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Full Length Research Paper

Factors shaping on-farm genetic resources of sorghum [*Sorghum bicolor* (L.) Moench] in the centre of diversity, Ethiopia

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Ethiopia is cited as one of the centres of sorghum diversity. In order to assess the on-farm genetic resources management of sorghum various research methodologies were employed. These were focus group interviews with 360 farmers, key informant interviews with 60 farmers and development agents and semi-structured interviews with 250 farmers. Besides, diversity fair was done with over 1200 farmers. For quantifying on-farm diversity, direct on-farm monitoring and participation with 120 farmers were made. Quantification of varietal diversity per farm was counted by a participatory zigzag sampling in the diagonal direction of the plot with the farmer and all encountered varieties were counted. Soil samples were taken from 120 farms and were subjected to analyses of soil pH, P, available nitrogen, organic matter and exchangeable potassium. Altitude and other related climatic data were collected. The number of varieties conserved by farmers ranged from one to twenty per farm and this is affected by socio-economic and biophysical factors. The mean numbers of 8.3 and 6.3 varieties were grown by *Oromo* and *Amhara* farmers respectively. The minimum and maximum range did not vary for both ethnic groups. There was no significant difference in the number of varieties held by various wealth groups. With respect to farm size as explained by the quadratic model, it significantly accounted and predicted for the variation in the number of varieties. The role of soil pH, P, available nitrogen, organic matter, and exchangeable potassium on-farm genetic diversity is described. P was a positive limiting factor for varietal diversity. As to the effect of crop ecology, there were higher number of varieties in the intermediate altitudes than in the lowland and highland. Both the quadratic and linear equation expressed that distance from the house and town and showed non-significant relationship to the number of varieties planted per farm. Varietal mixture is one of the strategies used by the farmers for improved on-farm genetic diversity management. Farmers' underlying principles for conserving genetic diversity is described. Three models developed, namely; Bioecogeographic genetic diversity model, Farmer induced genetic diversity model and Farmer-cum-bioecogeographic genetic diversity model are explaining the processes shaping on-farm genetic diversity of sorghum in Ethiopia.

Key words: Biophysical factors, farmer varieties, germplasm, genetic diversity, genetic diversity model, socio-economic factors, on-farm.

INTRODUCTION

The United Nations Convention on Biological Diversity (UNEP, 1992) defines biodiversity as 'the variability among living organisms from all sources, including terrestrial, marine and the ecological complexes of which they are part.' Agro-biodiversity encompasses the variety and variability of plants, animals, micro-organisms at genetic, species and ecosystem level which are necessary to sustain key functions in the agro-ecosystem, its structure and processes for, and in support of food production and food security (FAO, 1999). Food security and biodiversity

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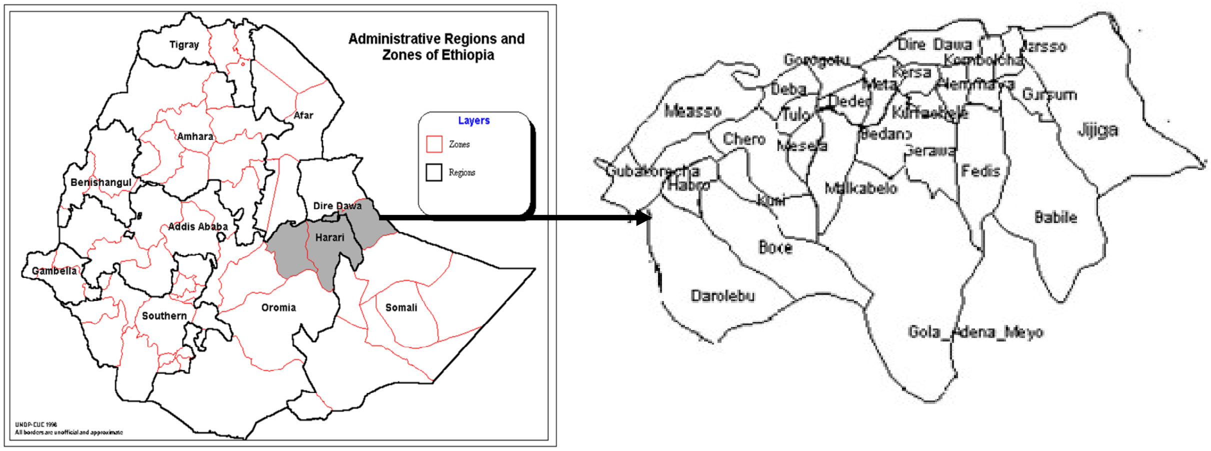

Figure 1. Position and map of the study site in Ethiopia. Detail wereda map of the study region.

are the most obvious current challenges of the century (Wilkes, 1988). Agro-biodiversity has spatial, temporal, and scale dimensions especially at agro-ecosystem levels. These agro-ecosystems are determined by three sets of factors, namely the genetic resources, the physical environment, and human management practices.

The Ethiopian region is characterised by a wide range of agro-climatic conditions, which account for the enormous resources of agro-biodiversity that exist in the country (Worede, 1992). The most important of these resources is the immense genetic diversity of the various crop plants in the country. The genetic diversity are contained in traditional varieties and modern cultivars, as well as crop wild relatives and other wild species.

Ethiopia is identified as one of the eight gene centres of crops (Vavilov, 1951). Many crops such as *Tef* (*Eragrostis tef*), *Noog* (*Guizotia abyssinica*), *Gesho* (*Rhamus prinoides*), *Enset* (*Enset ventricosum*), Coffee (*Coffee arabica*) and *Khat* (*Chata edulis*) are supposed to have originated in Ethiopia (Harlan, 1969). Vavilov (1951) indicated that about 38 species are connected with Ethiopia as primary or secondary gene centre. Crops which developed wide genetic diversity in Ethiopia include cereals such as barley, sorghum, durum wheat, *tef*, finger millet, pearl millet; oil crops such as Ethiopian mustard, noog, linseed, sesame, safflower; and pulses such as faba bean, field pea, chickpea, lentil, cowpea, fenugreek, and grasspea.

Doggett (1988) suggested that sorghum is domesticated and originated in the North-East quadrant of Africa, most likely in the Ethiopian-Sudan border. The presence of wild sorghums and their cultivated forms and their ecotype differentiation of sorghum into different races and their presence in different parts of the country supports that Ethiopia is one of the centre of origin and diversity for sorghum. Sorghum is produced in Ethiopia on an area of 1,468,070 ha with a total production of 2,173,598 Mt (CSA, 2006) and worldwide on 43,727,353ha with a total production of 58,884,425 Mt (FAO, 2005). In view of the enormous diversity, various germplasm collections have been made. These collections have been characterised and evaluated at the Ethiopian Institute for Biodiversity Conservation and Research (IBCR) and different national and international research centres in and outside the country, which has resulted in identifying desirable accessions with useful traits for direct use or crossing programmes (Gebrekidan and Kebede, 1977).

Crop on-farm genetic diversity is a function of socio-cultural, economic, physical and biological factors. The tremendous interplay of these factors shapes and affects extent and prevalence of on-farm genetic diversity in various crops (Hawkes, 1983; Hernandez, 1993; Brush, 2000; Gaston, 2000; Zimmerer, 1991).

