. Although yield is a complex characters, liable to have more environmental influence, heritability of tuber weight per hill was the maximum in this study. For example, Baye *et al.* (2005) found heritability of only 18.22% for tuber yield per plant in potato, which is very low compared to the heritability obtained in this study even although the crop is different**.** Therefore, further investigation should be undertaken in order to verify such a useful result. On the other hand, internode lengths, number of stems per hill, plant height, number of branches and stem girth have relatively low heritability estimates (Table 2). The expected genetic advance values expressed as a percentage of the accession mean also indicated which the progress that could be expected from selection of the top 5% of the accessions ranged from 11.80% for days to 50% flowering to 86.86% for tuber weight per hill (Table 2). High genetic advance as a percentage of the mean was recorded for tuber weight per hill and number of tubers per hill.

High heritability coupled with high genetic advance is an important factor for predicting the resultant effect for selecting the best individuals. In this investigation, high heritability along with high genetic advance as a percentage of mean was obtained for tuber weight per hill and number of tubers per hill. High GCV along with high heritability and high genetic advance will provide better information than single parameters alone (Saha *et al.,* 1990). Hence, in this study, tuber weight per hill, number of tubers per hill, and days to flower initiation exhibited high genotypic coefficients of variation, high heritability together with high genetic advance as percentages of means. This indicates that these characters would be very useful as a base for selection in *P. edulis* improvement programs.

3.5. Correlation Analysis

The value of phenotypic correlation coefficients indicated that tuber yield per hill was significantly and positively correlated with plant height, stem girth, number of branches, tuber diameter and number of tubers per hill (Table 3). This is in agreement with Murat and Vahdettin (2005) who also reported positive correlations of tuber yield per plant with plant height, tuber number per hill and tuber diameter in potato. On the other hand, tuber weight was negatively correlated with flower length and tuber dry matter content although the correlation was non-significant. In addition to tuber yield per hill, tuber dry matter content showed a non-significant and negative correlation with stem girth, number of branches, leaf width, internode length, leaf length and tuber weight per hill. It was significantly and positively correlated with number of tubers per hill. Number of tubers per hill, the major yield component in root and tuber crops (IITA, 1990), exhibited no significant correlation with most of the traits investigated except plant height, tuber dry matter content and tuber weight per hill. Diameter of the tuber was significantly and positively correlated with stem girth, number of branches, leaf length and width, flower length and tuber weight per hill. The trait was significantly and negatively correlated with tuber dry matter content. Based on the correlations between characters at phenotypic level, accessions with tall plant height, wide in stem girth, a higher number of branches and tubers and large tuber diameter should be given due consideration in efforts towards tuber yield improvement. Such a view is also in agreement with the works of Amsalu (2003) on cassava for most of the characters.

Unlike the phenotypic correlation coefficients, the value of genotypic correlation coefficient for the majority of the characters showed a non-significant ($P > 0.05$) correlation (Table 3). For example, no character that showed significant association with tuber weight per hill although some of them have a higher degree of correlation with it. This may suggest that the phenotypic association of such characters with tuber weight per hill is not genotypic inheritance but more likely environmental influence. Tuber diameter was significantly and negatively correlated with tuber dry matter content, concurring with the result found at phenotypic level. In addition to this, genotypic correlation between the two characters is higher than its phenotypic correlation coefficient, indicating that the association between them is genetically inherited but not environmentally influenced. Therefore, during selection attention must be paid to the size of tubers because the bigger tubers have a low dry matter content. Plant height was significantly and positively correlated with number of stems per hill. This genotypic correlation coefficient is also higher than its phenotypic correlation coefficient (Table 3). The result demonstrated that, as stem numbers per hill increased, plant height also increased, which could be due to competition for light.

In general, the nature of phenotypic and genotypic correlation coefficients observed were more or less similar among most of the characters studied. It is of interest to note that the significant positive correlation coefficients estimated at genotypic level were also found to be significant and positive at phenotypic level. Moreover, the significantly higher magnitudes of positive genotypic correlation compared to the corresponding phenotypic correlation for some of the characters suggest that they were genetically controlled. Furthermore, although there was no statistically significant difference between the correlations of plant height, stem girth, number of branches, internode length, tuber diameter and number of tubers per hill with tuber weights per hill at genotypic level, their magnitude was moderately higher. This indicates that it may be possible to exploit these characters in an attempt to improve the tuber yield in *Plectranthus edulis*.

Table 2. Estimates of means, ranges, components of variance, PCV, GCV, heritability and genetic advance for 15 traits in *Plectranthus edulis.*

Trait	Mean	Range	σ^2_p	σ^2_g	PCV (%)	GCV (%)	h^2 (%)	GA	GAM (%)
PH	104.61 ± 1.87	87.50 – 146.75	169.692	97.701	12.45	9.45	57.58	15.45	14.77
SG	1.63 ± 0.03	1.01 – 2.06	0.048	0.030	13.38	10.69	63.77	0.29	17.58
NN	19.95 ± 0.33	15.10 – 27.00	6.775	5.481	13.05	11.74	80.90	4.34	21.75
NS	2.26 ± 0.08	1.40 – 4.10	0.300	0.173	24.25	18.40	57.59	0.65	28.76
NB	16.30 ± 0.32	12.40 – 22.20	5.229	3.207	14.03	11.00	61.33	2.89	17.73
FL	17.89 ± 0.40	12.82 – 25.50	9.091	6.789	16.85	14.56	74.67	4.64	25.92
LW	4.27 ± 0.07	3.00 – 5.13	0.247	0.182	11.62	10.00	73.66	0.75	17.63
DFI	138.11 ± 2.34	97.00 – 162.00	367.487	334.131	13.88	13.24	90.92	35.91	26.00
DF	153.18 ± 1.56	124.00 – 171.50	141.474	104.376	7.76	6.67	73.78	18.08	11.80
IL	4.70 ± 0.07	3.89 – 5.96	0.259	0.147	10.81	8.14	56.73	0.59	12.63
LL	13.55 ± 0.17	11.28 – 17.16	1.876	1.537	10.11	9.15	81.95	2.31	17.06
TD	1.86 ± 0.03	1.43 – 2.44	0.055	0.040	12.55	10.76	73.49	0.35	19.01
TW	1.49 ± 0.08	0.37 – 3.15	0.416	0.402	43.17	42.42	96.50	1.28	86.86
NT	116.84 ± 5.36	37.77 – 219.33	1955.229	1815.299	37.85	36.47	92.84	84.53	72.38
TDM	20.75 ± 0.21	16.93 – 23.57	2.787	2.257	8.05	7.24	81.00	2.79	13.42

PH= Plant height (cm); SG=Stem girth(cm); NN=Number of nodes(n); NS=Number of stems per hill(n); NB=number of branches(n); FL= Flower length(cm); LW=Leaf width(cm); DFI=Days to flower initiation; DF=Days to 50% flowering; IL=Internodes length(cm); LL=Leaf length(cm); TD=Tuber diameter(cm); TW=Tuber weight per hill(kg); NT=Number of tubers per hill and TDM=Tuber dry matter content(%); GA=genetic advance in absolute units; GAM= genetic advance as percent of mean

Table 3. Phenotypic (above diagonal) and genotypic (below diagonal) correlation coefficient among 15 traits of *Plectranthus edulis.*

	PH	SG	NN	NS	NB	FL	LW	DFI	DF	IL	LL	TD	TW	NT	TDM
PH	1	0.305	0.564**	0.460**	-0.094	0.024	0.015	0.077	0.046	0.686**	0.138	0.005	0.375*	0.362*	0.192
SG	0.243	1	0.322	0.140	0.158	-0.175	0.199	-0.047	0.142	0.209	0.030	0.431**	0.542**	0.221	-0.138
NN	0.650	0.300	1	0.567**	-0.362*	-0.467**	-0.393*	0.416*	0.593**	-0.046	-0.363*	-0.249	0.192	0.235	0.268
NS	0.852*	0.231	0.734	1	-0.382*	-0.415*	-0.252	0.272	0.248	0.046	-0.400*	-0.261	0.180	0.157	0.057
NB	-0.437	-0.040	-0.528	-0.527	1	0.227	0.341*	-0.143	-0.237	0.218	0.192	0.481**	0.366*	0.039	-0.238
FL	0.228	-0.215	-0.528	-0.531	0.271	1	0.494**	-0.503**	-0.665**	0.445**	0.573**	0.380*	-0.012	-0.333*	-0.393*
LW	-0.256	0.243	-0.534	-0.360	0.323	0.680	1	-0.279	-0.445**	-0.365*	0.787**	0.529**	0.199	-0.240	-0.287
DFI	0.030	-0.037	0.503	0.356	-0.179	-0.525	-0.381	1	0.671**	-0.068	-0.177	-0.150	0.004	0.112	0.280
DF	0.042	0.278	0.729	0.343	-0.122	-0.738	-0.527	0.761*	1	-0.342*	-0.319	-0. 251	0.113	0.268	0.275
IL	0.615	0.215	-0.163	0.233	0.179	0.882*	0.299	-0.118	-0.598	1	0.499**	0.230	0.322	0.160	-0.047
LL	-0.077	-0.028	-0.496	-0.589	0.129	0.800*	0.775*	-0.257	-0.402	0.483	1	0.398**	0.091	-0.179	-0.083
TD	-0.113	0.514	-0.382	-0.574	0.700	0.570	0.668	-0.169	-0.278	0.234	0.498	1	0.435**	-0.212	-0.596**
TW	0.454	0.678	0.218	0.211	0.467	-0.017	0.203	0.001	0.137	0.402	0.075	0.484	1	0.567**	-0.280
NT	0.484	0.290	0.302	0.181	0.087	-0.395	-0.314	0.099	0.315	0.214	-0.245	-0.247	0.571	1	0.446**
TDM	0.343	-0.244	0.323	0.019	-0.315	-0.440	-0.351	0.300	0.366	-0.083	-0.117	-0.802*	-0.291	0.500	1

**, ** Significant at 0.05 and 0.01 levels of significance, respectively.*

PH= Plant height(cm); SG=Stem girth(cm); NN=Number of nodes(n); NS=Number of stem per hill(n); NB=number of branches(n); FL= Flower length(cm); LW=Leaf width(cm); DFI=Days to flower initiation; DF=Days to 50% flowering; IL=Internodes length(cm); LL=Leaf length(cm); TD=Tuber diameter(cm); TW=Tuber weight per hill(kg); NT=Number of tubers per hill (n) and TDM=Tuber dry matter (%)

3.6. Path Coefficient Analysis

Path coefficient analysis at the genotypic level revealed that 4 of the 15 quantitative traits (number of nodes on the main axis, leaf length, number of tubers per hill and tuber dry matter content in %) affected tuber weight per hill to the greatest extent (Table 4). The residual from these four traits was only 0.07; path analysis explained 93% of the genotypic correlation of these traits with tuber weight. All four traits had positive direct effects on tuber weight except tuber dry matter content which had a relatively large negative direct effect on the main trait. Number of tubers per hill and tuber dry matter content had the largest direct effects (in absolute value) and, are, therefore the most important determinants of tuber weight per hill. Ntawuruhunga *et al.* (2001) reported that the direct effect of storage root weight on cassava yield was also high and positive (p= 0.45) while its indirect effect through storage root number was negative.

Selecting accessions with many nodes on the main axis, with longer leaves and producing many tubers per hill is believed to result in identifying genotypes with high tuber yield. Since the indirect effect of both number of nodes and leaf length on tuber weight via number of tubers per hill is negative, precautions should be taken when selecting genotypes with many nodes and longer leaves. This finding was in line with the result of Pandey *et al.* (2005). They reported that number of tubers per plant showed a positive direct effect on tuber yield in potato and suggested that these traits be given due consideration during selection. Simultaneous selection should be made to assure that these genotypes have many tubers per hill. Accessions with high dry matter content should not be selected. Such genotypes give minimum tuber weight per hill. Both the genotypic correlation of tuber dry matter with tuber weight and its direct effect on tuber weight were negative. If accessions are sorted according to their tuber dry matter content, the bottom fourth of the accessions by this trait (accessions with the lowest tuber dry matter content) have an average tuber yield of 2.01 kg/hill, while the top fourth by tuber dry matter content have a mean tuber weight of only 1.38 kg/hill. Murat and Vahdettin (2005) also found that tuber yield per hill, dry matter content and number of tubers per hill had the greatest direct effect on tuber yield per unit area in their order of magnitude in potato. Baye *et al.* (2005) also reported that average tuber weight had the maximum positive direct effect (p = 3.546) followed by tuber number per plant (p = 3.114), leaf area (p = 2.261), days to maturity (p = 1.006), tuber dry matter content (p = 0.742) and plant height (p = 0.703) on tuber yield per plant on potato.

Table 4. Genotypic direct (bold and underlined) and indirect effects of four quantitative traits on tuber weight per hill of *Plectranthus edulis.*

	Number of Nodes	Leaf Length	No of Tubers Per hill	Tuber Dry Matter content	r_g
Number of nodes	**<u>0.4064</u>**	-0.2061	0.2965	-0.2794	0.2174
Leaf Length	-0.2014	**<u>0.4159</u>**	-0.2406	0.1009	0.0748
Number of tuber per hill	0.1227	-0.1019	**<u>0.9822</u>**	-0.4322	0.5709
Tuber dry matter content	0.1313	-0.0485	0.4910	**<u>-0.8646</u>**	-0.2907

h=0.07

4. Conclusions

This study clearly illustrated the existence of a wide range of variation among the germplasm accessions collected from different regions of Ethiopia. This indicates the presence of a considerable amount of variability for the different characters. However, this investigation was carried out at a single location and in a single season. It is possible that the trends could vary across location and the need for ascertaining genotypic-environment interaction through appropriate studies should be highlighted. The requirement for broadening the genetic base is also emphasized from the point of view of diversifying the prevailing gene pool. *P. edulis* collection representing diverse eco-geographical areas of the country should be organized for diversity analysis to derive further guidelines for conservation activities than reported here. Furthermore, the conventional approaches of characterization as adopted in this study have certain limitations in identifying duplicates, whereas the use of advanced biochemical (isozyme polymorphism) and molecular (RFLP, RAPD etc) approaches could precisely contribute to germplasm characterization, management and utilization and are needed for efficient characterization of *P. edulis* which would, in turn, be invaluable for the conservation and improvement of the crop.

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Effects of Crop Rotation and N-P Fertilizer Rate on Grain Yield and Related Characteristics of Maize and Soil Fertility at Bako, Western Oromia, Ethiopia

Tolera Abera[1]*, Daba Feyisa[1], and D. K. Friesen[2]

[1]Oromia Agricultural Research Institute (OARI), Bako Agricultural Research Center, P O Box 26, Bako, Western Oromia, Ethiopia
[2]CIMMYT/IFDC, Regional Coordinator, P O Box 5689 Addis Ababa, Ethiopia

Abstracts: A trial was conducted to determine the effects of crop rotation with N-P rates on grain yield of maize and soil fertility in Bako over a period of five years. The experiment was laid out in a randomized complete block design in factorial arrangement with rotation crops (Niger seed, haricot bean and tef) as main factor and two levels of NP fertilizers (half recommended (55/23 kg N-P_2O_5 ha^{-1} and recommended (110/46 kg N-P_2O_5 ha^{-1}) rate as sub factor and continuous maize with three replications. Higher mean grain yield of maize was recorded from maize following rotation crops with recommended rate of fertilizer compared to continuous maize. Maize following rotation crops gave mean grain yield advantage of 640 to 830 and 1921 to 1968 kg ha^{-1} compared to continuous maize at half and full recommended N-P fertilizer rate. Maize following Niger seed produced mean grain yield advantage of 971 and 1527 kg ha^{-1} compared to haricot bean and tef. Primary nutrient (N, P and K) composition of the tissue and grain of maize were significantly higher with maize following rotation crop compared to continuous maize, indicting the enhancement of the nutrient use efficiency of maize following rotation crops. Crop rotation with fertilizer amendment improved the pH of the soil. Crop rotation and N-P amendment enabled maize yields and soil fertility to be maintained at a higher level. Multiple advantages accrue from the use of crop rotation. Higher grain yield and high net return of maize were realized following Niger seed, haricot bean and tef compared to continuous maize. Maize following Niger seed followed by haricot bean with the recommended rate of fertilizer is a better management option for sustainable maize production in Western Oromia.

Keywords: Crop Rotation; Niger Seed; N-P Rate

1. Introduction

Soil degradation is occurring at an alarming rate and threatens soil productivity and maize production in Western Oromiya due to continuous cropping over the last three decades. Conventional agriculture (continuous cropping with inputs) has certain limitations in terms of maintaining long-term soil fertility (Charpentier *et al.*, 1999). Longer cultivation has further depleted the soil organic-matter content and fertility (Wu *et al.*, 2003). Crop rotation is the most among factors significantly increasing soil organic matters (Campbell *et al.*, 1996). Legume-cereal and Oilseed- cereal sequence is the predominant cropping pattern practice by smallholder farmers in western Ethiopia (Asfaw *et al.*, 1997). Crop rotation is necessary and the desirable management option to restore, maintain, enhance soil fertility, and maximize yield. Appropriate cropping sequence with continuous use of chemical fertilizers can increase the yield of annual crops in Alfisols (Henao and Bannante, 1999), which may be true for maize at Bako. Singh *et al.* (1987) reported that maize-wheat cropping systems with chemical fertilizers increased the grain yield of maize by 202 % and of wheat by 176 % compared to non-fertilized controls. The highest maize yield of 4550 kg/ha was obtained from the annual crop rotation of berseem (*Trifolium alexandrinum*) - maize followed by grain legume-maize sequence (3810 to 3870 kg/ha) (Ramteke *et al.*, 1986). Rotations with legumes built up the N status of the soil. According to Zentner *et al.* (2001) N-requirement of wheat in continuous wheat or wheat-lentil rotation varied from 5 to 60 kg ha^{-1}. The available soil N was increased by about 32 and 40 kg/ha following chickpea and lentil compared to the preceding wheat (Patwary *et al.*, 1989). Alvey *et al.* (2001), in their work, suggested that a wide spread use of cereal/legume rotations has been proposed as a means of sustainability to meet increasing food demands. Nugusse (1995) found that Haricot bean is the best precursor crop for maize at Awassa and Nazareth. Rao and Mathuva (2000) found that maize following annual legumes were 32 - 49 % more profitable than continuous maize. However, Tadesse and Tolessa (1998) reported that Niger seed is the best precursor crop for maize with a yield advantage of 50 % compared to sole cropping followed by haricot bean. Including oilseed crops in rotation with wheat may also increase soil productivity because of their deep root system to scavenge nutrients from lower root depths. It also produces root channels which may facilitate root development in subsequent cereal crop (Angus *et al.,* 1991).

Maintenance of the soil fertility at the economic optimum level with appropriate crop rotation and affordable fertilizer rate is essential for sustainable maize production in the region. Identification of suitable crop rotation with optimum fertilizer was more reliable and generally maximized maize grain yield. Therefore, the objective of this study was to determine the appropriate crop rotation with optimum N-P rate for maize production.

2. Materials and Methods

A Crop rotation experiment was conducted during the 1999 to 2003 cropping seasons at Bako Agricultural Research Center (BARC), situated in Western Oromia, Ethiopia. The center is located in East Wollega Zone of the Oromia National Regional State. Geographically, it is

*Corresponding author. E-mail: thawwii@yahoo.com

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located between 9°6'N latitude and 37°09'E longitude. It has an aerial coverage of about 38 square kilometres; with a mean altitude of 1650 meters above sea level. The long-term (1961 - 2003) mean annual rainfall at BARC is 1239 mm with unimodal distribution. It has a warm humid climate with mean minimum, mean maximum and average air temperatures of 13.2, 28 and 21°C, respectively (NMSA, 2003). Sixty percent of the soil (1400 ha) at Bako Research Center, is reddish brown in colour, clay and loam in texture (Wakene, 2001).

Agro-ecologically, BARC is classified as tepid to cool sub humid mid highlands and is a mixed farming zone, encompassed by Gibe River and with abundant natural vegetation, and grasslands. The major annual and perennial crops of the area include maize (*Zea mays* L.), sorghum (*Sorghum bicolor* L. Monch), teff (*Eragrostis tef* (Zucc.) Trotter), noug (*Guizotia abyssinica*), hot pepper (*Capsicum frutescence* L.), haricot bean (*Phaseolus vulgars* L.), sweet potato (*Ipomoea batatas* Lam.), mango (*Mangifera indica* L.), banana (*Mussa* spp), and sugar cane (*Saccharum officinarum* L.) in order of importance (Asfaw *et al.,* 1997).

During the 1999 cropping season, the trial area was sown to maize with recommended fertilizer (110/46 kg N/ P_2O_5 ha^{-1}) in order to make the field uniform. First, in the 2000 cropping season, rotation crops sown were local Niger seed (*Guizotia abyssinica)* and tef (*Eragrostis Tef* (Zucc.) Trotter), and Roba-1 of haricot bean (*Phaseolus vulgars* L.) varieties as well as continuous maize. During the 2001 cropping season, maize hybrid (BH-660) was sown with two levels of fertilizers, half recommended (55/23 kg N-P_2O_5 ha^{-1} and recommended (110/46 kg N-P_2O_5 ha^{-1}) rate for the area.

In addition, during the 2002 cropping season, rotation crops (Niger seed, haricot bean and tef) and continuous maize were sown. During the 2003 cropping season, again maize hybrid (BH-660) was sown with two levels of fertilizers, half recommended (55/23 kg N-P_2O_5 ha^{-1} and recommended (110/46 kg N-P_2O_5 ha^{-1}) rate for the area. The rotation system was one phase rotation cycle. The main factors were tef (*Eragrostis Tef* (Zucc.) Trotter), Niger seed (*Guizotia abyssinica*), and Haricot bean (*Phaseolus vulgars* L.) and control maize (*Zea mays* L.) with recommended fertilizer rate. The seed rates used were 25 kg ha^{-1} for tef, 8 kg ha^{-1} for Niger seed and 75 kg ha^{-1} for Haricot bean.

