Concerns on Mismatches between Environments of Selection and Production of Crop Varieties in Ethiopia

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Abstract: Crop production plays a significant role in the Ethiopian economy. The sub-sector's output has, however, been very low partially due to the biophysical challenges constraining productivity in smallholder farms and inadequate technological interventions. Genetic modification of crops to improve productivity is preferred to the continual manipulation of the growing environment because of cost particularly to the large majority of resource-poor farmers who cannot afford for production inputs. Consideration of varietal selection vis-à-vis actual target production environment is vital to maximizing gains from breeding efforts. The tradition across most of the breeding programs in Ethiopia is to develop varieties under optimum management despite the fact that marginal management characterizes the ultimate target production environments. Whether selection under optimum management is likely to result in better productivity gain than under the actual target production environments is a crucial issue in varietal development. This paper discusses the logical framework for breeding success and the conventional approach to varietal selection and its challenges in Ethiopia. Based on the analyses, the paper proposes that the wheel of the current variety development schemes should be redirected and made more objective and focused towards better serving the major target beneficiaries, i.e. the resource-poor farmers.

Keywords: Direct Selection; Indirect Selection; Selection Environment; Target Environment

1. Introduction

Agriculture is the backbone of the Ethiopian economy. The sector contributes 85% of total employment, 46% of GDP and 92% of total export earnings (Beintema and Menelik, 2003). Crop production takes the lion's share of the contribution by agriculture as a whole in terms of employment, food, industrial raw materials and export earnings. For instance, more than 95% of the export earnings were contributed from exports of different crops and crop products in 2005, disregarding plant-animal mixed products (CSA, 2006). Despite the manifold merits, however, crop productivity has been very low due partly to a two-prong, the biophysical challenges constraining productivity under the smallholder farms' conditions on the one hand and inadequate technological interventions made to curb the culprit on the other. To bridge the widening gap between the radically increasing demand and the diminishing supply of food, industrial raw materials and export commodities, technological backing of production, among others, is absolutely essential. Among the important ways of confronting this challenge, the use of modern production inputs, better agronomic practices, and introduction of improved crop cultivars into the production system stand forefront.

Even though a good level of investment has been made in research particularly after the 1990's, the inception of formal crop breeding in Ethiopia may date back to the 1940's with the establishment of higher learning institutions (Beintema and Menelik, 2003). As a result, over 400 improved varieties of different crops have been released for common production (MoARD, 2005). Nevertheless, it is hardly possible to say that most of these varieties have been readily accepted, properly utilized and boosted productivity at farm level as desired. On-station yields are usually attractive but the spillover effects in farmers' fields were often observed to be negligible (Franzel, 1992). Improved cultivars of most of the crops are not yet sufficiently put under production and more than 95% of the cultivated areas in the country are still planted with local seeds produced by the farmers themselves. For instance, out of the 10,887,953 ha of land cultivated to different crops in the 2004/2005, only 346,522 ha (3.2%) was covered with improved seeds (CSA, 2005). The national average yields for most of the crops are low (Ethiopian Agricultural Sample Enumeration, 2002) and stagnant (Woldeyesus and Chilot, 2002) while yields of two to three folds of the respective crops have been commonly recorded from improved varieties with proper crop management and protection practices (EARO, 2000; Belay, 2004; Legesse, 2004). The situation is also similar in many other African countries (Ceccarelli, 1997).

The main reasons for less research impact in Ethiopia, among others, have often been stated as lack of proper multiplication, dissemination and utilization of improved technologies including improved seeds (Belay, 2004; Adugna *et al*., 2006). The weakness, or sometimes even the irrelevance, of "improved" technologies (including crop varieties) is also coming into picture, the main complaint being technology development processes including varietal generation often do not take into consideration the biophysical and the socio-economic situations of the target production systems (Franzel, 1992). The purpose of this review paper is not, by any means, to argue that past breeding efforts were ineffective and the varieties developed were irrelevant. With due

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respect to the efforts made and the achievements so far, the paper rather aims to challenge the conventional varietal development approach in Ethiopia based on some conceptual frameworks and available scientific evidence. That, I hope, would provoke critical discussion and useful dialogues among the scientific community on the need to revisit and redirect the scheme of variety development in order to make future breeding efforts in Ethiopia more objective and focused.

2. Conceptual Frameworks and Conventional Approaches to Selection

Progress in breeding depends on the magnitude of genetic variability among the germplasm, heritability of a given trait in a given environment and the level of selection intensity applied (Falconer, 1989; Singh, 2002). The higher the level of genetic variability, heritability and selection intensity for a given trait in a given environment, the higher will be the expected genetic gain from selection. This could be clearly revealed from the interrelationship between expected genetic gain from selection on the one hand and genetic variance, heritability and selection intensity on the other which will be discussed later in greater detail.

Environmental conditions and crop management practices interplay to determine the extent and pattern of genetic expression of different traits including yield potential. Therefore, the environment and the farming system for which breeding is undertaken, farmers' and consumers' preferences and characteristic to be modified under specific situations should be clearly defined and; accordingly, appropriate germplasm should be identified and proper breeding methods followed for a successful breeding program. The term environment in this sense refers to both natural components like climatic, edaphic and biotic (pests) factors and management and protection practices provided to crops (Annicchiarico, 2002).

The appropriateness of varieties for release in terms of performance consistency across a range of physical environments is confirmed by multi-location evaluation of varieties even if it is laborious, costly and time consuming. Hence, varieties are normally evaluated at few locations (primary breeding centers) at the initial stages when a large number of germplasm is handled. As the evaluation work is further kept on, at later stages, the number of varieties virtually gets smaller and smaller through selection while the number of locations is steadily increased over years. While planned specific breeding programs exist for potential and stress conditions in terms of physical environments like moisture and altitudinal regimes in different crops including cereals, pulses and oil crops (EARO, 2000), no such program exists for management levels despite the importance. The current conventional breeding approach in the tropics in general and in Ethiopia in particular is development of varieties under optimum management levels (favorable conditions) on experiment stations and release of the promising ones as registered varieties for inevitable production under marginal management levels (unfavorable conditions) in farmers' fields (Banziger *et al*., 1998; Gemechu *et al*., 2002). However, a number of varieties that performed better with optimal management on research stations could not consistently repeat the same performance under farmers' fields which are characteristically of sub-optimal conditions (Ceccarelli, 1989; Ceccarelli and Grando, 1996; Banziger and Edmeades, 1997; Banziger *et al.*, 1997; Banziger and Lafitte, 1997). The existence of genotype by management interactions reported from Ethiopia (Abdissa, 1996; Kenea, 2004; Getachew and Amare, 2004; Amare *et al*., 2005; Balesh *et al*., 2005) has made doubtful whether genotypes that performed better with optimal management on research stations could consistently perform the same under farmers' fields.

3. Why Develop Varieties Under Optimum Management?

Breeders tend to develop varieties under optimum conditions for an ultimate use under marginal management, which prevails in the target production environments. Different possible reasons could be given why selection under optimum conditions is the most common approach.

The main reason for varietal selection under optimum management in the tropics in general and in Ethiopia in particular, could be not necessarily because it is the best approach but breeding methodologies in the tropics are generally influenced by experiences from breeding in the temperate areas (Banziger *et al.*, 1998). The success stories from plant breeding as a science led the developed nations to technological breakthrough based not only on genetic manipulation of the crops but also on the integration of better management with improved genotypes that are responsive to such management options. The approach served best the purpose of developed nations because management levels applied on experiment stations could be afforded in farmers' fields whereas in the tropics, management levels applied on breeding stations are very different from those affordable by the farmers. The continued demand for food and the success of such efforts, in some parts of the world, as the Green Revolution, might be the main driving force for an ambitious approach to transform the whole farming system at once by adopting breeding methodologies which are successful in the developed nations without much modification. However, experiences from the Green Revolution did not repeat in a sustainable manner in most parts of Africa partially because the input level required along with the new varieties was too high for the resource-poor farmers (Singh, 2000). One should not also overlook the role, in modeling our research approach, of expatriates from the developed nations who dominated the research system during the early days in Ethiopia (Beintema and Menelik, 2003).

Another reason for selection under optimum management might be the assumption that heritability and expected genetic gains from selection are higher, and hence, there would be more success under favorable than under unfavorable management conditions (Simmonds, 1991; Banziger and Edmeades, 1997; Singh, 2002). The importance of this concept may emanate from the assumption that superior genotypes under optimum management would also be superior under low management condition (Brennan and Byth, 1979; Rosielle and Hamblin, 1981). If this assumption was true, breeders could have efficiently evaluated cultivars under optimum management for both optimal and marginal levels and thereby save resources. It was also used to be assumed previously that farmers could afford for and decide to take up improved varieties along with recommended crop management practices as a "package" provided that the package as a whole is profitable, which was later proved, beyond doubt, to actually be unlikely (Franzel, 1992; Getaw and Girma, 2004).

4. Challenges of the Conventional Approach to Selection

Under farmers' conditions, the full genetic yield potential of crops may be rarely attained because of environmental limitations imposed not only by the natural environment but also by the sub-optimal management. There is no purpose in breeding pest-resistant genotypes in pest-free environments, drought-resistant genotypes in drought-free environments or frost-resistant genotypes in frost-free environments. Similarly, varieties selected under high yield potential on research stations should not be assumed appropriate under farmers' fields where very marginal management prevails (Banziger *et al.*, 1998). Therefore, selection under optimum management conditions may not be the best approach for Ethiopia to boost productivity of all crops under marginal management conditions in farmers' fields.

Many studies claimed to have proved the concept that cultivars selected under favorable environments also suit to the unfavorable ones does not have sufficient scientific background (Ceccarelli, 1989; Ceccarelli and Grando, 1996; Banziger and Edmeades, 1997; Banziger *et al.*, 1997; Banziger and Lafitte, 1997). Many of such varieties developed under potential conditions failed to succeed under marginal conditions (Ceccarelli, 1989; Reijntjes *et al.*, 1992; Ceccarelli and Grando, 1996) because it is practically impossible to collect together genes responsible for superior performance in all environments into a single genotype (Annicchiarico, 2002). The reason for the poor performance of most of the modern cultivars developed this way in the tropics is widely attributed to the fact that they require management and input levels which most of the growers could not afford (Farrington and Martin, 1988; Franzel, 1992).

Some studies in Ethiopia report the existence of significant genotype by management interaction in a number of crops including sweet potato (Abdissa, 1996), chickpea (Kenea, 2004), faba bean (Getachew and Amare, 2004), field pea (Amare *et al.*, 2005) and tef (Balesh *et al.*, 2005). When the genotype by management interaction is a crossover type, it means that the two management levels are distinctly different and they do not represent one another in terms of variety generation (van Oosterom *et al.*, 1993). It is not only the nature of the test genotypes but also the degree of similarity between selection and target production environments that influences the magnitude of genotype by management interaction (Cleveland, 2001). In cases of high genotype by management interaction to the extent that it causes rank order changes among the genotypes, there is no scientific base to select varieties under one management level to indirectly improve productivity under another (Ceccarelli and Grando, 1996).

5. The Concept of Direct vis-à-vis Indirect Selection

The concept of direct and indirect selection was suggested by Falconer (1960) and later used in several investigations related to the determination of optimum selection environments (Ceccarelli, 1989; Ceccarelli and Grando, 1996; Banziger and Edmeades, 1997; Banziger *et al.*, 1997; Banziger and Lafitte, 1997). Accordingly, direct selection may refer to a kind of selection made directly under the target production environment or under simulated condition as the target environment. Indirect selection, conversely, refers to selection made under distinctly different environment from the actual target production environment but still to improve productivity under the latter; for example, selection under potential environment to improve productivity under marginal conditions.

Methods have been designed (Falconer, 1989) to determine the efficiency of selection under favorable environments like research stations for improving performance under unfavorable target environments like farmers' fields. The procedure assumes a character measured in two different environments not as one but as two characters with genetic correlation between them since the physiological mechanisms and the genes required for high performance may be different. If the genetic correlation between them is high, then performances in two different environments represent nearly the same character, determined nearly by the same set of genes. If it is low, however, the characters are likely to differ to a great extent, and high performance requires a different set of genes.

Given genetic variances in a target environment ($\sigma^2_{g(TE)}$), heritability in selection ($h^2_{(SE)}$) and target ($h^2_{(TE)}$) environments, selection intensity (δ) and genetic correlation between the performances under the selection and target environments (r_g), the expected response to direct selection (DR) in a target environment and the expected response to indirect selection in a selection environment (IR) can be determined as (Falconer, 1989):

$$DR = \delta \,.\, \sigma_{g(TE)} \,.\, h_{(TE)} \qquad (1)$$

$$IR = \delta \,.\, r_g \,.\, \sigma_{g(TE)} \,.\, h_{(SE)} \qquad (2)$$

The relative efficiency (RE) of indirect selection under selection environment as compared to direct selection under target environment (DR) is calculated as:

$$RE = r_g.h_{(SE)}/h_{(TE} \ or\ IR/DR \qquad (3)$$

A value of 1.0 indicates that indirect selection under the selection environment to improve productivity under the target environment is predicted to be equally efficient as selection under the target environment itself. Similarly, a value of less than 1.0 indicates more efficiency of direct selection and a value of more than 1.0 indicates more efficiency of indirect selection (Banziger and Edmeades, 1997; Banziger *et al.*, 1997; Banziger and Lafitte, 1997). A simplified schematic presentation of the appropriateness of direct or indirect selection under different levels of genotype by management interactions is presented in Figure 1.

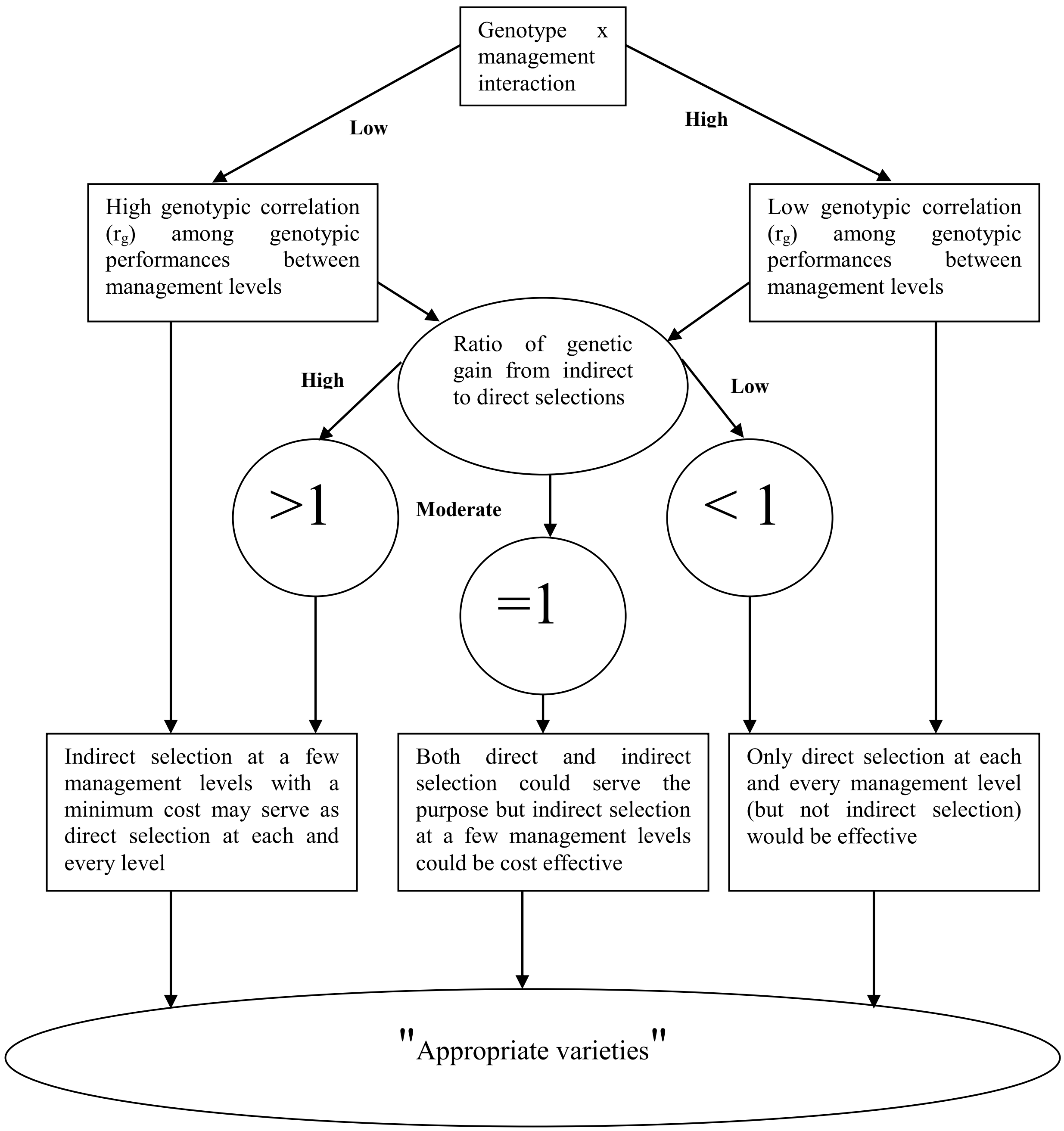


Figure 1. Schematic presentation of appropriate uses of direct or indirect selection where low or high genotype by management interaction prevail

6. Where Do We Stand?

In countries like Ethiopia where resource-poor farmers dominate and crops are produced under marginal situations, it is not feasible to develop and universally utilize resource-demanding varieties. Although high inputs could boost productivity, high-input technologies may not be widely adopted by resource-poor farmers because such practices must be repeated each season and are hence expensive.