Despite the fact that Ethiopia is endowed with vast production and diversity of sorghum enhanced by farmers' amazing contribution for sorghum domestication and development, factors affecting on-farm genetic diversity has not been studied exhaustively in the region. How to quantify on-farm genetic diversity? What is the level of on-farm genetic diversity? What are the bio-physical factors affecting the regional sorghum diversity? What are the socio-economic factors affecting on-farm genetic diversity? What modalities can be suggested for the process and factors shaping the prevalent on-farm genetic diversity? Hence, the objectives of this study were to assess (i) the level and quantity of on-farm genetic diversity, (ii) factors affecting on-farm genetic diversity, and (iii) to suggest models shaping on-farm genetic diversity.

MATERIALS AND METHODS

Eastern Ethiopia (Figure 1) has been selected for the following reasons: (i) sorghum is the first food crop in the region in area, production and importance, (ii) the region is one of the micro-centres of diversity for sorghum and, hence, ideal sites for studying on-farm genetic diversity management, (iii) the production of Indigenous sorghum in the diverse ecologies (altitude, rainfall, soil type, landscape etc.,) helps to assess the diversity management versus envi-

Table 1. Range and mean number of varieties as affected by ecology and plot size.

Sites (Wereda)	Ecology	Total plot size*†	Range of number of varieties	Mean number of varieties
Dire Dawa	Lowland	7.90	7-19	7.60
Babile	Lowland	5.05	1-12	6.95
Alemaya	Intermediate	5.00	5-20	11.35
Hirna (I)	Intermediate	5.28	5-12	8.30
Hirna (H)	Highland	8.75	5-15	5.65
Girawa	Highland	11.13	2-11	8.30

*=Significant at 5% and NS=Non Significant at 5%; †plot size is in *timmad.* 1ha=8 t*immad.*

ronmental factors, (iv) the diverse social, cultural and economic conditions prevalent in the region helps to tap the Technical Knowledge (ITK) associated with the crop and, (v) there is a diverse cropping system, namely, mono-cropping, intercropping associated with pulses and other cereals, alley-cropping with different perennial crops, which need a *de facto* diversity to fit into the different cropping system.

In order to assess farmers' management of on-farm genetic diversity, survey research was undertaken. These were, focused group interviews with 360 farmers; on- farm monitoring and participation with 120 farmers; key informant interviews with 60 farmers and development agents, and semi-structured interviews with 250 farmers.

Diversity fair was one of the tools employed for assessing and inventorying on- farm genetic diversity. This was done around physiological maturity of the crop. An average of 50 farmers participated in the 24 of the diversity fairs that is, a total of 1200 farmers. Both women and men brought all the varieties grown in their field to the fair and discussed prevalence, distribution and importance of each variety.

In order to quantify on-farm genetic diversity, in all the directly monitored farms a participatory zigzag sampling in the diagonal direction of the plot was made with the 120 directly on-farm monitored farmers. All encountered varieties were counted. For varieties in the field that were not encountered in the course of monitoring, discussion was made with the farmer. This is needed because of the variation in the type of varietal mixture grown over the field. Samples were then taken from each variety for on station assessment of farm genetic diversity for both quantitative and qualitative traits.

For soil sampling and characterisation, the same plots amounting to 120 were selected randomly with crop history of having sorghum mono-cropping for at least two years. A soil sampling auger was used to collect surface soil samples (depth: 0 - 30 cm plow layer) around crop physiological maturity. Samples (3 - 5) were taken from various representative points (up to 5) of the farm plots and were composited (bulked). The samples were air-dried and sieved in 2 and 1 mm sieves for soil texture using the pipette method; Soil pH was measured in water at a ratio of 1:1; available phosphorus (P) using the Mehlich method (1960); available nitrogen (NH_4^+-N and No_3^-N) using Bremner method (1960); organic matter using Black and Walkey method (1947), and exchangeable potassium (K) in flame photometer after leaching with NH_4OAc.

Climatic data of rainfall and temperature for Haramaya, Gerawa and Dire Dawa was obtained from Haramaya Univ. weather station, National metrology organization and Dire Dawa office of the Bureau of Agriculture respectively. Altitude of the sites was measured with GPS and altimeter. Collected data were subjected to descriptive statistics, analysis of variance, log-linear regression, cluster, and discriminant analysis using STATSTICA, SPSS version 10 and MINITAB Ver. 14 statistical softwares.

RESULTS AND DISCUSSION

On-farm genetic diversity

Genetic diversity is usually thought of as the amount of genetic variability among individuals of a variety or populations of species (Brown, 1983). The genetic diversity on-farm in eastern Ethiopia is highly dictated by social, cultural, economic, biological and environmental factors. These factors varied considerably across the study sites, which influenced the type of *de facto* prevalent diversity in each sites. As Rao and Hodgkin (2002) indicated genetic diversity can be seen as a defence against problems caused by genetic vulnerability. Farmers have built this defence into Farmer Varieties (FVs) over years and hence it is essential to harness these defence mechanisms into Improved Varieties (IVs). Genetic diversity is the farmers' basis for survival and adaptation. It caters for complex, diverse, and risk-prone environments in the region.

The level and type of diversity, as measured in the number of varieties per farm, varied from one Farmers' Association (FA) into another within one wereda and among the weredas (Table 1). This is because of the variation in the aforementioned factors. There was significant variation for on-farm genetic diversity across FA. The mean range of diversity is from 1 to 20. The highest mean number per wereda level was observed for Alemaya (11.35) and the lowest was for Hirna highland (5.65).

However, as to the diversity at community, FA level, it is much larger than the number of varieties owned by individual farmers in the community. This may suggest that there is a variation in the type of varieties grown by each farmer. Even the maximum number of varieties owned by the farmers falls short of the village total. In this study ten farmers per village were selected in order to quantify village level diversity.

Farmers do rank their varieties differently for level of varietal diversity, multiple value, stability and area coverage (Table 2). The varieties identified by ranking varied both by *wereda* and ecology. In Dire Dawa (Bishan Bihe, FA), Babile (Kitto FA), Alemaya, and Girawa the varieties rated for diversity, multiple value, stability and area coverage were similar. On the contrary, different varieties are

Table 2. On-farm rating of farmers' variety for diversity, multiple value, stability, and area coverage.

Sites	FA	Ecology	Diversity	Multiple value	Stability	Area coverage
Dire Dawa	Aseleso	Lowland	*Jeldi*	*Jeldi*	*Shashemene*	*Jeldi*
	Bishan Bihe	Lowland	*Muyra*	*Muyra*	*Muyra*	*Muyra*
Babile	Likale	Lowland	*Chamme*	*Bullo*	*Bullo*	*Bullo*
	Kitto	Lowland	*Bullo*	*Bullo*	*Bullo*	*Bullo*
Alemaya	Dangago	Intermediate	*Fendisha*	*Fendisha*	*Fendisha*	*Fendisha*
	Fendisha	Intermediate	*Fendisha*	*Fendisha*	*Fendisha*	*Fendisha*
Hirna (I)	Belena	Intermediate	*Wegere*	*Gebabe*	*Cheffere*	*Gebabe*
	Cheffe	Intermediate	*Daslee*	*Cheffere*	*Cheffere*	*Cheffere*
Hirna (H)	Ades	Highland	*Fechee*	*Fechee*	*Gebabe*	*Gebabe*
	BurkaGudina	Highland	*Fendisha*	*Fendisha*	*Gebabe*	*Fendisha*
Girawa	Lencha	Highland	*Muyra*	*Muyra*	*Muyra*	*Muyra*
	Hundolafto	Highland	*Cheffere*	*Cheffere*	*Cheffere*	*Cheffere*

I=Intermediate Ecology; H=Highland Ecolog

selected for the other *weredas* and FAs. The ranking points at two issues: first, the need to focus at specific (local) adaptation breeding and to make a specific recommendation and, second, the smallest environment and socio-economic unit for genetic resources collection and diversity analysis should be the Farmers Association.