The experiment was laid out in a randomized complete block design in factorial arrangement with rotation crops as main factor and N-P rate as sub-factors. The total gross plot size was 5.1 x 4.5 m with 3 x 5.1m net plots. The spacing was 75 x 30 cm. The seed rate used for maize was 25 kg ha^{-1}. Sowing dates followed recommended date of planting ranged May 1 - 30. Full dose of phosphorus (as DAP) was applied once at planting, while nitrogen (as Urea) was applied in split doses, half at planting and the remaining half applied 30 to 40 days after planting. The maize grain yield was adjusted at 12.5 % moisture level and given in kg ha^{-1}. The data were analysed using MSTAT-C statistical packages (Freed *et al.,* 1989).

The soil sample was collected at the depth 0 - 20 cm with augur three times, first before application of the treatment (1999), second after harvesting of the rotational crops in 2000 and when the field was ready for maize planting; third after harvesting of the main crop maize in 2003. Determination of soil particle size distribution was carried out using the hydrometer method (Dewis and Freitas, 1984). Soil pH was measured using digital pH meter in 1:2.5 soil to solution ratio with H_2O. Exchangeable basis were extracted with 1.0 Molar ammonium acetate at pH 7. Ca and Mg in the extract were measured by atomic absorption spectrophotometer while Na and K were determined using flame photometry (Van Reeuwijk, 1992). Cation exchange capacity of the soil was determined following the modified Kjeldahl procedure (Chapman, 1965) and reported as CEC of the soil. Percent base saturation was calculated from the sum of exchangeable basis as a percent of the CEC of the soil. Exchangeable acidity was determined by extracting the soil samples with M KCL solution and titrating with sodium hydroxide as described by McLean (1965). Organic carbon was determined following wet digestion methods as described by Walkley and Black (1934) whereas kjeldahl procedure was used for the determination of total N as described by Jackson (1958). The available P was measured by Olsen method as described by Olsen *et al.* (1954) and Bray II method (Bray and Kurtz, 1945). The electrical conductivity was estimated from saturated extracts of soil samples.

Plant tissues (leaves, stalk and grain) in 2001 and (leaves and stalk) in 2002 were collected during harvesting of maize crop. The plant tissue collected was analyzed in National Soil Research Center laboratory using standard procedures for different selected nutrient compositions.

For partial budget and marginal rate of return analysis, maize grain yield was valued at an average open market price of EB 265 per 100 kg for the last 10 years and maize seed price was EB 500 per 100 kg. Labour cost for field operation was EB 7 per man-day. The yield was adjusted down by 10% to reflect actual production conditions (CIMMYT, 1988). The cost of fertilizers (Urea and DAP) amounted to EB 606 and 857 per 100 kg at the current market price.

3. Result and Discussion

3.1. Cropping Season

The results of maize grain yield in 1999 and continuous maize and rotational crops in 2000 and 2002 cropping season are shown in (Table 1). The grain yields of different crops indicated the variation of yield across cropping seasons. Combined yields across years averaged 5615 kg ha^{-1}, but 6641 and 4579 kg ha^{-1} in 2001 and 2003 cropping seasons (Table 3). Mean plant height over years averaged 267 cm, but 290 and 244 cm in 2001 and 2003 cropping seasons (Table 3). Higher mean plant height and grain yield were found in 2001 cropping season. This might be due to the prevailing environmental conditions (sunshine, rainfall and temperature) during the growing seasons (Table 3). Year significantly ($p<0.05$) affected mean plant height and grain yield of maize but non-significantly affected 1000 seed weight (Table 2 and 3). This might be due to the variation in climatic factors during the growing period of maize. Year by cropping rotation interaction significantly ($p<0.05$) affected plant height and grain yield of maize indicating that the performance of rotational crops affects their residual effects and their contribution to soil fertility and grain yield of maize. Thus, cropping sequence consideration during crop rotation plays a significant role in the enhancement of soil fertility and grain yield of maize. In 2001 cropping season, higher mean plant height and grain yield of maize was recorded following haricot bean compared to Niger seed and tef. However, higher 1000 seed weight of maize was recorded following Niger seed and tef crops, respectively. Higher mean plant height, 1000 seed weight and grain yield maize were recorded following Niger seed compared to haricot bean and tef in 2003 and combined over years (Table 4).

Table 1. Mean grain yield of maize in 1999 and rotational crops (2000 and 2002) and continuous maize from 2000 to 2002.

Maize (kg ha^{-1})		Yield (kg ha^{-1})		
1999	Rotation crops	2000	2001	2002
4870	Niger seed	742		734
4708	Niger seed	749		664
6070	Haricot bean	1436		1810
5738	Haricot bean	1422		1897
4697	Tef	356		396
4515	Tef	392		464
5567	Continuous maize	8270	5544	2957

3.2. Plant Height

Crop rotation significantly ($p<0.05$) affected mean plant height in 2003 and combined over years but had a non-significant ($p>0.05$) effect in 2001(Table 2 and 3). Mean plant height in 2003 and combined over years were significantly ($p<0.05$) affected by N/P fertilizer rate (Tables 2 and 3). Plant height significantly increased with the rate of fertilizers. Recommended N-P rate gave higher plant height compared to half recommended in 2001, 2003 and combined over years (Table 3). The interactions of crop rotation and N-P fertilizer rate non-significantly ($p>0.05$) affected mean plant height of maize (Table 2 and 3). Higher mean plant height of maize was observed from all three cropping sequences with recommended fertilizer compared to with half recommended (Table 3). This justifies the assertion that cropping sequence by itself does not boost the performance of maize without appropriate fertilizer rate.

3.3. Thousand Seed Weight

Cropping sequence and N-P rates non-significantly ($p>0.05$) affected thousand seed weight (Table 2 and 3). The interactions of cropping sequence and N-P fertilizer rate non-significantly affected mean 1000 seed weight of maize (Table 2 and 3). Higher mean thousand seed weight of maize was recorded following cropping sequence with recommended fertilizer compared to half recommended (Table 3).

3.4. Grain Yield

Cropping sequence significantly ($p<0.05$) affected mean grain yield in 2003 and combined over years but had a non-significant effect in 2001 (Table 2 and 3). This revealed that cropping sequence had a significant effect on grain yield increment of maize. Maize following Niger seed produced 971 and 1255 kg ha^{-1} higher combined grain yield advantage compared to following haricot bean and tef (Table 4). Mean grain yield was significantly ($p<0.05$) affected by N-P fertilizer rate (Table 2, 3 and 4). Grain yield significantly increased with the rate of fertilizers. Mean grain yield increased by 1281, 1138 and 1209 kg ha^{-1} respectively as the rate of N-P increased from half recommended to recommended rate in 2001, 2003 and combined over years (Table 4). This justifies the claim that crop rotation with recommended dose of N-P fertilizers significantly increased grain yield of maize. Similarly, Shepherd and Sylvester-Bradley (1996) reported that the performance of succeeding crop was apparent when high, super-optimal fertilizer levels had been applied to preceding crops. Crop rotation by N-P fertilizer rate interaction non-significantly affected mean grain yield of maize (Table 2 and 3).

Maize following haricot bean produced higher mean grain yield at half recommended and recommended fertilizer compared to following Niger seed and tef in 2001 cropping season (Table 4). This might be due to the free nitrogen fixed by legumes in the soil which ameliorates the nitrogen status of the soil compared to oil crops and cereals. Conversely, maize following Niger seed in 2003 cropping season and combined over years gave a higher mean grain yield with half recommended fertilizer and recommended fertilizer compared to following haricot bean and tef (Table 3 and 4).

All crop rotations produced greater yield advantage of maize compared to continuous maize with recommended and half recommended fertilizer rates. At half the recommended fertilizer rate mean grain yield advantages of 640, 830 and 735 kg ha^{-1} were obtained following rotation crops compared to continuous maize in 2001, 2003 and combined across years (Table 3 and 4). However, at recommended fertilizer rate, maize following rotation crops gave mean grain yield advantage of 1921, 1968 and 1944 kg ha^{-1} compared to continuous maize in 2001 and 2003 cropping season and combined over years (Table 3 and 4). In the same way, Higgs *et al.* (1990) reported 10 to 17 % greater yield for corn grown in rotation with other crops compared to continuous cropping. A Similar result was reported by Halvorson *et* *al.* (2000); and Soper and Grenier (1987). Crop rotations with recommended fertilizer application produced better grain yield of maize. Similarly, Habtamu *et al.* (1996) found that crop rotation is more productive if it is supplemented with fertilizer application. The sustainable production of maize is possible by integrating crop rotation with recommended fertilizer levels. Sayre (1999) suggest that sustainable crop production practices involve the use of break crops and optimum fertilizer application which minimize nutrient losses. This could be due to the improvement in soil fertility status with different crops compared to continuous maize. The result agrees with (Reddy *et al.*, 1994); and (Riedell *et al.,* 1998). The higher yield of maize in crop rotation is due to the change in spatial and temporal difference of crops with time dimensions. In addition, variation in root structure and depth is one of the other benefits of crop rotation for change in soil fertility and can influence yield of crops by altering the physical and morphological properties of the soil. Higher mean grain yield increases of maize were achieved following Niger seed compared to haricot bean and tef with recommended and half recommended fertilizer rate. For sustainable production of maize, the use of different crop rotations with recommended and half recommended fertilizer rates are better than continuous planting of maize.

3.5. Soil Chemical and Physical Properties

The soil pH in H_2O ranged from 5.0 to 5.5 and 3.7 to 4.9 in KCl in 2000 (Table 5). According to FAO, 1990 and Landon, 1991 such soils are acidic to strongly acidic. The soil pH in H_2O ranged from 5.9 to 6.1 in 2003 (Table 6), indicating change in soil reaction from strongly acidic to moderately acidic. Crop rotation and N-P amendment significantly increased pH of the soil. Total N ranged from 0.13 to 0.17 % in 2000 (Table 5) and 0.15 to 0.18 % in 2003 (Table 6), which is categorized as low range according to FAO (1990). Soil from haricot bean field gave higher total N than from Niger seed and Tef crop fields (Table 5 and 6). This might be attributed to the nitrogen fixing nature of haricot bean. Similarly, Kumar *et al.* (1983); and Holford and Crocker (1997) reported legumes in crop rotation improve soil fertility, particularly soil N content.

Table 2. Mean square for plant height, 1000 seed weight and grain yield ofr maize for each year and across two years at Bako.

Source of variation	DF	Mean square								
		Plant height (cm)			1000 seed weight (g)			Grain yield (kg ha^{-1})		
		2001	2003	combined	2001	2003	combined	2001	2003	combined
Year	1			18815**			355			37266465**
Rotation crops (A)	2	2510	620.20**	1380**	1231	5317	3753	2030640	9293369**	5199292**
N-P fertilizer rate (B)	1	1300	4050**	4970**	20.06	5760	2550	7385041**	5828836**	13167898**
Ax B	2	1524	1.167	799	184	2061	988	396311	80474	309123
Year x A	2			1749			2795			6124717**
Year x B	1			380			3230			45979
Year x A x B	2			727			1257			167662
Error	10 (20)	620.7	100.533	360.628	864.19	3108.6	1986	898233	148720	523476
CV (%)		8.59	4.10	7.11	8.45	16.31	12.92	13.89	8.05	12.46

*(20) Combined degree of freedom for error, ** significant at 5 % probability level*

Table 3. Effects of rotation crops and N-P fertilizer rate on plant height, 1000 seed weight and grain yield of maize.

Rotation crops	N-P fertilizer rate	Plant height (cm)			1000 seed weight (g)			Grain yield (kg ha^{-1})		
		2001	2003	Mean	2001	2003	Mean	2001	2003	Mean
Niger seed	Half recommended	255	240	247	357	369	363	6228	5488	5858
Niger seed	Recommended	301	270	285	365	366	365	7594	6884	7239
Haricot bean	Half recommended	322	228	275	338	362	350	6484	3263	4874
Haricot bean	Recommended	305	257	281	327	334	331	8231	4333	6282
Tef	Half recommended	267	220	243	346	347	347	5839	3909	4874
Tef	Recommended	290	250	270	355	271	313	6569	4858	5713
Continuous	Recommended	322	251	273	327	374	350	5544	3390	4467
Mean		295	245	268	345	346	346	6641	4589	5615
LSD (5%)	Rotation crops	Ns	12.90	Ns	Ns	Ns	Ns	Ns	496.1	930.7
	N-P rate	Ns	10.53	13.20	Ns	Ns	Ns	995	405	503
	Rotation crops x N-P rate	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
CV (%)		8.59	4.10	7.11	8.45	16.31	12.92	13.89	8.05	12.46

Recommended= 110/46 kg N-P$_2$O$_5$ ha^{-1}, Half recommended= 55/23 kg N-P$_2$O$_5$ ha^{-1}, Ns= non-significant

Table 4. Effects of rotation crops and N-P fertilizer rate on grain yield of maize.

Treatment	2001		2003		Mean		Rotation mean
	Half recommended	Recommended	Half recommended	Recommended	Half recommended	Recommended	
Niger seed	6228	7594	5488	6884	5858	7239	6549
Haricot bean	6484	8231	3263	4333	4874	6282	5578
Tef	5839	6569	3909	4858	4874	5713	5294
Mean	6184	7465	4220	5358	5202	6411	
Rotation crops	Ns		496.1				930.7
N-P rate	995		405		503		
CV (%)	13.89		8.05			12.46	

Campbell *et al.* (1992) reported accumulative enhancement of the N-supplying power of the soil in wheat-lentil rotation. The increase in total N following haricot bean helps to reduce the amount of N required to optimize maize yield. Organic carbon contents of the soil ranged from 1.96 to 2.45 % in 2000 and from 1.70 to 1.90 % in 2003 (Table 5 and 6) found in low range (FAO, 1990). This might be due to continuous cultivation of the field for the past three decades. Soil organic carbon contents declined regardless of inputs application for continuously cultivated land (Kapkiyai, 1996). Higher Organic carbon content next to before planting (1.98 %) was recorded from haricot bean field in 2000 and (1.90 %) in 2003 from field treated with recommended fertilizer following Niger seed (Table 5 and 6). Higher C: N was recorded from Niger seed field in both years followed by haricot bean (Table 5 and 6). Available P in Olsen and Bray II method ranged from 6.4 to 21 and 5.6 to 36 ppm and higher for preplant soil analysis compared to post harvest soil analysis result in 2000 (Table 5). In 2003, using Olsen procedure, available P ranged from 5.12 to 7.86 ppm (Table 6). This situation can be attributed to the high phosphorous fixing capacity of acid soil. The phosphorous content of the soil was found to be between moderate to adequate range for maize production (FAO, 1990). The exchangeable K, Ca, and Mg contents of the soil ranged from 0.21 to 0.41, 1.10 to 1.33 and 1.32 to 1.56 in 2000 and 1.24 to 2.55, 4.19 to 6.44 and 0.99 to 1.56 Meq 100 g of soil^{-1} in 2003 (Table 5 and 6). The CEC of the soil ranged from 9.99 to 11.79 and 13 to 15 Meq 100 g of soil^{-1} (Table 5 and 6) and location in the low range for maize production (FAO, 1990). The texture of the soil was sandy clay loam to clay (Table 5). Base saturation ranged from 24 to 34 and 41 to 78 % (Table 5 and 6). The preplant soil analysis results were higher than post harvest soil analysis for different nutrients. The relatively low soil nutrient concentrations were due to continuous monocropping and cultivation over the last three decades which is consistent with Wakene *et al.* (2001).

Table 5. Result of soil chemical and physical analysis before sowing and after harvesting of break crops in 2000.

Treatment	PH		T. N	O.C	C: N	Available P (ppm)		K	Ca	Mg
	H_2O	KCl	(%)	(%)		Olsen	Bray II	Meq 100 g soil^{-1}		
Before sowing	5.2	4.2	0.17	2.45	15	21.0	36	0.41	1.33	1.56
Niger seed	5.5	3.9	0.13	1.96	15	7.2	8.0	0.28	1.18	1.48
Haricot bean	5.0	3.7	0.15	1.98	13	7.6	9.0	0.24	1.10	1.40
Tef	5.0	3.8	0.14	1.90	14	6.8	9.0	0.21	1.13	1.32
Continuous	5.0	4.9	0.17	1.96	12	6.4	5.60	0.28	1.31	1.56

T.N, total nitrogen; O.C, organic carbon; C.N, carbon nitrogen ratio

Table 5. Result of soil chemical and physical analysis before sowing and after harvesting of break crops in 2000...continued

Treatment	Soil texture				CEC Meq/100	Base Saturation	Exchange acidity
	Sandy (%)	Silt (%)	Clay (%)	Class			
Before sowing	44	14	42	C	9.99	34	0.29
Niger seed	38	14	48	C	9.99	31	0.78
Haricot bean	58	10	32	SCL	11.79	24	0.88
Tef	36	14	50	C	10.99	25	0.83
Continuous	38	14	48	C	11.59	28	0.53

3.6. Plant Tissue

Nitrogen contents of the leaves were significantly higher in rotation compared to continuous maize in 2001 (Table 7). In 2003, N contents of the leaves were higher in maize following Niger seed and haricot bean with half recommended N-P rates compared to continues maize (Table 8). Nitrogen contents of the leaves ranged from 0.64 to 1.01 % and 0.40 to 0.55 %, respectively in 2001 and 2003 (Tables 7 and 8). A Significant increase in N concentration in leaves occurred following crops compared to continuous cropping. An appreciably higher (1.01 %) N concentration resulted from maize following haricot bean (Table 7), indicating higher carry over effect of N following haricot bean. This indicates high residual N following haricot bean was available for maize. Thus, use of crop rotation improved nutrient uptake efficiency of maize. Phosphorous concentration of the leaves of maize in rotation was higher, up to 240 and 140 ppm, in 2001 and 2003 than continuous maize except maize following tef in 2001 and maize after Niger seed in 2003 planted with half recommended fertilizer rate (Tables 7 and 8). The K concentration of the leaves was higher in continuous maize, except maize following tef with half recommended fertilizer rate (Table 7). Stalk N concentration was inconsistent across two years (Tables 7 and 8). Higher N concentration 0.88 and 0.48 % in 2001 and 2003 was recorded in maize following Niger seed and tef. P content of the stalk less or equivalent to continuous maize except maize following tef with recommended fertilizer rate in 2003 (Table 7 and 8). With the exception of maize following Niger seed and tef with recommended fertilizer rate, the other treatments had higher potassium in the stalk compared to continuous maize in 2001 (Table 7).

Table 6. Result of soil chemical analysis after harvesting of maize crops in 2003.

Rotation crops	N-P rate	PH: H_2O	T.N (%)	O.C (%)	C: N	Available P (ppm)	K Meq 100 g soil^{-1}	Ca	Mg	E.C Ds m^{-1}	CEC Meq100^{-1}	Base Saturation %
Niger seed	Half recommended	5.9	0.15	1.70	11	5.60	1.62	5.89	1.40	0.06	14	67
Niger seed	Recommended	5.9	0.15	1.90	13	6.48	1.56	5.14	1.32	0.07	15	55
Haricot bean	Half recommended	6.0	0.15	1.82	12	7.50	1.58	5.59	1.24	0.08	15	59
Haricot bean	Recommended	5.9	0.16	1.78	11	7.38	1.24	4.54	0.99	0.06	17	41
Tef	Half recommended	6.0	0.16	1.72	11	7.38	1.24	4.49	1.15	0.07	16	44
Tef	Recommended	5.9	0.15	1.70	11	7.86	1.59	4.19	1.07	0.06	15	47
Continuous	Recommended	6.0	0.18	1.78	10	6.52	2.55	5.69	1.56	0.06	13	78

Recommended = 110/46 kg N-P_2O_5 ha^{-1}, Half recommended = 55/23 kg N-P_2O_5 ha^{-1}
T.N, total nitrogen; O.C, organic carbon; C.N, carbon nitrogen ratio

Table 7. Maize tissue analysis (leave, stalk and grain) for primary nutrients in 2001.

Rotation crops	N-P fertilizer rate	Maize tissue analysis								
		Leaves			Stalk			Grain		
		N (%)	P (ppm)	K (ppm)	N (%)	P (ppm)	K (ppm)	N (%)	P (ppm)	K (ppm)
Niger seed	Half recommended	0.74	580	4900	0.88	150	18440	1.15	2390	4020
Niger seed	Recommended	0.95	630	4700	0.23	80	14490	1.27	2720	4630
Haricot bean	Half recommended	1.01	730	4890	0.30	130	17510	4.44	1880	3690
Haricot bean	Recommended	0.74	600	4830	0.25	160	19770	3.63	1590	3240
Tef	Half recommended	0.71	320	8040	0.46	120	17520	5.95	2200	4280
Tef	Recommended	0.74	590	4840	0.44	220	16780	1.17	2980	5340
Continuous	Recommended	0.64	490	5920	0.30	160	16940	1.00	2380	4260

Recommended = 110/46 kg N-P_2O_5 ha^{-1}, Half recommended = 55/23 kg N-P_2O_5 ha^{-1}

Maize grain nitrogen concentrations significantly increased in rotation compared to continuous cropping (Table 7). Maize grain N concentration in rotation ranged from 0.142 to 4.94 % (Table 7). Higher mean N grain concentration was recorded from maize following haricot bean followed by tef compared to Niger seed and continuous maize (Table 7). Application of higher N reduced N concentration in maize grain (Table 7). This might be due to the increase of N use efficiency of maize with higher application N fertilizer. Non-significant increase in maize grain P concentration occurred with maize following Niger seed with half recommended fertilizer but a significant increase was registered following Niger seed and tef with recommended fertilizer rate compared to continuous maize (Table 7). A Significant decrease in maize grain P concentration was achieved from maize following haricot bean with both fertilizers as compared to continuous maize (Table 7). Maize grain K concentration ranged from 1020 to 1080 (Table 7). With the except of maize following haricot bean, grain P and K concentration increased with additional increment of P application (Table 7). In general, the concentration of NPK in maize tissue and grain was higher with maize following break crops than continuous maize which agrees with the report of Copeland and Crookston (1992). Macronutrients (N.P and K) accumulation in corn tissue at physiological maturity and grain yield were greater in rotation than corn grown in monoculture.