A variety may show outstanding performance at a research station under optimal management conditions and inferior performance under the target marginal management conditions prevailing in the farmers' fields. The specificities for management requirement among crop genotypes suggests that either varieties must be selected under representative management conditions or under management levels with which they are going to be extended. The success stories from varietal introductions during the Green Revolution were mainly based on the abilities of countries to manipulate their growing environments in such a way that the varietal requirements could be satisfied. On the other hand, the failure of technology introductions like the pure breeds of European livestock, particularly dairy cows, under small-scale production in Africa was at least partially related to inability of the farmers to provide the required management level (Tesfaye, 1988).

Table 1. Comparison of selection and target production environments for different crops in Ethiopia

Crops	Parameter of comparison	Selection environment	Target environment
All crops	Farm implement for land preparation	Tractor mounted (mold board, disc plow, etc.)	Simple local implements (*maresha**, hoe, etc.)
Pulses	Plowing frequency	2-3 plowings with local plow or one disc plowing followed by two disc-harrowing	A single plowing plus another plowing to cover the seed in most of the cases
	Fertilizer	Blanket application of 18-48 kg N-P_2O_5 ha^{-1} at most of the locations and no fertilizer is added in some others	Not added in most of the cases
	Weeding	Twice hand weeding or sometimes weed free particularly in breeding blocks	Not weeded in most of the cases or often late weeded once
	Cropping system	Sole cropping	Sole or mixed culture of faba bean and field pea
	Field selection	Mostly potential land for full genetic expression	Mostly marginal land for fertility restoration
Cereals	Plowing frequency	May be less frequent than in the target production environments but with tractors	3-7 times depending on the type of crop
	Fertilizer	Agronomic recommendation of each of N and P_2O_5 or sometimes even more particularly in breeding blocks	Below the blanket recommendation in most of the cases, tendency to use more P_2O_5 than N
	Weeding	Agronomic recommendation or even weed free in breeding blocks	Weeded mostly later than recommended or use herbicide or hand weeding supplemented with *shilshalo***
	Cropping system	Selection under sole cultures	Sole culture dominates but mixed culture is still important
Oil crops	Plowing frequency	May be as frequent as in the target production environment but with tractors	0-2 times depending on the type of crop
	Fertilizer	Agronomic recommendation of each of N and P_2O_5	Not added in most of the cases
	Weeding	Agronomic recommendation of each crops or even weed free in breeding blocks	Not weeded in most of the cases
	Cropping system	Selection under sole cultures	Both sole and mixed cultures are important

Source: Personal observations, and extracted from Amare and Adamu (1994), Hauilu *et al.* (1994), Rezene (1994) and Hailu *et al.* (1996)

**Maresha is a small iron point at the tip of a wooden plow used to crumble the soil 15-20 cm deep.*

*** Shilshalo is inter-row cultivation with a local plow for weed control and thinning particularly in maize and sorghum.*

As noted, the crop management levels in varietal selection and target production environments in Ethiopia are very different (Table 1). Reasons for larger genotype by environment interaction include difference in varietal response and environmental distinctness in terms of biophysical and management factors (Annicchiarico, 2002). From the apparent differences between selection and target production environments presented in Table 1, one can easily expect system incompatibility between the two as even a single or a few components of a management package with a few genotypes might result in a significant genotype by management interaction (Abdissa, 1996; Kenea, 2004; Getachew and Amare, 2004; Amare Ghizaw *et al*., 2005; Balesh *et al*., 2005). As varieties developed for resourceful conditions may not be flexibly suited under resources-poor situations, so do those that are developed under researcher managed sole cultures for production under a more complicated target mixed cultures (Smith, 1986).

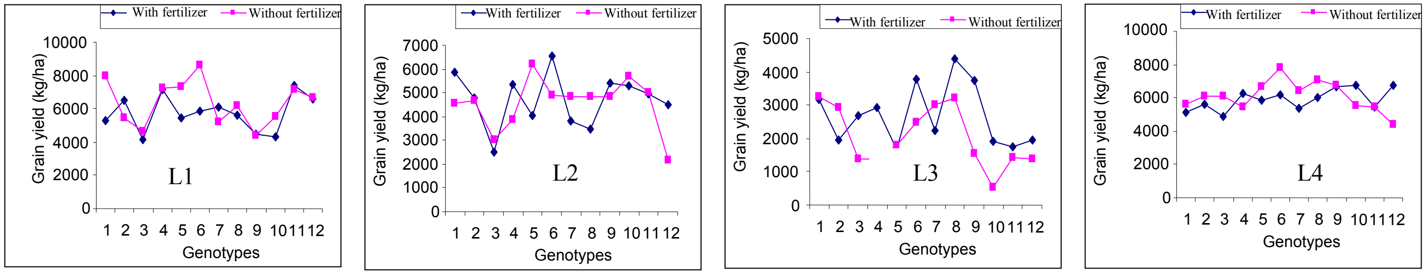
Among the key management inputs, for instance, commercial fertilizers are the most important but most expensive in Ethiopia. The rate of fertilizer applied by Ethiopian farmers is very low compared to the rate used at research stations (Table 1). The main problem is not only the limited supply but also the higher price of the limited amounts availed to farmers. Unfortunately, the cost of fertilizer may continue to rise to the level farmers in developing countries in general may not afford to purchase (FAO, 1984). It is likely that fertilizer prices will rather rise in the future due to the dwindling oil reserves (Beem and Smith, 1997). Organic sources like farmyard manure are also limited (Quinones *et al*, 1997). Therefore, production is mostly based on the traditional approach although farmers realize the importance of using inputs. With the rising price of inputs, therefore, the breeding of genotypes that efficiently utilize resources, i.e. genotypes that are able to mobilize the limiting resources in greater amounts and yield better than a standard cultivar (Graham, 1988; Bowen and Zapata, 1991), instead of genotypes responsive to management, may be a dependable approach to address the problem of the majority of the resource-poor farmers in Ethiopia.

Apart from some variety evaluations made both under fertilized and unfertilized conditions during the 1980's and a number of genotype by management interaction studies conducted on different crops, systematic efforts made to establish optimum selection environments in Ethiopia are very limited. Among a few systematic studies include on faba bean to determine if selection of good genotypes under drained condition is also efficient for identification of appropriate genotypes for the undrained target environments on waterlogged Vertisols (Gemechu *et al.*, 2001). Another similar case was a study done on barley to determine the effectiveness of selection under high soil nitrogen level for low nitrogen target environments (Woldeyesus *et al.*, 2002). Both studies clearly revealed the relative advantage of direct selection under the target environments than if indirect selection were done under more favorable environments particularly as the level of marginality increases, although indirect selection as well may be useful in some cases to identify better genotypes. These indicate that if the breeders' selection environment does not properly represent the actual target production conditions, selection gains under the former may be of little or no help to improve yield under the latter. Verifying a few "finished" candidate varieties under the target condition at the final stage of variety evaluation can also not make up for the useful genetic variation that might have already been lost when large number of genotypes that would have been suited under marginal conditions were discarded on the station under breeders' own condition (Banziger *et al.*, 1998).

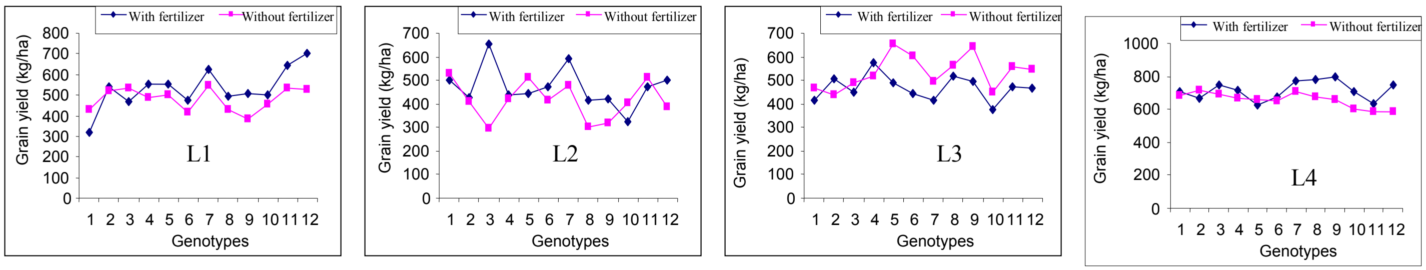
At times in the 1980's, it was almost a general trend to evaluate varieties under fertilized and unfertilized conditions. Analysis of the data showed existence of crossover types of genotype by soil fertility level interactions causing changes in rank orders among the performances of the genotypes of different crops including cereals, pulses and oil crops in most of the cases (Fig. 2). This clearly shows that the fertilized and the unfertilized soil environments were distinctly different and the genotypes responded differently to the different soil fertility levels. This could also be further confirmed from weak correlations between varietal performances under the two fertility levels in most of the cases (data not shown). Such weak associations indicate that selection of better performing genotypes for grain yield under fertilized could not identify better performing genotypes for unfertilized conditions (Banziger *et al*., 1997; Banziger and Edmeades, 1997). The production of varieties developed for fertilized condition might not, therefore, be recommendable under unfertilized condition and there may be a need to specifically bred varieties for the latter.

7. Future Considerations

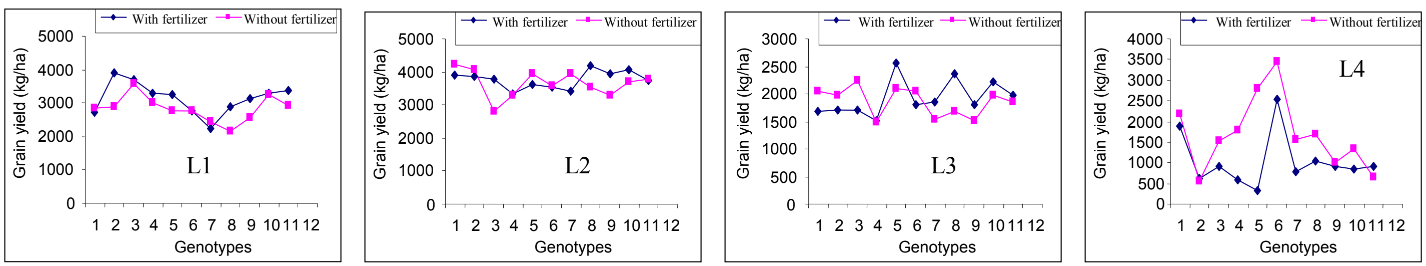
In order to boost the productivity of crops in this country to the desired level, among other factors, the demand for varieties appropriate under farmer circumstances need to be satisfied. Therefore, the mismatch between selection and target production environments could be of paramount importance for future consideration. It does not mean that the existence of any level of differences between the selection and the target production environments necessarily indicate selection for one condition does not serve for the other. In case when relative efficiency of direct selection under one condition is proven superior over indirect selection under the other, it means that the two environments are exclusively independent. In such cases, we may need to separately address optimal and marginal management situations or to redirect the varietal generation process as a whole towards the vast majority of the resource-poor farmers. To the less favored resource-poor farmers in Ethiopia, there is no doubt that a variety giving reasonably good yield under their own circumstances is more important than a high-yielding variety based on high investment for inputs.



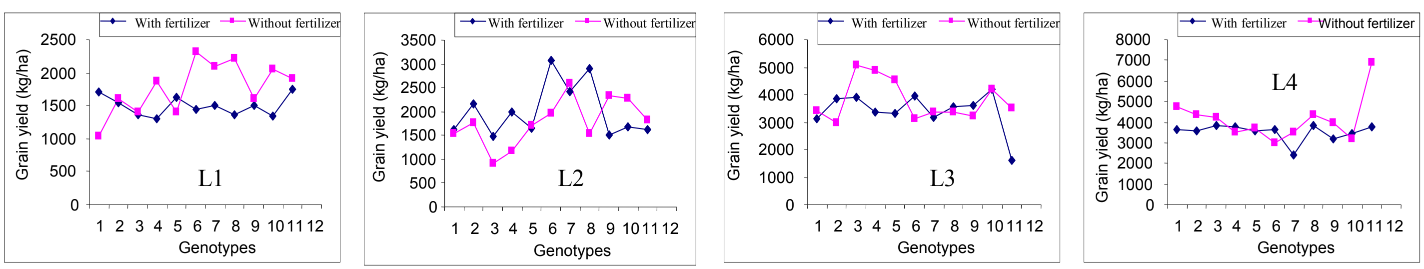
(A) Maize (composites)



(B) Niger seed



(C) Faba bean



(D) Field pea

Figure 2. Grain yield performances of maize, Niger seed, taba bean and field pea genotypes across four locations each (L1-L4) under fertilized and unfertilized conditions showing the existence of cross-over type genotype by management interaction (data taken from IAR (1986) and re-manipulated by the author)

Depending on the practical situations existing in a given farming system, several assumptions could be thought of in the process of generation of appropriate varieties suitable under the target condition in Ethiopia. The first assumption is that farmers would afford to take up the whole production packages along with the varieties. The ultimate goal of this option is yield potential based on the full exploitation of productivity improvements from genotype, management and any positive synergic interaction between them. However, the option did not widely apply for an obvious reason that the majority of the resource-poor farmers may not afford the cost of production inputs. With the rising price of inputs, therefore, the breeding of productive genotypes, which are suitable under low management levels and simulated farmers' circumstances, could prove one of the dependable approaches to address the problem of the majority of the resource-poor farmers in Ethiopia. Research and extension experiences over the last couple of decades in Ethiopia also showed that this assumption did not work and technology adoption may rather follow a step-by-step pattern where components of the same package may be adopted separately at different times (Franzel, 1992).

The second option is that breeders must recognize farmers' unique situations and develop varieties based on their socio-economic needs as ignoring farmers' practical situations may end up in shelving the varieties without any significant adoption to bring-up impact on agricultural development. Contrary to the first option, the ultimate goal here is not yield potential but resistance to biotic and abiotic stresses in farmers' fields including adaptation to marginal management. With this assumption breeding efforts should build on farmers' practices to complement them and not to substitute them. The process in which cultivars are adapted to fit the prevailing environment is encouraged instead of the environment being altered to fit the cultivars (Coffman and Smith, 1991; Wallace and Yan, 1998). This option is normally more appropriate under very marginal production conditions where price ratios between external inputs and farm outputs do not allow the use of large quantities of purchased inputs (de Boef *et al.*, 1996). Landraces have considerable breeding values under these kinds of situations as they contain valuable adaptive genes to different circumstances (Ceccarelli, 1994; Bunder *et al.*, 1996; Chahal and Gosal, 2002). Once appropriate varieties are made available this way their adoption may involve no additional expense apart from the initial seed cost, and the existing cropping system and soil and water management practices may not be affected (Buddenhagen and Richards, 1988). Experience also shows that seed based technologies are easier to transfer to farmers than more complex knowledge based agronomic practices (Edmeades *et al.*, 1998). However, this approach has also its own limitations. We should not anticipate dramatic results from breeding efforts in marginal environments but only small gradual changes should be expected (Buddenhagen and Richards, 1988). The development of suitable genotypes to marginal management situations may not provide the required productivity levels as lower genetic gains expected from selection under such circumstances (Rosielle and Hamblin, 1981; Buddenhagen and Richards, 1988; Singh, 2002) may limit yield improvements, result in further depletion of soil nutrients and thereby put at risk the national desire to double or triple productivity in order to feed the increasing population (Woldeyesus and Chilot, 2002).

Thirdly, there could be a compromise between researchers and farmers in such a way that researchers may consider only those pertinent socio-economic backgrounds of the farmers while at the same time farmers also try to take up affordable packages. This option assumes that certain level of productivity could be achieved from a compromise between management levels and from appropriate genotypes that are capable of efficiently exploiting the limited management levels that could be affordably provided by the farmers. Some authors advise that the use of modest level of inputs or intermediate environment is feasible for small-scale farmers over both high and low yielding environments (Allen *et al.*, 1978; Franzel, 1992). This approach seems to be socially acceptable but it does not concur with the concept of "agronomic optimum" advocated by agronomists. If we make this our choice, it is biologically true that we cannot achieve the maximum desired level of development we could have liked to see but it could at least be considered, compared to the second option, as a matter of "choosing the lesser evil when we are between two evils".