Farmers' rating of on-farm variability

Farmers consider sorghum not just as sorghum *per se* but more than that, as 'a monument' or 'a mountain' with a lot of associated memories and anecdotes (Mekbib, 2007a).

Farmers have rated the prevalent on-farm diversity as high (6%), medium (38.8%) and low (55.2%). Based on the results of semi-structured interviews, farmers were in need of more diversity. Probably, this emanated from an under-estimation of on-farm genetic diversity in the FA, *wereda* or at regional level. As it can be seen in Table 1, the range of varieties grown by individual farmers in one farmers association varied very much as compared to the mean number grown in each FA. Hence, two scenarios are evident here: the number of varieties grown by an individual farmer can be greater than the mean number available in the community or the total holding of the number of varieties present in the community will be normally greater than any of the individual holdings. Based on the type of varieties, very commonly the type of varieties is more in the community than in the individuals. In both cases, there is freely available diversity for the farmers to use. This infra-specific on-farm sorghum genetic diversity results from the interplay between demand and supply for the diversity at the individual and community level. This demand arises from farmers' diverse interests and concerns that include: various growing environments, coping with production risks, multiple needs, biotic and abiotic stress (Mekbib, 2006).

Based on the qualitative assessment, farmers indicated that they have 'enough' varieties on-farm. However, if they get a different and interesting variety they would like to have it as a component to the existing varietal portfolio. They do maintain their varieties intentionally and commonly preserve them as seed or as panicle near to the kitchen or in a pit (Mekbib, 2007b). The choice of varieties can be seen as a process by which farmers assemble various bundles of traits to suit specific production conditions, consumption preferences, or marketing requirements.

Effect of wealth and ethnic group on on-farm genetic diversity

The two dominant ethnic groups encountered in the course of on-farm monitoring were *Oromo* and *Amhara* farmers, of which Oromo comprises 85.8% and *Amhara* comprises less than 14.2%. There was a significant difference ($p > 0.05$) in the number of varieties held by the two ethnic groups. The mean number of 8.3 and 6.3 varieties were grown by *Oromo* and *Amhara* farmers respectively. It is a common scenario that indigenous people conserve more varieties than immigrated ones. The minimum and maximum range did not vary for both ethnic groups. Even, there was no significant difference in the number of varieties held by various wealth groups. This is not in agreement with what Bellon (1996) has suggested. The largest diversity is not either with rich farmers. However, there were differences in types of varieties among farmers depending on specific sorghum growing conditions. The mean number was 8.45, 7.94 and 7.80 for rich, average and poor farmers respectively. Even though there was a significant variation in the land size holdings among rich (11.42 *timmad*), average (6.21 *timmad*) and poor (3.87 *timmad*), this was not reflected in the number of varieties grown. 1 ha amounts to 8 timmad. This finding is in disagreement with Hernandez (1993) findings in maize in Mexico where an inverse rela-

Table 3. Descriptive statistics of the factors affecting on-farm varietal diversity.

Factors	Min.	Max.	Mean	Std. Dev
Number of varieties				
Highland	1	12	6.98	2.88
Intermediate	5	20	9.83	3.37
Lowland	2	15	7.28	2.51
Plot size (*timmad*)	2	24	7.18	4.05
Altitude (m asl)	1190	2530	1965	364
Farm distance (km)				
House	0.005	20	0.63	2.11
Market	0.01	21	8.78	5.16
Sand (%)	1.00	74.00	16.83	9.51
Silt (%)	14.00	52.00	34.09	9.22
Clay (%)	11.00	68.00	50.32	10.19
pH (1:1)	6.00	7.90	6.96	0.44
NH_4 -N (ppm)	4.00	29.00	14.05	6.02
No_3-N (ppm)	8.00	90.00	20.85	12.76
P (ppm)	0.00	78.00	24.38	16.03
K (meq/100 gm soil)	0.104	2.59	0.54	0.41
Organic Matter (%)	0.57	10.05	3.76	2.26

tionship existed between genetic variation of crops and the economic resources of farmers. Hence, rural people with limited financial resources typically maintain a greater diversity of crops and varieties than more market-oriented ones as in the case of bean growers in Mexico.

Eco-geographical (bio-physical and agro-climatic) factors affecting diversity

There are many biological, climatic and physical factors that affected on-farm genetic diversity in eastern Ethiopia. These were farm size, yield, altitude, rainfall, temperature and various edaphic factors. On-farm genetic diversity was affected considerably through the individual and interaction effects of these factors. The mean, minimum, maximum and range values of the various ecogeographical and socio-economic factors are shown in Table 3. Details of the role of each factor are discussed under each sub-heading.

Effect of farm size (plot) on diversity

As the varietal mixture is a tradition of the sorghum farming system in Ethiopia, the number of named varieties grown is used to quantify on-farm diversity. *Simpson varietal diversity* could not be made because it was very difficult to proportionate the area allocated to the number of varieties grown on-farm.

The range of farm size sampled ranged from 2 *timmad* (0.25 ha) to 24 *timmad* (3 ha) (Table 3). It varied from the lowland to the highland. The size was very large in the lowland but it became less in size in the highlands because of higher population density in the latter. Farm size-diversity relation curve (Figure 2) indicates that the number of varieties increased to a certain level then it curved down. However, there was a variation in the number of varieties grown by individual farmers. Commonly there is higher number of varieties in the community in the FA than in the hands of individual farmers. Few exceptional farmers retained most of the varieties grown in the community.

The quadratic model explained the relationship between plot size and number of varieties properly. The plot size the number of varieties. However, the linear model did not explain the relationship significantly.

Hawkes (1983) indicated that a smaller area in traditional crops reduces diversity. However, as long as some areas continue to be planted in FVs, the relationship between area and diversity is complicated by the population structure of FVs and by the role of conscious (artificial) selection not by plot size *per se*. On the other hand, Teshome et al. (1999) showed that the diversity of the smallest field approached that of the largest ones. The same pattern was also observed in eastern Ethiopia. The overall size of a farm is not significantly correlated with diversity because of conscious selection and management of diversity (Table 5), which agreed with the findings of Brush (1992). This vividly indicated that area-diversity relationship in crops is complicated by conscious selection and management of crop populations. Hence many more factors besides variety number are needed to explain the pattern of relationship.