The results of economic analysis for N-P fertilizer rate and rotation crops are shown in (Tables 9 and 10). The highest net benefit of EB 13210 ha^{-1} and marginal rate of return 177 % came from the application of recommended (110/46 kg N-P_2O_5 ha^{-1}) rate compared to the half recommended that was EB 11365 ha^{-1} (Table 9). The values to cost ratio EB 10.92 and 6.34 per unit of investment was for half recommended and recommended N-P fertilizer rate. The result for rotation crops indicted that the highest net benefit of EB 15619 ha^{-1} of maize was obtained from maize following Niger seed (Table 10). The second net benefit of EB 13304 ha^{-1} was achieved from maize following haricot bean (Table 10). The net economic returns of maize following Niger seed, haricot bean and tef were EB 4965, 2650 and 1972 ha^{-1} respectively, higher than continuous maize (Table 10). This indicates that rotating maize with oil crops and legumes gave better cereals. It was found that yield and economic return from the rotation crops were significantly higher than from continuous cropping. Rotating maize improved to a greater extent than adding inputs to continuous maize.

Table 8. Maize tissue analysis (leave and stalk) for primary nutrients in 2003.

Rotation crops	N-P fertilizer rate	Maize tissue analysis			
		Leaves		Stalk	
		N (%)	P (ppm)	N (%)	P (ppm)
Niger seed	Half recommended	0.31	420	0.31	260
Niger seed	Recommended	0.40	300	0.28	300
Haricot bean	Half recommended	0.34	260	0.36	280
Haricot bean	Recommended	0.55	380	0.28	160
Tef	Half recommended	0.60	360	0.23	200
Tef	Recommended	0.54	340	0.48	180
Continuous	Recommended	0.44	200	0.32	300

Recommended = 110/46 kg N-P_2O_5 ha^{-1}, Half recommended = 55/23 kg N-P_2O_5 ha^{-1}

Table 9. Partial budget and marginal rate of return analyses for N-P fertilizer rate on the mean grain yield of maize at Bako.

Items	N-P_2O_5 fertilizer rate	
	100-50 kg ha^{-1}	200-100 kg ha^{-1}
Average yield (kg ha^{-1}) maize	5202	6412
Adjusted yield (kg ha^{-1}) maize	4681.8	5770.8
Gross field benefit of maize	12407	15293
Costs Urea (EB ha^{-1})	606	1212
Costs DAP (EB ha^{-1})	428.5	857
Fertilizer application cost (EB ha^{-1})	7.00	14.00
Total costs that vary (EB ha^{-1})	1041.5	2083
Net benefit	11365.5	13210
Values to cost ratio	10.92	6.34
Marginal rate of return (MRR)		177 %

Note: Grain price = EB 2.65 kg^{-1}, Seed price = EB 5 kg^{-1}, Labour cost = EB 7.00 /day Yield was down adjusted with 10% coefficient, Cost of Urea = EB 6.06 kg^{-1} DAP = EB 8.57 kg^{-1}.

Table 10. Partial budget and marginal rate of return analyses for rotation crops on the mean grain yield of maize at Bako.

Items	Rotation crops			Continuous maize
	Niger seed	Haricot bean	Tef	
Average yield (kg ha^{-1}) maize	6549	5578	5294	4467
Adjusted yield (kg ha^{-1}) maize	5894.1	5020.2	4764.6	4020.3
Gross field benefit of maize	15619	13304	12626	10654
Net benefit	15619	13304	12626	10654

Note: Grain price = EB 2.65 kg $^{-1}$, Seed price = EB 5.00 kg $^{-1}$, Labour cost = EB 7.00 /day Yield was down adjusted with 10% coefficient

4. Conclusion

Maize grain yields increased significantly following rotation crops compared to continuous cropping. Primary nutrient (N, P and K) composition of the tissue and grain of maize increased following rotation crops. The maintenance and enhancement of soil fertility is possible through appropriate application of N-P rate and crop rotation. The use of crop rotation is the cheapest method of soil fertility replenishment for resource poor farmers. The result demonstrated the residual benefits of crop rotation with N-P fertilizer, enhancing the grain yields and fertility of the soil. Therefore, maize following Niger seed and haricot bean with recommended N-P fertilizer application is recommended for sustainable maize production in Bako area.

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Performance of Variety Cross Hybrids of Maize (*Zea Mays* L.) in the Mid-Altitude and Highland Transition Areas of Ethiopia

Mosisa Worku*, Wende Abera, Berhanu Tadesse, Legesse Wolde, Dagne Wegary and Girum Azmach

National Maize Research Project, Bako Agricultural Research Center, P O Box 03, Bako, West Shoa, Oromia, Ethiopia

Abstract: Improved open-pollinated varieties (OPVs) have been developed and released for commercial production in maize growing areas of Ethiopia. However, the dissemination of these improved varieties is limited because of a low level of interest of seed producers in the production and marketing of OPV seed. The dissemination of broad based improved varieties could be increased by the development and release of adapted commercial high yielding variety cross hybrids. This study was conducted in 2002 at seven locations in the mid-altitude (1000 – 1800 meter above sea level, masl) and highland transition areas (1800 – 2000 masl) of Ethiopia to evaluate the performance of variety cross hybrids. Twenty-nine variety cross hybrids and nine parental OPVs/populations along two checks were tested in randomized complete block design with three replications at each location. Analysis of variance revealed significant difference ($P<0.01$) among the entries. The mean grain yield ranged from 3.9 to 8.3 t ha^{-1}. Some variety cross hybrids gave a better performance than the improved OPVs. Kuleni (Pool-9A) x Abo-Bako outyielded the high parent (Kuleni) by 29.7% and Gibe-1 x Kuleni outyielded the best OPV and high parent (Gibe-1) by 14.7%. Gibe-1 x Kuleni also had a more stable performance across the testing locations than the parental OPVs. This implied that moving from OPVs to variety cross hybrids, particularly under small scale farmers' conditions, could increase the productivity of maize.

Keywords: Grain yield; Open Pollinated Variety; Variety Cross Hybrid; *Zea mays*

1. Introduction

In Ethiopia, maize production has increased over the years (Kebede *et al*., 1993; Mosisa *et al*., 2002; CSA, 2007). However, the demand for maize grain is expected to increase due to the high rate of population increase in the country. To fulfill the demand for maize grain in the future, maize production must be performed predominantly on the existing cultivated land. Expansion of cultivated land is decreasing more and more because of population increase, environmental concerns and urbanization.

Improved varieties play a great role in increasing maize productivity on currently cultivated land. The National Maize Research Project has developed a number of improved maize varieties through different breeding methodologies (Benti *et al*., 1993; Mosisa *et al*., 2002). The improved maize varieties include open-pollinated varieties (OPVs) and different types of hybrids (top cross, three-way cross and single cross hybrids). The superiority of the improved varieties over the local checks (farmers' variety) and superiority of the hybrids over the improved OPVs has been demonstrated on the farmers' fields (Ibrahim and Tamene, 2002; Chimdo *et al*., 2002). However, only about 20% of the maize area in Ethiopia is planted with improved maize varieties, mainly conventional hybrids (Adungna and Melaku, 2002; Yonas and Mulugeta, 2002), indicating that the majority of farmers still plant local varieties and/or recycled seed of improved varieties.

Paliwal *et al.* (2000) reported that variety cross hybrids (cross between two OPVs/populations) have 17% yield advantage over improved OPVs, but lower yield potential compared to conventional and top cross hybrids. The authors emphasized that the depression in the yield with the use of F_2 seed is lower in the variety cross hybrids than in the conventional hybrids. Research results in Ethiopia also showed that grain yield reduction in F_2 generation of top-cross hybrid (BH-140), three-way cross hybrid (BH-660) and single-cross hybrid (BH-540) is 11.7%, 18.9% and 23.0%, respectively (National Maize Research Project, 1996), showing less yield reduction in F_2 of the broad based hybrid (top-cross hybrid) compared to in the narrow based hybrids. This indicates the importance of variety cross hybrids (broad based hybrids) in small scale farmers' conditions where the continuous supply of improved seed is limited and use of F_2 grain as seed is common.

Benti *et al.* (1989) evaluated variety cross hybrids at Bako and reported 1.8 to 4.6% higher grain yield for the best variety cross hybrid than for the best OPV. They associated this low heterosis among the crosses of locally adapted old OPVs with the lack of distinct genetic difference among the OPVs included in the study. Since then, different improved OPVs and breeding populations have been developed. However, the cross performance of these improved materials has not been studied. Thus, this study assesses the performance of variety cross hybrids and their parents in the sub-humid mid-altitude (1000 – 1800) and highland transition (1800 – 2000) areas of Ethiopia.

2. Materials and Methods

Nine OPVs and breeding populations adapted to sub-humid areas (areas with sufficient rainfall) were used in the formation of the variety cross hybrids. The sources and adaptation areas of these materials are presented in Table 1. For each material, two seeds were planted in 10 rows of 5.0 m length, in 2001 main season at Bako Agricultural Research Center. Then, 200 plants were maintained in each plot after thinning. Twenty nine crosses were made among selected materials, previously selected for grain yield and other important agronomic traits, using bulk pollen for each material. At harvest, all the harvested ears were shelled and the seed was bulked for each cross.

*Corresponding author. E-mail:

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Table 1. Maize materials used for the formation of variety cross hybrids and their areas of adaptation (meter above sea level, masl).

Maize materials	Source	Status	Altitude (masl)	Adaptation
Kuleni	CIMMYT	OPV	1700 – 2200	Highland transition
Gibe-1	Ethiopia	OPV	1000 – 1700	Mid-altitude
Gambela Composite	IITA	OPV	300 – 1000	Low-altitude
Abo-Bako	IITA	OPV	300 – 1000	Low-altitude
Obatanpa	Gahana/IITA	BP	300 – 1000	Low-altitude
Pop-43	CIMMYT	BP	1000 – 1500	Mid-altitude
Gutto LMS5*	CIMMYT	BP	1000 – 1700	Mid-altitude
SC Group Pool	Ethiopia	BP	1000 – 1700	Mid-altitude
Gutto Group Pool	Ethiopia	BP	1000 – 1700	Mid-altitude

** Female parent of BH-140, OPV- Open-pollinated variety*
BP- Breeding population

In 2002, the 29 variety cross hybrids, along with the nine parental materials and two checks were planted under rain fed condition at seven locations in the mid-altitude and highland transition areas using randomized complete block design with three replications (Table 2). The experiments were planted according to the recommended fertilizer rate and other cultural practices for maize at each site. Plot size was 5.1 m x 1.5 m with two rows for each entry. The spacings were 0.75 m and 0.30 m between rows and plants, respectively, giving 44,444 plants per hectare.

Agronomic data were recorded for all the entries. Silking date was recorded when 50% of the plants in the plot were with emerged silk. Then days from emergence to silking (DFF) were calculated. Plant height (PH) was measured from ground level to the point where the tassel starts branching. Similarly, ear height was measured from ground level to the node bearing the top ear for the same plants. Gray leaf spot (*Cercospora zeae-maydis*), Turcicum leaf blight (*Exserohilum turcicum*) and common rust (*Puccinia sorghi*) were scored on a scale of 1 (clean, no infestation) to 5 (severely diseased). Grain yield was recorded from all ears in the harvest area at harvest. Then grain yield (t ha^{-1}) was calculated using average shelling percentage of 80% and adjusted to 12.5% moisture.

Analysis of variance was conducted for each location. After Bartlett's test for the homogeneity of the error variance, combined analysis was conducted. Finally, stability analysis was conducted using Additive Main effect and Multiplicative Interaction, AMMI2 Model (the most suitable model for the data) (Crossa *et al.*, 1990; Purchase, 1997), Wricke's ecovalence analysis (Westcott, 1985; Purchase, 1997) and Shukla's stability variance analysis (Shukla, 1972). MSTAT-C software computer program (Fred *et al.*, 1991) and AGROBASE software computer program (Agronomix software INC. and AGROBASE, 2000) were used for the analysis of the data.

Table 2. Testing locations in the mid-altitude and highland transition areas of Ethiopia.

Site	Altitude (masl)	Annual Rainfall (mm)	Catagory
Bako	1650	1200	Mid-altitude
Awasa	1700	1110	Mid-altitude
Jimma	1750	1595	Mid-altitude
Pawe	1100	1250	Mid-altitude
Areka	1800	1615	Highland transition
Finote-Selam	1800	1200	Highland transition
Arsi-negele	1960	900	Highland transition

3. Results and Discussion

3.1. Grain Yield and Some Related Traits

Analysis of variance for grain yield at each location showed significant difference (P<0.01) among the entries (Table 3). The mean grain yield ranged from 3.9 t ha^{-1} (for POP-43) to 8.3 t ha^{-1} (for Kuleni x Abo-Bako). Gibe-1 had the highest mean grain yield among the OPVs (Table 3). The lowland adapted OPVs, Abo-Bako and Gambela composite were the top yielding among the OPVs at Pawe whereas they were among the low yielding in the highland transition areas, Areka and Arsi-negele. Kuleni x Abo-Bako was among the top yielding hybrids across the testing locations except at Areka (Table 3). This indicated that crosses of lowland material and highland transition materials might adapt to mid-altitude and highland transition areas. The cross of mid-altitude material, Gibe-1 and highland transition material, Kuleni (Gibe-1 x Kuleni) was also among the high yielding hybrids across the testing locations. On the other hand, the top yielding hybrid at Pawe, Gibe-1 x Abo-Bako was relatively low yielding in the highland transition areas, Areka and Arsi-negele, compared to Kuleni x Abo-Bako and Gibe-1 x Kuleni. This may indicate that crosses of lowland and highland transition materials and crosses of mid-altitude and highland transition materials had better adaptation across mid-altitude and highland transition areas than the crosses of lowland and mid-altitude and crosses of lowland and lowland materials which had relatively specific adaptation (Table 3). In line with these findings, Eberhart (1989) found that highland transition materials performed relatively before in the low elevations than lowland materials in the high elevations.

The combined analysis for grain yield showed significant genotype by environment interaction (P<0.01) showing the inconsistency of the performance of the maize materials across the testing locations. IPCA1 was significant (P<0.01) and explained 34.6% of the genotype by environment interaction. IPCA2 was also significant (P<0.01) and explained 25.7% of the genotype by environment interaction. Thus, the two principal components explained 60.3% of the genotype by environment interaction (data not shown).

Stability parameters showed differences among the maize materials for their stability performance for grain yield across the testing locations (Table 4). The closer the IPCA scores (Interaction Principal Component Analysis scores, IPCA1 and IPCA2) to zero the more stable the maize materials are across the locations.

Table 3. Grain yield (t ha^{-1}) of maize variety cross hybrids and their parental OPVs/populations at seven different testing locations in the mid-altitude and highland transition areas in Ethiopia.

	Entry	Bako	Awasa	Areka	Arsi-negele	Pawe	Finote-Selam	Jimma	Mean
1	Gibe-1 x Gutto Group Pool	8.6	5.6	6.0	3.8	7.9	4.7	6.7	6.2
2	Gibe-1 x Kuleni	9.1	8.0	6.1	5.7	8.6	8.4	8.8	7.8
3	Gibe-1 x Gambela composite	8.4	7.2	3.0	5.5	9.8	6.3	8.6	7.0
4	Gibe-1 x Abo-Bako	10.0	8.9	4.7	4.7	10.2	7.0	8.9	7.8
5	Gibe-1 x Gutto LMS5	8.4	7.4	6.8	4.8	8.6	5.7	8.2	7.1
6	Kuleni x POP-43	9.4	8.1	5.6	5.8	8.2	5.9	9.8	7.5
7	Kuleni x Gutto Group Pool	8.9	8.1	6.1	5.1	7.1	5.9	8.5	7.1
8	Kuleni x Gambela composite	9.2	8.3	4.5	6.0	8.7	6.9	7.3	7.3
9	Kuleni x Gutto LMS5	8.8	8.4	6.0	5.9	8.4	6.0	9.6	7.6
10	Kuleni x Abo-Bako	10.0	9.9	5.4	6.0	10.0	6.5	10.4	8.3
11	Kuleni x SC Group Pool	9.7	8.0	7.1	6.3	7.8	6.0	9.6	7.8
12	Gibe-1 x SC Group Pool	9.1	7.1	8.5	6.0	8.7	6.5	8.5	7.8
13	SC Group Pool x Gambela composite	7.9	6.6	5.5	6.1	8.9	6.2	7.7	7.0
14	SC Group Pool x POP-43	9.3	8.2	6.5	4.8	8.6	6.2	7.7	7.3
15	SC Group Pool x Gutto Group Pool	8.6	7.2	6.0	4.5	8.4	6.3	8.3	7.0
16	SC Group Pool x Abo-Bako	9.8	7.4	6.0	4.7	10.2	6.1	8.0	7.5
17	SC Group Pool x Gutto LMS5	8.2	8.2	7.6	4.8	8.3	5.6	8.2	7.3
18	Gutto Group Pool x Abo-Bako	8.8	7.2	4.2	4.2	8.0	5.6	4.9	6.1
19	Gutto Group Pool x POP-43	5.8	6.2	4.7	4.5	7.0	4.7	5.6	5.5
20	Gutto Group Pool x Kuleni	6.8	7.8	4.9	5.6	7.6	5.3	6.9	6.4
21	Gutto Group Pool x Obatanpa	7.4	7.3	5.2	3.7	8.1	6.6	5.6	6.3
22	Gutto Group Pool x Gambela composite	8.0	6.0	4.1	4.4	6.2	5.4	6.2	5.8
23	Gutto Group Pool x Gutto LMS5	6.2	5.8	5.1	4.1	7.2	4.8	4.8	5.4
24	Gambela composite x Obatanpa	8.8	6.8	3.3	3.3	8.7	5.1	5.5	5.9
25	Gambela composite x Abo-Bako	7.1	6.1	2.9	3.6	9.1	5.1	5.7	5.6
26	Abo-Bako x Obatanpa	5.9	4.0	2.1	1.3	6.8	5.1	3.7	4.2
27	Abo-Bako x Gutto LMS5	8.5	7.8	5.1	4.0	8.7	5.1	5.9	6.4
28	POP-43 x Gibe-1	8.2	7.4	4.7	4.9	8.0	7.4	7.4	6.9
29	Gutto LMS5 x POP-43	7.2	5.6	4.9	4.4	7.0	5.5	4.4	5.6
30	Gibe-1	8.4	7.6	7.0	5.1	7.4	5.5	7.0	6.8
31	Gambela composite	6.5	5.6	3.2	2.9	8.3	5.1	5.8	5.3
32	Kuleni	8.1	7.0	3.9	5.3	5.7	6.9	8.2	6.4
33	Gutto LMS5	6.8	5.2	4.0	3.6	6.6	4.0	5.7	5.1
34	Abo-Bako	7.0	6.7	2.5	3.6	8.4	5.5	5.8	5.6
35	Obatanpa	7.8	7.1	4.7	3.3	7.0	6.0	5.5	5.9
36	POP-43	4.5	5.0	2.2	2.8	5.6	5.0	2.5	3.9
37	SC Group Pool	7.9	5.6	5.0	4.3	7.3	5.5	7.7	6.2
38	Gutto Group Pool	6.1	5.7	3.9	3.9	6.9	4.5	5.4	5.2
39	BH-140	8.7	8.3	6.0	4.5	7.4	5.3	7.0	6.8
40	BHQP-542	8.7	6.4	5.2	4.6	7.8	5.8	7.8	6.6
	Mean	8.1	7.0	5.0	4.6	8.0	5.8	7.0	6.5
	CV%	12.2	11.8	26.1	18.9	14.4	19.2	19.4	17.0
	F-test	**	**	**	**	**	*	**	**
	LSD 0.05	1.6	1.3	1.4	1.4	1.9	1.8	2.2	0.7

Similarly, the materials with the small ecovalence and stability variance are considered to be stable (Lin et al., 1986; Crossa *et al.*, 1990; Purchase, 1997). The hybrid with the high mean grain yield, Kuleni x Abo-Bako, was among the hybrids with high negative IPCA scores (IPCA1 and IPCA2). In addition, this hybrid had high stability variance and ecovalence, indicating that the performance of this hybrid was not stable across the testing locations. However, Gibe-1 x Kuleni had low stability variance, ecovalence and IPCA scores (negative) as compared to the parental OPVs. This indicates that some specific variety cross hybrids were more stable than the improved OPVs for grain yield performance across the testing locations.

The stable variety cross hybrid, Gibe-1 x Kuleni, outyielded the best OPV, Gibe-1 by 14.7%, indicating the superiority of variety cross hybrids over the improved OPVs in grain yield (Table 4). This hybrid had also good tolerance to major foliar diseases common at the testing locations and had less than 250 cm and 150 cm plant height and ear height, respectively (Table 5). This justified the feasibility of variety cross hybrids for commercial production, particularly on small scale farms of resource poor farmers who have limited access to input and output markets.

In this study, the best variety cross hybrids outyielded the commercial top cross hybrid, BH-140 (Table 3). However, these hybrids may not outyield the best available conventional hybrids in Ethiopia (Mosisa *et al.*, 2002). This may limit the production of variety cross hybrids in the large commercial maize farms. On the other hand, the simplicity of seed production and low seed price of variety cross hybrids may increase the demand for variety cross hybrids, particularly under small scale farmers' conditions. Thus, considering the interest of small scale farmers, who are the major maize grain producers in Ethiopia, development of variety cross hybrids is important for sustainable maize production. Paliwal (2000) also suggested the use of non-conventional hybrids in tropical environments where the field size is small, recycling of F_2 seed is common and maize is harvested by hand.

3.2. Heterosis for Mean Grain Yield

The percentage of high-parent heterosis for the mean grain yield showed considerable variation among the crosses (Table 4). It ranged from -28.8% (for Abo-Bako x Obatanpa) to 29.7% (for Kuleni x Abo-Bako). Out of all the crosses, 6.9% showed negative high-parent heterosis while 24.1% showed more than 15.0% positive high-parent heterosis. All the mid-altitude and lowland materials manifested positive high-parent heterosis when crossed to Kuleni, highland transition material. The hybrid, Kuleni x Abo-Bako manifested the highest positive percentage of high-parent heterosis, indicating genetic divergence between the two OPVs. Leta *et al.* (1999) reported high heterosis between the cross of Kitale composite B (KCB) and Abo-Bako. Since Kuleni was mainly synthesized from east African materials (Lothrop, 1989), the high heterosis between Kuleni and Abo-Bako in this study may indicate that Abo-Bako is heterotic to some of east African materials. On the other hand, most of the crosses among lowland materials showed low or negative high-parent heterosis, suggesting close affinity among these materials.