Fourthly, testing of varieties under both optimal and marginal or sub-optimal conditions could be one of the stable options to create alternative varieties that suit both conditions but the cost of germplasm evaluation would obviously be greatly increased.

8. Conclusion

It is obvious that if a variety developed for better agronomic performance by breeders is ultimately unacceptable to farmers for some reasons and is not adopted, all the resources invested to the development of that variety will be lost. I think that we do not have to oscillate among many choices but only two. The first is that the actual situation on the ground must be properly assessed, defined and appropriate varieties suitable under the real-life situations of our farmers must be developed, made available, accepted and properly utilized in production. Another choice, may be a more sound one, is that farmers must be enabled with policy supports (in terms of access to education, credit, input supply, markets and extension services, etc) to alter their growing environments through the application of improved inputs and agronomic practices that suit newly developed cultivars. Whatsoever the future may come with, we need to critically reassess and redirect the wheel of the scheme of variety development in order to make our future breeding efforts more objective and focused. To this effect, scientists and research institutions may be responsible at the technical level to decide on the appropriate models to be followed in the future based on the prevailing circumstances or the national vision as the case may be. Above all, fundamental changes in this aspect, apart from research, must be expected from enabling policy and strategy directives that envisaged transforming crop production from a means of survival to a profitable business.

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Effect of Poultry Manure on Pepper Veinal Mottle Virus (PVMV), Yield and Agronomic Parameters of Pepper (*Capsicum annuum*) in Nigeria

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Abstract: Four fertilizer treatments were applied to two PVMV susceptible pepper (*Capsicun annuum)* varieties (NHV1-D96 and NHV1-E96) and one PVMV tolerant variety (NHV1-G96) to determine their effects in reducing the incidence and severity of pepper veinal mottle virus disease and on yield and agronomic parameters. The treatments were: (1) no manure application, (2) poultry litter organic manure at the rate of 10 tons/ha, (3) poultry litter organic manure at the rate of 20 tons/ha, and (4) NPK (20:10:10) at the rate of 0.26 tons/ha inorganic fertilizer. Broadcasting method was used for all the fertilizer applications. The experiment was carried out both in the field using a randomized complete block design and in 5 kg sterilized soil-potted experiment in the greenhouse in complete randomized design. The treatments showed a significant effect ($P < 0.01$) on PVMV disease incidence and severity, plant height, leaf number, internodes distance, number of fruit per plant, and fruit yield both in the field and greenhouse plants. The interactions between the treatments were also significant ($P < 0.05$) for PVMV disease incidence and severity, plant height, leaf number, internodes distance, number of fruit per plant and fruit yield. Mean PVMV disease incidence and severity, plant height, leaf number, internodes distance, number of fruit per plant and fruit yield, varied significantly ($P < 0.05$) in all the treatments applied. The application of 10 tons/ha and 20 tons/ha poultry manure showed a significant ($P < 0.01$) effect in reducing the incidence and severity of PVMV disease on the three pepper varieties. The poultry manure treatments were also observed to have positively and significantly contributed ($P < 0.05$) to the plant height, leaf number and fruit yield of PVMV infected pepper plants in all the three pepper varieties used both in the field and in the greenhouse. The yield of pepper decreased with increasing PVMV disease incidence and severity in all the treatments.

Keywords: *Capiscum annuum*; Pepper Veinal Mottle Virus; Poultry Organic Manure

1. Introduction

Pepper veinal mottle virus (PVMV) (genus Potyvirus, family Potyviridae) disease has been a major constraint to pepper production, contributing to low yield and reduced fruit quality and leading to great economic loss (Cook, 1991). In Nigeria, 100% losses of marketable fruit due to infection with PVMV have been reported causing whole field to be abandoned prior to harvest and in some areas making cultivation of pepper to be uneconomical (Alegbejo and Uvah, 1987). Peppers infected by PVMV exhibit varied symptom expression depending on the severity, age of plant, time of infection and pepper variety. These symptoms may appear on the leaves, stem, flowers and fruits (Zethner, 1991). The symptoms exhibited include mild mottle, mosaic, vein banding, ring spots, various types of necrosis, leaf discoloration, deformation, blistering and severe stunting of the whole plant (Green and Kim, 1991).

The issue of satisfactory control of this PVMV has been a major problem that has led to reduce cultivation of this crop in most part of the world and especially in Nigeria. Many control methods have been practiced, which include, host resistance, biological control, plant quarantine, chemical control and field sanitation (Hussey, 1990; Kirkby, 1990; Gahukar, 1991). But an adequate control of the PVMV disease under field conditions has not been achieved (Zethner, 1991).

The economic control of many insect pests that are the major vectors of PVMV has led to the excessive use of chemicals, which has many hazardous effects on the environments. Insecticide application and removal of infected plants are usually inadequate in reducing virus spread (Beth, 2005). Most of these insect pests are fitted to thrive in agro ecosystems and to adapt to changing crop production conditions.

In view of this, Pottorff (2004) suggested the use of organic manure as a cultural control method in controlling viral diseases of most horticultural crops. Organic manure encourages beneficial microorganism to live in a symbiotic relationship with plants, improving their fertility and disease resistance. It initiates the cycling of organic material, within the soil, by the microorganisms, which cause decomposition. The organic soil relies on this cycling to produce organic solutions, which are aimed at being preventative, by improving the natural balance within the garden to build a healthy soil (Robert *et al*., 2001). This organic manure serves as a source of slow release of required nutrient and trace elements, which are critical to plant health, and this is a good way to add these essential nutrients (Beth,

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2005). This helps to avoid high nitrogen fertilizers that may result from the use of inorganic fertilizers, such as NPK, as soft new growth makes the plants to be very vulnerable to viral diseases (Pottorff, 2004). It is for this prudent reason that we must understand nature's mechanisms of regulating population and maximizes their applications for successful viral disease control.

Therefore, this study was targeted at determining the efficacy and effect of cured poultry litter manure as a source of organic nutrient in reducing the incidence and severity of the PVMV disease and its effect on the yield and other agronomic parameters of cultivated pepper.

2. Materials and Methods

The experiment was carried out in 2004 and 2005 in the green house and experimental field of the University of Agriculture Abeokuta, Alabata, located on 7º 10′ N and 3º 2′ E in Odeda Local Government area of Ogun State Nigeria. The area lies in the southwestern part of Nigeria having a prevailing tropical climate with a mean annual rainfall of about 1037 mm and mean ambient temperature ranges from 28 ^{O}C in December to 30 ^{O}C in February with a yearly average of 34 ^{O}C.

2.1. Treatments

Three pepper varieties, NHV1-D96 and NHV1-E96, PVMV susceptible varieties and NHV1-G96, a highly PVMV tolerant variety (Fajinmi *et. al.,* 1998), obtained from National Horticultural Research Institute (NIHORT) Idi-Ishin, Ibadan were used for this experiment. The highly tolerant variety used served as control check. Poultry litter was used as source of organic manure, while the inorganic fertilizer treatment used was NPK fertilizer (N- 20%, P_2O_5 – 10%, K_2O – 10%). The poultry litter used as source of organic manure for the treatment was collected from droppings of poultry laying chickens of the University of Agriculture Abeokuta and left in the open for four weeks to compost (so as to reduce the acidity content) before application. The nutrient composition of the poultry litter used was analyzed and determined. Healthy pepper seedlings varieties were raised in the greenhouse and transplanted at 5 weeks old in May during the rainy season.

2.2. Experimental Design for Field Experiment

The experimental design used in the field was a randomized complete block design. The plot size was 2 m x 2 m with an interplot spacing of 1.0 m and inter-block spacing of 2.0 m. The plots were replicated three times for each level of fertilizer treatment application in each variety of pepper used. Sixteen healthy and five week old pepper seedlings of each variety were transplanted at a spacing of 50 cm x 60 cm per plot replicated three times.

The three pepper varieties (NHV1-D96, NHV1-E96 and NHV1-G96) were used as main treatments while fertilizer application at different ratio were used as sub-plot treatments. Using the recommendation of Olasantan (1994), four treatments were used in the sub-plot: (1) no manure application, (2) 10 tons/ha poultry manure (3) 20 tons/ha poultry manure and (4) 260 kg/ha of NPK (20:10:10) fertilizer. Broadcasting method was used for all the fertilizer application to allow for good distribution and uniform spreading of the manure across the plot.

The organic fertilizers were applied two weeks before pepper seedling transplant while the inorganic fertilizer was applied three weeks after pepper seedling transplant. To increase density of PVMP inoculum, two rows of four weeks old pepper seedlings of bell fruit shaped "Tattasai" varieties each mechanically inoculated with PVMV and which has been confirmed through PAS-ELISA were planted at a spacing of 50cm by 60cm within the inter-block spacing. There was no insecticide application. Weeding of the plot was done at three weeks interval after transplanting.

Before the fertilizer application, a representative soil sample from each plot was collected and the nutrient composition analyzed and determined in the soil laboratory of University of Agriculture Abeokuta after eight weeks of pepper transplant. The representative soil sample from each plot was recollected and the nutrient composition analyzed and determined in the soil laboratory to determine the increase in nutrient composition of the plots. The nutrients analyzed were: nitrogen (N), phosphate (P_2O_5), potash (K_2O), calcium, magnesium, sulphur, sodium, iron, zinc, % organic carbon and % organic matter, soil particle analysis, excess acidity and the pH.

Viral disease incidence and severity were monitored on the pepper plants (four center plants from a population of sixteen plants per plot) in each treatment plot leaving the guard rows by using a modified formula-grading scheme (Steel and Torrie, 1980; Merritt, *et al.,* 1999), for disease incidence and severity as follow:

1. No disease symptoms
2. Leaf mottling
3. Chlorosis / leaf mottling
4. Severe mottling / leaf bunching
5. Leaf defoliation.

$$\text{Disease Severity} = \frac{1 \times P_1 + 2 \times P_2 + 3 \times P_3 + 4 \times P_4 + 5 \times P_5}{N(G-1)} \times \frac{100}{1}$$

$$\text{Percentage Disease Incidence} = \frac{N-n}{N} \times \frac{100}{1}$$

Where: P_1 to P_5 = Total number of observations in each disease symptoms grading.

G = Number of grading = 5

N = Total number of observations

n = Total number of plants with no disease symptoms

Pepper leaf samples showing virus disease symptoms were sampled for serological analysis using PAS-ELISA as described by Green (1991) to confirm the presence of PVMV. Representative pepper leaf samples infected with PVMV were collected and sent to Dr. Stephan Winter, Head, DSMZ Plant Virus Division Braunschweig Germany for the virus electron microscopy and characterization. The yield of the pepper fruit was recorded in each plot for a period of 12 weeks. Other agronomic data such as, plant height, leaf number, internodes distance, and fruit number were recorded.

The results were analyzed statistically using analysis of variance procedure. The means were separated using least significant difference (LSD) tests.

2.3. Pot Experiment

In the greenhouse thirty-six pots were filled with 5 kg of sterilized soil in the greenhouse. The soil was collected from the field used for the field trial and representative soil sample was taken for nutrient composition analysis. The nutrients analyzed for were: nitrogen (N), phosphate (P_2O_5), potash (K_2O), calcium, magnesium, sulphur, sodium, iron, zinc, % organic carbon and % organic matter, soil particle analysis, excess acidity and the pH. The organic fertilizers were applied two weeks before pepper seedling transplant while the inorganic fertilizer was applied three weeks after pepper seedling transplant. There was no insecticide application. Weeding of the pot was done weekly after transplanting.

Four treatments were also used in the pot experiment; (1) no manure application, (2) 30.692 gram of poultry litter organic manure per pot replicate (i.e. at the rate of 10 tons/ha), (3) 61.384 gram of poultry litter organic manure per pot replicate (i.e. at the rate of 20 tons/ha), and 0.58 gram of N.P.K (20:10:10) inorganic fertilizer treatment per pot replicate (i.e. at the rate of 260 kg/ha inorganic fertilizer). The three pepper varieties (NHV1-D96, NHV1-E96 and NHV1-G96) were also used for this pot experiment. One healthy five-week-old pepper seedling of each variety was transplanted per pot and replicated five times for each treatment. After the fifth day of the four-week-old pepper seedling transplant, all the transplanted seedlings for each variety were inoculated with PVMV sap extract that has been maintained on a bell shaped pepper variety and confirmed to be PVMV serologically positive through PAS-ELISA as described by Green (1991). The potted plants were arranged in complete randomized design.

2.4. PVMV Sap Extract Inoculation

The inoculum was prepared by grinding 10g of freshly harvested pepper leaves taken from the PVMV infected pepper plant in a sterilized mortal with a pestle in 20 ml of 0.01M phosphate buffer, pH 7.3; for sap extraction. The leaf shaft was removed from the sap extract containing the virus through the use of a cotton mesh.

Inoculation was carried out five days after transplant to allow for plant stability. Four young apical leaves of five weeks old pepper plant per plant was selected and dusted with 600-mesh carborundum as a source of abrasive to aid inoculation process and virus penetration. Sterilized cotton bud was dipped into the sap extract containing the virus and on each dusted leaf, a swab was done with the soaked cotton bud-containing virus from petiole of the leaf to the tip while supporting the leaf at the underside with fingertips. Five swabs of virus saturated cotton bud were made on each marked leaf renewing the inoculum in the bud frequently. The inoculated leaves were rinsed with sterilized distilled water to remove excess inoculum.

PVMV disease severities were then monitored on the potted pepper plants. The yield of the pepper fruit was also taken in each potted plant for a period of 12 weeks. Other agronomic data taken included; plant height, leaf number, internode's distance, and fruit number. The averages for two-year data were recorded and the results were analyzed statistically. Using analysis of variance procedure, the means were separated by using least significant difference (LSD) tests at five percent significance level.

3. Results

The electron microscopy of antiserum decorated isolated PVMV particles showed flexuous filamentous particles of 780 nm in length and 10 nm wide.

3.1. Effect of Fertilizers Treatments on the Incidence and Severity of PVMV on the Varieties

There was no significant difference in the two-year results collected, similar trend of results were observed. The application of poultry organic manure and the inorganic manure on the field cultivated pepper showed a high significant effect ($P < 0.01$) on the incidence and severity of PVMV disease within the varieties and the treatments used (Table 1). There was also a significant difference in the occurrence of PVMV disease and its severity on the cultivated pepper in the interaction between the varieties and the fertilizers.

The potted pepper varieties had PVMV disease severity expressions that were not significantly different from each other in all the treatments (Table 1). But on the field cultivated pepper, PVMV disease incidence and severity varied significantly ($P < 0.05$) in all the varieties, fertilizers applied and their interactions.

Interactions between varieties and fertilizers showed that the PVMV variety NHV1-G96 recorded the lowest PVMV disease incidence (25.67%) and severity (26%) when treated with 10 tons/ha poultry manure. At an application rate of 20 tons/ha poultry manure it was recorded 32.22% PVMV disease incidence and 32% severity. The inorganic manure treatment, recorded 49.53% PVMV disease incidence and 49% severity (Table 2). In the interaction between varieties and fertilizers PVMV susceptible variety NHV 1-E96 recorded the least PVMV disease incidence (33.31%) and severity (33%) which were not significantly different ($P < 0.05$) from PVMV tolerant variety NHV1-G96 (Table 2). Similar trends of observations were recorded in the potted pepper experiment.

Table 1: Mean squares of the effect of varieties, fertilizer treatment and their interactions on PVMV incidence, severity and some agronomic parameters in field cultivated pepper and potted pepper plants.

Source		Plant height (cm)		Leaf number		Internode's distance (cm)		Average number of fruit /plant		Fruit yield (ton/ha)		Viral disease Incidence (%)		Viral disease Severity (%)	
	Df	Pot	Field	Pot	Field	Pot	Field	Pot	Field	Pot	Field	Pot	Field	Pot	Field
Fertilizer	3	1630.2**	7526.9**	198421.5**	119058.2**	9.2**	5.1**	1142.7**	10293.9**	132833.4**	10.4**		7476.4**	7.7NS	0.7**
Variety	2	13189.3**	24854.9**	1193871.0**	1094835.4**	95.5**	48.1**	443.3**	3932.4**	122796.1**	0.9*		1157.2**	5.3NS	0.11**
Fertilizer x Variety	6	410.2**	5221.2*	60654.04**	41811.5**	1.5*	2.2**	185.5*	717.5**	13094.5**	0.2 NS		296.2*	3.6NS	0.02*

** * Significant at P< 0.01 * Significant at P< 0.05 NS = Not Significant*

Table 2: The effects of varieties, fertilizer treatments and their interactions on PVMV incidence, severity and some agronomic parameters in field planted and potted pepper plants.