Soil physico-chemical property and diversity relationship

The on-farm sorghum diversity, both in number and type, affects nutrient cycling and utilization. The presence of many varieties in a particular field is associated with efficient utilization of resources. This is because of the significantly accounted and predicted for the variation in variation in growth, phenology and development of the mixed varieties. Hence, with increased number of varieties there must be totally less nutrient available though it might vary from spot to spot because of the variation of varietal mixture components in the fields. Similarly leaching of nutrients will be very less as we increase the number of mixed varieties. Farmers have noted the variation among varieties for nutrient uptake, for example, *Fendisha* has been rated by the farmers as 'the heavy nutrient miner' compared to the other varieties. In general, in eastern Ethiopia, the diversity of sorghum grows on the range of soil types having various levels of pH, Organic Matter, Silt, Clay, Sand, N, P and K. There is a variation for silt, sand, NH_4^+N, K and OM (Table 4).

pH

Many soil properties and processes are affected by soil

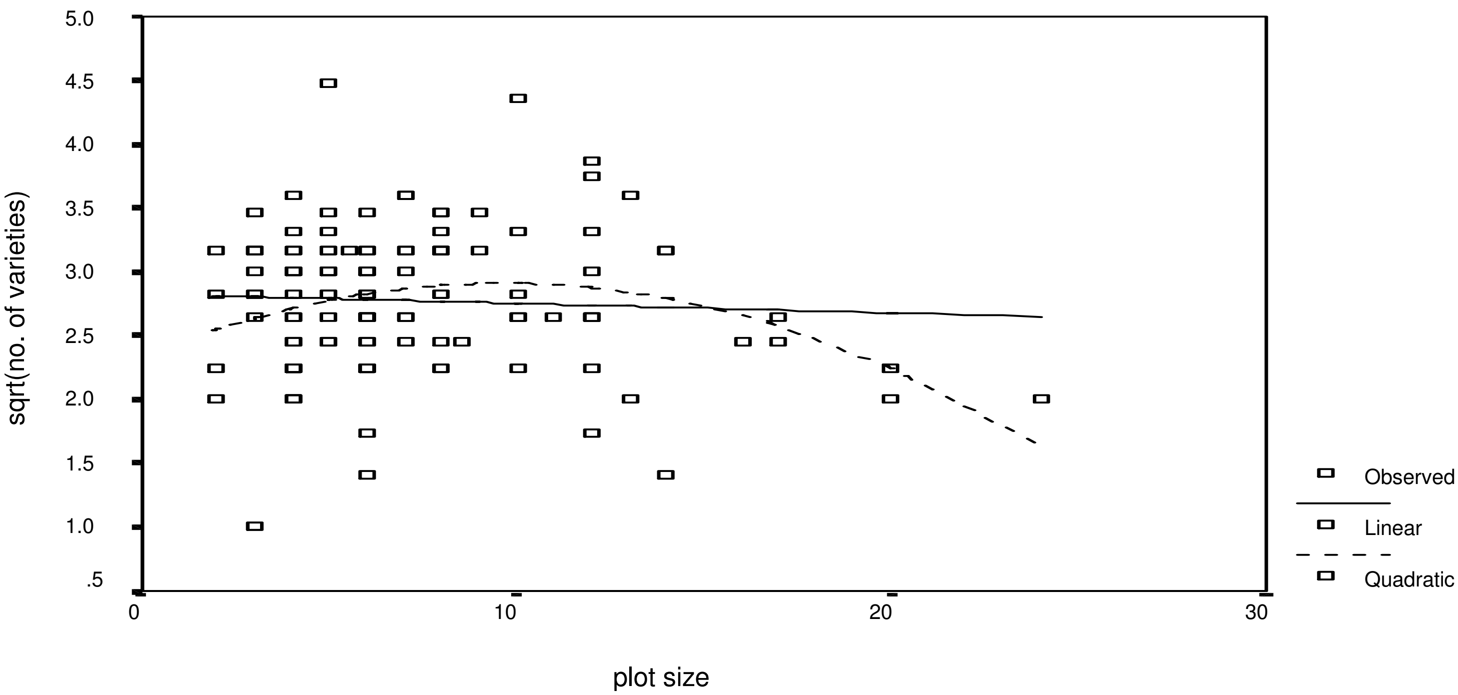

Figure 2. Effect of plot size on number of varieties. Quadratic: sqrt (no. of var.) = 2.34 + 0.119 plot -0.006 plot^2. R^2 = 0.099 and significant at 1%.

Table 4. Mean variation of soil property by ecology

Ecology	Clay (%) (NS)	Silt* (%)	Sand* (%)	pH* (1:1)	Phosphorus in ppm (NS)	NH_4+-N (ppm)*	K (meq/ 100 gm soil)*	$N0_3$-N in ppm (NS)	OM (*) (%)	Soil texture group†
Highland	52.03	36.50	11.65	6.85 sl. acidic	23.68	18.70	0.77	23.18	4.45	Clay to Clay loam
Intermediate	47.75	38.45	16.73	7.14 sl. alkaline	28.20	12.68	0.42	18.78	4.56	Clay Loam
Lowland	51.24	26.76	22.54	6.89 sl. acidic	21.03	10.51	0.41	20.60	2.16	Clay loam to Sandy Clay

NS=non significant at 5% and *=significant at 5%; †-according to soil texture triangle. Actually, this must be done by FA for precision .It is provided here as an information.

more alkaline than the other two ecologies. Nevertheless, the mean range is within that of the sorghum pH requirement. The pH is positively correlated with P (0.255), N (NH_4-N) (-0.273*) and $N0_3$ –N (-0.317*) but not with diversity (Table 5).

Available nitrogen

Available nitrogen measured in ammonium and nitrate form ranged from 4 to 29 and 8 to 90 ppm respectively (Table 3). This wide range of values is due to the variation in the amount of organic matter, which upon mineralization give to Nitrogen and variation in fertility management and cropping systems. The available nitrogen in the ammonium form, but not in the nitrate form, is significantly different in the various ecologies (Table 4) where we have the highest in the highlands followed by intermediate and then in the lowlands. This corresponds to the amount of biomass production in the same. Nitrogen was negatively correlated with pH. N increases with organic matter content and hence organic matter is correlated with N (NH_4) (0.409*) and $N0_3$ (0.397*) but not with diversity (Table 5).

Potassium (exchangeable)

The values obtained here ranges from 0.104 to 2.59 (meq/100 gm soil) (Table 3). However, low K does not mean that the low amount of K but it can be associated with Ca and Mg. There was significantly higher variation for K in the highland as compared to the intermediate and

Table 5. Pearson correlations for the factors affecting on-farm genetic diversity

	No. of var	Plot size	Altitude	Yield	Dist. house	Dist. town	Clay	Silt	Sand	pH	P	NH_4	K	No_3	OM
No. of var	x														
Plot size	-0.053	x													
Altitude	-0.036	-0.450*	x												
Yield	-0.020	0.616*	-0.195*	x											
Dist. house	0.119	0.142*	-0149	-0.082	x										
Dist. town	0.079	0.203*	-0.294*	0.224*	0.109	x									
Clay	-0.024	0.030	0.141	0.086	0.105	0.112	X								
Silt	0.112	-0.205	0.193*	-0.083	-0.045	0.109	-0.457*	x							
Sand	0.002	0.243*	-0.379*	-0.004	-0.098	-0.112	-0.608*	-0.337*	x						
pH	0.158	0.110	-0.029	0.153	-0.070	0.216*	-0.049	0.225*	-0.002	x					
P	0.240*	0.015	-0.017	0.102	0.039	0.388*	-0.003	0.184*	-0.076	0.255*	x				
NH_4	-.0.279*	-0.299*	0.465*	-0.178	-0.055	-0.369*	0.012	0.131	-0.232	-0.273*	-0.147	x			
K	-0.384*	-0.141	0.256*	-0.062	-0.064	-0.115	0.002	0.103	-0.170	0.019	-0.059	0.368*	X		
$N0_3$	-0.094	-0.125*	0.136	-0151	-0.054	-0.124	0.110	0.08	-0.291*	-0.317*	-0.101	0.691*	0.309*	X	
OM	-0.012	-0.344	0.397*	-0121	-0138	-0.335*	-0.190	0.257*	-0.077	-0.301	-0.166	0.409*	0.212*	0.397*	X

*significant at 5%

the lowland (Table 4). Hence, more K fertilization is required in the same. Potassium is negatively correlated (-0.384*) with number of varieties but it is positively correlated with altitude (0.256*) and Nitrogen (NH_4) (0.368*) (Table 5).