The cross of the two heterotic populations, SC Group Pool and Gutto Group Pool, showed 12.9% high-parent heterosis, indicating the success in the formation of the two heterotic populations (Mosisa *et al.*, 1996). However, the lower heterosis between the two populations compared to some specific combinations in this study indicated the need for improving the two heterotic populations. Eberhart (1989) also suggested that the best population cross performance could be expected from populations improved by recurrent selection, particularly through reciprocal recurrent selection.

In conclusion, the higher grain yield and the more stable the performance of specific variety cross hybrids compared to improved OPVs implies that moving from OPVs to variety cross hybrids, particularly under small scale farmers' conditions, will increase the productivity of maize. In addition, the positive high-parent heterosis observed between the improved OPVs, Kuleni and Abo-Bako and Gibe-1 and Kuleni, showed that Kuleni and Abo-Bako and/or Gibe-1 and Kuleni could be good alternative heterotic combinations in the development of hybrids adapted to the mid-altitude potential areas in Ethiopia.

Table 4. Stability parameters [Interaction Principal Component Analysis axes (IPCA1 and IPCA2) ecovalence and stability variance] and mean grain yield (GY, t ha^{-1}) for maize variety cross hybrids and their parental OPVs/populations tested at seven locations in Ethiopia.

	Entry	IPCA1	IPCA2	Ecovalence	Stability variance	GY t ha^{-1}	Percent of high parent
1	Gibe-1 x Gutto Group Pool	-0.34	0.10	4.0	2.0	6.2	91.2
2	Gibe-1 x Kuleni	-0.34	-0.06	2.6	1.3	7.8	114.7
3	Gibe-1 x Gambela composite	0.06	-0.73	4.7	2.4	7.0	102.9
4	Gibe-1 x Abo-Bako	0.35	-0.67	6.6	3.4	7.8	114.7
5	Gibe-1 x Gutto LMS5	-0.35	0.21	2.3	1.2	7.1	104.4
6	Kuleni x POP-43	-0.77	-0.43	6.2	3.2	7.5	117.2
7	Kuleni x Gutto Group Pool	-0.44	0.29	3.9	2.0	7.1	110.9
8	Kuleni x Gambela composite	0.36	-0.19	3.2	1.6	7.3	114.1
9	Kuleni x Gutto LMS5	-0.75	-0.30	5.3	2.7	7.6	118.8
10	Kuleni x Abo-Bako	-0.79	-1.22	17.1	8.9	8.3	129.7
11	Kuleni x SC Group Pool	-0.80	0.22	6.1	3.1	7.8	121.9
12	Gibe-1 x SC Group Pool	-0.61	0.51	6.5	3.4	7.8	114.7
13	SC Group Pool x Gambela composite	-0.12	-0.13	2.3	1.1	7.0	112.9
14	SC Group Pool x POP-43	-0.03	0.25	1.4	0.7	7.3	117.7
15	SC Group Pool x Gutto Group Pool	-0.25	-0.03	1.1	0.5	7.0	112.9
16	SC Group Pool x Abo-Bako	0.05	-0.34	3.4	1.7	7.5	121.0
17	SC Group Pool x Gutto LMS5	-0.38	0.60	5.6	2.9	7.3	117.7
18	Gutto Group Pool x Abo-Bako	0.63	0.12	5.1	2.6	6.1	108.9
19	Gutto Group Pool x POP-43	0.04	0.43	3.2	1.6	5.5	105.8
20	Gutto Group Pool x Kuleni	0.03	0.33	3.9	2.0	6.4	100.0
21	Gutto Group Pool x Obatanpa	0.54	0.33	3.7	1.9	6.3	106.8
22	Gutto Group Pool x Gambela composite	-0.10	0.06	2.1	1.0	5.8	109.4
23	Gutto Group Pool x Gutto LMS5	0.18	0.50	3.5	1.8	5.4	103.9
24	Gambela composite x Obatanpa	0.63	-0.43	6.6	3.4	5.9	100.0
25	Gambela composite x Abo-Bako	0.61	-0.57	5.9	3.0	5.6	100.0
26	Abo-Bako x Obatanpa	0.58	-0.15	6.1	3.2	4.2	71.2
27	Abo-Bako x Gutto LMS5	0.42	0.16	3.6	1.8	6.4	114.3
28	POP-43 x Gibe-1	0.23	-0.13	2.4	1.2	6.9	101.5
29	Gutto LMS5 x POP-43	0.31	0.46	4.6	2.4	5.6	109.8
30	Gibe-1	-0.27	0.70	4.1	2.1	6.8	-
31	Gambela composite	0.39	-0.41	3.2	1.6	5.3	-
32	Kuleni	-0.35	-0.10	9.5	5.0	6.4	-
33	Gutto LMS5	-0.15	0.07	0.5	0.2	5.1	-
34	Abo-Bako	0.66	-0.47	5.5	2.9	5.6	-
35	Obatanpa	0.38	0.35	3.1	1.6	5.9	-
36	POP-43	0.82	0.37	9.2	4.8	3.9	-
37	SC Group Pool	-0.45	-0.18	2.1	1.1	6.2	-
38	Gutto Group Pool	0.10	0.16	1.1	0.5	5.2	-
39	BH-140	-0.06	0.50	3.6	1.9	6.8	-
40	BHQP-542	-0.31	-0.18	1.2	0.6	6.6	-

Table 5. Mean days to silking (DFF), plant height (PHT), ear height (EHT), gray leaf spot (GLS), turcicum leaf blight (TLB) and common rust for maize variety cross hybrids and their parental OPVs/populations tested at seven locations in Ethiopia.

	Entry	DFF	PHT	EHT	GLS	TLB	Rust
1	Gibe-1 x Gutto Group Pool	77	229	124	2.0	1.8	1.9
2	Gibe-1 x Kuleni	76	237	128	2.2	1.6	1.7
3	Gibe-1 x Gambela composite	77	226	113	2.2	1.9	2.3
4	Gibe-1 x Abo-Bako	79	244	137	1.6	1.9	2.2
5	Gibe-1 x Gutto LMS5	78	230	120	1.6	2.0	1.9
6	Kuleni x POP-43	76	232	123	1.9	1.8	1.9
7	Kuleni x Gutto Group Pool	76	231	124	1.6	1.9	1.8
8	Kuleni x Gambela composite	76	233	124	1.9	1.9	1.9
9	Kuleni x Gutto LMS5	79	235	130	1.8	1.9	1.8
10	Kuleni x Abo-Bako	78	248	144	1.8	1.8	1.9
11	Kuleni x SC Group Pool	77	246	138	1.6	1.7	1.8
12	Gibe-1 x SC Group Pool	77	240	131	1.9	1.7	1.9
13	SC Group Pool x Gambela composite	76	223	119	2.2	1.9	2.1
14	SC Group Pool x POP-43	76	232	124	1.7	1.9	2.2
15	SC Group Pool x Gutto Group Pool	77	232	127	2.0	1.7	1.9
16	SC Group Pool x Abo-Bako	77	242	132	2.2	2.1	2.1
17	SC Group Pool x Gutto LMS5	79	231	126	1.9	1.9	2.1
18	Gutto Group Pool x Abo-Bako	78	229	129	1.5	1.9	2.3
19	Gutto Group Pool x POP-43	77	216	114	1.8	2.3	2.0
20	Gutto Group Pool x Kuleni	77	228	123	1.7	1.7	1.8
21	Gutto Group Pool x Obatanpa	77	221	122	1.9	1.9	2.2
22	Gutto Group Pool x Gambela composite	76	217	116	1.8	1.9	2.2
23	Gutto Group Pool x Gutto LMS5	79	207	111	1.8	1.9	2.0
24	Gambela composite x Obatanpa	77	215	114	2.0	2.1	2.5
25	Gambela composite x Abo-Bako	80	225	123	1.8	2.1	2.6
26	Abo-Bako x Obatanpa	76	209	110	1.6	2.1	2.5
27	Abo-Bako x Gutto LMS5	80	227	124	1.5	1.8	2.4
28	POP-43 x Gibe-1	76	228	116	2.0	1.9	2.1
29	Gutto LMS5 x POP-43	78	215	112	1.8	2.2	2.1
30	Gibe-1	78	236	124	2.1	2.0	2.0
31	Gambela composite	78	218	117	2.2	2.0	2.7
32	Kuleni	78	243	134	1.4	1.8	1.6
33	Gutto LMS5	80	209	110	1.7	2.1	2.1
34	Abo-Bako	80	239	134	2.2	2.2	2.5
35	Obatanpa	76	228	117	1.7	2.1	2.5
36	POP-43	78	204	100	1.4	2.4	2.6
37	SC Group Pool	77	234	129	2.0	1.9	2.0
38	Gutto Group Pool	75	222	114	1.6	2.0	2.1
39	BH-140	80	232	124	1.3	1.9	2.2
40	BHQP-542	77	224	109	1.5	1.9	2.5
	Mean	77	228	122	1.8	1.9	2.1
	CV%	2.6	6.6	11.7	21.1	25.1	17.1
	F-test	ns	**	ns	*	ns	**
	LSD 0.05	-	24.2	-	0.6	-	0.6

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Combining Ability Analysis for Bread Wheat (*Triticum Aestivum* L.)

Habtamu Seboka[1*], Amsalu Ayana[2] and Habtamu Zelleke[3]

[1]Haramaya University , P O Box 48, Haramaya, Ethiopia
[2]Oromia Agricultural Research Institute, P O Box 81265, Addis Ababa
[3]Haramaya University, P O Box 147, Haramaya, Ethiopia

Abstract: Choice of promising genotypes from a diverse genetic base and subsequent utilization for hybridization is one of the strategies for improving productivity of bread wheat. The data from eight parents and their F_1 progenies of half-diallel crosses were analyzed for combining ability for yield and yield related traits in triplicate randomized complete block design in 2005 at Sinana, south-east Ethiopia. Significant differences among all the genotypes were apparent for all traits, except for biomass per plant. Both GCA and SCA mean squares revealed significant differences in plant height, harvest index, grain yield per plant, 1000-kernel weight and maturity traits, indicating the important of both additive and non-additive gene actions in the inheritance of these traits with the predominant effect of non-additive gene action. For the remaining traits, only mean square due to GCA showed significant variation, indicating the greater importance of additive gene action in controlling the inheritance of these characters. Abola gave highly significant GCA effects in the desirable direction and was the best general combiner for most of the traits, followed by Galema and Sofumer, while Dashen was the only parent which showed significant positive GCA effect for grain yield per plant. Cross combinations of Dashen x Galema, Abola x Dure, Dashen x Meda-Welabu, Abola x Galema, and Galema x Dure, exhibited significant SCA effects in the desired direction for at least two and, at most, for four traits, for which SCA variance showed significant differences. Hence, these crosses revealed possibility for commercial exploitation of heterosis as well as selection of potential homozygous lines from transgressive segregants for improvement of yield levels of bread wheat.

Keywords: Combining Ability; Diallel Cross; GCA; SCA; Triticum aestivum

1. Introduction

Bread wheat (*Triticum aestivum* L.) is a member of the tribe Triticeae of the family Poaceae to which all the major cereals belong. It is an autogamous allo-hexaploid species (2n = 6x = 42) and three genomes, designated as A, B and D (AABBDD), were involved in its evolution (Morris and Sears, 1967). It combines the genomes of three diploid ancestrals, *Triticum urartu* (2n = 14, AA), *Aegilops squarrosa* (2n = 14, DD) and *Aegilops* species (2n = 14, BB). Bread wheat has been cultivated for more than 10,000 years (Poehlman and Sleeper, 1995) and it is the world's leading food crop due to the viscoelastic properties of its endosperm gluten proteins.

Ethiopia is the largest producer of wheat in sub-Saharan Africa. The country ranks first in area coverage and second in production (FAO, 2005). An estimated area of 1.4 million hectare is under wheat production (CSA, 2005). The area under bread wheat has significantly increased from almost nil to 60% of the national wheat area (Amsal *et al*., 1995; Payne *et al*., 1996). This is because of its higher productivity, broader adaptation and use of semi-dwarf, input responsive high yielding improved varieties.

Despite the significant increases in area of wheat production in the country, the mean national wheat yield is 1.5 t/ha (CSA, 2005).This relatively low productivity may be partially attributed to the prevalence of virulent crop pathogens, lack of a durable resistant variety, soil nutrient depletion and grass weeds in major wheat producing areas. To this effect, the choice of promising genotypes from a diverse genetic base and their subsequent utilization for hybridization is one of the strategies for improving productivity of bread wheat. Therefore, advanced materials from international and national wheat improvement programs have been immediate sources of bread wheat varieties for release or for use as parental stocks (Amsal *et al*., 1996; Getachew *et al*., 1997).

Further advancement in the yield of bread wheat requires adequate information regarding the nature of combining ability of the parents to be used in the hybridization program and also the nature of gene actions involved in the expression of quantitative and qualitative traits of economic importance. Combining ability analysis developed by Griffing (1956) has been widely used to derive information about the ability of parents to transfer their desirable traits to their progenies and compare the performance of lines in hybrid combinations. It also helps to identify the best hybrid combinations and supplies data on the type of gene action, which is a key to selecting an appropriate breeding procedure in any breeding program (Cukandor-Olmedo *et al.,* 1997; Nazir *et al.,* 2005). The general combining ability (GCA) and specific combining ability (SCA) effects are very effective genetic parameters in deciding the next phase of the breeding program. It appears that the GCA rank for grain yield is related to the GCA for the useful yield components and it is, therefore, recommended that the breeder should breed for superior combining ability for the component traits with an ultimate objective of improving the overall GCA for grain yield in bread wheat (Joshi *et al*., 2004).

In this study, therefore, an effort was made to generate information about eight released cultivars of bread wheat crossed in half-diallel fashion so as to identify the best combining parents and their crosses on the basis of their general and specific combining abilities effects for yield and yield related traits for further improvement of grain yield in bread wheat. In addition, this study also

*Corresponding author. E-mail: hseboka@yahoo.com

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determined the type of gene actions involved in the inheritance of yield and its components.

2. Materials and Methods

Combining ability analysis for yield and yield related traits in bread wheat (*Triticum aestivum* L.) using 8 x 8 half-diallel cross was conducted at Sinana Agricultural Research Center (SARC), on-station, during the main cropping season of 2005. The center is characterized by bimodal rainfall and, hence, wheat is produced twice a year. Rainfall data for the last 16 years (1990-2005) showed that average total annual rainfall was 752 mm which ranged from 535 to 1018 mm. The main season receives 230 to 546 mm (average 353 mm) rainfall, in which the lowest level was observed in 2005 main cropping season, and the short season receives from 225 to 560 mm (average 364 mm). For the same period, the average annual maximum temperature was 21.2 ^{o}C and minimum temperature was 9.4 ^{o}C. The dominant soil type is pellic Vertisol and is slightly acidic (pH = 6).

The experimental materials consisted of a total of 36 genotypes, which comprised the parents and 28 F_1's obtained from 8 x 8 half-diallel crossing of genetically diverse bread wheat cultivars selected based on their individual merits. The parents basically originated from CIMMYT/Ethiopia and were released as high yielding and adapted varieties by the agricultural research system during the period 1984 – 2001 (Table 1). These parents have genetic variability for yield, disease resistance as well as for various yield components. Crossing was done at SARC in 2004 in both seasons on field and in greenhouse to obtain sufficient amount of F_1 seeds.

Table 1. Passport data and characteristics of bread wheat varieties included in 8 x 8 half-diallel cross.

Parent	Origin/Source	Pedigree	Year of release	Attributes
Wabe (HAR-710)	CIMMYT/ Ethiopia	MRL 'S" - BUC 'S'	1995	High yielder, long spike, susceptible to yellow and stem rusts, and semi-dwarf, White seeded
Mitike (HAR 1709)	CIMMYT/ Ethiopia	BOW 28 / RBC	1994	Susceptible to yellow rust, moderately high yielder, tall, resistant to stem rust, and good competitive to weed
Dashen	CIMMYT/ Ethiopia	VEE17, KUZ- BUHO "S"x KAL – BB CM33027-F-15M-500y-1M-OY-OPtz-OY	1984	Good baking quality, white seeded, high tillering capacity, susceptible to yellow and stem rust, and high yielder
Sofumer (HAR 1889)	CIMMYT/ Ethiopia	LIRA'S'/YAN'S'	1999/00	High yielder, susceptible to moderately, susceptible to yellow and stem rusts, frost tolerant, high tillering capacity, white seeded, and short spike
Abola (HAR 1522)	CIMMYT/ Ethiopia	BOW'S'/BUC'S'	1997	High yielder, susceptible to yellow and stem rusts, and very long spike and White seeded
Galema (HAR-604)	CIMMYT/ Ethiopia	4777(2)//FKN/GB/3/ PVN "S"	1995	High yielder, late maturing, high tillering capacity, and moderately resistance to yellow and stem rusts
Meda-Welabu (HAR-1480)	CIMMYT/ Ethiopia	TL/3/FR/Th/Nar59*2/4/BOL'S'C M56569-/AP-1AP-5AP-2AP-OAP	1999/00	High yielder, has good resistance to yellow, susceptible to stem rust, long spike, Plump seed
Dure (HAR 1008)	CIMMYT/ Ethiopia	BOW"S"/YD"s"/ZZ'S" CM62045-1Y-1M-1Y-1M-6Y-1M-OY	2001	Moderately High yielder, early maturing, white seeded and good for moisture stress area

The resulting seeds of 36 genotypes (28 F_1's and 8 parents) were sown in a triplicate randomized complete block design (RCBD) at SARC, on station in August 24, 2005. Planting was done manually by dibbling two seeds per hill, which were later thinned to one plant. Each plot consisted of four rows of 1.5 m length and spacing of 20 cm between rows and 15 cm between plants. Recommended doses of 41- 46 kg N-P_2O_5/ha fertilizer were applied at planting and hand-weeding was done three times. The systemic fungicide, Propiconazole (Tilt) was sprayed at a rate of 0.5 l/ha (125g a.i/ha) at booting and heading to control yellow and stem rusts, respectively.

Five plants, randomly taken from two central rows of each plot, were used for recording observations for characters considered on a sample basis: plant height, spike length, flag leaf area, tillers/plant, seeds/spike, seeds/spikelet, spikelets/spike, seeds weight/spike, grain yield/plant, biomass/plant and harvest index. On the other hand, two central rows were used for recording observations for characters considered on a plot basis: days to heading, days to maturity, days to grain filling and thousand kernel weight.

Analysis of variance (ANOVA) was carried out following the procedures outlined by Steel and Torrie (1980) to determine the presence of significant differences among the genotypes using SAS computer program. Griffing's (1956) model I (fixed effect model) method 2 combining ability analysis was employed to estimate GCA and SCA for characters that showed significant differences among the genotypes using SPAR-1 statistical software (Doshi and Gupta, 1991).

Test of significance for GCA and SCA mean squares was made using the F-test. The significance of GCA and SCA effects was tested by comparing with tabular 't' values of 1.96 and 2.58 multiplied by standard errors in which they were associated (1.96 x SE (g_i) and 2.58 x SE (s_{ij})) at 5% and 1% probability levels, respectively. The estimated values of g_i and s_{ij} greater than 1.96 x SE (g_i) and 1.96 x SE (s_{ij}) for GCA and SCA effects were regarded as significant at 5% probability level and the estimated values greater than 2.58 x SE (g_i) and 2.58 x SE (s_{ij}) were regarded as significant at 1% probability level (Dabholkar, 1992). Taking the expectation mean squares for model I Method 2 into consideration, the estimated component of genetic variance due to GCA of parents and SCA of the hybrids were computed. The predominance of additive versus non-additive gene action in the expression of the character was compared from the ratio of components of GCA variance (σ^2_{GCA}) to SCA variance (σ^2_{SCA}).

3. Results and Discussion

The analysis of variance revealed highly significant (P<0.01) differences among the 36 genotypes for all traits studied, except biomass yield per plant (Table 2), indicating the presence of inherent variation among the materials. Further partitioning of the sum of squares due to genotypes into that of parents, crosses and parents vs. crosses indicated that mean square due to parents was highly significant (P<0.01) and significant (P<0.05) for all traits except seed weight per spike, grain yield and biomass per plant. Hybrids also showed highly significant and significant differences for all traits except days to maturity and seed weight per spike. Highly significant difference was recorded for parent vs. hybrids in flag leaf, plant height, days to heading, days to grain filling, days to maturity, seed weight per spike, grain yield per plant, harvest index and 1000-kernel weight, indicating the presence of directional dominance which resulted in heterosis for these traits. Similarly, several previous studies reported significant differences among genotypes for grain yield and yield related traits in different sets of material of wheat (Menon and Sharma, 1997; Ali and Khan, 1998; Javaid *et al.,* 2001; Solomon, 2002). Therefore, it was justifiable to estimate GCA and SCA effects for those traits which showed significant differences for genotypes.

Table 2. Mean squares due to genotypes, parents, crosses, and parent vs. crosses for 15 yield and yield related traits from the analysis of variance (ANOVA) in 8 x 8 half-diallel cross of bread wheat in 2005 at Sinana, south east, Ethiopia.