Treatment	Disease Incidence (%)	Disease Severity (%)		Plant height (cm)		Leaf number		Internode's distance (cm)		Average number of fruit /plant		Fruit yield tons/ hectare	
Variety	Field	Pot	Field	Pot	Field	Pot	Field	Pot	Field	Pot	Field	Pot	Field
NHV1-D96 (1)	40.9a	38a	40a	24.0c	26.5b	35.6b	50.52b	2.15c	2.0c	5.16b	13.1c	0.12b	2.6b
NHV1-G96 (2)	36.0b	38a	36b	41.88a	52.3a	192.9a	199.9a	2.73b	2.6b	8.41a	19.8b	0.38a	3.2a
NHV1-E96 (3)	41.0a	71a	40a	38.94b	43.7a	193.7a	203.1a	3.76a	3.2a	7.93a	23.4a	0.35a	2.45b
$LSD_{(0.05)}$	2.12	4.5	0.2	1.48	9.15	15.23	17.57	0.208	0.12	1.57	2.51	7.5	0.079
S.E $\pm$	0.96	0.97	0.09	0.57	2.25	4.2	6.12	0.067	0.047	0.60	1.12	3.52	0.035
Fertilizer (organic manure / inorganic fertilizer)													
0 tons/ ha (1)	50.9a	89a	51a	30.33d	31.1c	77.5b	104.9c	2.66b	2.32c	3.7c	4.4c	0.03c	0.45c
10 tons/ ha Organic (2)	32.2d	33b	32d	39.41a	51.2a	156.95a	183.3a	3.29a	2.82a	11.1a	23.9a	0.42a	3.7a
20 tons/ ha Organic (3)	34.8c	35b	35c	36.44b	38.8bc	155.9a	162.5b	2.86b	2.74ab	8.41b	25.5a	0.39a	3.75a
260 kg/ha Inorganic (4)	39.5b	39a	39b	33.44c	42.5ab	172.6a	154.0b	2.7b	2.62b	5.47c	21.5b	0.30b	3.05b
$LSD_{(0.05)}$	2.5	5.3	0.2	1.74	10.78	17.9	20.69	0.245	0.15	0.53	2.960	1.48	0.09
S.E $\pm$	0.05	0.9	0.08	0.97	3.13	9.6	12.84	0.097	0.27	0.64	1.09	3.58	0.03
Variety x Fertilizer (organic manure / inorganic fertilizer)													
1 x 1	53.05a	50	53a	21.98g	26.2de	35.25e	48.7f	1.86a	1.67g	2.67d	3.66d	0.02d	0.13d
1 x 2	37.55cd	33	37cd	27.25f	29.9cde	34.64e	61.9f	2.27a	2.3de	10.22ab	17.30c	0.17d	3.3a
1 x 3	34.86cde	31	35cde	23.49g	23.6e	39.17e	45.8f	2.28a	2.2ef	6.05c	14.61c	0.15d	3.6a
1 x 4	38.33e	36	38e	23.38b	26.4de	33.28e	45.7f	2.19a	2.0ef	1.66d	16.94c	0.12d	3.3a
2 x 1	49.53f	50	49f	32.40fe	26.8de	119.53c	162.0d	2.59a	2.5d	6.41c	6.47d	0.05e	1.05c
2 x 2	25.67a	28	26a	49.94a	78.8a	223.66b	231.3abc	3.25a	3.1b	10.25ab	24.91b	0.6a	3.95a
2 x 3	32.22f	36	32f	45.87b	45.0bcd	203.30b	199.5c	2.54a	2.5d	11.16ab	28.25b	0.53ab	4.2a
2 x 4	36.89e	36	37e	39.29cd	58.6b	225.02b	206.8bc	2.55a	2f	5.80c	19.53c	0.37c	3.6a
3 x 1	50.36ed	66	50ed	36.63d	40.2bcde	77.61d	104.1de	3.54a	2.8c	2.00d	2.92d	0.03e	0.2d
3 x 2	33.31a	36	33a	41.05c	44.7bcd	212.55b	256.8a	4.38a	3.1b	12.70a	29.39ab	0.53ab	3.8a
3 x 3	37.25cd	36	37cd	39.96c	47.7bc	225.08b	242.1ab	0.14a	3.5a	8.00bc	33.53a	0.49b	3.45a
3 x 4	43.17b	45	43b	38.10cd	42.5bcde	259.55a	209.6bc	0.12a	3.4a	8.94bc	27.92b	0.31c	2.2b
$LSD_{(0.05)}$	4.135	N.S	0.41	2.88	17.84	29.69	34.24	N.S	0.2431	3.071	4.899	14.71	0.1554
S.E $\pm$	1.488	N.S	1.48	1.037	6.416	10.68	12.32	N.S	0.087	1.105	1.762	5.293	0.055

Means with the same letter are not significantly different from each other at 5% level of probability.

Also there was significant difference in PVMV disease incidence and severity between the two susceptible varieties (NHV1-D96 and NHV1-E96) in the fertilizers applied in the field cultivated and potted pepper (Table 2). The application of 10 tons/ha poultry manure recorded the least PVMV disease incidence and severity compared with other fertilizer treatments applied both on the field cultivated pepper and potted pepper.

3.2. Effect of Fertilizers Treatments on Pepper Yield and Agronomic Parameters

The fertilizers applied and the varieties used showed a high significant effect ($P < 0.01$) on the plant height, leaf number, internode's distance, number of fruit per plant and fruit yield in the field cultivated and potted pepper plants (Table 1).The effect of the interactions between the fertilizers and the varieties were also significant on the plant height, leaf number, internode's distance, number of fruit per plant and fruit yield.

There was a high significant variation in the mean plant height, leaf number, internode's distance, number of fruit per plant and fruit yield within the varieties, fertilizers and interaction between the varieties and the fertilizer treatments (Table 2). Variety NHV1-G96 varied significantly in all the fertilizer treatments and the varieties used. It had the highest mean height of 41.88 cm in potted pepper plants and 52.3 cm in field cultivated pepper plants while variety NHV1-D96 had the lowest mean height of 24.0 cm in potted pepper plant and 26.5 cm in field cultivated pepper plant. Varieties NHV1-G96 and NHV1-E96 recorded the highest leaf number both in the field cultivated and potted pepper. Variety NHV1-E 96 had longer internodes distance both in field cultivated and potted pepper plants, while variety NHV1-G96 had the highest mean yield compared with other varieties both in field cultivated and potted pepper plants.

Application of 10 tons per hectare of cured poultry litter as a source of organic manure to field cultivated pepper recorded the highest mean plant height (51.2 cm), leaf number (183.3), internode's distance (2.82 cm) and yield (3.7 tons/ha), while application of 0 tons per hectare recorded the lowest plant height (31.1 cm), leaf number (104.9), internodes distance (2.32 cm) and yield (0.45tons/ha) (Table 2). These trends of responses were also observed in the potted pepper plants.

The effect of the interactions between varieties and fertilizer treatments showed that variety NHV1-G96 at an application rate of 10 tons per hectare of cured poultry litter as source of organic manure recorded the highest plant height and fruit yield both in the field cultivated and potted pepper plants compared with other variety / fertilizer interactions (Table 2).

There was a significant interaction between the yield and the disease incidence and severity among all the varieties, because as disease incidence and severity increase it resulted in significant ($p<0.05$) reduction in the fruit yield (Figure 1)

3.3. Effects of Application of Poultry Organic Manure on Soil Nutrients

The soil particle size analysis before the application of poultry organic manure was made up of 91.30% sand, 1.8% clay, 6.9% silt. Using the guide for USDA soil textural classification (Robert Nuss *et. al. 2001,* Beth Jarvis, 2005) the soil was classified as sandy soil. The laboratory analysis of the soil nutrient before the application of poultry organic manure (Table 3) indicated an increase in the soil nutrient composition of the cultivated plot after eight weeks of pepper transplant, ten weeks after application of organic manure and five weeks after application of inorganic fertilizer especially in plots were poultry organic manure was applied while plots with inorganic fertilizer showed much increase in nitrogen, potassium and phosphorus levels (Table 4).

4. Discussion

The application of poultry organic manure and inorganic fertilizers did not prevent the occurrence of PVMV incidence and severity on the three cultivated varieties of pepper, but the PVMV characteristic symptoms and severity were expressed at varied degree, which were similar to earlier described symptoms (Green and Kim, 1991; Fajinmi *et al.,* 1998; Robert *et al.,* 2001). This suggest for the ability of PVMV to successfully infect pepper and its endemic nature on cultivated pepper.

Five agronomic parameters have been used in this study to determine the contributive effect of the poultry organic manure application on cultivated pepper plant infected with PVMV disease. The contributive effect was identified when values associated with the agronomic parameters of PVMV infected pepper plant that poultry organic manure has been applied, is greater than the values of those PVMV infected pepper plant that poultry organic manure was not applied. How and the manner this contributive effect has been made in the physiological structure of the PVMV infected pepper plant could not be determined in this study.

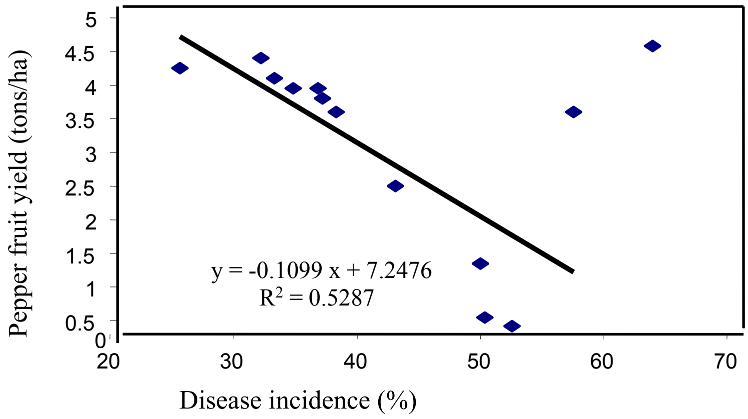
Table 3: Soil nutrient composition per kilogram of sample before pepper seedling transplant

	pH	% Organic carbon	% Organic matter	Potassium (K_2) kg	Sodium (Na^+) kg	Calcium (Ca^{2+}) kg	Magnesium (Mg^{2+}) kg	%Total Nitrogen kg	Iron Fe^{++} kg	Phosphorus (P) kg	Sulphur (S) kg	Zinc (Zn) kg	Excess Acidity (ml)
Poultry manure	6.8	23.74	41.05	0.01626	0.0104	0.016	0.0027	0.018	0.012	0.025	0.00336	0.0002	
Soil	5.53	0.3	0.52	0.0005	0.0008	0.0054	0.0084	0.00042	0.026	0.0013	0.00127	0.00032	0.6ml

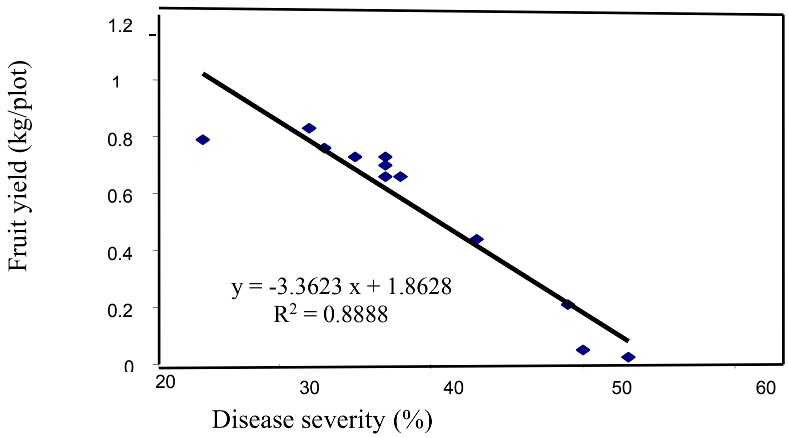
Table 4: Soil nutrient composition per kilogram of soil sample after 8 weeks of pepper seedling transplant

Plot	pH	% Organic carbon	% Organic matter	Potassium (K_2) kg	Sodium (Na^+)	Calcium (Ca^{2+}) kg	Magnesium (Mg^{2+}) kg	%Total Nitrogen kg	Iron Fe^{++} kg	Phosphorus (P) kg	Sulphur (S) kg	Zinc (Zn) kg	Excess Acidity (Ml)
Inorganic plot		0.4	0.58	0.0018	0.0022	0.0068	0.0092	0.00097	0.028	0.0056	0.0018	0.00028	
Poultry manure plot	A) 6.72	2.662	5.862	0.0214	0.026	0.025	0.0182	0.029	0.024	0.054	0.0048	0.00026	
	B) 6.04	3.82	6.224	0.026	0.028	0.029	0.0189	0.032	0.025	0.058	0.0049	0.00029	
Zero fertilizer plot	5.54	0.28	0.55	0.00052	0.00078	0.0055	0.0080	0.00038	0.025	0.0015	0.0010	0.0003k	0.68ml

A= 10 tons/ha of poultry manure plot   *B= 20 tons/ha of poultry manure plot*



(A) Linear curve estimation showing reduction in the fruit yield of field cultivated pepper as disease incidence increases



(B) Linear curve estimation showing reduction in potted pepper fruit yield as disease severity increases

Figure 1. The relation of pepper veinal mottle virus (PVMV) incidence (A) and severity (B) with pepper fruit yield

However, as noted by Robert *et al.,* (2001) and Beth (2005), organic nutrient originates from living organism and are broken down in the soil by bacteria into water soluble forms to amend and condition the soil. It contains the required nutrients elements nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), manganese (Mn), Copper (Cu), zinc (Zn), iron (Fe) and boron (Br)) which are gradually released in small amounts for plant use through the process of decay for a longer period of time, cation exchange capacity are increased, so that soils can hold and release more nutrients for good healthy growth of the plant.

The change and increase in the nutrient composition of the soil in plots that poultry organic manure had been applied, as suggested by Beth (2005), was due to the biodegrading activities of the soil microorganism on the organic matter leading to the slow release of nutrients into the soil compared with the commercial inorganic fertilizers where three major elements (NPK) are supplied and other elements supplied inform of impurities.

Pepper varieties that were fertilized with poultry organic manure, though infected with PVMV disease, had better reduction in PVMV disease incidence and severity and an increased fruit yield compared with the inorganic fertilizer and unfertilized infected varieties. This was due to the amounts of nutrients taken up, which determines the quantity of fruit and dry matter they produce, which in turn is influenced by a number of genetic and environmental variables as suggested by Hedge, (1986) and Green and Kim (1991).

The application of 10 tons/ha of poultry organic manure was observed by this study to be most effective in reducing PVMV disease incidence and severity and improving the yield potential of PVMV infected pepper variety. These compliment the reports by Green and Kim (1991) and Pottorff, (2004), that plants grown under good optimum conditions will have fewer disease problems. But the quantity of nutrients, which the farmer needs to apply, depends on the yield potential of that cultivar, the level of available plant nutrient already in the soil and growth condition. Thus, the significant reduction effect in the PVMV disease incidence and severity in all the cultivated pepper both on the field and potted pepper plant by the application of poultry organic manure as soil fertilizer treatment, might be due to the availability of constant slow release of required nutrient to the plant, which facilitated improvement in vigour of the pepper plant to develop a tolerance level to the PVMV infection.

Plants should be fertilized properly based on soil nutrient analyses using either organic or commercially prepared (inorganic) fertilizers. Control of most plant diseases can therefore be accomplished without pesticides, but Pottorff, (2004), reported it is important to realize that one must accept some disease caused loss.

5. Acknowledgement

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Advances in Improving Harvest Index and Grain Yield of Maize in Ethiopia

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Abstract: The local maize varieties are inefficient in transferring assimilates to the ear sink and as a result they are low yielding. To replace these low yielding local varieties by high yielding ones, different breeding methods have been used in Ethiopia. This study was undertaken to compare improved maize varieties released in Ethiopia for their harvest index and other important agronomic traits. Twelve improved maize varieties which were released from 1970s to 1990s in Ethiopia and 8 breeding populations were tested in a randomized complete block design at Bako Agricultural Research Centre under sub-optimum and optimum soil fertility conditions in 1997 and 1998. The analysis of variance for harvest index and other important agronomic traits showed significant differences ($P<0.01$) among the varieties. The mean harvest index varied from 31.1% (Bako composite) to 45.0% (BH-540), indicating wide differences among the varieties in partitioning the photosynthate into grain and vegetative plant part. The mean grain yield also varied from 4.3 t ha^{-1} (EAH-75) to 7.2 t ha^{-1} (BH-660). All the varieties released in the 1990s had a better harvest index than the old maize composites, indicating the breeding progress made was successful for both grain yield and harvest index. Further progress in maize breeding to improve harvest index and grain yield would be possible with the use of refined breeding methods and tools.

Keywords: Genotype; Grain Yield; Harvest Index; Maize Varieties; *Zea mays L*.