Available P

The P content varies from soil to soil and region to region. On average, the total P content in surface soils ranges from 50 to 80 mg p/100 g (Stevenson, 1986). A Phosphorus content of 50mg/100g is equivalent to 1120 kg p/ha. In the sampled sites, the available P ranged from nil to 78 ppm (Table 3). This showed the wide range of available P. There is a variation in the P availability in the lowlands, intermediate and highlands. P is more available both in the intermediate than in the highlands and lowland ones (Table 4). The most appropriate level depends on the type of varieties and soils. The low level of P requires application of P based fertilizers such as DAP. Hence, more P fertilization is needed in both highlands and lowlands. P is positively correlated with number of varieties (0.240*), distance from town (0.388), silt (0.184*) and pH (0.255*) (Table 5).

Organic matter

In general, the decomposed fraction of soil organic matter or the humus in the region ranged from 0.57 - 10.05% (Table 3) and the mean organic matter content for highlands, intermediate and lowlands is 4.45, 4.56 and 2.16% respectively (Table 4). The low organic matter in the lowlands is due to high mineralisation rates as a result of high temperature. Hence, more application of inorganic and organic fertilizers to enrich the organic matter content of sorghum growing soils is imperative in particular in the lowlands. Organic matter is positively correlated with altitude (0.397*), silt (0.257*), NH_4 (0.409*), K (0.212*), $N0_3$ (0.397) and negatively correlated with farm distance from the town (-0.335*) (Table 5).

Soil texture

Sand, silt and clay ranged from 1 - 74%, 14 - 52% and 11 - 68% respectively (Table 3). Sand and silt but not clay fraction of sorghum growing soils is significantly different in the three ecologies (Table 4). The sand fraction is more in the lowlands and silt proportion is high in the intermediate altitudes. Hence, the soil texture is more coarse in the lowlands and heavy in the intermediate and high altitude areas. Clay is negatively correlated with silt

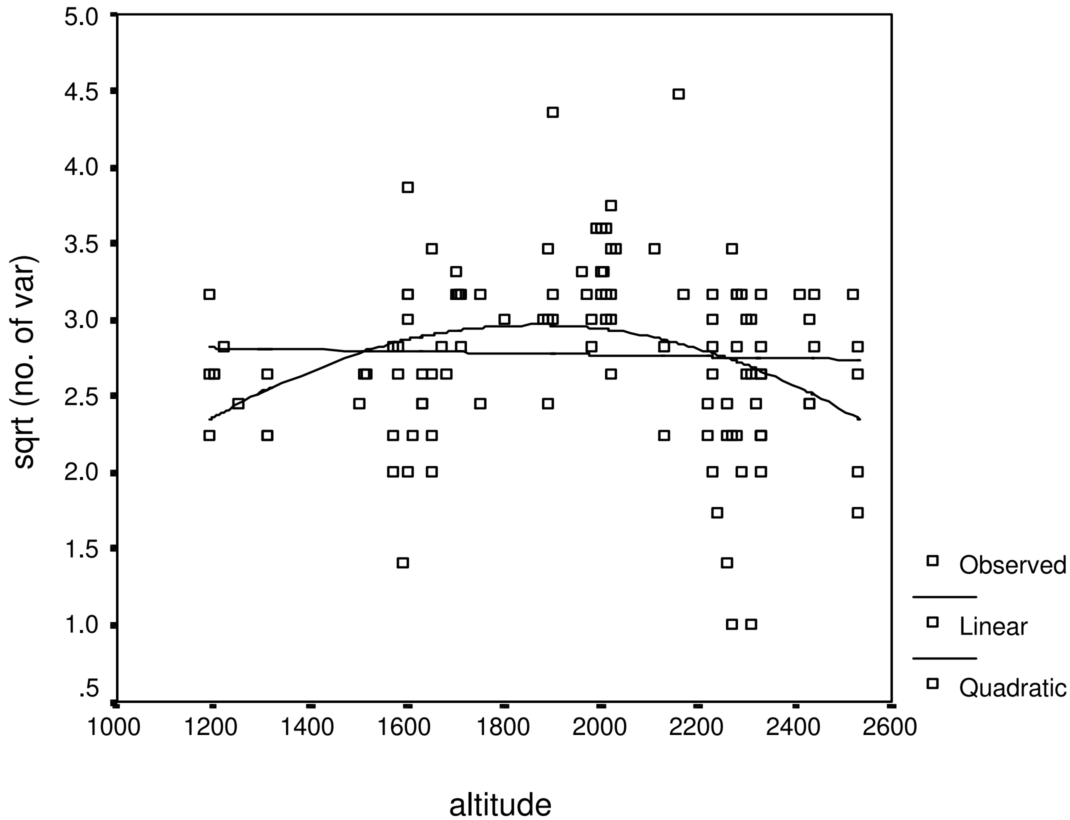

Figure 3. Effect of altitude on number of varieties on-farm. Sqrt (diversity) = -1.81 + 0.05 alt -0.00001 alt^2. R^2 = 0.099. Linear and quadratic terms are significant at 1%. The linear model did not express significantly relationship between altitude and diversity.

(-0.457*). Silt is correlated with altitude (0.193*). Sand is correlated with plot size (0.243*), altitude (-0.379*), clay (-0.608*) and silt (-0.337*) (Table 5).

Effect of altitude on diversity

Altitude is a proxy variable for cropping systems, rainfall, and temperature, thus it affects crop growth and development. Altitude has an impact on diversity in Ethiopia. The altitude of the sampled sites ranged from 1190 to 2530 m asl (Table 3). The lowest diversity occurred in the highland and lowland; where the highest was in the intermediate (Figure 3).

Unlike the global trend, where sorghum is grown in the dry lowlands, in eastern Ethiopia it is also partly grown over 3000 m asl which is the highest altitude sorghum is growing in the world and is reported for the first time**.** The high altitude chains of mountains in eastern Ethiopia are where cold-tolerant sorghums are extensively grown. In view of this sorghum diversity did not decline expecting that sorghum is a C_4 plant and grows less in low temperature areas. This is not a surprising scenario to be encountered in the centre of diversity.

Sorghum varieties such as *Merturasse, Gebabe, Cheffere, Fendisha, Sheffere* and *Chiquere* are dominant varieties grown in this cold chain of mountains (Mekbib, 2006). The reason why sorghum diversity is lower in the lowlands is because the genetic base of lowland sorghum is narrow in Ethiopia (Gebrekidan, 1981). It is assumed in this study that sorghum moved from the intermediate to both highland and lowlands through ecotype differentiation (Mekbib, 2007b).

There is a higher number of varieties in the intermediate altitudes as compared to the others. This might be attributed to the availability of energy and water at the same time in which case energy is limited in the highlands and water is scanty in the lowlands (Gaston, 2000). Altitude is negatively correlated with yield (-0.195*), distance from town (-0.294*), and sand (-0.379*). It is positively correlated with silt (0.193*), NH_4 (0.465*), K (0.256*) and organic matter (0.397*) (Table 8 and 5).

Effect of climate on varietal diversity

Diversity is also a function of climate (rainfall and temperature) (Table 6). The climatic factor is signified in describing bioecogeographical modality of diversity. The more the climate is conducive, the more the diversity is. In the context of eastern Ethiopia, the intermediate altitude is the conducive ecological regimes for sorghum

Table 6. Effect of rainfall and temperature on number of varieties.