	Mean Squares						
	Replications	Genotypes	Parents	Hybrids	Parents vs. Hybrids	Error	CV
Trait	df (2)	(35)	(7)	(27)	(1)	(70)	(%)
DH	15.45	74.38**	147.42**	35.86**	603.19**	5.62	2.99
DGF	18.78	51.19**	121.21**	29.43**	148.60**	7.55	2.05
DM	32.62	17.77**	17.19*	12.91	153.02**	8.18	1.98
PH	15.94	48.92**	52.89**	47.77**	52.30*	11.22	3.48
TPP	50.77	19.90*	23.79*	19.17*	12.60	11.09	19.88
FLA	59.92	62.02**	105.83**	45.70**	195.80**	12.73	7.48
SL	3.26	1.09**	2.76**	0.69*	0.12	0.39	5.09
SPS	302.12	149.53**	445.71**	77.70**	15.89	38.16	8.06
SPPS	0.69	1.85**	3.71**	1.44*	0.01	0.72	3.79
SPSP	1.15	0.34**	0.57**	0.28*	0.35	0.16	11.99
SWS	0.17	0.28**	0.24	0.20	2.69**	0.14	11.21
GYP	268.11	138.20**	30.17	142.67*	773.57**	71.58	20.26
BMP	2020.93	595.57	303.16	654.87*	1041.35	379.5	19.54
HI	5.20	28.07**	27.71**	21.54**	206.82**	8.92	7.18
TKW	6.06	35.82**	42.72**	23.24**	327.23**	5.73	5.76

*Note: - *, **, Significant at 0.05, 0.01 level of probability, respectively, df = degree of freedom.*

DH= Days to heading, DGF = Days to grain filling, DM = Days to maturity, PH = Plant height (cm), TPP = Number of tillers per plant, FLA = Flag leaf area (cm2), SL = Spike length (cm), SPS = Number of seeds per spike, SPSP = Number of seeds per spikelet, SPPS = Number of spikelets per spike, SWS = Seed weight per spike (g), GYP = Grain yield per plant (g), BMP = Biomass per plant (g), HI = Harvest index (%), TKW = 1000 kernel weight (g).

3.1. Combining Ability Analysis

Analysis of variance for combining ability revealed that both GCA and SCA mean squares were highly significant (P<0.01) for plant height, days to heading, days to grain filling, days to maturity, harvest index, 1000-kernel weight and significant (P<0.05) for grain yield per plant (Table 3), suggesting the importance of both additive and non-additive gene actions in determining the inheritance of these characters. The Results of this study are in accordance with the findings of Necdet (2001) and Joshi *et al.* (2004), who reported highly significant difference for both GCA and SCA for these traits. However, further variance ratio analysis showed that non-additive gene action has primary importance for the inheritance of these traits except days to grain filling (Table 3). The present findings thus supported the results of Menon and Sharma (1997), who reported non-additive genetic variance as the main component of genetic variance of these traits. However, preponderance of additive gene effects were reported by Joshi *et al.* (2004), Javaid *et al.* (2001) and Nazir *et al.* (2005) for these traits, except 1000-kernel weight, which was predominantly controlled by non-additive gene action.

The mean squares for general combining ability were highly significant (P<0.01) and significant (P<0.05) for all the remaining traits, flag leaf area, tillers per plant, spike length, seed per spike, spikelets per spike, seed per spikelet and seed weight per spike, indicating the greater importance of additive gene action in controlling the inheritance of these characters, since SCA mean squares were non-significant for these traits. As indicated by various authors (Gravois and McNew, 1993; Joshi *et al.,* 2004), when GCA is only important, especially in self-pollinated crops, selection is the best method of breeding to improve the character in question. This is because additive effects are readily transmissible from one generation to another. In addition, Habib and Khan (2003), Joshi *et al.* (2004) and Nazir *et al.* (2005) also reported the greater importance of additive gene effect in controlling the expression of these traits. Contrary to these observations, Ali and Khan (1998)) reported the importance of both additive and non-additive gene action for flag leaf area, tillers per plant and seeds per spike. Arshad and Chowdhry (2002) detected the predominant effect of non-additive variances in flag leaf area, tillers per plant, seeds per spike and grain yield per plant.

Table 3. Analysis of variance and components of genetic variance for GCA and SCA, error variance (σe2) and σ2gca/σ2sca ratio for yield and yield related traits in 8 x 8 half-diallel cross of bread wheat in 2005 at Sinana, south east, Ethiopia.

Trait	Mean squares			Variance component			
	GCADF *(7)*	SCA*(27)*	Error*(70)*	σ^2_{gca}	σ^2_{sca}	σ_e^2	$\sigma^2_{gca}/\sigma^2_{sca}$ ratio
DH	77.62**	11.59**	1.88	7.57	9.71	1.88	0.78
DGF	60.81**	6.13**	2.52	5.83	3.61	2.52	1.62
DM	7.25*	5.59**	2.73	0.45	2.86	2.73	0.16
PH	44.75**	9.20**	3.74	4.10	5.46	3.74	0.75
TPP	23.06**	2.53	3.70	1.94	1.16	3.70	-
FLA	80.63**	5.68	4.24	7.64	1.44	4.24	-
SL	1.37**	0.11	0.13	0.12	0.02	0.13	-
SPS	205.42**	10.95	12.72	19.27	1.77	12.72	-
SPPS	2.42**	0.17	0.24	0.22	0.07	0.24	-
SPSP	0.40**	0.04	0.05	0.03	0.009	0.05	-
SWS	0.19**	0.07	0.04	0.01	0.02	0.05	-
GYP	75.05**	38.82*	23.86	5.12	14.95	23.86	0.34
HI	12.29**	8.62**	2.97	0.93	5.65	2.97	0.16
TKW	22.23**	9.37**	1.91	2.03	7.46	1.91	0.27

Note:-, **, Significant at 0.05 and 0.01 level of probability, respectively, df = degree of freedom.*

DH= Days to heading, DGF = Days to grain filling, DM = Days to maturity, PH = Plant height (cm), TPP = Number of tillers per plant, FLA = Flag leaf area (cm^2), SL = Spike length (cm), SPS = Number of seeds per spike, SPPS= Number of spikelet per spike, SPSP = Number of seeds per spikelet, SWS = Seed weight per spike (g), GYP = Grain yield per plant (g), HI = Harvest index (%), TKW = 1000 kernel weight (g).

3.1.1. Estimates of General Combining Ability Effects

Based on the results from analysis of variance for combining ability, the GCA effects of parents for yield and its component characters were estimated (Table 4). For grain yield, three parents revealed significant GCA effects, out of which Dashen gave desirable significant positive GCA effect and was the best general combiner for this trait. Sofumer, Meda-Welabu, and Galema also recorded positive GCA effect and were equally important for use in parental combination for grain yield. Dure and Mitike showed negative and significant GCA effect and were the poorest general combiners for grain yield in this study. Therefore, from this study, Dashen, Sofumer and Meda-Welabu could be utilized in bread wheat grain yield improvement programs as a selection from these crosses which could be expected to lead to substantial genetic improvement. In this study, it is also interesting to observe that there was concurrence between *per se* performance and GCA effects for grain yield per plant. This study is in agreement with Arshad and Chowdhry (2002) and Joshi *et al.* (2004), who reported greater and positive GCA effects in most of the crosses for grain yield. They also reported those parents with higher GCA effects resulting in higher SCA effects for grain yield.

All parents, except Wabe, showed highly significant (P<0.01) and significant (P<0.05) GCA effect, out of which three parents were in the desirable positive direction for 1000-Kernel weight. Dure, Sofumer and Meda-Welabu were the best general combiners, while Abola was the poorest general combiner for this trait followed by Dashen and Mitike. In this study, even though Dure was the best general combiner for 1000-kernel weight, it exhibited highly significant negative GCA effects for all spike traits, which may be attributed to negative GCA effect for grain yield.

For spike length, all parents, except Mitike, showed highly significant (P<0.01) GCA effects, out of which Dure, Dashen and Sofumer had undesirable negative GCA effect and were poor general combiners for this character. Galema and Meda-Welabu followed by Abola and Wabe were good general combiners for spike length. The results of this study are in conformity with the findings of Arshad and Chowdhry (2002), Topal *et al.* (2004) and Nazir *et al.* (2005), who reported both positive and negative GCA effects for 1000-kernel weight and spike length.

All of the parents, except Wabe and Meda-Welabu exhibited significant GCA effect for number of tillers per plant, out of which Dure, Abola, and Mitike had unfavorable negative GCA effects for this trait. Dashen, Galema and Sofumer exhibited significant positive GCA effect and so were good general combiners for this trait. For flag leaf area, Wabe, Abola, Galema and Meda-Welabu revealed positive and highly significant GCA effects. All these parents were equally good general combiners, while Mitike, Sofumer and Dure recorded negative and highly significant GCA effects and were poor general combiner for this trait. Arshad and Chowdhry (2002) and Nazir *et al.* (2005) reported similar results for tillers per plant and flag leaf area, respectively.

Two parents, Dashen and Abola, had negative and highly significant GCA effect, while Mitike and Galema showed highly significant positive GCA effects for plant height. Thus, the former two parents were the best general combiners for dwarfness, while the latter two were poor general combiners. One half of the parents showed negative GCA effect out of which 25% showed significant GCA effect in the negative desirable direction for plant height in bread wheat improvement. This result is in accordance with Arshad and Chowdhry (2002), Javaid *et al.* (2001) and Nazir *et al.* (2005), who reported significant negative GCA effects in most of the crosses and strong positive association of dwarfness with grain yield.

In the present study, six of the 8 parents, showed highly significant GCA effects, out of which Dure and Mitike had negative GCA effects in the desirable direction for days to heading. While, Galema, Abola, Sofumer and Dashen showed highly significant positive GCA effects in an undesirable direction. Dure was the best general combiner for early heading and maturity; Galema and Abola were the poorest general combiners for respective traits. There was a close agreement between parental lines selected on the *per se* performance and their GCA effects for these traits. This was also true with respect to the poor general combiners parental genotypes for these particular traits in this study. Similarly, Joshi *et al.* (2004) and Javaid *et al.* (2001) reported considerable amount of negative GCA effects for days to heading and maturity.

The results of this study revealed significant GCA effects for number of seeds per spike and spikelets per spike in four parents, out of which only Abola had positive and highly significant GCA effects for the former and Abola and Sofumer for the latter trait. Similarly, significant GCA effects were recorded in five and two parents for number of seeds per spikelet and seed weight per spike, respectively, out of which Abola and Galema had positive and highly significant GCA effects for the former and only Abola for the latter trait. Therefore, it was observed that Abola was the best general combiner for number of seeds per spike, spikelets per spike, and seeds per spikelet and seed weight per spike. Moreover, Sofumer and Galema were also best general combiners for number of spikelets per spike and seeds per spikelet, respectively. However, Dure, Sofumer and Wabe exhibited significant negative GCA effects and were poor general combiners for seeds per spike; Dure and Wabe were poor general combiners for number of spikelets per spike; Dure, Sofumer and Mitike were poor general combiners for seeds per spikelet and Mitike was the poorest general combiner for seed weight per spike.

Generally, Abola was the best general combiner for all spike traits (number of seeds per spike, seeds per spikelet and seed weight per spike), while Dure followed by Wabe and Mitike showed negative GCA effects for all these traits and were poor general combiners for respective traits. These results revealed a close agreement between *per se* performance and GCA effect for these characters and hence, selection from the transgressive segregating generations of crosses of Abola could be expected to lead to substantial genetic improvement for these traits. Contrary this results, Javaid *et al.* (2001), Arshad and Chowdhry 2002) and Nazir *et al.* (2005) reported positive GCA effects in most of the crosses for these traits.

Table 4. Estimates of general combining ability effect for 14 yield and related quantitative traits of eight parental genotypes of bread wheat in 2005 at Sinana, south east, Ethiopia.

Trait	Parent								SE(d)gi±	SE(d)gi-gj±
	Wabe	Mitike	Dashen	Sofumer	Abola	Galema	Dure	Meda-Welabu		
DH	0.63	-1.74**	1.13**	1.79**	1.63**	3.09**	-5.81**	-0.71	0.41	0.61
DGF	-0.18	2.12**	-1.88**	-2.15**	-0.25	-3.08**	4.38**	1.05	0.47	0.71
DM	0.44	0.38	-0.76	-0.36	1.38**	0.01	-1.43**	0.34	0.49	0.74
PH	-0.98	3.55**	-2.51**	0.46	-2.59**	1.81**	0.93	-0.68	0.57	0.86
TPP	-0.07	-1.17*	2.10**	1.30*	-1.33*	1.70*	-1.90**	-0.63	0.57	0.86
FLA	2.42**	-3.47**	-0.36	-2.92**	2.65**	3.18**	-3.15**	1.66**	0.61	0.92
SL	0.26**	-0.02	-0.32**	-0.29**	0.22**	0.39**	-0.61**	0.37**	0.11	0.16
SPS	-2.29*	-1.83	-1.03	-3.59*	10.04**	2.01	-3.99*	0.68	1.05	1.59
SPPS	-0.34*	-0.06	-0.04	0.39**	0.93**	-0.01	-0.74**	-0.12	0.15	0.22
SPSP	-0.05	-0.15*	-0.12	-0.15*	0.38**	0.22**	-0.15*	0.02	0.07	0.10
SWS	-0.08	-0.13**	-0.09	-0.08	0.27**	0.06	-0.06	0.11	0.06	0.10
GYP	-2.71	-3.12*	3.56*	2.10	0.40	1.35	-3.54*	2.00	1.44	2.18
HI	-2.08*	-0.83	0.34	1.17*	0.82	-0.69	0.36	0.90	0.51	0.77
TKW	-0.19	-1.29**	-1.06*	1.31*	-1.46**	-0.99*	2.61**	1.07**	0.41	0.62

*Note: - *, **, Significant at 0.05 and 0.01 level of probability, respectively*

DH= Days to heading, DGF = Days to grain filling, DM = Days to maturity, PH = Plant height (cm), TPP = Number of tillers per plant, FLA = Flag leaf area (cm^2), SL = Spike length (cm), SPS = Number of seeds per spike, SPPS= Number of spikelets per spike, SPSP = Number of seeds per spikelet, SWS = Seed weight per spike (g), GYP = Grain yield per plant (g), HI = Harvest index (%), TKW = 1000 kernel weight (g).

3.1.2. Estimates of Specific Combining Ability Effects

In this study, crosses manifested considerable variation in SCA effects for a few traits (Table 5). For grain yield per plant, six of the 28 crosses manifested significant SCA effect. The maximum significant SCA effect was recorded in Dashen x Meda-Welabu followed by Sofumer x Galema and Sofumer x Meda-Welabu, whereas the lowest (negative) and significant SCA effect was obtained from Dure x Meda-Welabu. This indicated that Dashen x Meda-Welabu, Sofumer x Galema and Sofumer x Meda-Welabu crosses combined well to give higher grain yield than mean performances of their respective parents. Based on this result, these crosses could be selected for their specific combining ability and useful for transgressive breeding for grain yield improvement. In this study, good SCA for grain yield was observed in a few crosses. However, Arshad and Chowdhry (2002) and Hussian *et al.* (2004) reported significance of SCA effects in a considerable number of crosses and indicated the predominance of non-additive genetic variance in the case of grain yield.

For 1000-kernel weight, seven of the 28 crosses manifested highly significant SCA effect, out of which only one cross, Wabe x Sofumer, showed a negative and significant SCA effect. The maximum SCA effect was recorded in Dashen x Meda-Welabu cross followed by Abola x Meda-Welabu and Sofumer x Dure, whereas the lowest (negative) SCA effects were obtained from Wabe x Sofumer. This indicated that Dashen x Meda-Welabu, Abola x Meda-Welabu and Sofumer x Dure crosses combined well to give higher 1000-kernel weight mean performances than their respective parents and could be selected for their specific combining ability to improve 1000-kernel weight. Moreover, it was observed that actual 1000-kernel weight recorded for these crosses (*per se* performance) was superior to other crosses. Thus, there was close agreement between crosses selected on the basis of their SCA effects and *per se* performance for 1000-kernel weight and grain yield in this study.

In this study, most of the crosses identified as desirable, on the basis of their SCA effects for these traits, had at least one of the parents involved as a good general combiner for the trait. Hence selection from the transgressive segregating generations of these crosses is most probably lead to substantial genetic improvement for 1000-kernel weight and grain yield in bread wheat. This study is in agreement with Topal *et al.* (2004) and Nazir *et al.* (2005), who reported greater positive SCA effects in most of the crosses for 1000-kernel weight. Arshad and Chowdhry (2002) and Joshi *et al.* (2004) also reported that crosses involving one of the parents with high GCA effect also resulted in high SCA effect for most of the traits they studied. Contrary to the present study, Necdet (2001) reported negative and significant SCA effects in most of the crosses for 1000-kernel weight. For harvest index, seven crosses manifested significant SCA effect in desirable positive direction, while Dure x Meda-Welabu and Wabe x Dure showed significant SCA effect in a negative direction. For this trait, Abola x Dure and Wabe x Galema were the best specific combiners.

Similarly, seven crosses exhibited significant SCA effects for plant height out of which three crosses combined well in the desirable direction in reducing plant height. The best specific combiners for plant height were Dashen x Galema followed by Wabe x Dashen which had a shorter plant height than the mean value of the parent involved in each crosses, while Sofumer x Dure was the poorest combiner for this trait. This study also revealed that there was close agreement between crosses selected on the basis of their SCA effects and *per se* performance for dwarfness. This was also true with respect to the poor specific combiner as well. Similarly, considerable negative and significant SCA effects for plant height and its importance for wheat improvement were reported by Topal *et al.* (2004), Arshad and Chowdhry (2002) and Javaid *et al.* (2001).

For maturity traits, eight and five crosses revealed highly significant and significant SCA effects for days to heading and maturity, respectively. None of the crosses showed significant negative SCA for days to grain filling in this study, indicating that hybrids were later in grain filling than what would have been predicted based on their parental performances.

Significant positive SCA effects were recorded in Sofumer x Galema for heading, Abola x Galema and Mitike x Meda-Welabu for grain filling and Mitike x Meda-Welabu and Dure x Meda-Welabu for maturity which were also poor specific combiners for respective traits. Those crosses that recorded maximum negative SCA effect such as, Abola x Galema and Wabe x Sofumer for heading and Abola x Dure and Wabe x Dure for maturity were good specific combiners for respective traits and may be used as good sources for earliness. Even though only one cross showed significant SCA effect, most of the crosses involving Dure as a parent exhibited negative SCA effect for these maturity traits. This result revealed that a good specific combiner for days to heading may not necessarily be a good specific combiner for grain filling.

It was also observed that some crosses involving parents with good general combiners showed poor specific combiners, indicating parents with high GCA effect might not always give crosses with high SCA effects. In this study, negative direction was considered as a desirable SCA effect for traits like days to heading, grain filling, maturity and plant height. Similarly, Topal *et al.* (2004) and Javaid *et al.* (2001) reported negative and significant SCA effects for days to heading and maturity.

Table 5 Estimates of specific combing ability effects for yield and some yield related traits of 28 hybrids in 8 x 8 half-diallel cross of bread wheat in 2005 at Sinana, south east, Ethiopia.

Cross	DH	DGF	DM	PH	GYP	HI	TKW
P_1 x P_2	-2.00	2.12	0.19	1.48	-1.08	2.86*	0.65
P_1 x P_3	-1.20	0.46	-0.75	-4.26**	-4.29	0.39	-1.99
P_1 x P_4	-3.87**	1.72	-2.15	0.58	-5.26	-0.07	-2.68*
P_1 x P_5	-2.70*	0.49	-2.22	-0.85	0.04	-1.06	-2.12
P_1 x P_6	-1.84	0.32	-1.52	-0.77	2.62	4.09**	0.68
P_1 x P_7	-0.60	-2.14	-2.75*	0.18	3.21	-2.69*	-0.45
P_1 x P_8	0.96	-1.81	-0.85	2.31	4.47	2.90*	1.35
P_2 x P_3	-1.84	-0.84	-2.68*	-2.98	-1.59	-2.47	-1.22
P_2 x P_4	-2.84**	0.76	-2.08	1.06	-1.06	1.28	0.15
P_2 x P_5	-0.67	1.86	1.19	-1.90	-0.06	-1.25	0.39
P_2 x P_6	-1.47	0.36	-1.12	2.18	-2.67	0.60	0.31
P_2 x P_7	-0.24	-1.11	-1.35	0.26	1.31	1.29	1.92
P_2 x P_8	-1.00	3.89**	2.89*	2.79	7.71*	-0.93	1.52
P_3 x P_4	-0.04	1.42	1.38	-3.22*	-1.00	-0.36	-0.75
P_3 x P_5	0.13	0.86	0.99	2.56	5.83	0.95	1.95
P_3 x P_6	-3.34**	1.36	-1.98	-4.57**	-1.95	3.00*	2.95**
P_3 x P_7	-0.44	-0.78	-1.22	3.92*	6.73	1.02	1.49
P_3x P_8	0.13	-0.78	-0.65	-1.49	13.69**	3.07*	4.75**
P_4x P_5	-1.20	0.12	-1.08	-2.07	-1.70	0.53	-0.08
P_4x P_6	2.99**	-0.71	2.29	1.07	9.11*	2.17	1.85
P_4 x P_7	0.23	-0.84	-0.62	4.42**	-1.00	-0.64	3.86**
P_4x P_8	-3.20**	0.82	-2.38	1.08	8.13*	-0.89	1.46
P_5 x P_6	-6.50**	6.72**	0.22	3.98*	7.91*	-182	3.02**
P_5 x P_7	-2.94**	-1.08	-4.02**	3.73*	-0.53	7.87**	0.23
P_5x P_8	-2.04	0.59	-1.45	-0.87	2.66	2.22	4.56**
P_6x P_7	-1.07	1.09	0.02	-0.60	3.22	2.82*	2.89**
P_6 x P_8	-0.17	1.09	0.92	1.27	-4.89	-0.73	0.02
P_7 x P_8	1.40	1.62	3.02*	1.15	-9.47*	-3.48**	-0.64
SE(d)Sij ±	1.08	1.25	1.30	1.53	3.85	1.36	1.09
SE(d)Sij-Sik	1.84	2.13	2.22	2.59	6.55	2.31	1.85
SE(d)Sij-Skl	1.73	2.01	2.09	2.45	6.17	2.18	1.75

*Note: - *, **, significant at 0.05 and 0.01 probability Level, respectively, SE. = Standard error*

DH= Days to heading, DGF = Days to grain filling, DM = Days to maturity, PH = Plant height (cm), HI = Harvest index (%), TKW = 1000 kernel weight (g).