1. Introduction

Local maize varieties were inherently inefficient because of their tall stature, abundant foliage and large tassels that resulted in relatively low harvest index (Benti, 1988; Dowswell *et al*., 1996). Inefficient transfer of assimilates to the ear sink is also one of the limitations in most of tropical maize materials (Benti *et al*., 1993).

Maize breeders have explored various breeding methods to shorten tropical maize and increase grain yield and harvest index. Since the major dwarfing genes in maize are associated with some undesirable morphological traits, breeders employed recurrent selection method to shorten plant height and improve grain yield and adaptation of maize germplasm (Johnson *et al*., 1986; Dowswell *et al*., 1996).

In Ethiopia, the local maize varieties are low yielding and inefficient in transferring assimilates to the ear sink. To replace these low yielding local varieties by high yielding ones, a nationally co-ordinated maize breeding program was started in the late 1960s. Recurrent selection, introgression of exotic improved materials into locally adapted maize materials followed by recurrent selection and introduction of improved materials from international and national research organisations and selection under local conditions were the methods used to improve grain yield and harvest index of maize (Benti *et al*., 1993; NMRPPR, 1996). Thus, the objectives of this study were to compare maize varieties released in Ethiopia in the past three decades and other elite maize populations for their harvest index and grain yield and thereby assess progress made in improving these traits.

2. Materials and Methods

Twelve improved maize varieties which were released in Ethiopia from 1970s to 1990s and 8 elite breeding populations (Table 1) were tested in a randomised complete block design with three replications at Bako Agricultural Research Centre under sub-optimum and optimum soil fertility conditions (0/0 and 100/100 kg N/P_2O_5 ha^{-1}) during the main season of 1997 and 1998. Bako, with an elevation of 1650 meters above sea level, has relatively good distribution of rainfall for maize production as it receives over 1200 mm per annum. The soil at Bako is Nitosol with pH of 5.33 and total phosphorus and nitrogen contents of 9.24 ppm and 0.26%, respectively (Legesse *et al*., 1987). No fertilizer was applied under the sub-optimum soil fertility condition; while under the optimum soil fertility condition phosphorus (P) was applied at planting. Nitrogen (N) was applied in two splits: the first half applied at planting and the remaining half when the varieties were nearly at knee height stage. Urea and diamonium phosphate (DAP) were used as sources of Nitrogen and Phosphorus fertilizers, respectively. All other agronomic practices were undertaken as recommended for the centre.

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Table 1. Maize Varieties used for the study.

Entry No.	Varieties	Year of release	Remark
1	Alemaya Composite RC-2	-	Breeding population
2	Alemaya Composite	1970s	Open pollinated variety
3	UCB RC-2	-	Breeding population
4	UCB	1970s	Open pollinated variety
5	Beletech RC-2	-	Breeding population
6	Beletech S_1 C_1 RC-2	-	Breeding population
7	Beletech	1980s	Open pollinated variety
8	Late RC-5	-	Breeding population
9	Synthetic RC-3	-	Breeding population
10	BH-660	1990s	Hybrid
11	EAH-75	1970s	Open pollinated variety
12	Bako Composite	1970s	Open pollinated variety
13	Kuleni	1990s	Open pollinated variety
14	INT-A	-	Breeding population
15	INT-B	-	Breeding population
16	Gibe-1	1999/2000	Open pollinated variety
17	BH-140	1980s	Hybrid
18	BH-540	1990s	Hybrid
19	A-511	1970s	Open pollinated variety
20	BH-530	1990s	Hybrid

The data recorded were grain yield (GY), harvest index (HI), aboveground biomass (AGB), days to female flowering (silking) (DFF), ear height (EH) and plant height (PH). Fresh biomass weights were recorded and samples were also taken and dried to constant weight. Then total aboveground dry matter and harvest index (ratio of economic yield to total aboveground dry matter) were calculated. Grain yield (t ha^{-1}) was calculated using shelling percentage of 80% and adjusted to 12.5% moisture content.

Analysis of variance was made for grain yield, harvest index, aboveground biomass, days to female flowering, ear height and plant height. SAS computer program (SAS, 2001) was used for data analysis.

3. Results and Discussion

Analysis of variance revealed significant difference ($P<0.01$) for all the traits measured among the varieties under both fertility conditions in both years (Tables 2 and 3). The combined analysis of variance also showed that the effects of the genotypes were significant ($P<0.01$) for all traits measured (Table 4). The significant effect of genotype for harvest index indicates that the genotypes varied in partition of their total biomass to grain. On the other hand, interactions of genotype with year, genotype with soil fertility level, and genotype with fertility level and with year were not significant for harvest index, indicating the consistency of performance of the varieties for harvest index across years and soil fertility conditions. This implied possibility of determining harvest index of genotypes under both sub-optimum and optimum soil fertility conditions. However, the result may be different under severe stress of soil fertility conditions as less biomass is partitioned to reproductive structures under very low soil fertility conditions (Andrade *et al.*, 1999). Although grain yield reduction was less than 50% under low soil fertility conditions in both years (Table 2), the interaction effects of genotype by year, genotype by soil fertility level and genotype by soil fertility level by year were significant for grain yield (Table 4), indicating the inconsistency of performance of some varieties over years and soil fertility conditions. In both years, BH-660 was the highest yielding in both soil fertility levels.

Table 2. Grain yield (GY, t ha^{-1}), harvest index (HI, %), aboveground biomass (AGB, t ha^{-1}) of 12 released maize varieties and 8 breeding populations evaluated at Bako western Ethiopia, in 1997 and 1998 under sub-optimum and optimum soil fertility levels

	1997						1998					
	Sub-optimum			Optimum			Sub-optimum			Optimum		
Entry No.	GY	HI	AGB	GY	HI	AGB	GY	HI	AGB	GY	HI	AGB
1	5.1	42.8	10.6	7.0	40.3	15.2	3.8	40.8	8.0	6.9	42.5	14.5
2	4.1	35.9	10.2	7.1	34.7	17.8	4.4	35.8	10.7	6.2	34.3	13.3
3	4.9	41.5	10.2	7.1	40.8	15.3	4.2	40.7	9.0	6.4	39.7	14.2
4	4.4	33.8	11.4	7.2	33.5	18.9	3.3	34.5	8.6	6.9	38.3	15.6
5	4.0	41.2	8.5	5.5	36.8	13.2	3.2	42.0	6.8	5.3	40.2	11.5
6	4.0	42.7	8.3	6.7	39.1	14.9	3.5	39.1	7.7	5.5	40.3	12.0
7	4.0	37.4	9.4	7.4	37.1	17.4	2.8	35.5	6.9	5.9	40.4	12.7
8	4.6	38.8	10.3	7.4	33.6	19.4	3.4	33.7	8.6	6.8	37.3	15.9
9	5.0	42.3	10.4	7.8	38.6	17.5	3.1	35.6	7.4	6.2	41.2	12.3
10	6.2	42.5	12.8	8.5	36.7	20.3	4.7	41.4	9.8	9.5	44.5	18.6
11	3.0	33.1	7.9	5.6	31.0	16.0	2.9	32.7	7.8	5.6	38.8	12.5
12	4.7	33.0	12.3	6.8	31.1	19.1	2.8	28.7	8.6	6.0	31.6	16.4
13	3.9	40.6	8.5	7.0	38.1	16.2	3.9	38.4	8.5	6.9	42.9	14.1
14	3.3	40.7	7.1	6.6	43.6	13.2	2.2	37.6	5.2	5.9	49.2	10.5
15	4.4	43.2	8.8	7.0	40.0	15.5	3.3	42.0	6.8	5.7	43.9	11.2
16	4.7	42.6	9.6	8.2	43.9	16.5	4.5	44.2	8.8	9.0	45.2	17.5
17	4.4	43.6	8.8	7.4	44.1	14.8	4.1	40.8	8.9	7.2	44.7	14.2
18	4.1	41.7	8.4	7.8	43.3	15.7	4.4	46.7	8.3	8.2	48.1	15.0
19	4.1	42.8	8.5	7.0	43.7	14.1	3.7	40.1	8.1	5.3	41.2	11.0
20	4.8	42.0	10.2	8.4	42.7	17.1	4.3	40.5	9.2	6.5	43.2	13.4
Mean	4.4	40.1	9.6	7.2	38.6	16.4	3.6	38.5	8.2	6.6	41.4	13.8
F-test	**	**	**	**	**	**	**	**	**	**	**	**
CV (%)	13.1	7.4	10.6	9.5	8.5	10.4	14.1	9.0	12.7	9.9	10.7	13.0
LSD (0.05)	0.9	4.9	1.7	1.1	5.4	2.8	0.8	5.7	1.7	1.1	7.3	3.0

*** = Significant at $p < 0.01$*

Table 3. Days to female flowering (DFF), ear height (EH, cm), plant height (PH, cm) of 12 released maize varieties and 8 breeding populations evaluated at Bako western Ethiopia, in 1997 and 1998 under sub-optimum and optimum soil fertility levels

	1997						1998					
	Sub-optimum			Optimum			Sub-optimum			Optimum		
Entry No.	DFF	EH	PH	DFF	EH	PH	DFF	EH	PH	DFF	EH	PH
1	81	98	225	73	137	277	75	97	210	69	107	227
2	84	108	238	76	137	260	81	122	228	75	172	278
3	80	112	227	73	112	242	78	92	203	68	120	245
4	87	145	297	81	153	272	82	113	223	74	165	288
5	77	78	202	73	133	253	75	95	190	67	108	237
6	77	102	220	71	122	243	75	87	195	66	127	248
7	83	110	217	78	117	247	79	107	218	72	133	255
8	83	132	232	77	165	277	85	120	228	71	153	273
9	83	93	205	77	128	253	79	97	225	70	138	250
10	78	118	232	82	157	270	84	118	235	72	160	277
11	85	172	250	83	150	272	82	125	235	72	153	272
12	86	148	270	82	162	290	85	123	238	75	193	300
13	88	90	212	74	122	240	75	100	205	66	120	255
14	78	68	167	69	90	203	73	62	164	65	88	208
15	74	72	193	68	97	203	71	85	173	65	95	217
16	73	85	208	76	100	240	75	88	198	68	98	240
17	80	80	225	77	103	220	75	100	193	71	113	223
18	79	82	193	79	120	232	73	85	198	69	122	235
19	86	95	195	67	97	233	67	90	207	60	97	222
20	71	97	215	76	115	245	74	77	192	68	102	232
Mean	81	104	221	76	126	249	77	99	208	69	128	249
F-test	**	**	**	**	**	**	**	**	**	**	**	**
CV (%)	2.2	18.4	11.1	2.5	14.5	6.4	3.4	14.1	5.9	3.3	11.9	5.9
LSD (0.05)	2.9	31.7	40.7	3.1	30.2	26.2	4.9	23.2	20.2	3.8	25.3	24.4

*** = Significant at 0.01 levels of probability*

The mean harvest index over all the environments was 39.7%, with individual genotypic mean ranging from 31.1% (Bako composite) to 45.0% (BH-540), indicating variability among the varieties in transferring assimilates to the ear sink. Genotypic differences were also observed for mean total aboveground biomass production that ranged from 9.0 to 15.4 t ha^{-1}. The mean grain yield ranged from 4.3 t ha^{-1} (EAH-75) to 7.2 t ha^{-1} (BH-660) as shown in Table 5.

Aboveground biomass, ear height and, plant height were reduced under low soil fertility conditions. On the other hand, days to female flowering (silking) was delayed under low soil fertility condition in both years (Tables 2 and 3). Edmeades *et al.* (1993) also found similar results in tropical lowland maize under stress conditions. Harvest index was negatively correlated with plant height (r = -0.83), ear height (r = -0.87) and days to silking (r = -0.67), indicating that the tall late maturing old composites were poor in partitioning of assimilates to the economic yield. These old composites had also relatively high total aboveground biomass, however, they had low harvest index. Similar results were reported by Johnson *et al*. (1986) in which they indicated that unimproved tropical maize materials have low harvest index.

Table 4. Combined analysis of variance for harvest index (HI), grain yield (GY), aboveground biomass (AGB), days to female flowering (DFF) and ear height (EH) and plant height (PH) of 12 released maize varieties and 8 breeding populations tested at Bako western Ethiopa, in 1997 and 1998

Source	df	Mean squares					
		HI	GY	AGB	EH	PH	DFF
Year (Y)	1	20.5^{ns}	27.3**	242.4**	106.7^{ns}	2356.3**	1470.2**
Fertility env. (FE)	1	28.3^{ns}	494.6**	2315.6**	38506.7**	70452.3**	2653.4**
Y x FE	1	281.2**	0.5^{ns}	20.4**	881.7^{ns}	2747.3**	163.4**
R/(FE x Y)	8	33.3*	2.9**	14.8**	512.9^{ns}	856.8**	24.3**
Genotypes (G)	19	166.0**	6.0**	27.6**	6072.7**	6223.7**	220.7**
Y x G	19	12.7^{ns}	1.0**	3.7*	358.2^{ns}	379.8^{ns}	15.8**
FE x G	19	13.7^{ns}	1.0**	3.9*	410.4^{ns}	216.4^{ns}	6.9^{ns}
Y x FE x G	19	8.6^{ns}	0.6*	2.5^{ns}	460.4^{ns}	563.2^{ns}	7.8^{ns}
Error	152	12.8	0.4	2.1	283.6	306.2	5.2

**, ** = Significant at $p < 0.05$ and $p<0.01$ ^{ns} = Not significant at $p > 0.05$*

On the other hand, the relatively early maturing varieties (NT-A, ENT-B and A-511) had low grain yield and aboveground biomass but harvest index was over 40% (Table 5). The earlier version of Beletech, Beletech S_1 C_1 RC-2, which was developed through S_1 selection had also better harvest index than the original Beletech. However, the improved version had relatively lower aboveground biomass and grain yield than Beletech. This showed high harvest index alone could not indicate high grain yield. Hence, it is important to select for both plant architecture and high biological yields along with high harvest index. Similar conclusion was made by Frey (1984). In this experiment, the high yielding varieties, BH-660 and Gibe-1, had also high aboveground biomass and harvest index, which indicated the importance of improvement for both traits. In addition, the simple linear correlation analysis showed positive relationship (r = 0.69) between aboveground biomass and grain yield.

Beletech which was developed from Bako composite through full-sib family selection under the optimum soil fertility condition (Benti *et al*., 1993) had better harvest index than the original composite which implied the successful improvement of harvest index through recurrent selection (Table 5). Johnson *et al*. (1986) also reported the successful improvement of harvest index through recurrent selection in tropical maize, Tuxpeno-1.

Alemaya composite RC-2 and UCB RC-2 were synthesised by introgressing CIMMYT, Pioneer and selected East African germplasm into Alemaya composite and UCB, respectively (NMRPPR, 1996). The two breeding populations had better grain yield and harvest index than the original composites which indicated the possibility of improving harvest index and grain yield through selection following introgression of improved genotypes into locally adapted materials. Gibe-1 was also synthesised from selected East African, Pioneer and CIMMYT materials. Mass selection was used to improve this population and it had better grain yield and harvest index than all the other open pollinated varieties. This also showed that the East African maize breeders could improve the harvest index and grain yield of locally adapted maize genotypes through introgression followed by selection. On the other hand, Late RC-5 which was mainly synthesised from locally adapted East African materials was inferior in harvest index and grain yield as compared to the other improved materials.

Kuleni (Pool-9A) was selected from introduced CIMMYT materials (Benti *et al*., 1993) and this variety had better harvest index, grain yield and other agronomic traits than the old East African composites. This also indicate that the CIMMYT improved maize materials have better harvest indices than the East African composites and hence, CIMMYT could be a good source of improved germplasm for East African maize breeding programs. In addition, CIMMYT improved maize materials were shorter than the old East African composites. This permits cultivation of high density plant stands and provides new inter-cropping alternatives for the farmers (Dowswell *et al*., 1996). Most of the East African materials were tolerant to leaf diseases (data not presented) and they could be good sources of genes for disease resistance.

All the varieties released in the 1990s had better harvest indices than the old composites, indicating that the progress made is not only for grain yield but also for harvest index (Figures 1 and 2). When the mean grain yields and harvest indices of all the varieties released in the 1990s were compared to the mean grain yields and harvest indices of the varieties released in the 1970s, the mean grain yields and harvest indices were increased by 24 and 20%, respectively. The new maize varieties had harvest indices above 40% while the old composites had below 40% except A-511. This indicates the progress made over the years in improving grain yield and harvest index in Ethiopia. Dowswell *et al*. (1996) reported that the harvest index of most improved tropical maize increased from about 30% to 43% and the present study also proved similar trends. The simple linear correlation analysis also showed positive relationship (r = 0.40) between grain yield and harvest index.