Weredas		Mean Annual rainfall	Mean annual temperature			Mean no. of varieties
			Min	Max	Ave	
Alemaya	Long term*	880	10.9	23.2	17.1	11.35
	Year 2000	713.3	9.27	24.03	16.68	
Dire Dawa (Aseleso)	Long term**	576	18.2	31.3	24.8	7.60
	Year 2000	471.1	15.19	25.79	20.49	
Girawa	Long term**	1108.5	12.5	22.5	17.5	8.30
	Year 2000	1075.8	10.0	25.6	17.8	

**Long-term average.

production. For instance, in the intermediate altitude, Alemaya, rainfall and temperature is so conducive that high numbers of varieties were prevalent on-farm. As indicated in Mekbib (2007a), agriculture thereby sorghum farming moved from the intermediate to the highland and lowlands. Number of varieties was correlated with annual rainfall (0.897), minimum temperature (-0.939*), maximum temperature (-0.781) and average temperature (-0.883). But this indicates that favourable sorghum growing environment should not include very low temperature, this is due to the physiological characteristics of sorghum. This is corroborated by high level of on-farm genetic diversity in the intermediate altitudes compared with other ecologies.

Effect of farm distance on diversity

The farm distance from the house and market were 0.005 to 20 km and 0.01 to 21 km respectively (Table 4). Farm distance and yield were related. The yield is very high for farmers near to the house as farm plots do receive good management, but the number of varieties did not vary between those who are far and those who are near to both the house and the market.

Both the quadratic and linear equation expressed that distance from the house and the town showed non-significant relationship to the number of varieties planted per farm. Farm distance from the house was correlated with plot size (0.142*). Farm distance from the market was correlated with plot size (0.203*), altitude (-0.294*), yield (0.224*) and organic matter (-0.335*) (Table 5).

Varietal mixture for management of on-farm genetic diversity

Varietal mixture is described as one of the important methods for management of on-farm genetic diversity. As genetic diversity management method, it cuts across most of the farmers and crop ecologies. When selections are made by the farmers, in particular those who do mass selection (both simple and modified) and bulk selection, the varietal portfolio is managed accordingly form one cropping season into another. This varietal portfolio is dictated by farmer needs and prevailing bio-physical and socio-economic environments (Mekbib, 2008b). The varietal portfolio varied in the highlands, midlands, and lowlands. It varied also across farmers in the same community. Even if sometimes the type of varieties present in the farming community are the same, the proportion of each component varied by the individual farmers. The culture of growing varietal mixtures is one of the important factors for improved crop evolution. Crop evolution of the cultivated sorghum is linked to the mixture of species and genotypes which promotes hybridisation and crossing among the different types (Mekbib, 2008b). Besides heterogeneous fields, farmers do maintain also more uniform plantings.

The varietal mixture, in Ethiopia, as on-farm genetic diversity management measure bestows the following benefits:

1) It allows gene flow through introgression among cultivated sorghum races.
2) It allows gene flow through introgression between cultivated and wild plants. This can be witnessed by the presence of 'shatter cane' *Harchatee* (*Keelo* or Fool)–a wild cultivated cross in most farmers fields.
3) Reduces pest and disease epidemics thereby reduces genetic vulnerability and promotes stability.
4) Confers resistance for abiotic stresses, thereby maintains the variety that could be wiped out in mono-varietal cropping due to disease and pest epidemics.
5) It maintains the temporal and spatial diversity thereby reduces genetic vulnerability over time and space.
6) The diverse topography in the region also allowed the maintenance of different sets of varietal mixtures in the various ecological and cropping systems niches. The rugged and undulating mountains and gorges reduce gene flow but promote geographical isolation and genotypic differentiation. This is a gene isolation, which results in the genetic differentiation thereby creating spatially diversified sets of varietal mixture.
7) Varietal mixture is one of the strategies for resisting

Table 7. Eigen values of the correlation matrix and the proportion and total of variance explained by the five largest principal components.

Principal Components	Eigen values	% total Variance	Cumulative Eigen values	Cumulative. %
PC1	5.23	34.80	5.23	34.84
PC2	2.99	19.97	8.22	54.80
PC3	2.45	16.35	10.67	71.16
PC4	1.46	9.72	12.13	80.88
PC5	1.09	7.24	13.22	88.12

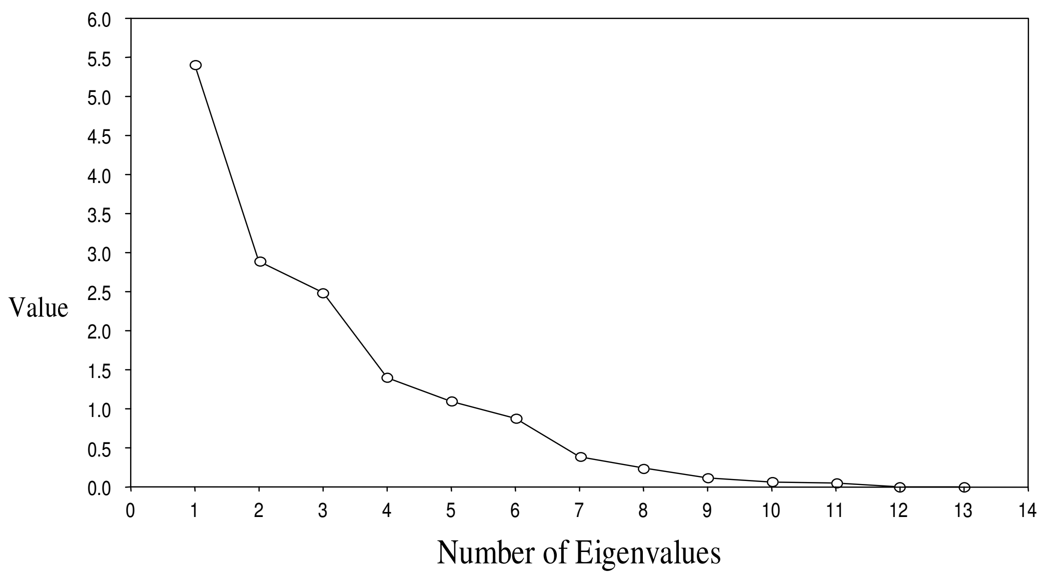

Figure 4. Plot of Eigen values.

genetic erosion at varietal, gene or DNA level. Even if a variety is lost from the varietal mixture the gene or a part of the genetic makeup of the variety lost can be found with other varieties in the varietal mixture. Out-crossing seems to be a strategy for sorghum better to resist genetic erosion since a whole range of genes will be naturally spread through out the population and hence it might be difficult to say genetic erosion has occurred at the gene level. However, this needs to be verified by molecular data.

8) It meets the multi-need of the farmers that emanates from infra-specific genetic diversity.

MULTIVARIATE ANALYSIS: CLUSTER, PCA AND DISCRIMINANT ANALYSIS

Principal component analysis

The biological values of the principal components are explained in Table 8. PC1 is explained more by K and Sand. PC2 is explained more by P, pH and number of varieties. PC3 is explained more by farm distance from the house and market. PC4 by clay and silt. PC5 by yield, plot size and altitude.

The PC1, PC2, PC3, PC4 and PC5 explain 34.8, 19.9, 16.4, 9.71 and 7.24% respectively of the overall variance (Table 7). All the five principal components together explain 88% of the overall variance while the remaining principal components explain the rest of 12% of the overall variance. This is also partly explained by the graph of the *Eigen* values where the five principal components elaborate most of the variation in the sampled on-farm sites (Figure 4).