4. Conclusions

The presence of both additive and non-additive variances suggested the utilization of certain genotypes and crosses for future breeding work. Therefore, use of diallel mating with recurrent selection and integration with pedigree selection could be suggested as a breeding program to exploit both additive and non-additive gene effects for the genetic improvement of bread wheat. Thus, parental genotypes with good GCA like Abola, Dashen, Sofumer, Meda-Welabu and Galema and specific crosses scored highly. SCA like Dashen x Galema, Abola x Dure, Dashen x Meda-Welabu, Abola x Galema, and Galema x Dure, should be included in multiple crosses for tangible improvement of grain yield in bread wheat.

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Comparison of Two Approaches for Estimation of Genetic Variation for Two Economic Traits in Faba Bean Genotypes Grown under Waterlogged Verisols

Gemechu Keneni* and Musa Jarso

Holetta Agricultural Research Center, P.O.Box 2003, Addis Abeba, Ethiopia.

Abstract: There is little experimental evidence about whether component of variance calculated from separate analysis of variance in waterlogged conditions is effective in estimating the extent of heritable variation and the effectiveness of selection. Seven faba bean variety trials consisting of 17-25 different genotypes each were conducted at four locations in lattice or RCB designs with 2 or 3 replications on drained (using broad bed and furrow, BBF) and undrained (flatbeds) Vertisols between 1996 and 1999. Records on 1000 seed weight and grain yield were subjected to statistical analyses using SAS computer software. Grain yield was more sensitive to waterlogging stress than 1000 seed weight. Heritability and expected genetic gains calculated from separate analysis were higher than those calculated from pooled analysis of variance for both grain yield and 1000 seed weight. The relative precision improvement of pooled analysis of variance over separate analysis ranged from 57-83% for grain yield and 7-25% for thousand seed weight. Thousand seed weight was more heritable than grain yield. There was weak association between heritability and expected genetic gains calculated from separate and pooled analyses of variance for grain yield and strong positive association for 1000 seed weight, indicating that genetic variation and effectiveness of selection for thousand seed weight could, more accurately, be calculated from separate analysis of variance than grain yield. Thus, studies on genetic variability and effectiveness of selection for grain yield based on separate analysis of variance could be misleading under both drained and waterlogged Vertisols because of the potential danger of wrong conclusions that could be drawn from the confounding effects of genotype by environmental interaction.

Keywords: Broad-Sense Heritability; Expected Genetic Gain; Genotypic Variation; Phenotypic Variation; Pooled Analysis of Variance; Separate Analysis of Variance

1. Introduction

Plant breeders use biometrical techniques to assess genetic variability among and within genotypes, to develop selection criteria, heterotic parents for hybridization, effective breeding procedures and varietal stability (Singh, 1990). Selection of superior genotypes across locations and thoughtout years is a complicated process as it is based on the phenotypic performances of genotypes and the phenotype is the result of not only genetic but also environmental and genotype by environment interaction. Estimation of genetic variation among genotypes is, therefore, the main concern of breeders as the effectiveness of selection depends on the proportion of the heritable variation, i.e. heritability. However, heritability *per se* is not sufficient to predict the effectiveness of selection unless it is considered along with expected genetic gain from selection (Allard, 1960). Environmental and genotype by environment interaction effects are not heritable and, hence, the higher the environmental and the genotype by environment interaction effects, the lower the level of success from selection.

The magnitude of components of variance is commonly calculated from the analysis of variance. It is generally believed that genotype by environment interaction arises from changes in genotypic performances over environment. Whether components of variances calculated from an evaluation of genotypes conducted at only one location for a season (separate analysis of variance) is effective for estimating the extent of heritable variation and the effectiveness of selection is a matter of some concern. A number of authors in Ethiopia have based their analyses of components of variation in different crops on separate analysis of variance, particularly as part of thesis research (Gemechu, 1996, Gemechu *et al*., 1999; Tesfaye, 1999; Temesgen, 2002), including faba bean under waterlogged vertisols (Wondafrash, 2002). However, others argue that genotypic variances estimated in such a way are biased upward as they do not contain genotype by environment interaction variances (Singh, 1990) especially in a stressed environment where genotype by environment interaction is greater (Briggs and Knowles, 1967; Rosielle and Hamblin, 1981).

Grain yield and seed size are economic traits representing the first and the second priority as prime objectives of the Ethiopian faba bean breeding program (Asfaw *et al*., 1994). Among the target environments for specific breeding are the waterlogged vertisols of the highlands, where genotypes have been evaluated both in drained conditions (moderately stressed) using broad bed and furrow (BBF) and undrained flatbeds (highly stressed). In stressed conditions, where genotype by environment interaction is high, (Rosielle and Hamblin, 1981; Singh, 1990; Simmonds, 1991; Banziger and Edmeades, 1997), it is expected that evaluation of genotypes only at one location for a season may not be enough to determine genetic variation and the effectiveness of selection. However, there is little experimental evidence, not only in faba bean but also in several other crops, which supports most of these arguments. The objective of this study was, therefore, to determine the effectiveness of separate analysis of variance for estimating genetic variation and effectiveness of selection for grain yield and seed size compared to

*Corresponding author. E-mail: gemechukeneni@yahoo.com

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pooled analysis of variance in faba bean genotypes grown in drained and undrained vertisols.

2. Materials and Methods

Seven variety trials consisting of 17-25 different genotypes each were used in this study. The entries consisted of genotypes extracted from different germplasm collected from Ethiopia, a few introductions from ICARDA and local and improved cultivars. The trials were conducted at four locations (Ginchi, Enewari, Bichena and Sinja) in drained (BBF) and undrained (flatbed) vertisols between 1996 and 1999 (Table 1). The experiments were arranged either in lattice or RCB designs in 2 or 3 replications. Analysis of variance was made assuming RCBD in all the cases for simplicity. Management was undertaken as per the recommendation at each location. Data on grain yield (g plot^{-1}) and 1000 seed weight (g) were collected on a plot basis. Grain yields recorded on a plot basis were converted to a hectare (kg ha^{-1}) basis for statistical analyses. Separate and pooled analysis of variance over location was made according to the following standard methods using SAS computer software (SAS Institute, 1996).

Components due to genotype (σ_G^2), environment (σ_E^2), genotype by environment interaction (σ_{GE}^2) variances, and broad-sense heritability (h^2) and the expected genetic gain from selection (GA) were calculated from the separate and pooled analyses of variance by assuming various observed mean squares equal to their expected mean squares as shown in Table 2 (Singh and Chaudhary, 1985). The mean values of h^2 and GA from separate analysis of variance were averaged over locations for each experiment and then they were compared with values obtained from pooled analysis of variance of the same experiment.

Table 1. Multilocation faba bean variety trials grown in drained and waterlogged vertisols (1996-1999).

Experiment	Year	No. of entries	Design	No. of reps	Location
EXP 1	1996	24	RCB	2	Ginchi and Enewari
EXP 2	1997	25	Lattice	2	Ginchi, Enewari and Bichena
EXP 3	1997	17	RCB	3	Ginchi, Enewari, Bichena and Sinja
EXP 4	1998	25	Lattice	2	Ginchi and Enewari
EXP 5	1998	18	RCB	3	Ginchi, Enewari, Bichena and Sinja
EXP 6	1999	25	RCB	2	Ginchi and Sinja
EXP 7	1999	18	RCB	3	Ginchi and Bichena

Table 2a. Separate analysis of variance followed in faba bean variety trials grown in drained and waterlogged Vertisols based on a replicated experiment under randomized complete block design.

Source of variation	Degree of freedom[1]	Mean square (MS)	Expected mean square (EMS)[2]
Replication	r-1	MS1	$\sigma_E^2 + g\sigma_r^2$
Genotypes	g-1	MS2	$\sigma_E^2 + r\sigma_G^2$
Error	(r-1)(g-1)	MS3	σ_E^2

Table 2b. Combined analysis of variance followed in faba bean variety trials grown under drained and waterlogged vertisols based on a replicated experiment under randomized complete block design.

Source of variation	Degree of Freedom[1]	Mean Square (MS)	Expected Mean Square (EMS)[2]
Locations	l-1	MS1	$\sigma_e^2 + r\sigma_{gl}^2 + gr\sigma_l^2$
Replications/location	l(r-1)	MS2	$\sigma_E^2 + g\sigma_r^2$
Genotypes	g-1	MS3	$\sigma_E^2 + r\sigma_{gl}^2 + rl\sigma_g^2$
Genotype x Environment	(g-1)(l-1)	MS4	$\sigma_e^2 + r\sigma_{gl}^2$
Error	l(g-1)(r-1)	MS5	σ_e^2

[1] *l, r, and g are number of locations, replications and genotypes, respectively.*
[2] *σ_e^2, σ_r^2, σ_l^2, σ_g^2, and σ_{gl}^2 are error, replication, location, genotypic and genotype × location (or genotype by environment) interaction variances, respectively.*

3. Results and Discussion

The comparison of average performances of grain yield and 1000 seed weight in each experiment on BBF and flatbeds clearly revealed that the magnitude of responses to environmental change (drainage) varied between the two traits (Table 4). On average, relative reductions (RR) on flatbeds compared to the ones on BBF were 17% for grain yield and only 1% for thousand seed weight. This indicates that grain yield was more sensitive to environmental change than thousand seed weight. Other authors also reported grain yield to be greatly influenced by environmental changes (Dantuma and Thompson, 1983; Lawes *et al.,* 1983) and seed weight to be among the most stable components, least affected by changes in the environment (Dantuma and Thompson, 1983).

Heritability and expected genetic gains of grain yield calculated from separate analysis of variance were higher compared to those calculated from pooled analysis of variance in all the cases. The average relative precision improvements (RPI) of pooled analysis of variance over separate analysis of variance, calculated as 1-[Value of pooled analysis/Value of separate analysis], were 66% for heritability and 83% for genetic gain on BBF and 57% for heritability and 75% for genetic gain on flatbeds. However, lower differences were observed between values calculated from separate and pooled analysis of variance for thousand seed weight compared to grain yield. On average, RPI values were only 7% for heritability and 23% for genetic gain on BBF and 13% for heritability and 25% for genetic gain on flatbeds (Tables 5a and b).

Table 3. Calculations of the components of variance (σ_g^2, σ_e^2 and σ_{ge}^2), broad-sense heritability (h^2) and expected genetic advance (GA) from separate and pooled analyses of variance in faba bean variety trials grown in drained and waterlogged vertisols (1996-1999).

Variance[1]	Separate analysis[2]	Pooled analysis
σ_g^2	$= [(\sigma_e^2 + r\sigma_g^2) - \sigma_e^2]/r$	$= [(\sigma_e^2 + r\sigma_{gl}^2 + rl\sigma_g^2) - (\sigma_e^2 + r\sigma_{gl}^2)]/rl$
	= MS2-MS3	= (MS3-MS4)/RL
σ_e^2	$= \sigma_e^2$	$= \sigma_e^2$
	= MS3	= MS5
σ_{ge}^2	____	$= [(\sigma_e^2 + r\sigma_{gl}^2) - (\sigma_e^2)]/r$
		= (MS4-MS5)/r
h^2	$h^2 = \sigma_g^2 / [\sigma_g^2 + \sigma_e^2/r]$	$\sigma_g^2 / [\sigma_g^2 + \sigma_{ge}^2/l + \sigma_e^2/rl]$
GA	$\delta.\ \sigma_g.\ h$	$\delta.\ \sigma_g.\ h$

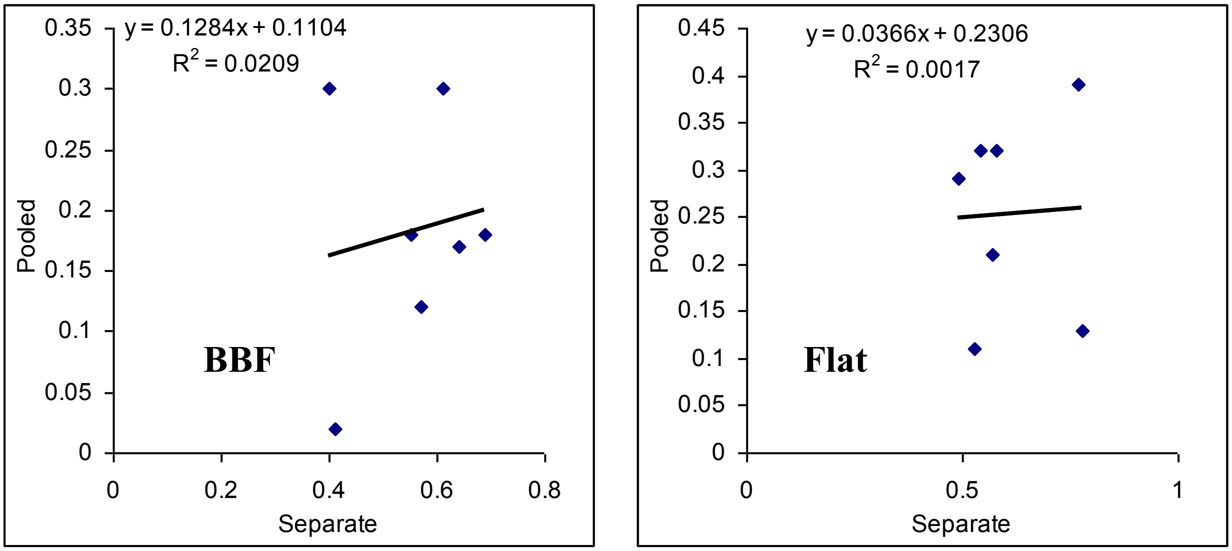
[1] h^2 = heritability in the broad-sense, GA = expected genetic gain from selection
[2]δ= selection differential (assuming a standardized selection differential of 1, Falconer 1989),
h = square root of heritability in the broad-sense and other components of the equations are described under Table 2b.

Table 4. Mean performances for grain yield (kg ha^{-1}) and its determinants in faba bean variety trials grown in drained and waterlogged vertisols (1996-1999).

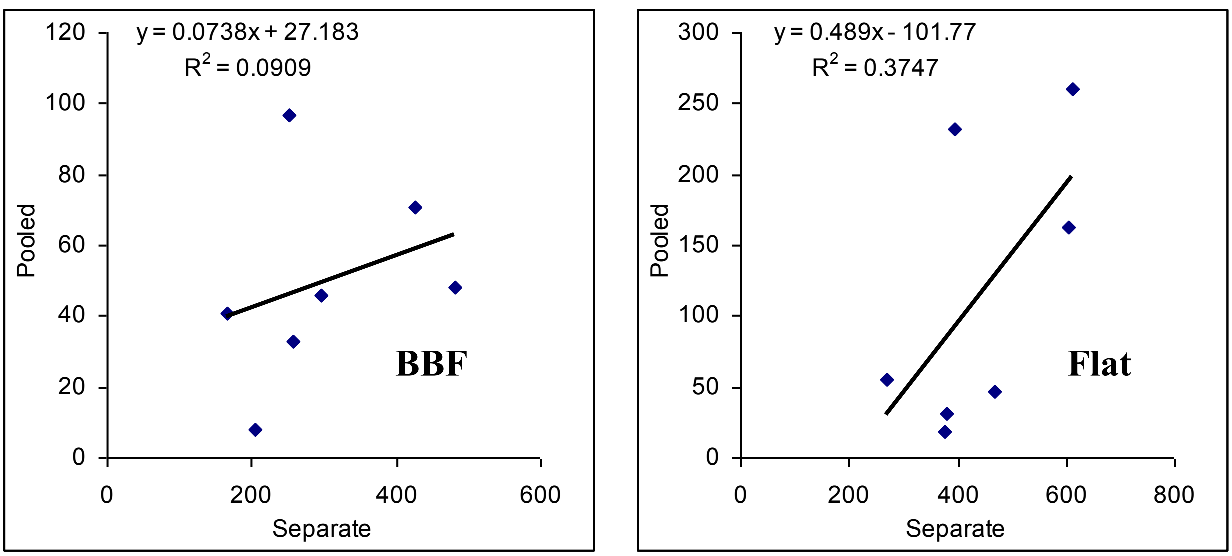
Experiment	Thousand seed weight			Grain yield (kg ha^{-1})		
	BBF	Flat	RR*	BBF	Flat	RR
EXP 1	284.88	284.26	0.00	1769.48	996.84	0.44
EXP 2	332.74	331.56	0.00	2209.79	2061.83	0.07
EXP 3	366.27	357.66	0.02	2567.5	2186.82	0.15
EXP 4	342.43	332.21	0.03	1461.00	1324.23	0.09
EXP 5	356.80	340.58	0.05	2354.83	1973.19	0.16
EXP 6	378.24	371.92	0.02	3085.23	2724.79	0.12
EXP 7	366.43	379.80	-0.04	3210.99	2710.26	0.16
Mean	346.83	342.57	0.01	2379.83	1996.85	0.17

**RR is relative reductions, calculated as 1-(values under flat beds / values under BBF)*

The magnitudes of heritabilities and expected genetic gains from selection calculated using separate analysis of variance for both grain yield and 1000 seed weight were plotted against values calculated using pooled analysis of variance. Linear regressions were adjusted to show the trends (Figures 1 and 2). There were weak interrelationships (R^2 = 0.00-0.37) between heritability and expected genetic gains of grain yield calculated from separate and pooled analyses of variance both on BBF and flatbeds in almost all cases (Figure 1). This indicates that heritability and expected genetic gains from selection calculated from separate and pooled analyses of variance were dissimilar. Normally, there should have been a perfect positive interrelationship between the two in order for values calculated from separate analysis of variance to serve as the measure of their counterparts calculated from pooled analyses of variance. The weak association could be due to the fact that genotype by environment interaction effects were confounded in the case of separate analysis of variance while they were included in estimations based on pooled analysis of variance. Thus, heritability and expected genetic gains calculated from separate analysis of variance were biased upwards, and this indicates that basing studies on genetic variability and effectiveness of selection on separate analysis of variance for grain yield could be misleading because of overestimation. This could be due to the use of broad-sense heritability which is composed of additive and non-additive gene effects. On the other hand, there were positive, strong associations (R^2 = 0.66-0.88) between the heritability and expected genetic gains calculated from separate and pooled analysis of variance for thousand seed weight (Figure 2). Genetic variability and effectiveness of selection determined from separate analysis of variance could be used for thousand seed weight with certain levels of uncertainty.

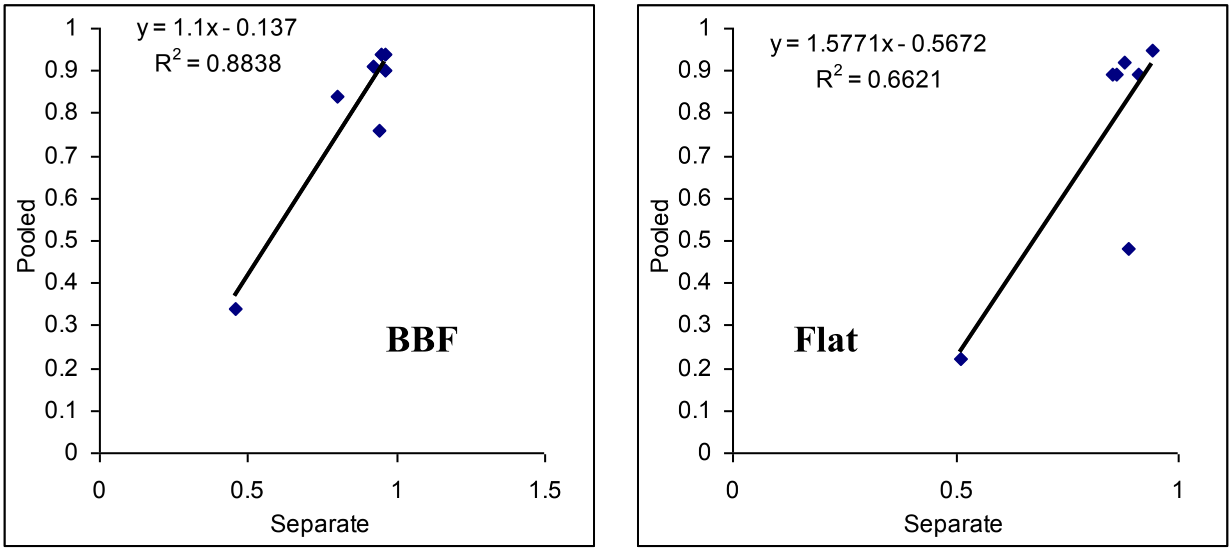


(A) Heritability

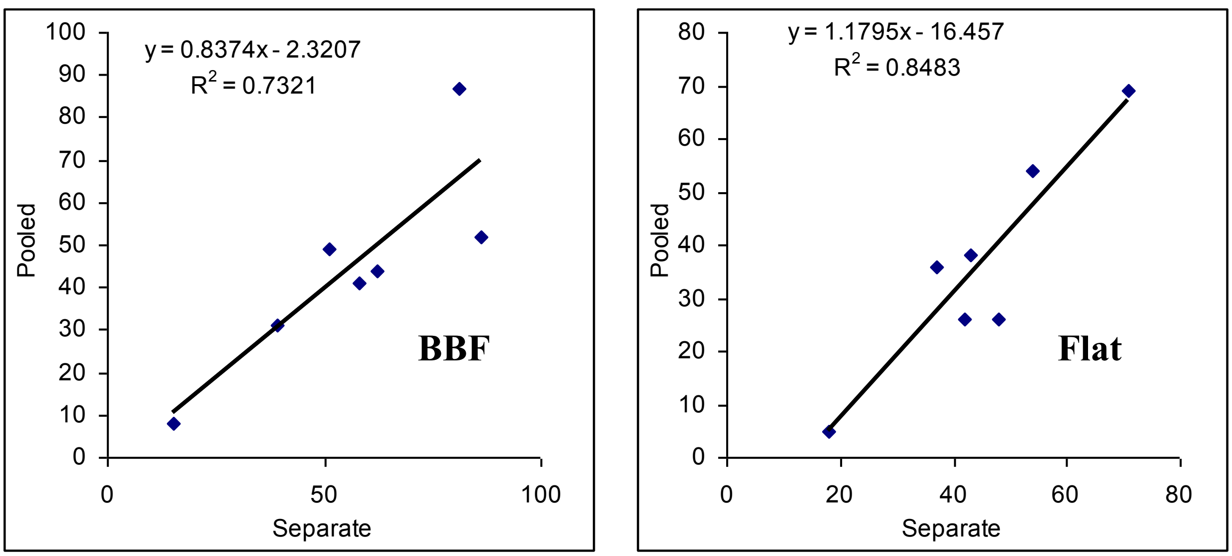


(B) Genetic gain

Figure 1. Joint plot of heritability and expected genetic gains for grain yield determined from separate and pooled analyses of variance in faba bean variety trials grown under drained and waterlogged vertisols (1996-1999).