The superiority of the new maize varieties in harvest index as compared to the old composites also indicated that the new maize varieties allocate much of the available photosynthetic products to the grain as compared to the old composites. This has been reflected in their better response in grain yield to favourable soil fertility condition than the old composites. Sinclair (1998) reported that the germplasm with nitrogen and other assimilates will allocate to the grain to allow subsequent increases in harvest index.

The present study clearly demonstrated that better grain yield performance of the improved open pollinated and hybrid varieties is mainly due to an increase in harvest index. It also indicated that harvest index of the East African old maize composites could be improved through introgression of other improved materials into them followed by recurrent selection. The study also demonstrated that the CIMMYT improved germplasm had better harvest indices than the East African old maize composites. Thus, the CIMMYT improved germplasm could be potential sources to develop improved varieties in East Africa.

Although all the hybrids tested in this experiment had harvest indices of 40-45%, further improvement is necessary to develop hybrids with better harvest index. The success of US maize breeders who have already achieved 50-55% harvest index for the US maize belt hybrids (Dowswell *et al*., 1996) could be a good example for the national maize breeders.

Table 5. Mean performance for days to female flowering (DFF), ear height (EH), plant height (PH), grain yield (GY), aboveground biomass (AGB) and harvest index (HI) of 12 released maize varieties and 8 breeding populations tested at Bako in 1997 and 1998.

Entry No.	DFF	EH (cm)	PH (cm)	GY (t ha^{-1})	AGB (t ha^{-1})	HI (%)
1	74	110	235	5.7	12.1	41.6
2	79	135	251	5.5	14.0	35.2
3	75	109	229	5.6	12.2	40.7
4	81	144	270	5.5	13.6	35.0
5	73	104	220	4.5	10.0	40.0
6	72	109	227	4.9	10.7	40.3
7	78	117	234	5.0	11.6	37.6
8	79	143	253	5.6	13.6	35.8
9	76	114	233	5.5	12.0	39.4
10	81	138	253	7.2	15.4	41.3
11	81	150	257	4.3	11.1	33.9
12	83	157	275	5.1	14.1	31.1
13	74	108	228	5.5	11.8	40.0
14	70	77	186	4.5	9.0	42.8
15	69	87	197	5.1	10.6	42.3
16	75	93	222	6.6	13.1	44.0
17	76	99	215	5.8	11.7	43.3
18	77	102	215	6.2	12.0	45.0
19	66	95	214	5.1	10.4	42.0
20	75	98	221	6.0	12.5	42.1
Mean	76	114	232	5.5	12.1	39.7
CV (%)	3.0	14.7	7.6	11.2	12.0	9.0
LSD 0.05	3.6	27.0	28.0	1.0	2.3	5.7

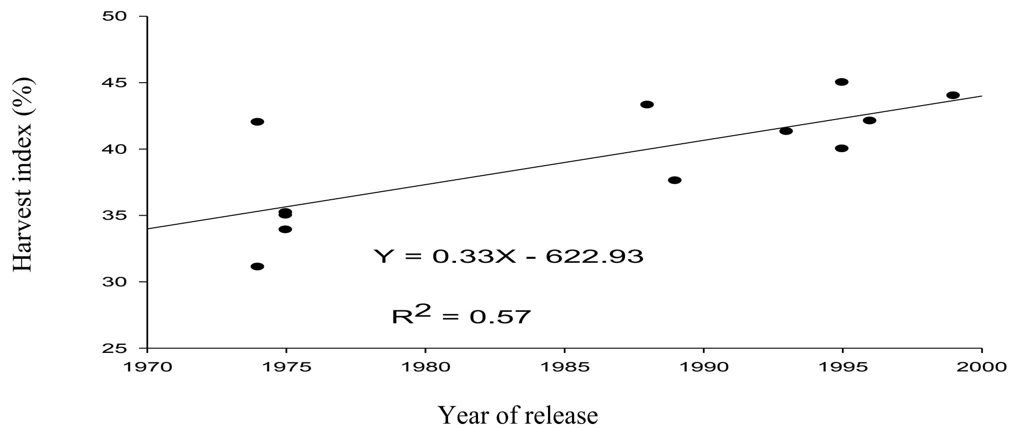

Figure 1. Mean harvest index of 12 maize varieties released in Ethiopia from 1970 to 2000.

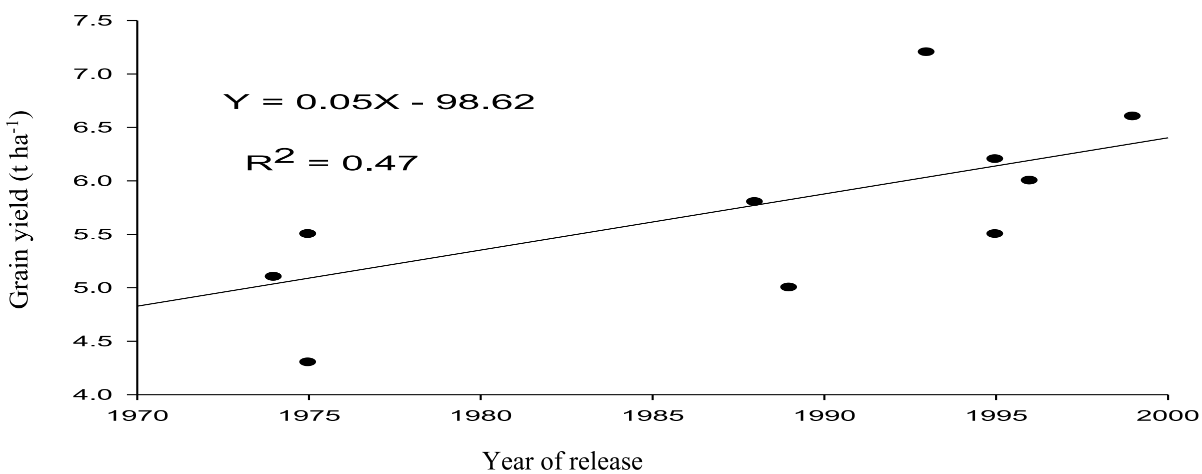

Figure 2. Mean grain yield of 12 maize varieties released in Ethiopia from 1970 to 2000.

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Response of Anchote (*Coccinia Abyssinica*) to Organic and Inorganic Fertilizers Rates and Plant Population Density in Western Oromia, Ethiopia

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Abstract: A comparative study of organic and inorganic fertilizer, and intra-row and inter-row spacing experiments were conducted at Bako Agricultural Research Center for three consecutive years (2002-2004) to determine optimum nutrient supply and plant population, respectively, for anchote production. The experiments were laid out in a randomized complete block design with three replications. The fertilizer study consisted of four nitrogen levels: 0, 46, 92 and 138 kg N ha^{-1} and three phosphorous levels: 0, 20 and 40 kg P ha^{-1} in a factorial arrangement along with farmyard manure (FYM) at rates of 5, 8 and 10 t ha^{-1}. The spacing study was conducted using three intra-rows: 10, 20 and 30 cm and four inter rows: 40, 60, 80 and 100 cm. Analysis of variance showed highly significant difference among N rates with respect to root length and root yield. Similarly, P and FYM supply resulted in highly significant difference in root yield. Apparently, application of 5 and 8 t ha^{-1} FYM resulted in an improved root yield of 44% and 63% over control, respectively. The supply of FYM was found to be superior over inorganic fertilizer supply perhaps due to its merits in improving soil structure, organic matter and enhancement of nutrient uptake. Intra-row spacing affected root yield highly and significantly while inter row spacing affected root yield and average root weight per plant. The reduction of intra-row spacing from 30 cm to 10 cm resulted in increase of total tuberous root yield by 137%. Reduction of inter row spacing from 100 cm to 40 cm resulted in high total tuberous root yield by 37.4%. From the present findings, therefore, 5-8 t ha^{-1} FYM or 46/20 kg ha^{-1} N/P and 40-60 cm inter row and 10 cm intra-row spacing are recommended for high yield of anchote production and enhancement of soil structure and its nutrient contents for the western sub-humid zones of Oromia, Ethiopia.

Keywords: Anchote; Farm Yard Manure; Inorganic Fertilizer; Root Yield; Spacing

1. Introduction

Root and tuber crops have been the main components of the traditional foods of the southern, southwestern and western parts of Ethiopia, particularly in densely populated areas (PGRC/E, 1988). Various native and exotic root and tuber crops are cultivated in these densely populated areas. Of the native root and tuber crops to Ethiopia, which are believed to have enormous genetic diversity, as they are indigenous and have been cultivated by farmers for a long time are anchote (*Coccinia abyssinica*), kote hare (*Dioscorea bulbifera*), enset (*Ensete ventricosum* C.), Oromo dinchi (*Coleus edulis*) and yam (*Dioscorea abyssinica* and *Dioscorea schimperiona*).

Anchote belongs to the family Cucurbitaceae, which are fruit bearing plants. However, anchote is the only root-bearing crop in the genus Coccinia and family Cucurbitaceae. Anchote is one of the indigenous root and tuber crops, which has been grown over a wide range of environments (1300-2800 meter above sea level.), with sporadic distribution. It is commonly produced by botanical seed. Basically anchote produces one root per plant. Its stem is a vine like cucurbit with tendrils and usually requires staking for seed production. The vine of anchote can grow on average up to 2 m heights. Anchote produces many branched stems just at the base of the plant. It also produces large above ground biomass, which may grow at the expense of tuberous root growth and deserves some agronomic management studies.

Anchote is a good source of protein, carbohydrate, calcium and iron (Amare, 1973). Except for some preliminary work undertaken at Bako Agricultural Research Center, no planned and coherent research has been conducted on anchote. On the other hand, anchote farmers, especially women, have been carrying out anchote husbandry from time immemorial.

In western Oromia zones, anchote is produced on several hectares of land with an average yield varying from 10–15 t ha^{-1} (Abdissa, 2000). Farmers usually grow local varieties of anchote under sub-optimal management practices like method of planting (broadcasting), weeding (varies from farmer to farmer), blanket fertilizer levels, mainly from organic sources such as crop residue, farm yard manure, household garbage, etc. It is significant to note that inappropriate agronomic packages may be some of the factors limiting crop productivity, quality and nutritive value of anchote. Of which, lack of recommended optimum organic and inorganic fertilizer rates and spacing were found to overweigh the other problems in the case of anchote.

Fertilizer studies conducted on different crop species over different locations in Ethiopia in general and in the

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western parts in particular entails that most of the soils of Ethiopia are deficient in P and N and are unable to support high crop productivity (Gemechu *et al.,* 1991; Tadesse and Tolessa, 1998). On the other hand, it was observed that anchote responds strongly to soil fertility, particularly to wood ash, burnt crop residues and household garbage, and produces large sized and quality roots of good shape (Abera, 1995; Girma, 1997). Further, like other root and tuber crops, anchote is a short cycle crop which bulks high yield in a relatively shorter period of time, and hence requires high fertilizer supply.

In the traditional anchote production system, farmers on average use about 15-20 cm spacing in broadcasting for anchote production. This spacing is apparently not optimum to provide sufficient soils for root coverage and to undertake some agronomic management practices. Spacing is of primary importance in greatly influencing root yield by affecting root size categories and quality. The manipulation of row spacing, plant populations, and the overall spatial arrangement of crop plants in a field has been the subject of considerable discussion among farmers and agronomists for many years.

Therefore, understanding the shortages of information pertaining to anchote production and management system, agronomic studies (fertilizer and spacing) were initiated with the objectives to understand anchote response to different fertilizer sources, determine optimum fertilizer rates and spacing for high yield and quality anchote production.

2. Materials and Methods

The studies were conducted at Bako Agricultural Research Center, western Oromia, Ethiopia. Bako Agricultural Research Center is situated at an altitude of 1650 m asl. The area receives total annual rainfall of 1213 mm (30 years average) with the rainfall season extending from April to October with the highest peak received in June and August. The mean minimum, optimum and maximum temperatures (30 years average) are 13 ^{O}C, 21 ^{O}C and 34 ^{O}C, respectively. The experiments were laid out in a randomized complete block design with three replications.

The study was undertaken on reddish brown Nitisols, which is acidic with a pH of 4.83 (Table 1). The fertilizer level bases for this study have been potato and sweet potato fertilizer studies so far made at Bako. The fertilizer study consisted of four N levels: 0, 46, 92 and 138 kg N ha^{-1}, in the form of urea, and three P levels: 0, 20 and 40 kg P ha^{-1}, in the form of triple super phosphate, in a factorial arrangement along with organic fertilizer at the rate of 5, 8 and 10 t ha^{-1} FYM. The FYM was well decomposed before use.

Seed of local anchote variety was sown on June 14th, 17th, and 9th in 2002, 2003 and 2004, respectively. Local anchote variety is herbaceous prostrating and climbing type which can produce up to 2 m long vine depending on the management and moisture supply of the area. It is ready for harvesting after 4 to 5 months after planting. The size of the plot was 8 m^2. The spacing used was 80 cm between rows and 20 cm between plants. Half the quantity of N was applied in band on the row and incorporated into the soil at the time of planting while the remaining N was side-dressed 5 cm around the root zone at one and a half months after planting. The entire quantity of P was applied at the time of planting in band on the row and incorporated in to the soil.

The spacing study involved three intra-row spacings: 10, 20 and 30 cm and four inter row spacings: 40, 60, 80 and 100 cm. Seed of local anchote variety was sown on June 21st, 17th and 8th in 2002, 2003 and 2004, respectively, on various plot size according to factorial arrangement of spacing. Blanket recommendation of fertilizer for root and tuber crops, 40 kg P ha^{-1} in the form of DAP and 66 kg N ha^{-1} in the form of urea was applied on every plot. The entire quantity of DAP and half of the total urea required were applied at the time of planting in band on the row and incorporated into the soil while the remaining urea was side-dressed 5 cm around the root zone at one and half months after planting.

2.1. Soil Sampling and Analysis

Soil samples were collected from a depth of 0–30 cm from different places of the experimental site before planting to form one composite sample to determine some soil physico-chemical properties (Table 1).

The collected soil samples were air-dried and ground to pass through a 2 mm pore size sieve for analysis. Particle size distribution was determined by Bouyoucos Hydrometer Method (Day, 1965). The soil pH at 1:2.5 soil-water ratio was measured using a digital pH meter (Page, 1982).

Table 1. Physico-chemical characteristics of the soil of experimental site in 2004

pH	EC	Sand (%)	Silt (%)	Clay (%)	CEC	BS	TN (%)	OC (%)	Phosphorus (ppm)		AvK (meq/100g)
									AvP	TP	
4.83	0.08	14.7	28.0	57.3	29.5	54.84	0.21	3.68	0.54	706.03	1.88

EC= electric conductivity, CEC= cation exchange capacity, BS = base saturation, TN = total nitrogen, OC = organic carbon, AvP = available phosphorous, TP = total phosphorous, AvK = available potassium and ppm= parts per million.

The organic matter content of the soil was determined by Walkley and Black method (Dewis and Freitas, 1970). Total nitrogen was estimated by micro-Kjeldahl method (Dewis and Freitas, 1970), available K by flame photometry (Anon, 1984) and soil cation exchange capacity (CEC) and basic exchangeable cations (Ca, Mg, K and Na) were determined by ammonium acetate method (Chapman, 1965). The available and total soil P were estimated following THE standard procedure (Olsen and Dean, 1965). Percentage base saturation was calculated by dividing total exchangeable base by CEC of the soil and multiplied by 100.

Data collected included total root yield, root diameter, root length and root weight per plant. Root diameter (cm) was measured by caliper at mid point of the root length at harvesting time. Root length indicates the measurement of root from tip to tip in cm by using measuring tape or ruler at harvesting. Root yield in this report indicates fresh root yield as soon as harvested. Roots were evaluated for root disease and found immune from any diseases. Data were analyzed by GENSTAT software program (Version 7) as factorial combinations and also as single factor. When a significant treatment effect was found, the test of least significance difference (LSD, P at 0.05 and 0.01) was used to separate means. After separate each year data was analyzed and normality of error variance was validated, over years data were pooled together.

3. Results and Discussion

3.1. Inorganic Fertilizer Response

The years combined analysis of variance showed highly significant difference ($p < 0.01$) among nitrogen levels with respect to root length and yield, whereas root diameter and average root weight per plant were found to be non-significant (Table 2). The increment of nitrogen supply from 0 to 46 kg ha^{-1} resulted in an increase of 20% root yield and then afterwards declined (Table 2). The increase in root yield was found to be low when compared with root yields of potato and sweet potato on the same soil implying that anchote can perform on poor marginal soils or it is less N nutrient demanding root crop. Basically in any root and tuber crops, yield increase is attributed to the increase in nutrient supply probably resulted from promoting yield components and prolonging the vegetative growth. Hence, the contribution of anchote yield components towards root yield increase cannot be underestimated (Table 2). Similar findings were reported on sweet potato at Bako by Girma *et al.* (2003).