The PCA plot (Figure 5) indicated graphically the correlation evident among the variables (Table 5) where number of varieties, P and pH are around the same region, while yield, distance from the market and plot size are the other groups and altitude, organic matter and nitrogen are also related.

Cluster analysis

Clustering the 12 FAs, based on the factors shaping diversity, from five *weredas* has resulted in their usual expected ecological grouping (Figure 6). With the exception of *Cheffe* FA from the intermediate altitude was clustered into the highland FA group, all the other FAs are classified within their ecological domains. This is

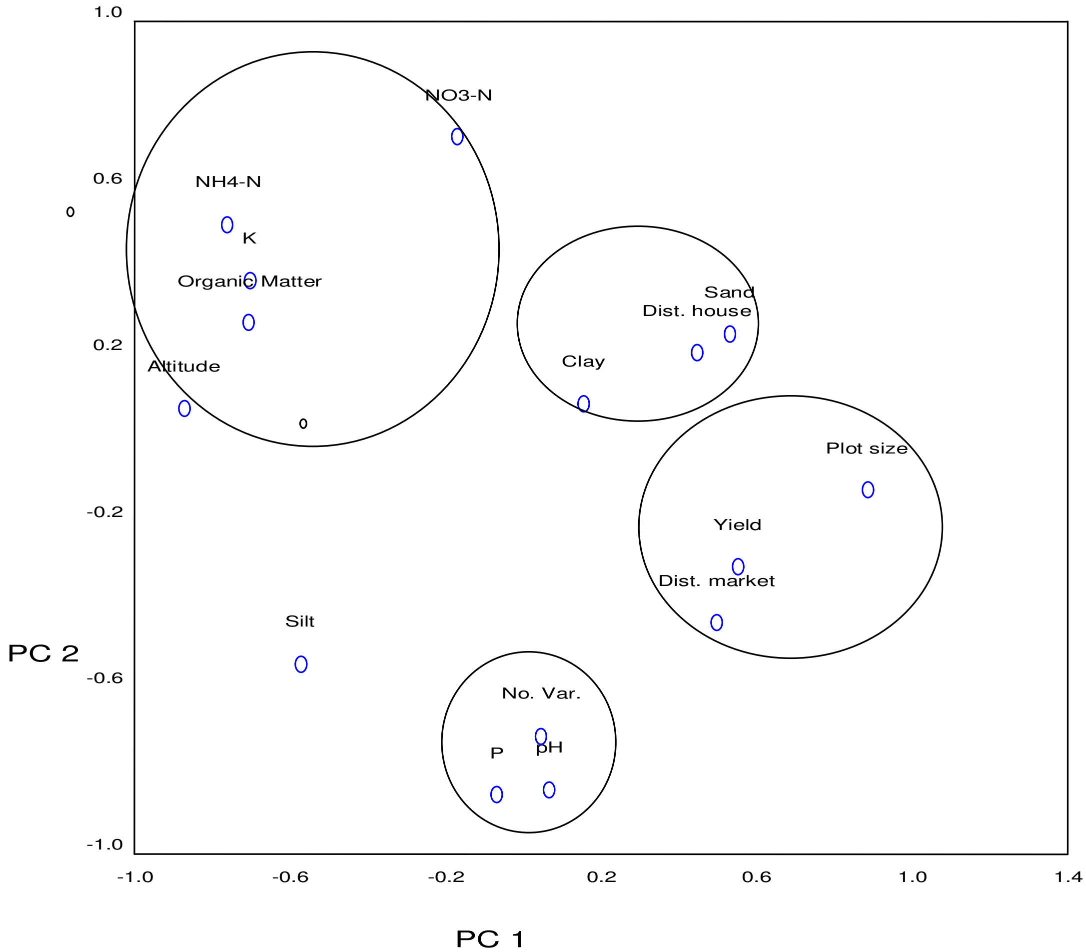

Figure 5. Plot of PC 1 and PC2 for various factors affecting diversity.

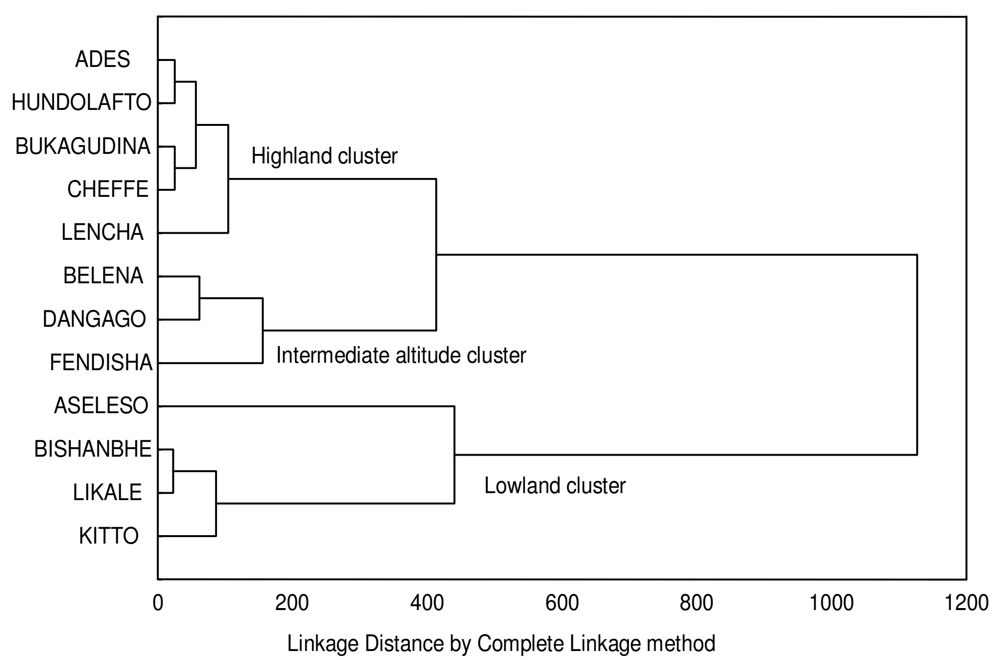

Figure 6. Cluster analysis of on-farm monitored 12 FAs of the six weredas.

Table 8. Eigenvectors of the principal components representing a linear combination of the original variables based on the mean data.

Factors	PC1	PC2	PC3	PC4	PC5
Plot size	-0.568	0.062	0.110	0.075	-0.779
Altitude	0.595	-0.098	-0.476	0.175	0.546
Yield	-0.015	-0.139	0.181	0.160	-0.812
Dist. house	-0.032	0.129	0.952	0.151	0.015
Dist. mark	0.051	-0.392	0.772	0.030	-0.433
Clay	0.275	-0.104	0.091	0.917	-0.221
Silt	0.476	-0.350	-0.114	-0.752	0.018
Sand	-0.873	0.296	-0.003	-0.254	0.085
pH	0.017	-0.789	0.034	-0.151	-0.270
P	0.186	-0.891	0.206	-0.062	-0.087
NH_4-N	0.742	0.484	-0.143	-0.038	0.384
K	0.788	0.374	0.089	-0.145	0.336
NO_3-N	0.193	0.456	0.289	0.531	0.546
OM	0.369	0.260	-0.473	-0.191	0.429
No. Var.	-0.315	-0.851	-0.128	0.075	0.159
Expl. Var	3.223	3.215	2.191	1.930	2.658
Prop.Totl	0.215	0.214	0.146	0.129	0.177

Table 9. Classification results of the samples of on-farm monitored farmers using discriminant analysis.