(A) Heritability



(B) Genetic advance

Figure 2. Joint plot of heritability and expected genetic gains for thousand seed weight determined from separate and pooled analyses of variance in faba bean variety trials grown under drained and waterlogged vertisols (1996-1999).

It also seems that heritability could be more safely determined from separate analysis of variance than expected genetic gains from selection. However, as this study did not consider genotype by environment interaction effects due to seasonal variation, the calculations could have affected even thousand seed weight if such interactions differed considerably from the genotype by environment interactions due to locations. Even though the relative importance of spatial variation over temporal variation was reported for faba bean variety trials in waterlogged vertisols of Ethiopia (Mussa and Gemechu, 2004), temporal variation may also sometimes be more influential than the former (Lawes *et al.,* 1983; Mussa *et al.*, 2003).

Table 5a. Broad-sense heritability (h^2) and expected genetic gains (GA) for thousand seed weight (g) and grain yield (kg ha^{-1}) calculated from separate analysis of variance averaged over location and pooled analysis of variance in faba bean variety trials grown under drained (BBF) Vertisols.

Experiment	h^2			GA		
	Separate analysis	Pooled analysis	RPI*	Separate analysis	Pooled analysis	RPI
Thousand seed weight						
EXP 1	0.46	0.34	0.26	15	8	0.47
EXP 2	0.96	0.94	0.02	51	49	0.04
EXP 3	0.92	0.91	0.01	62	44	0.29
EXP 4	0.95	0.94	0.01	81	87	-0.07
EXP 5	0.96	0.90	0.06	86	52	0.40
EXP 6	0.80	0.84	-0.05	39	31	0.21
EXP 7	0.94	0.76	0.19	58	41	0.29
Mean	0.86	0.80	0.07	56	45	0.23
Grain yield						
EXP 1	0.57	0.12	0.79	258	33	0.87
EXP 2	0.61	0.30	0.51	251	97	0.61
EXP 3	0.40	0.30	0.25	166	41	0.75
EXP 4	0.55	0.18	0.67	296	46	0.84
EXP 5	0.64	0.17	0.73	482	48	0.90
EXP 6	0.41	0.02	0.95	204	8	0.96
EXP 7	0.69	0.18	0.74	425	71	0.83
Mean	0.55	0.18	0.66	297	49	0.83

**RPI = relative precision improvement of pooled analysis over separate analysis of variance, calculated as 1-[Value of pooled analysis/ Value of separate analysis]*

Table 5b. Broad-sense heritability (h^2) and expected genetic gains (GA) for thousand seed weight (g) and grain yield (kg ha^{-1}) calculated from separate analysis of variance averaged over location and pooled analysis of variance in faba bean variety trials grown under undrained (Flat) Vertisols.

Experiment	h^2			GA		
	Separate analysis	Pooled analysis	RPI*	Separate analysis	Pooled analysis	RPI
Thousand seed weight						
EXP 1	0.51	0.22	0.57	18	5	0.72
EXP 2	0.91	0.89	0.02	43	38	0.12
EXP 3	0.86	0.89	-0.03	48	26	0.46
EXP 4	0.94	0.95	-0.01	71	69	0.03
EXP 5	0.88	0.92	-0.05	54	54	0.00
EXP 6	0.89	0.48	0.46	42	26	0.38
EXP 7	0.85	0.89	-0.05	37	36	0.03
Mean	0.83	0.75	0.13	45	36	0.25
Grain yield						
EXP 1	0.57	0.21	0.63	270	55	0.80
EXP 2	0.77	0.39	0.49	613	261	0.57
EXP 3	0.58	0.32	0.45	379	31	0.92
EXP 4	0.78	0.13	0.83	469	47	0.90
EXP 5	0.53	0.11	0.79	377	19	0.95
EXP 6	0.54	0.32	0.41	395	232	0.41
EXP 7	0.49	0.29	0.41	606	163	0.73
Mean	0.61	0.25	0.57	444	115	0.75

**RPI = relative precision improvement of pooled analysis over separate analysis of variance, calculated as 1-[Value of pooled analysis/ Value of separate analysis]*

4. Conclusion

This study clearly showed that, where environmental differences are great, as in drained and un-drained waterlogged Vertisols, it may be expected that genotype by environment interaction effect is also high. In such cases, care must be taken not to use statistical models that omit inclusion of the genotype by environment interaction effects unless otherwise proven that the performance of the given crop or the given trait is not considerably influenced by environmental fluctuations.

5. Acknowledgments

The authors wish to thank all the staff of the Highland Pulses Research Program at Holetta, Adet, Sinana and Sheno Agricultural Research Centers who managed the trials.

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Effect of *Bacillus thuringiensis*, Neem, and Karate on Diamondback Moth (*Plutella xylostella* L.) (Lepidoptera: Plutellidae) Damage on Cabbage in the Central Rift Valley of Ethiopia

Lidet Sitotaw[1], Gashawbeza Ayalew[1] and Tadele Tefera[2*]

[1]Ethiopian Institute of Agricultural Research, P O Box 436, Nazareth, Ethiopia
[2]Haramaya University, P O Box 138, Dire Dawa, Ethiopia

Abstract: The effect of two serotypes of *Bacillus thuringiensis (Bt)*, namely, *kurstaki* and *aizawai*, which are referred to as Dipel and Xen Tari by their trade name, respectively, neem seed water extract at the rate of 25 g (Neem 25) and 50 g (Neem 50) per liter of water, neem oil (Nimbecidine) and Karate (λ-cyhalothrin) were tested on diamondback moth (DBM) (*Plutella xylostella*) at two major cabbage growing areas, Melkassa and Wonji for two seasons, October 2005 to January 2006 and March 2006 to July 2006. Dipel, Xen Tari, Neem 25 and Neem 50 were effective in controlling DBM at both locations. As a result, the yield of cabbage improved; for instance at Wonji, marketable yield ranged from 33.4 to 35.1 ton ha^{-1}, for Neem 25, Neem 50, Xen Tari and Dipel treatments; while marketable yield ranged from 19.7 to 22.5 ton ha^{-1} for Karate and Nimbecidine. This finding indicates that the use of Bt and neem seed extract should be considered in an integrated management strategy for the diamond backmoth.

Keywords: *Bacillus thuringiensis; Brassica oleracea; Plutella xylostella; Azadirachta indica*

1. Introduction

The diamondback moth (DBM) (*Plutella xylostella* L.) (Lepidoptera: Plutellidae), is one of the most significant pests of cruciferous plants throughout the world and it has developed resistance to all insecticides widely used to control it (Talekar and Shelton, 1983). In some parts of the world, economic production of crucifer crops has become increasingly difficult due to insecticides' failure to control the pest (Metcalf, 1980). Extensive uses of non-selective insecticides, which kill DBM's natural enemies, particularly parasitoids, set the insect free of its biological control agents and help the insect to attain pest status in most parts of the world (Talekar and Shelton, 1983).

In addition to posing health problems, insecticides are frequently unavailable and are expensive for subsistence farmers in Africa. Environmentally safe and economically feasible DBM control practices need to be available. Use of *Bacillus thuringiensis* (*Bt*) and neem based products have proven successful in controlling insect pests in several parts of the world (Talekar and Shelton, 1983). In addition, these products are reported to be safe for natural enemies (parasitoids and predators) and, with less danger of development of resistance, are believed to form an important integral component of IPM program (Schmutterer, 1990). This study, reports on the efficacy of *Bacillus thuringiensis,* neem and a synthetic insecticide (Karate) in controlling DBM and improving cabbage yield.

2. Materials and Methods

2.1. Description of the Experimental Sites

The experiment was conducted at two major cabbage growing sites, Melkassa (8^o 24' N; 39^o 21' E, 1550 m above sea level.) and Wonji (8^o 27' N, 39^o 13' E, 1550 m above sea level) for two seasons, October 2005 and January 2006, and March 2006 to June 2006.

2.2. Cabbage Planting

Seeds of the cabbage (*Brassica oleracea* var. *capitata*) variety, Copenhagen Market, were used. During the first season, seeds were sown on seed bed (5 m^2) on September 5, 2005 and transplanted to the experimental plot on October 21 and 22, 2005 at Melkassa and Wonji, respectively. In the second season, seeds were sown on seed bed (5 m^2) on February 10, 2006 and transplanted to the experimental plot on March 13 and March 15, 2006 at Melkassa and Wonji, respectively. Seedlings were transplanted when they attained three to four true leaves. There were 10 rows per plot. Each row was 6 m long. The spacing between rows within a plot was 60 cm. The spacing between plants within a row was 40 cm. Spacing between plots within a block and between adjacent blocks were 1 m and 1.5 m, respectively. Plots were arranged in randomized complete block design (RCBD) with three replications.

At both locations, fields were irrigated twice per week for the first three to four weeks after transplanting and once weekly thereafter. Fields at Melkassa were fertilized with diammonium phosphate (DAP) and Urea at the rate of 200 and 100 kg /ha, respectively. The entire amount of DAP was applied just before transplanting, while urea was applied by splitting the total amount into two; half of the amount was applied one week after transplanting and the remaining half at the beginning of head formation. Weeding, cultivation and maintenance of ridges were carried out as needed.

2.3. The Treatments

The treatments were, Neem 25, Neem 50, Karate, Nimbecidine, Xen Tari, Dipel and untreated control (Table 1). Two serotypes of *Bacillus thuringiensis*, *kurstaki* and *aizawai* (named Dipel and Xen Tari, respectively) were brought from the International Center of Insect Physiology and Ecology (ICIPE), Nairobi. Neem Oil (Nimbecidine) and Karate were purchased from local pesticide traders.

*Corresponding author. E-mail: tadeletefera@yahoo.com

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Table 1. Description of treatments used against DBM at Wonji and Melkassa in 2005 and 2006 cropping seasons.

Treatment	Chemical group	Description	Rate of application
Neem 25	Botanical	Aqueous seed powder extract at the rate of 25 g/l	100 to 200 g of powder (dependent on the leaf cover)
Neem 50	Botanical	Aqueous seed extract at the rate of 50 g/l	200 to 400 g of powder (dependent on the leaf cover)
Neem oil (Nimbecidine®)	Botanical	A commercial preparation of seeds of *Azadirachta indica*	1500 ml/ 500 l of water
Karate 5 EC ® (λ-cyhalothrin)	Synthetic insecticide	a pyrethroid insecticide (Check)	320 ml/ ha
Dipel ® 2X	Microbial pesticide	*Bacillus thuringiensis* var. *kurstaki*. Wettable powder (WP)	0.5 kg/ ha
Xen Tari ™	Microbial pesticide	*Bacillus thuringiensis* var. *aizawai*. Water Dispersible Granule	0.5 kg/ ha
Water		Control	4 to 8 liters depend on leaf cover

Neem seeds were collected from neem trees grown in Dire Dawa, Eastern Ethiopia. To prepare the aqueous neem seed extract, one day before treatment, application seeds were crushed into fine powder using a wooden mortar and pestle, and sieved using wire mesh. The powder was mixed with water in a plastic container at the rate of 25 g powder (referred as Neem 25) and 50 g powder (referred as Neem 50) per liter of water. After mixing, the solution was stirred carefully until all powder aggregates were diluted and was left for about 12 hrs at room temperature (20-23 ^{0}C). The following morning the extract was filtered into the sprayer using plastic mesh. For each week's treatment, the total amount of neem seed powder mixed with water varied between 100 and 200 g for the lower rate and between 200 and 400 g for the higher rate, depending on the crop growth stage.

2.3. Treatment Application

Application of treatments started two weeks after transplanting. Treatments were applied weekly until about ten days before harvest. Spray was made using a manually operated Knapsack sprayer of 15 liters capacity with a flat fan nozzle. Sterile water was applied to the untreated control plot.

2.4. Data Collected

DBM population: To determine the effect of treatments, a day before treatment application, 10 randomly selected plants from the central six rows were examined for DBM larvae and pupae. The assessment continued weekly for nine weeks.

Leaf damage: At harvest, ten plants per plot were randomly tagged. Diamondback moth leaf damage score was taken based on a scale of 0 to 5 (0 = no leaf damaged; 1 = up to 20 % of the total leaf area damaged; 2 = 21-40% of the total leaf area damaged; 3 = 41-60% of the total leaf area damaged; 4 = 61-80 % of the total leaf area damaged; and 5 = more than 80 % leaf area damaged). Percentage leaf injury level was calculated based on the equation: $P = \frac{\sum(nv)}{5N} * 100$ (Iman *et al.,* 1990).

Where: P = percentage leaf injury level; n = total number of leaves in an infestation class; v = numerical value of infestation class 0 to 5 as described above and N = total number of leaves observed.

Yield: At harvest, marketable yield data were taken from the central six rows of each plot; the whole plant population in the six rows were assessed by removing the outer damaged leaves and discarding heads with less than 4 cm in diameter. The yield data of only the second season were collected.

2.5. Data Analysis

Number of DBM and percent leaf injury were log transformed to stabilize the variances. Yield data were not transformed. The data were subjected to analysis of variances. Mean separation was done using Student-Newman-Keuls Test (SNK). Back transformed means are presented. Data were analyzed using the statistical package SAS (SAS, 1999).

3. Results

3.1. Effects of Bt, neem and karate on Number of DBM and Leaf Injury

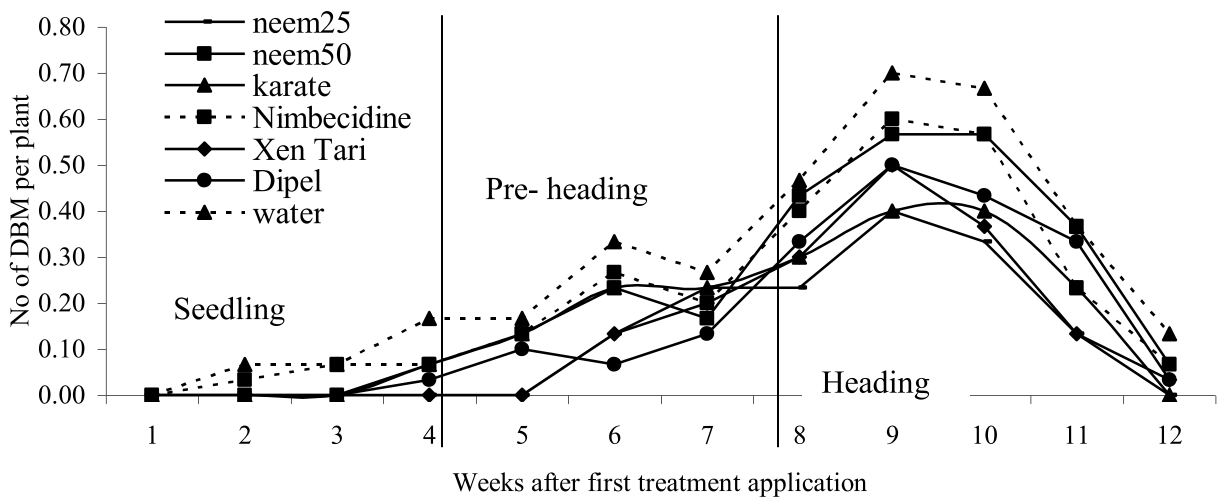
In the first season, from October 2005 to January 2006, the number of DBM at both locations was not high enough to cause significant differences between treatments (Table 2, Figureure 1 a and b). However, at Wonji, percentage leaf injury recorded from the Nimbecidine treated plot was higher than that of the Dipel treated plot.

Table 2. Mean number of diamondback moth per plant and percentage leaf injury on cabbage sprayed with neem, Bt and karate at Melkassa and Wonji, October 2005 to January 2006 (season-I).

Treatment	Melkassa		Wonji	
	Mean No. of DBM	Percentage leaf injury	Mean No. of DBM	Percentage leaf injury
Neem 25	0.23±0.07a	0.33±0.06a	0.10±0.03a	0.29±0.09ab
Neem 50	0.40±0.10a	0.26±0.10a	0.08±0.04a	0.24±0.06ab
Karate	0.30±0.04a	0.23±0.06a	0.14±0.09a	0.30±0.10ab
Nimbecidine	0.41±0.08a	0.28±0.06a	0.13±0.10a	0.33±0.06a
Xen Tari	0.39±0.04a	0.24±0.05a	0.01±0.01a	0.24±0.03ab
Dipel	0.26±0.11a	0.24±0.08a	0.07±0.03a	0.21±0.07b
Control (water)	0.52±0.09a	0.33±0.07a	0.10±0.04a	0.29±0.12ab

Means in a column followed by the same letter are not significantly different from each other at 5% significance level (Means were separated by Student-Newman-Keuls Test (SNK).

(a)



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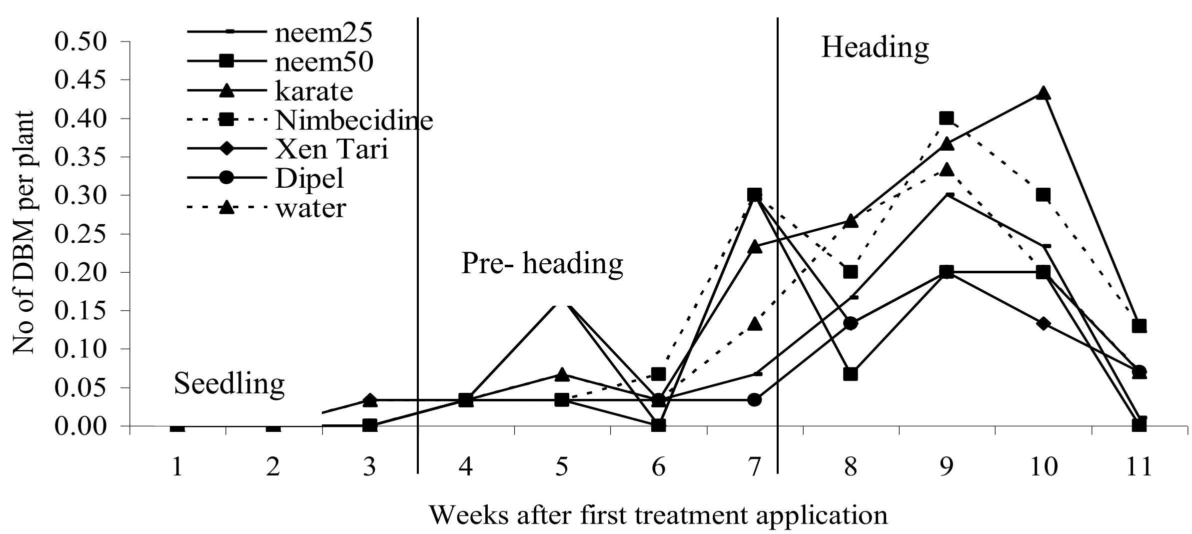


Figure 1. The effect of Neem, *Bacillus thuringiensis* and Karate on number of DBM at different crop growth stage at (a) Melkassa and (b) Wonji, from October 2005 to January 2006.

However, during the second season (March to July 2006**)**, at both locations, the number of DBM per plant varied among treatments throughout the sampling weeks (Figure. 2 a and b). At both locations, plots treated with Neem 50, Dipel and Xen Tari had the lowest number of DBM. Plots treated with Karate and Nimbicidine, however, had the highest number of DBM.

Significant differences ($P < 0.05$) were observed between treatments in the number of DBM per plant and percent leaf injury at both locations (Table 3). Plots treated with Neem 25, Neem 50, Xen Tari and Dipel, had the lowest number of DBM compared to the rest at both locations. Similarly, plots treated with Neem 50, Xen Tari and Dipel, had the lowest percent leaf injury. However, treatment with Karate and Nimbecidine appeared less effective and not apparently different from the control.

3.2. Effects of Bt, neem and karate on Marketable Yields of Cabbage

There were no significant differences ($P < 0.05$) between treatments in marketable yields at Melkassa (Table 4). However, there were significant differences ($P < 0.05$) between treatments in marketable yields at Wonji. The highest marketable yield was obtained from plots treated with Neem 25, Neem 50, Xen Tari and Dipel. Treatment with Karate and Nimbecidine, however, did not differ from the control.

Table 4. Marketable yield (tons per ha) of cabbage sprayed with different insecticides at Melkassa and Wonji, during season-II (March 2006 to July 2006).