Table 2. Influence of different rates of nitrogen fertilizer on tuberous root yield and yield components of anchote at Bako during 2002 to 2004 cropping seasons.

Nitrogen (kg ha^{-1})	RY (t ha^{-1})	RD (cm)	RL (cm)	FRW per plant (kg)
0	9.88	7.142	13.274	0.383
46	11.81	7.711	14.289	0.426
92	11.73	7.422	13.304	0.416
138	10.23	7.451	13.622	0.383
CV	19.07	13.24	10.62	13.83
LSD	1.72*	n.s.	0.786*	n.s.

*RY = Root yield; RD = Root diameter; RL = Root Length; FRW = Fresh root weight per plant; n.s = Non-significant at 5% probability level; * = Significant at 5% and 1% probability level, respectively.*

Similarly, phosphorous supply resulted in highly significant difference ($P < 0.01$) of root yield among the levels. Apparently an increase in phosphorous supply from 0 to 20 kg ha^{-1} resulted in an increase of root yield by 30%. Although the difference was not significant in root diameter, length and average root weight/plant, the trend was increasing (Table 3). The current positive response of anchote to P supply is not in conformity with potato and sweet potato findings in which there was no response to P supply owing to the acidity of the soils and fixation of P probably in the forms of Fe and Al compounds (Girma *et al*., 2003 and Girma and Ravishankar, 2004). The positive response of anchote to P supply was probably related to its deep root growth that facilitates more soil P reserve exploitation as compared to potato and sweet potato. Usually anchote root grows downwards in to the soil and never requires ridging or mound making as compared to most other root and tuber crops. The NP interactions showed non-significant response to all parameters studied. No interaction effect of N and P does not warrant recommending application of the two nutrients separately

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Table 3. Influence of different rates of phosphorous fertilizer on tuberous root yield and yield components of anchote at Bako during 2002 to 2004 cropping seasons.

Phosphorous (kg ha^{-1})	RY (t ha^{-1})	RD (cm)	RL (cm)	FRW per plant (kg)
0	9.10	7.079	13.411	0.375
20	11.85	7.526	13.600	0.403
40	11.80	7.690	13.856	0.427
CV	19.07	13.24	10.62	13.83
LSD	1.49**	n.s.	n.s.	n.s.

*RY = Root yield; RD = Root diameter; RL = Root Length; FRW = Fresh root weight per plant; n.s = Non-significant at 5% probability level; *, ** = Significant at 5% and 1% probability level, respectively.*

3.2. Response of Anchote to Organic Fertilizer

The anchote plots which received FYM produced vigorous, deep green and strong vine. The plants remained vegetative and green for longer as compared to the plants that received inorganic fertilizers (Table not shown). The supply of FYM significantly influenced root yield (Table 4). Maximum root yield was recorded when 8 t ha^{-1} FYM was applied. The yield then declined afterward when the rate increased to 10 t ha^{-1} FYM. The supply of 5 and 8 t ha^{-1} FYM resulted in increased root yield by 44% and 63% over the control, respectively. The yield improvement achieved by applying FYM was double to triple in contrast to inorganic N and P fertilizers supply. The effects of NP combined levels however did not show clear trends as opposed to the FYM levels (Table 5). This could be explained that anchote prefers organic fertilizer sources that contain several macro and micronutrients because of good water holding capacity, cation exchange capacity and slow release of nutrients as to plants need; besides improving soil structure.

From practical experience, farmers mainly grow anchote on the fields of burned crop residues, household garbage and near homestead on manured plots. This may suggest that anchote demands more balanced N, K, P and micro-nutrient fertilizers than others, which is substantiated by the present findings of FYM supply (Abera, 1995; Girma, 1997). Hence, the superior response of anchote to FYM may, therefore, be linked to the balanced supply of N, P, K and micronutrient supply potential of FYM. It was reported by different researchers that K has more quality determinant effect in root crops than doing productivity. From the present finding, therefore, we recommend 46/20 kg ha^{-1} N/P or 5-8 t ha^{-1} FYM for anchote production as multiple options for farmers of different wealth status (Table 5). We also suggest further investigation of anchote response towards different organic sources and also to study the influences of nutrient supply on basic biochemical composition of anchote. In a nutshell, the positive response of anchote to both organic and inorganic fertilizer supply is corroborated by laboratory soil test that indicated the very low nutrient content of the study soil with regard to total N, available and total P and OM (Table 1). These indicate that the soils of Bako are poor in primary macronutrients to support successful plant growth and high yield, suggesting application of different sources of fertilizers to boost anchote and other food crops yield.

3.2. Spacing

The over years combined analysis of variance showed a highly significant difference ($P < 0.01$) among intra-row spacing on total root yield (Table 6). The increase of intra-row spacing from 10 to 30 cm resulted in reduction of plant population by 200%, and subsequently in reduction of total tuberous root yield by 137%. Production of dry matter depends on the conversion of radiant energy into carbohydrate through the process of photosynthesis which takes place in the leaves.

Table 4. Influence of different rates of farmyard manure on tuberous root yield and yield components of anchote at Bako during 2002 to 2004 cropping seasons.

FYM (t ha^{-1})	RY (t ha^{-1})	RD (cm)	RL (cm)	FRW per plant (kg)
0	9.84	7.022	13.133	0.401
5	13.68	7.500	13.400	0.413
8	15.42	7.701	14.356	0.454
10	14.95	8.122	14.767	0.414
CV	14.23	10.18	11.24	12.53
LSD	3.23**	n.s.	n.s.	n.s.

*RY = Root yield; RD = Root diameter; RL = Root Length; FRW = Fresh root weight per plant; n.s = Non-significant at 5% probability level; *, ** = Significant at 5% and 1% probability level, respectively.*

Table 5. Effect of combined NP and farmyard manure (FYM) fertilizer on tuberous root yield and yield components of anchote at Bako during 2002 to 2004 cropping seasons.

N x P (kg ha^{-1}) and FYM	RY (t ha^{-1})	RD (cm)	RL (cm)	FRW per plant (kg)
0 x 0	9.84	7.022	13.133	0.401
0 x 20	8.59	7.178	12.933	0.410
0 x 40	11.20	7.227	13.778	0.371
46 x 0	9.70	7.281	14.022	0.391
46 x 20	13.80	7.861	14.400	0.388
46 x 40	13.05	7.982	13.756	0.458
92 x 0	8.97	7.200	13.467	0.368
92 x 20	13.66	7.340	12.733	0.411
92 x 40	12.55	7.838	13.711	0.387
138 x 0	8.47	6.924	12.689	0.480
138 x 20	11.34	7.714	14.000	0.414
138 x 40	11.51	7.714	14.178	0.407
5 t FYM	13.68	7.500	13.400	0.413
8 t FYM	15.41	7.701	14.356	0.454
10 t FYM	14.95	8.122	14.767	0.414
CV	25.69	12.89	10.89	35.69
LSD	2.84**	n.s.	n.s.	n.s.

*RY = Root yield; RD = Root diameter; RL = Root Length; FRW = Fresh root weight per plant; n.s = Non-significant at 5% probability level; *, ** = Significant at 5% and 1% probability level, respectively.*

The present study did not show significant variation among intra-row spacing with regard to leaf number per plant (Table 6). The average leaf number recorded was 50 per plant while average vine length recorded was 2 m. However, quite tremendous variations in leaf number and leaf areas were expected per hectare in response to plant population variation recorded. Therefore, one might assume that the greater the number of leaves in a field, the better interception of sunlight and the higher the tuberous root yield and vice versa. However it was observed that root length, root diameter and root weight were found superior under wider intra-row spacing at the expense of total root yield (Table 6). Similar result on tuber size and yield response was reported to the number of tuber per plant, N application and intra-row spacing of potato (Arsenault *et al.*, 2001).

On the other hand, inter row spacing resulted in significant difference in root yield, average root weight per plant and root diameter (Table 7). Similar to intra-row spacing, the increase in inter row spacing from 40-100 cm resulted in root yield reduction of 37% (Table 7). Therefore, there was a decreasing trend in root yield as intra-row and inter row spacing increased from 10 to 30, and 40 to 100 cm, respectively, explaining optimum population of anchote in the ranges of 40-60 cm for inter row spacing along with 10 cm intra-row spacing (Tables 6 and 7).

Table 6. Influence of intra-row spacing on root yield and yield components of anchote at Bako during 2002 to 2004 cropping seasons.

Intra-row (cm)	RY (t ha^{-1})	RL (cm)	RD (cm)	FRW per plant (kg)	Leaf No. per plant
10	29.06	13.194	7.183	0.298	61
20	16.94	13.928	7.195	0.320	52
30	12.27	13.736	7.474	0.333	
					44
CV	13.41	11.78	13.89	26.97	10.90
LSD	3.05**	n.s.	n.s.	n.s.	n.s

RY = Root yield; RD = Root diameter; RL = Root Length; FRW = Fresh root weight per plant;
*n.s = Non-significant at 5% probability level; *, ** = Significant at 5% and 1% probability level, respectively.*

Table 7. Influence of inter row spacing on root yield and yield components of anchote at Bako during 2002 to 2004 cropping seasons.

Inter row (cm)	RY (t ha^{-1})	RL (cm)	RD (cm)	FRW per plant (kg)	Leaf No. per plant
40	22.05	13.341	7.068	0.263	51
60	20.63	13.389	6.827	0.297	40
80	18.96	13.807	7.580	0.333	38
100	16.05	13.941	7.541	0.376	42
CV	13.41	11.78	13.89	26.97	12.50
LSD	3.53**	n.s.	0.547*	0.045**	n.s

*RY = Root yield; RD = Root diameter; RL = Root Length; FRW per plant = Fresh root weight per plant; n.s = Non-significant at 5% probability level; *, ** = Significant at 5% and 1% probability level, respectively.*

Anchote is a prostrating vine which can spread its branches up to 2 meters and above. Hence, the high yield under high plant population is attributed to high photosynthesis as there is not much shading effect of the leaves due to the spreading type of plant architecture.

On the other hand, the spacing at which anchote produced optimum yield is quite narrow, when compared to potato (Girma *et al*., 2005). This would be due to the fact that anchote produces only one tuberous root that grows downwards and requires less space and soil cover for optimum yield.

The interaction effect of intra-row and inter-row spacing was not significant on root yield and other yield components. The root yield decreased with an increase of intra-row spacing and inter-row spacing (Table 7). This implies that the recommendation can be based on the separate intra-row and inter-row spacing levels at which optimum yield was registered. Therefore, based on the present finding, 40-60 cm inter-row with 10 cm intra-row spacing is recommendable for anchote production in western Oromia, Ethiopia.

4. Conclusion

From these studies we observed that anchote production was predominantly influenced by spacing or by plant population adjustment. This is because crop canopy has often been manipulated by row spacing and population adjustments in an attempt to improve yields, production efficiencies, and profits by enhancing photosynthetic efficiency.

The study pointed out that anchote was more responsive to organic fertilizer source than inorganic fertilizer sources. Contrary to potato and sweet potato, anchote was found highly responsive to P supply under the acidic soil condition. But, except we postulate that anchote has deep root system rather than potato and sweet potato, the mechanism was not well explored. Therefore, the study suggested the inclusion of more organic sources to reach at conclusive result of anchote response in contrast to the inorganic sources. There is also a need of investigating the mechanism how anchote response was enhanced under such acidic soil condition.

Essentially, based on the present studies, we recommended different options for different wealth categories of farmers for sustainable anchote production in the sub-humid agro-ecologies of western Oromia, Ethiopia. These recommendations are 5-8 t ha^{-1} FYM which is usually affordable by poor farmers, while the inorganic fertilizer at the rates 46/20 N/P kg ha^{-1} is suggested as optimum fertilizer for the well to do farmers. Correspondingly, 10 cm intra-row spacing and 40-60 cm inter-row spacing were found superior in optimum quality tuberous root yield production and, hence, found to be very practical for anchote production.

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Development and Performance Evaluation of Indigenously Made Cooling Chambers for Extending the Shelf Life of Mangoes and Sweet Oranges

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Abstract: A study was conducted to develop, construct and evaluate the performance of cooling chambers made from factory pressed burnt clay (structure-1), locally molded mud blocks (structure-2) and wood wall (structure-3) for extending the shelf life of mangoes and sweet oranges. It was observed that structure-1 significantly ($p \leq 0.05$) registered low temperature and high relative humidity over structure-2 and structure-3. Significant lower physiological loss ($p \leq 0.05$) in weight (PLW) was observed in commodities stored under structure-1 due to the low temperature and high RH probably arising from the low vapor pressure. Structure-2 registered significantly ($p \leq 0.05$) low PLW as compared to structure-3 attributable to the differences in wall thickness. Total soluble solids increased as storage time progressed. The rate of increment, however, was significantly lower in mangoes stored under structure-1 as compared to the other chambers. The juice content of the commodities decreased over time irrespective of cooling chambers. The rate of reduction in juice content was, however; significantly lower in structure-1 than the other two.

Keywords: Cooling-Chamber; Mango; Shelf-life; Sweet-Orange

1. Introduction

In Ethiopia, the post-harvest losses of some horticultural commodities at state farms and peasant sectors are estimated to be around 25-30 per cent (Celis and Stenning, 1997). Thus, reducing post-harvest losses through adoption of appropriate post-harvest technologies may result in increased food supply. As far as storage of fruits and vegetables is concerned, hardly any cost-effective significant attempt had been made in Ethiopia in the past to improve farmer's traditional practices of on-farm handling and storage. Under tropical conditions, through the adoption of appropriate evaporative cooling technology, it is possible to a certain extent, to manipulate the temperature and relative humidity, inside a given storage environment which are important factors influencing post-harvest life of horticultural commodities. It is a natural way of cooling the commodity by evaporation of water. The concept of evaporative cooling works through a process, when the air is not saturated (very low relative humidity) and as a consequence, it evaporates the water used for cooling and thus lowers the temperature of the air and the surface in contact. Evaporative cooling technology thus appears to have immense adaptability potential under Ethiopian conditions as it could be established even in remote areas on small and marginal holdings to provide low-cost storage facilities. Accordingly, the present study aimed at development and performance evaluation of indigenously made cooling chambers for extending the shelf-life of mangoes and sweet-oranges, which are the most commonly grown fruit crops in Ethiopia.

2. Materials and Methods

2.1. Structural Construction

Three different types of cooling chambers of dimensions (61 X 127 X 330) cm were developed and constructed using locally available raw materials viz., wood, factory pressed burnt clay and locally molded mud blocks. Accordingly, the cooling chambers were constructed in triplicate as outlined below:

Structure-1 = Cooling chamber made with factory pressed burnt clay. This represented evaporative cooling chamber technology.

Structure-2 = Cooling chamber made with locally molded mud blocks.

Structure-3 = Cooling chamber prepared with wooden walls representing the control.

All cooling chambers were uniformly provided with a concrete floor and thatch roof coverings. Structure-1 and structure-2 comprised of double walls of 7.5 cm cavity space, which was filled uniformly with river bed sand (2 mm thick). Structure-3 was plastered with mud on both internal and external surfaces. The top of each cooling chamber was provided with thatch roof made of eucalyptus and bamboo frames laced with dry grass cover. The tops of the cooling chambers were kept moist uniformly throughout the period of study. Since the crates required to be stacked by a person, a suitable height of 61 cm was selected. Twenty wooden crates each of dimension (34 x 33 x 52) cm were stacked one above the other in two parallel rows and columns spaced between 20 cm and 6 cm respectively.

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2.2. Experimental Design

The experimental design adopted was factorial completely randomized design (CRD) with three replications for the analysis of average temperature and relative humidity (Gomez *et al.*, 1984). The CRD experimental design with three replications for the entire cooling chamber x time combination of the treatments was realized and was arranged as indicated inTable1.

Table 1. Treatment-time combinations adopted over storage period of Mangoes and sweet Oranges

Cooling chambers commodity	Mangoes	Sweet Oranges
Treatment-time combinations	Structure-1 0 Days	Structure-1 0 Days
	Structure-1 3 Days	Structure-1 7 Days
	Structure-1 6 Days	Structure-1 14 Days
	Structure-1 9 Days	Structure-1 21 Days
	Structure-1 12* Days	Structure-1 28 Days
	Structure-2 0 Days	Structure-1 35 Days
	Structure-2 3 Days	Structure-1 38* Days
	Structure-2 6 Days	Structure-2 0 Days
	Structure-2 9* Days	Structure-2 7 Days
	Structure-3 0 Days	Structure-2 14 Days
	Structure-3 3 Days	Structure-2 21 Days
	Structure-3 6* Days	Structure-2 28* Days
		Structure-3 0 Days
		Structure-3 7 Days
		Structure-3 14 Days
		Structure-3 21* Days

**Indicate threshold level of physiological loss in weight in each cooling chamber.*

2.3. Test Samples

Two types of fruits, mango and sweet orange were used for evaluating the performance of different cooling chambers at different times. These fruits were selected on the basis of their popularity in terms of consumption both by rural and urban dwellers.