		Ecological regions	Predicted Group Membership			Total
			Highland	Intermediate	Lowland	
Original	Count	Highland	38	2	0	40
		Intermediate	8	32	0	40
		Lowland	0	1	39	40
	%	Highland	95.0	5.0	.0	100.0
		Intermediate	20.0	80.0	.0	100.0
		Lowland	.0	2.5	97.5	100.0

90.8% of original grouped cases correctly classified.

expected because *Cheffe* FA is closer to the high altitude ecology.

Discriminant analysis

The classification of the on-farm sampled sites into highland, intermediate and lowland (Figure 6) was 90.8% correct (Table 9). Hence future genetic resources management related studies have to follow ecologically based sampling strategy.

Modalities for explaining the factors that shape on-farm genetic diversity

The diversity, as quantified by the total number of varieties per farm, expresses on-farm genetic diversity which may refer to any of the following: *average diversity* (the diversity among cultivars grown in any specified region unweighted by the cultivar areas), *temporal diversity* (α-diversity) (a measure of change in diversity over time), *spatial diversity* (β-diversity) (a measure of a change of diversity over space), *resource diversity* (the total diversity available as genetic resources to plant breeders, *ex situ* and *in situ*, and in primary, secondary and tertiary gene pools) (Harlan and deWet, 1971). The largest gene-pool is found in the silently shrinking landraces and folk varieties of indigenous and peasant agriculture (Brush et al., 1981). By the same token, increasingly, the centres of genetic diversity for crop plants have become the mega-gene bank seed storage facilities (Wilkes, 1988). These were also evident in eastern Ethiopia.

As indicated above, a considerable level of diversity prevails on-farm. Why is this diversity present? What is the deriving force behind for the prevalence of on-farm diversity? Is the diversity prevalence for its own sake of diversity only? Is it nature-driven or farmers-influenced or both? What concept can explain the pattern of on-farm diversity? The models indicated below have been suggested in order to answer the aforementioned questions.

The enormous on-farm sorghum genetic diversity present in eastern Ethiopia can be explained by three modalities suggested. These three models are the first comprehensive models ever suggested to describe sufficiently the factors and process for prevalence of on-farm genetic diversity.

Bio-eco-geographic diversity model: This model explains that the diversity present in eastern Ethiopia is due to the fact that sorghum is grown in diverse ecological and geographic ranges and the in-built biological nature of the crop. Ecologically, it spans from the dry lowlands of Dire Dawa, Medico and Darolabu to the cool high rainfall highlands of Girawa and Hirna and this has resulted in the presence of various races, hybrid races, ecotypes and varieties. The differentiation of races over altitudes and clinal variation of traits over ecological ranges are casted by multitudes of eco-geographic factors (Mekbib, 2007a, 2008a). In the wider context of sorghum cultivation in Ethiopia, the micro-centres are partly due to the various eco-geographic factors. This model explains the presence of diversity through various bio-eco-geographic factors; namely, rainfall, temperature, LGP (Length of Growing Period), edaphic factors, wind for introgression, the topography for gene isolation and differentiation. Hence, the on-farm genetic diversity present in the region is partly explained by eco-geographic diversity model and biological nature of the crop *per se*. This model embodies all the natural causes (spatial scale and biological characteristics of the crop) of diversity. The significant variation for number of varieties across ecological ranges and FAs (Table 1) is partly explained by the eco-geographic diversity model. Introgression, gene flow and gene isolation are some of biological mechanism of the crop coupled with eco-geographical factors that shapes on-farm genetic diversity. This is in agreement with Hawkes (1983) who indicated that genetic diversity within most if not all cultivated crops is presumed to have arisen as the result of hybridisation and introgression among cultivated and wild species. The rugged topography, the undulating hills and valley bottoms in the region has resulted in the enhancement of on-farm genetic diversity. The eco-geographical approaches for molecular, biochemical, and morphological diversity has been studied on various crops in general and sorghum in particular (Aldrich et al., 1992; Deu et al., 1994; Rao et al., 1996; Dje et al., 1998; Ayana and Bekele, 2000).

Farmer induced genetic diversity model: This model includes all the human factors responsible for selection, production, storage and utilization of sorghum as an enhancing factor for the presence of diversity on-farm. The presence of a wide range of Ethnic groups (*Oromo, Amhara, Somali, Argoba*), cultural and social factors continuously shapes and enhances the prevalent on-farm genetic diversity. The growing of sorghum in various cropping systems is also one of the factors shaping on-farm diversity. The selection, production and use of varietal mixtures in the farm also partly explain the role farmers play in the diversity management. The detail of seed selection, production, storage and utilization in modulating, changing and directing on-farm diversity is described (Mekbib, 2007b). The range of variations on the type and number of varieties across individual farmers and communities is partly explained by the variation among farmers in the management of on-farm genetic diversity. This is also corroborated by the spatial differentiation of diverse taxa at the micro-centre levels due to farmers' management.

Farmer-cum-bio-eco-geographic genetic diversity model: The aforementioned models do partly play a role individually in shaping diversity, and together they play a significant role in the region as sorghum evolution is still in the hand of the farmers. However, none of the above models in isolation explains sufficiently the prevalence of on-farm genetic diversity. Both natural and human factors in the continuous and dynamic combinations are responsible to explain the presence of on-farm diversity. The role of farmer-cum-natural selection in farmer breeding is discussed in Mekbib (2006). In real terms, it is very difficult to single out the role human versus natural factors plays in isolation hence a concerted influence of the two models explains the overall process shaping on-farm genetic diversity. The role of human-bio-eco-geographic factors on shaping diversity have been indicated at various level of area units such as a single household (Brush et al., 1981), ethnic group (Alcorn, 1984) and continental assemblages of the people (Sauer, 1952).

In sum, the possible reasons that explain the aforementioned models for the presence of on-farm diversity in Ethiopia are:

-The long history of cultivation of sorghum in Ethiopia that dates back as early as 4 to 6BC (Philipson, 2000).
-The growing of sorghum in various ecologies and topographies has resulted in the genetic differentiation and eco-typing thereby to on-farm diversity (Mekbib, 2007b).
-The existence of many ethnic/tribal (closer to 80) and social groups growing sorghums dictates the need to have certain types that caters the need for each of them (Mekbib, 2007b).
-Introgression among wild and cultivated types and among different races of sorghum.
-The various traditional cropping systems harbour various type of variability on-farm. These various cropping systems are not only maintaining but they are also stabilizing the on-farm diversity (Mekbib, 1997, 2002, 2003, 2006).

Conclusion

Farmers' appreciation of diversity is considerably high and this momentum has to be maintained through various encouraging measures. On the contrary there is also under-estimation of on-farm genetic diversity by the farmers. Farmers need to be informed that the on-farm genetic diversity is not as low as they use to think. Most of the morphological diversity study takes only the crop aspect. However, attempts have to be made to have integrated soil, climate and plant diversity study for geting the holistic picture for on-farm genetic diversity distribution.

The factors that shaped on-farm genetic diversity in the region are modelled in the three categories. These models expound very well the processes shaping on-farm genetic diversity. This study showed a very comprehendsive description of the most important factors shaping on-farm genetic diversity. Hence, for integrated genetic resources management, enhancement and utilization, the factors need to be considered accordingly.

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