Treatments	Melkassa	Wonji
Neem 25	20.66±3.96a	33.43±0.64a
Neem 50	25.84±4.83a	35.13±2.26a
Karate	22.03±3.96a	19.71±0.71b
Nimbecidine	15.95±3.97a	22.51±2.14b
Xen Tari	29.38±3.83a	34.09±0.13a
Dipel	23.67±3.73a	35.16±1.74a
Control (water)	22.35±1.99a	20.87±2.61b

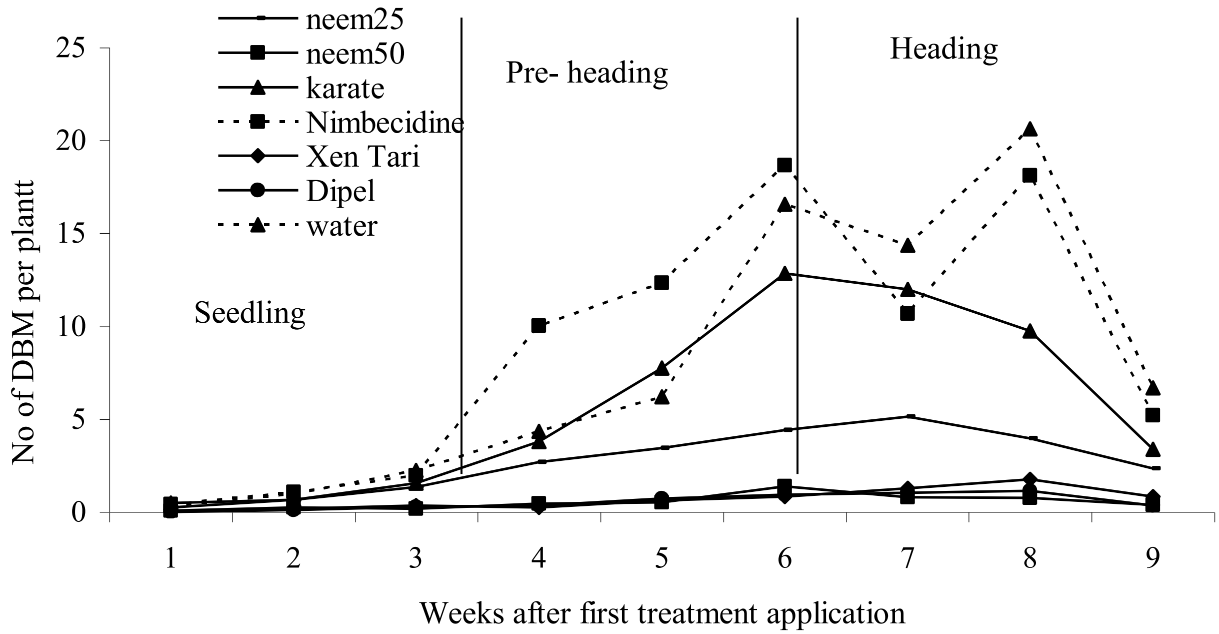
Means in a column followed by the same letter are not significantly different from each other at 5% significance level (Means were separated by Student-Newman-Keuls test (SNK).

Table 3. Mean number of Diamondback moth per plant and percentage leaf injury on cabbage sprayed with different insecticides at Melkassa and Wonji, March 2006 to July 2006 (season-II).

Treatment	Melkassa		Wonji	
	Mean No. of DBM	Percentage leaf injury	Mean No. of DBM	Percentage leaf injury
Neem 25	2.69±1.03c	10.70±2.32c	2.63±0.90c	14.4±3.61c
Neem 50	0.52±0.23c	1.00±0.06d	2.43±1.00d	6.11±1.36d
Karate	5.79±2.00b	16.00±5.08b	12.10±2.19a	35.10±4.53a
Nimbecidine	8.72±3.4a	19.20±4.40a	7.79±1.34b	25.6±6.11b
Xen Tari	0.67±0.23c	1.20±0.65d	0.68±0.37d	2.40±0.81d
Dipel	0.54±0.22c	1.40±0.46d	0.97±0.19d	6.78±2.33d
Control (water)	8.03±3.58a	17.00±4.25b	7.27±2.53b	23.20±3.15b

Means in a column followed by the same letter are not significantly different from each other at 5% significance level (Means were separated by Student-Newman-Keuls (SNK) test)

(a)



(b)

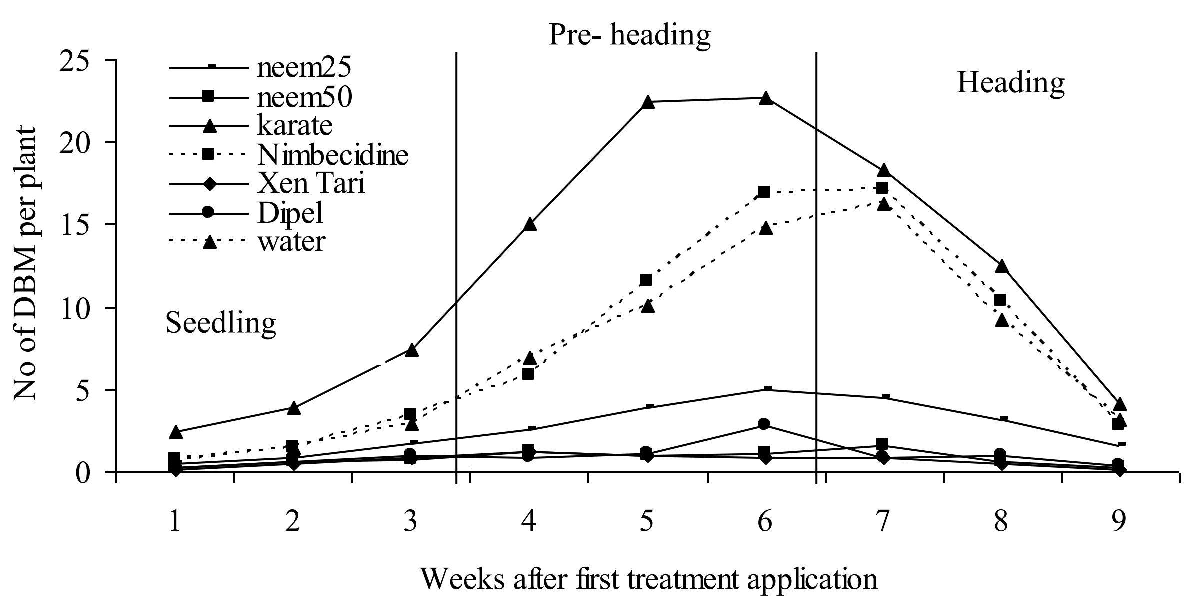


Figure 2. The effect of Neem, *Bacillus thuringiensis* and Karate on number of DBM at different crop growth at (a) Melkassa, and (b) Wonji, from March 2006 to July 2006.

4. Discussion

In general, at both locations, the population of DBM depended on cabbage growth stage. DBM showed a trend of high population during the pre-heading stage and low during the heading stage. In this study, treatment with neem seed extract and Bt had reduced the DBM population and leaf injury, and, as a result, the yield of cabbage was substantially improved. Schmutterer (1990) reported that aqueous neem extracts have proved to be effective in controlling those populations of DBM with high degrees of resistance to synthetic insecticides, even at low concentrations such as 12.5 g per liter; seed kernel extract was reported to reduce DBM adult fecundity by about 50 %. The good performance of neem in mitigating DBM infestation in areas where insecticides failed to provide control has also been reported by other researchers (Okoth, 1998; Goudegnon *et al*., 2000).

Though it is difficult to explain the observed high DBM number and percent injury level on Nimbecidine treated plots, similar reports have been made by Charleston *et al.* (2006). They observed a high level of DBM population on plots treated with a commercial preparation of *Azadirachta indica*, called Neemix 4.5® which was even higher than the untreated plot at a later stage of crop growth. Schmutterer (1990) also reported a better performance of water extracted lower concentration of neem seed kernel than formulated metanolic extract (AZT-VR-K-EC) in minimizing DBM damage.

The two Bt based products were highly effective against DBM. Tabashnik (1994) and Bauer (1995) reported that *Bt*-based products are the most promising alternative to conventional insecticides because they are highly toxic to certain pests and are compatible with IPM strategies due to their narrow host specificity, high amenability to genetic engineering, and because they cause little or no harm to humans, most beneficial insects and other non–target organisms.

The poor performance of Karate may be attributed to the presence of Karate resistant DBM population or Karate might have affected DBM natural enemies as Karate had been in use in the study areas for several years (Gashawbeza and Ogol, 2006). Frequent presence of pyrethroid resistance gene(s) in the population of DBM was reported when the pyrethroid was introduced (Hama, 1990). Host plant availability and action of its natural enemies are two key biotic factors which regulate DBM populations in the field (Harcourt, 1985). In many countries, synthetic insecticides are used to control DBM, which often eliminates natural enemies. This, in turn, can lead to continued intensive use of insecticides, eventually insecticide resistance and control failure (Sarfraz *et al.* 2005). Rowell *et al.* (2005) explained the higher DBM larval densities in the cypermetrin treated plots as a consequence of resistance to this commonly used insecticide and the probable distraction of non-resistant natural enemies.

In conclusion, neem seed extract and Bt should be encouraged for the integrated management of DBM as an alternative to synthetic insecticides.

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Registration of *Guta* Barley (*Hordeium vulgare* L.) Variety for Bale Highlands

Ayalneh Tilahun, Zerihun Jalata* and Amare Biftu

Sinana Agricultural Research Center, P O Box 208, Bale-Robe, Ethiopia

Abstract: *Guta* is a common name for this barley (*Hordeium vulgare* L.) variety with a pedigree designation of Acc.3260-18. The variety has been developed and released by Sinana agricultural research center for commercial production in the highlands of Bale. It has been tested at Sinana, Agarfa, Robe and Adaba major barley growing areas during 2003-2005 years and showed better performances in grain yield over local variety, *Aruso* and standard variety, *Shage*. Thus, the variety has shown high mean grain yield and relatively stable across locations and years. It also showed comparable responses to net blotch, scald and barley leaf rust diseases as compared to *Aruso*, but it appears that *Guta* was less resistant to these barley diseases as compared to *Shage* may be due to its earliness. On the other hand, as observed during evaluation *Guta* possess resistance or tolerance to barley shoot fly insect than *Shage;* and exhibit compensatory growth after shootfly damage and these needs further research. The early maturing characteristics of the variety suits to the different cropping systems in the area and give better adoption potential by the local farmers.

Keywords: *Guta*; Barley (*Hordeium vulgare* L); Yield Performance; Early Maturity

1. Introduction

Guta (Acc.3260-18) barley (*Hordeum vulgare* L.) variety is food barley variety released in 2007 under Oromia Agricultural Research Institute by Sinana Agricultural Research Center. It was originally developed from Ethiopian barley landrace collections and selected by pure line selection methods at Sinana Agricultural Research Center (SARC) in barley landrace enhancement program to develop a variety with high yielding potential and other better agronomic traits. The material has been evaluated together with other genotypes in different breeding nurseries from 2000-2002 and then advanced to variety trial to see its varietal performance across locations and years in barley producing areas of Bale highland. The variety was officially released as commercial production in Bale highlands after approval by the Ethiopian National Variety Release Committee in accordance with the guidelines of the national variety release system and variety registration of the country. Breeder seed and foundation seed of the variety is maintained by SARC.

2. Evaluation

Guta (Acc.3260-18) was tested together with 20 barley genotypes including checks in regional variety trial at 12 environments in major barley producing areas in Bale highlands during 2003- 2005 consecutive years. *Guta* was evaluated along with *Aruso* and *Shage* as the local and standard variety, respectively at altitudinal range of 2400-3000 meter above sea level at Sinana, Agarfa, Adaba and Robe locations in each year. Since there is high shoot fly presence in these areas, the variety together with other genotypes and checks was checked frequently for shoot fly resistance or tolerance under natural condition at hot spot areas before advanced to variety trials (by visual observation) as shoot fly damage is easily identified and the effect is usually seen as stunt growth and reduced yield.

3. Varietal Characteristics

Guta is early maturing and six-rowed variety with erect growth habit. The variety matures with an average of 103 days which is more than two weeks earlier in maturity than the standard variety, *Shage* (Table 1) so that it can utilize moisture more efficiently. This short maturing habit is preferred by the local community as it can be produced efficiently with in the two main cropping seasons, *Ganna* (March-July) and *Bona* (August-December). It is also characterized by better resistance/tolerance to main biological insect pest (shoot fly) than specially the standard variety (*Shage*) (visual observation); and showed rapid compensatory growth after damage by the insect. The variety is tall with average height of 93 cm. The average days to heading and maturity is 58 and 103, respectively. On the other hand, seed color is grey and has average thousand-kernel weight of 33.2 g (Table 1).

4. Yield and Stability Performance

The results of the evaluation indicated important information regarding variety performance and stability. Thus, grain yield performance of the released barley variety and checks is described below in Table (1). During evaluation seasons, the overall location mean grain yield of this variety was better than all genotype means. Beside this, *Guta* was higher in mean grain yield over check varieties, exceeding by 21% and 4.5% over *shage* (standard variety) and *Aruso* (local variety), respectively. On research field *Guta* gave yield ranging from 2.4 to 4.9 t/ha, whereas 2.0 to 4.3 t/ha on farmers' field. In addition, stability analysis was done on grain yield using three years (2003-2005) data. According to joint regression model, a variety with high mean yield, regression coefficient (bi) of unity and with deviation from regression (S^2di) =0 is stable (Eberhart and Russell, 1966). In this regard, *Guta* is stable variety with high mean grain yield, regression coefficient (bi) of 1.07 which is nearly unity and deviation from regression of 0.02 which is equivalent to zero. Therefore, it has shown stable yield performance across locations of evaluation as well as higher mean grain yield over check varieties (*Shage* and *Aruso*).

*Corresponding author. E-mail: jaluu_z@yahoo.com

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5. Disease Reaction

Data recording was done for all genotypes including this variety for major barley diseases such as net blotch (*Pyrenophora teres* Drechs.), scald (*Rhynchosporium secalis* Oud.) and barley leaf rust (*Puccinia hordei* Otth) at across all environments (Table 1). Data was taken at 51-69 plant growth stages (Zadoks *et al.*, 1974) across locations. Both diseases, net blotch and scald were scored using 00-99 double digit scale (Saari and Prescot,1975) in such a way that the first digit indicate the spread of disease in a plot (% incidence) and the second digit indicate the percentage of leaf area infected (% severity),i.e 1 = <10%, 2 = 10-20%, 3 = 20-30%, 4 = 30-40%, 5 = 40-50%, 6 = 50-60%, 7 = 60-70%, 8 = 70-80% and 9 = >80%. Whereas, barley leaf rust data was collected based on Stubs *et al.*(1986) methodology. Thus, it was observed that the disease responses of the early maturing candidate variety (*Guta*) to the above three diseases was comparable with local (*Arsuo*) variety; however, it appears that *Guta* was less resistant to these major barley diseases as compared to *Shage* (standard variety) which is late maturing type. Similarily, Parlevliet and Moseman (1986) and Getaneh *et al.*(1999) indicated in their reports as early maturing barley lines showed less resistance to leaf rust than late types. And, Yitbarek *et al.* (1998) also found early maturing barley populations as less resistant to net bloch and scald disease due to escaping mechanisms by late maturing types. Michael *et al.* (1989) reported positive relationship between earliness and grain yield.

6. Farmers Evaluation of the Variety

To evaluate the perception and preferences of the local farmers, farmers' participatory barley variety evaluation and selection was conducted at five representative sites in Bale highlands during 2007 *Bona* cropping season. Farmers made selection and evaluation individually and in-group. In this evaluation, 12 released varieties were included together with *Guta*. Among the best barley varieties ranked from one to four during selection is presented in Table 2. in this regard, *Guta* was almost selected or ranked as first variety preferred by the local farmers mainly due to its yield performance, early maturity, productive tillers and relatively disease free than other varieties tested.

7. Adaptation

Guta variety is recommended for production in the highlands of Bale with annual rainfall of about 590 mm in the *Ganna* and 560 mm in *Bona* season (Hailu *et al.*, 1996). Nevertheless, the variety can be adapted to other regions or areas with similar agro-ecologies through adaptation. It can best suit to the two main growing seasons in the area due to its early maturity and suitable in a sense that harvesting of the variety in the *Ganna* season could be followed by planting pulse crops during the *Bona* as rotation. On black soils, 50 kg DAP (diammonium phosphate) fertilizer is recommended to give good yield and with 125 kg seed rate. In addition, the variety can be planted early March for *Ganna* season and early August for *Bona* season.

Table 1. Overall mean grain yield, other important agronomic traits and disease reaction of *Guta* (Acc.3260-18) barley variety and checks across locations and years.

No.	Variety	Row type	DH	DM	PH (cm)	TKW (gm)	HLW (kg/hl)	NB (00-99)	Scald (00-99)	LR (Rxn)	GY (t/ha)
1	Acc.3260-18	six	58	103	93	33.2	61.6	83	82	40MS	2.3
2	Aruso (L. Vty)	irreg.	61	107	92	35.1	62	80	82	40MS	2.2
3	Shage (St.Vty)	six	67	119	88	35.5	60	61	61	5MS	1.9

DH=Days to heading, DM=Days to maturity, PH=Plant height, TKW=Thousand kernel weight, NB=Net Blotch, LR =Leaf Rust, Rxn=Reaction, HLW=hectoliter weight, kg/hl= Kilogram hectoliter^{-1},t/ha= ton hectare^{-1}, irreg.=irregular, St.Vty=standard variety, L.Vty=local variety & GY=Grain Yield.

Table 2. Farmers' rankings of best barley varieties at different five sites in Bale highlands.

Variety	Sites				
	Salka IV	Salka III	Salka II	Ilani	Rataba
Guta	1(2)	1(1)	1(1)	1(1)	1
Dinsho	2(1)	3 (2)	-	3(2)	4
Biftu	3	4	4	2(3)	2
Harbu	4	2	2(2)	4(4)	3
Dafo	(3)	5(3)	3	-	-
Meserach	-	-	- (3)	-	4

The number in the parenthesis indicate the rank given by farmers in group selection

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Registration of *Urjii*, Field Pea Variety for Bale Highlands, Ethiopia

Tadele Tadesse* and Edosa Fikru

Sinana Agricultural Research Center, P O Box 208, Bale-Robe, Ethiopia

Abstract: *Urjii* (Acc. 32615-1) a semi-erect white seeded field pea variety has been selected and developed by Sinana Agricultural Research Center. The variety was released in 2007 for Bale highlands and similar agro-ecologies. This variety was tested in a regional variety trial in 12 environments, at four locations (Sinana, Sinja, Selka and Agarfa) in the highlands of Bale for three consecutive years (2003/04 to 2005/06). Due to its superior performance *Urjii* was selected and verified at four locations during bona 2006/07 cropping season and, there after, released for production. This variety is characterized by a white seed coat, with a high yield and yield advantage of 6.62% and 23.2% over the standard and local checks respectively. It is stable, adapts well, has a large number of pods per plant, thousand seed weight, and is moderately tolerant to powdery mildew, downey mildew and ascochyta blight.

Keywords: *Urjii*; Variety Registration

1. Introduction

Urjii (Acc. 32615-1) is a field pea variety developed and released in 2007 by Sinana Agricultural Research Center. It was originally obtained from locally collected germplasm. It was tested at Sinana on-station in a preliminary and advanced observation nursery and regional preliminary yield before the regional variety trial was conducted. After the regional variety trial had been conducted for three consecutive years (2003/04 to 2005/06), *Urjii* was verified over locations and evaluated by the National Variety Releasing Committee as per the guideline of the variety releasing and registration of the country during the 2007 cropping season.

2. Evaluation

One hundred test lines were tested for the first time in a preliminary observation nursery in the 2000/01 cropping season at Sinana on-station. Out of these, 49 of them were retained for further evaluation and tested in 2001 as advanced observation nursery and promising test lines from an advanced observation nursery and were promoted to be evaluated in a yield trial in 2002. Finally, twenty test lines were promoted to a regional variety trial. In the regional variety trial, *Urjii* (Acc. 32615-1) was evaluated in 12 environments (4 locations x 3 years) along with Weyitu (standard check) and local check both at Sinana on-station and on-farmers field (nine sites) in the highlands of Bale from 2003/04 to 2005/06 in major field pea production areas having an altitude of 1800-2600 m.a.sl and with an annual rainfall of 750 mm to 1000 mm.

3. Varietal Characters

Urjii is a semi-erect white seeded field pea variety. On average, this variety needs 70 days for flowering, and 127 days to reach physiological maturity. It has a plant height of 119 cm. It has a white seed coat with yellow cotyledon and a white flower. The average weight of a thousand seeds is 178.49 g. On average, it produces 13 pods with medium length (Table 1).

4. Yield Performance

The average seed yield of *Urjii* combined over locations and over years is 4.16 t/ha, which is higher than Weyitu (standard check 3.9 t/ha), and the local check (3.3 t/ha). The variety provides a seed yield of 4.9 t/ha to 5.5 t/ha on the research field and 3.5 t/ha to 3.7 t/ha on the farmers' field. This variety has a yield advantage of 6.62% and 23.20% over the standard and local checks, respectively.

5. Reaction to Disease

The major field pea diseases according to their importance in the growing areas are powdery mildew *(Erysiphe polygoni)*, downey mildew *(Peronospora pisi) and* Aschochyta blight (*Mycosphaerella pinnodes*) (Asfaw *et al*., 1993). On a 1-9 rating scale, *Urjii* scored a mean of 3 for all the above mentioned diseases. The variety is characterized by moderately resistance types of reaction to these major diseases at all the sites. The disease score for the variety and the checks are summarized in Table 1.

Table 1. Mean grain yield, other agronomic traits and disease reaction of *Urjii* and the checks in multi-location testing, 2003/4-2005/06.

Entry	Days to flower	Days to maturity	Plant height (cm)	No Pods /plant	1000 Seed wt (g)	Disease score (1-9)[a] PM. DM. ASCBLT			Mean grain yield (t/ha)		
									On-station [b]	On-farm [c]	Mean [d]
Urjii (Acc. 32615-1	70	127	119	13	178.42	3	3	3	5.50	3.71	4.16
Weyitu	68	128	125	9	183.10	6	6	6	5.04	3.52	3.90
Local check	68	127	128	11	126.57	7	7	7	4.76	2.92	3.38
Mean	69	127	124	11	163.00						

Note PM = Powdery Mildew; DM =Downey Mildew; ASBLT = Ascochyta blight

[a] *Disease score based on 1-9 scale where 1 is highly resisitance and 9 is highly susceptible*

[b] *Average grain yield of research field for 3 environment (1 location x 3 years)*

c Average grain yield of on farm for 9 environment (3 locations x 3 yeas)

*Corresponding author. E-mail: tadeletadesse@yahoo.com

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6. Quality

The variety is preferred to a greater extent for *kik* rather than *shiro*. It is preferred both by consumers and producers due to its white seed color.

7. Adaptation

Urjii is released for the highlands of Bale. It performs very well in areas with an altitude of 1800 to 2600 m.a.s.l and an annual rain fall of 750 to 1000 mm. It could also be possible to extend the production of this variety to other areas with similar agro-ecologies. This variety gives a better grain yield if produced with a recommended fertilizer rate of 100 kg DAP/ha and with a seed rate of 75 kg/ha in clay-loam soil. For better performance of the variety, planting should be done from the end of July to early August in Meher and at the end of March during the Belg season.

8. Variety Maintenance

The Breeder and foundation seed of the variety is maintained by Sinana Agricultural research Center.

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