2.4. Test Procedures

Freshly harvested mangoes and sweet oranges at optimum stage of physiological maturity were obtained from Melkassa Agricultural Research Center, Ethiopia. The commodities were sorted and thoroughly washed in a stream of cold water, followed by treatment with sodium hypochlorite (0.1%). The moisture was drained out, fruits were surface dried and then stored in the cooling chambers of Structure-1, Structure-2 and Structure-3 (control). Before storing the commodities, the entire surface area of structure-1, sand and cover were fully moistened with water using hosepipe. The sand in the interspaces of structure-1 was kept moistened throughout the period of study by watering twice a day in morning and evening. The commodities were assorted into three lots of fifty kilograms each in four stackable-vented plastic containers. Each of these lots was then transferred to the three different cooling chambers/storage structures and covered.

2.5. Data Collection

2.5.1 Physiological Loss in Weight

The physiological loss in weight in per cent with respect to storage time was computed using the equation suggested by Teledo (1991).

$$\text{Physiological Loss, in Weight (\%)} = \frac{W_1 - W_2}{W_1} \times 100$$

Where, W_1 = the original weight (kg) of given fruit and vegetable; W_2 = weight (kg) of given commodity after periodical intervals of storage time.

2.5.2. Temperature (°C) and Relative Humidity

The average daily outside and inside temperatures and relative humidity of the storage structures were recorded on the days of observation and at interval of three days for mangoes and seven days for sweet oranges using ordinary thermometer and hygrometers respectively.

2.5.3. Total Soluble Solids (°Brix)

The juice samples obtained from random samples of the respective selected commodities were evaluated for total soluble solids content using hand refractometer and values expressed in terms of ^{0}Brix at initial point of storage and at different sampling intervals.

2.5.4. Juice Content

Laboratory juice extractor of the Horticulture Laboratory at Haramaya University was used for juice extraction and the extracted juice volume was measured using a graduated glass cylinder and expressed in milliliter of juice per kilogram of fruit weight (ml/kg). Juice content was determined at the initial point of storage time and at different sampling intervals as mentioned**.**

2.5.5. Shelf life in days

The shelf life of mangoes and sweet oranges was determined by subjectively judging the criteria of unmarketability parameter such as shriveling and softening of the fruits mainly attributable to physiological loss in weight.

3. Results and Discussion

3.1. Evaluation of Cooling Chambers

Structure-1 registered significantly ($p \leq 0.05$) lower temperature than the other chambers. The range of temperature obtained under different chambers during the period of study ranged from 18-21 ^{0}C for structure-1, 19-26 ^{0}C for structure-2 and 20-28 ^{0}C for structure-3 (Table 2). Therefore, structure-1 appeared to be more suitable in prolonging the shelf life of mangoes and sweet oranges. Edmund *et al. (*1957) and Roy *et al.*(1988) also explained that both plant factors as well as environmental factors such as temperature and relative humidity influenced the rate of respiration. Accordingly, the greater the storage temperature is, the higher would be the heat of respiration leading to lower storage life expectancy.

The relative humidity obtained in the cooling chambers varied significantly ($p \leq 0.05$) ranging from 83 - 90% in structure-1, 71 - 82% for structure-2 and 59 - 72% in structure-3. This indicated that structure-1 recorded lower temperature and higher relative humidity values as compared to other two structures (Table 3). Similar observations have been reported by Roy *et al.* (1988) and Thompson (1992). This appeared to be convenient in extending the shelf life of some high moisture containing (more than 80%) fresh horticultural commodities.

It is also interesting to note here that there were almost no fluctuations in temperature and relative humidity in structure-1 during the holding time (Table 2 and 3) as compared to wide fluctuations observed in the other two structures. This is important from the point of view of safe and effective storage of perishable commodities (ASHRAE, 1962; Burdon, 1997; Toledo, 1991).

In this study, structure-1 registered 4 ^{0}C and 7 ^{0}C lower temperatures over that of structure-2 and structure-3, respectively (Table 2). This could be attributed to the fact that water in the moistened sand might have assumed the wet bulb temperature, which led to the cooling of storage environment (Murata, 1997; Roy *et al.,* 1988). The relative humidity inside structure-1 was higher by 10 and 21% over that of structure-2 and structure-3, respectively (Table 3). Humidification of the storage environment perhaps occurred as a result of the vapor pressure exerted by the water of the moistened sand in the interspace of structure-1 being higher than that of the surrounding environment (Anon., 1959; ASHRAE, 1962 and Singh *et al.,* 1988).

The temperature and relative humidity values obtained in structure-3 (control) and structure-2 also varied significantly ($p \leq 0.05$) from each other (Table 2 and 3). The decrease in temperature and increase in relative humidity in structure-2 over structure-3 was of the order of 3 ^{0}C and 11%, respectively. This might be due to the differences in wall thickness and due to differences in thermal conductivity of the components of structures and presence of sand in the interspace of the structure-2, which served as a slab.

The temperature in the structure-2 might have reduced due to the barrier of chamber's wall to the flow of heat from outside to the inner part. Here, the thicker composite walls (12 cm thick mud block and 7.5 cm sand in the cavity as a slab) might conserve the low temperature obtained during the night time. In fact, the out side temperature is greater than the relatively low temperature of the inner one. Because of this the heat gradient was towards the inside part of the chamber. But the composite wall of the chamber was used as a barrier for the heat flow. Assuming other factors remain constant for all, total resistance to heat flow is directly proportional to the thickness of the wall components and inversely proportional to the thermal conductivity of the construction materials (Barre *et al.,*1959). Hence, the mud block chamber temperature was reduced as compared to the wooden wall chamber of thickness about 13 cm. This is corroborated by the findings of (Singh *et al*., 1988), who observed that the temperature difference of two points through composite walls made up of several materials of different thermal conductivity varied. The differences in thermal conductivity of the component materials of mud block and wooden wall chambers could account for the differences in temperature obtained.

3.2. Physiological Loss in Weight (PLW)

Significant ($p \leq 0.05$) variation in physiological loss in weight was observed among the three cooling chambers after the third days of storage period for both mangoes and sweet oranges (Tables 4 and 5). There was a sharp increase in physiological loss in weight of all

Table 2. Cooling chamber temperature (ºC) over the storage period of Mangoes and Sweet Oranges at Melkassa, Ethiopia

Storage structure	Holding period (days)									
	0	3	6	9	12	15	18	21	24	Mean
Structure-1	21	19	19	18	19	19	20	20	20	19
Structure-2	22	23	24	21	19	24	24	26	26	23
Structure-3 (Control)	28	28	26	24	20	27	28	28	28	26
Mean	24	24	23	21	19	23	23	25	25	

	Storage Structure*	Days*	Interaction*
CD (α=0.05)	0.49	0.85	1.48
S.Em(±)	0.10	0.30	0.52
CV (%)	3.92		

** Significant at 5% level of probability, CD = Critical difference, S.Em = Standard error of mean, CV= coefficient of variation*

Table 3. Relative humidity (per cent) of cooling chambers over the storage periods of Mangoes and Sweet Oranges at Melkassa, Ethiopia

Storage structure	Holding period (days)									
	0	3	6	9	12	15	18	21	24	Mean
Structure-1	83	83	87	85	83	88	89	89	90	86
Structure-2	72	76	71	75	73	76	78	81	82	76
Structure-3 (Control)	59	64	61	60	59	63	72	72	71	65
Mean	71	74	73	74	72	76	80	81	81	

	Storage structure*	Days*	Interaction*
CD (α= 0.05)	1.11	1.92	3.32
S.Em (±)	0.39	0.67	1.17
CV (%)	2.67		

** Significant at 5% level of probability.*
CD= Critical difference, S.Em= Standard error of mean, CV= Coefficient of variation.

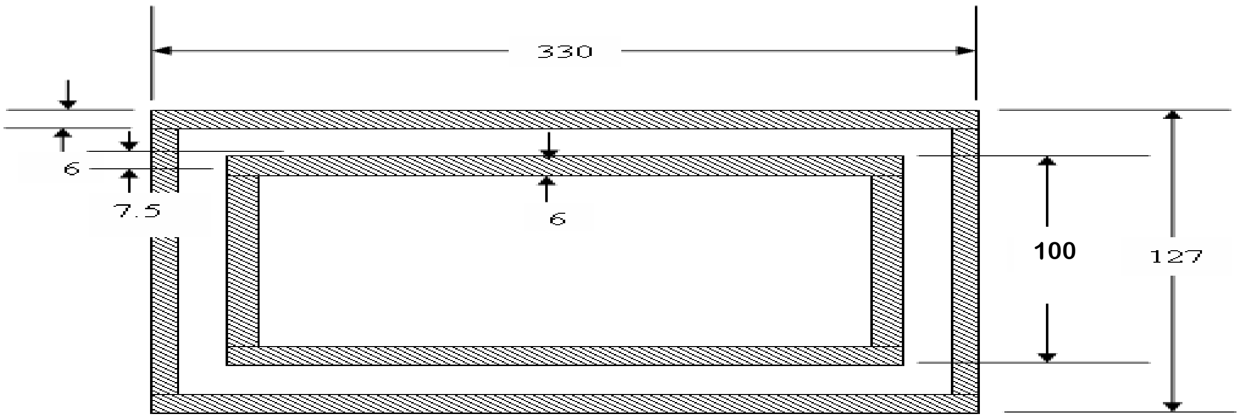
commodities stored in structure-3 (control), whereas, the increase in physiological loss in weight was found to be significantly ($p \leq 0.05$) less with regard to commodities stored in structure-1 as compared to the other structures. This could be attributed to the fact that the rate of respiration varied directly with temperature, (Edmond *et al.,* 1957). This implied that the higher the temperature, the higher would be the respiration and moisture losses leading to weight loss and shrinkage.

It is also evident from regression line equations worked out that the physiological loss in weight of different commodities increased over holding time, but the rate of increment was almost double in structure-3 and structure-2, respectively as compared to structure-1 (Figures 2 and 3). Among the three cooling chambers irrespective of commodity, the slope of the regression line of the estimate was found to be less in structure-1. This clearly demonstrated that the rate of change of physiological loss in weight was greater in structure-3 and structure-2 per unit change of holding time. Strong linear relationship was observed between physiological loss in weight and progress in holding time irrespective of commodity (R^2 values approaching one). Significantly, lower physiological loss in weight values resulting from lower moisture loss recorded by horticultural commodities stored in structure-1 as compared to that of structure-2 and structure-3 (control). This could be attributed to the differences in temperature and relative humidity as influenced by thermodynamic properties of both the components as well as construction features of the storage structures (Anon, 1959; Sing *et al.*, 1988). In the present study, ten per cent physiological loss in weight was considered as a threshold level for the termination of the shelf life. At this stage, the commodities presented good physical appearance with fruits stored in structure-1 in terms of attractive color, glossy appearance, having better edible qualities coupled with higher marketability. Based on these criteria, the physiological loss in weight of mango fruits in structure-1 on the 9th day of storage period was less by 34.98% as compared to the one in structure-3 on the 6th day of storage (Table 4).

Table 4. Effect of cooling chambers on physiological loss in weight, total soluble solids and volume of juice of mango fruits over storage period

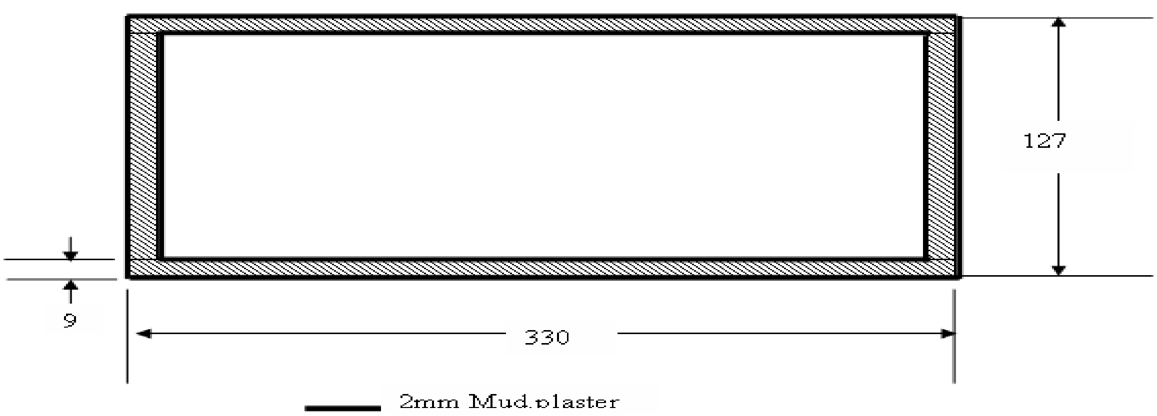
S.No	Cooling chambers/Storage period	Quality parameters		
		PLW (%)	TSS (^{0}B)	Juice (ml/kg)
1	Structure-1 0-day	0.00	11.00	599.7
2	Structure-1 3rd-day	1.84	13.44	554.2
3	Structure-1 6th-day	4.03	13.84	506.5
4	Structure-1 9th-day	9.61	14.37	502.5
5	Structure-1 12th-day**	13.72	14.33	486.4
6	Structure-2 0-day	0.00	11.00	599.7
7	Structure-2 3rd-day	2.41	14.33	528.8
8	Structure-2 6th -day	8.44	14.43	489.2
9	Structure-2 9th day**	18.92	13.71	466.4
10	Structure-3 0-day	0.00	11.00	599.7
11	Structure-3 3rd-day	2.62	14.56	536.0
12	Structure-3 6^{th-}day**	14.78	14.89	453.6
	Test	*	*	*
	S.Em (±)	0.75	0.30	11.03
	CD (α=0.05)	2.20	0.88	32.19
	CV (%)	20.52	3.92	36.30

** Significance at 5% probability level*
***Indicate threshold level of physiological loss in weight in each cooling chamber.*
PLW = Physiological loss in weight
TSS = Total soluble solids



Note: All dimensions are in centimeters, drawing is not to scale.

Figure 1A. Schematic drawing showing plan view of structure-1/evaporative cooling and structure-2/mud-block chambers



Note: All dimensions are in centimeters, drawing is not to scale.

Figure 1B. Schematic drawing showing plan view of structure-3/wooden wall chamber

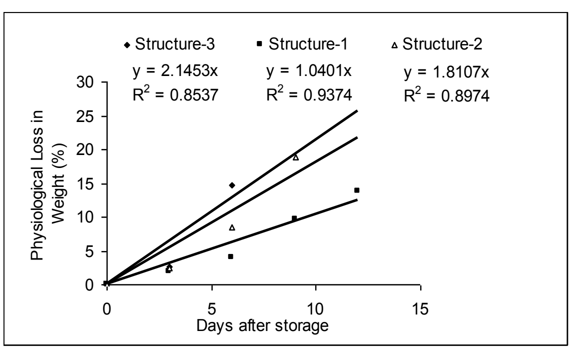


Figure 2. Effect of various cooling chambers on physiological loss in weight of Mango fruits over a storage period

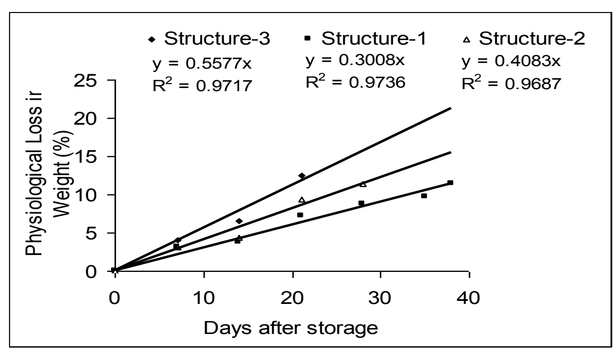


Figure 3. Effect of various cooling chambers on physiological loss in weight of sweet Orange fruits over a storage period

Similarly physiological loss in weight of mango in structure-1 on the 9th day was less by 49.21% than that of the one in structure-2 on the same holding time. This implied that structure-1 is more efficient in reducing the physiological loss in weight of mango fruits as compared to the ones stored in the other two structures at a given threshold level and over holding time. The efficiency of structure-1 in significantly reducing the physiological loss in weight could also be attributed to the effect of low temperature obtained in the cooling chamber environment on the water vapor pressure within the commodity, which is a potential index for desiccation. (Thompson, 1985; 1992)

The threshold physiological loss in weight of ten per cent of mango fruit was attained within six days in structure-3 (control), after six days but before nine days in structure-2 and within twelve days for structure-1 (Figure 4). The significantly higher efficiency of structure-1 in extending the storability of mango fruits appears to be of considerable importance especially for such a climacteric fruit where in high respiratory climacteric leads to faster rate of senescence (Wills *et al.,* 1998). The influence of structure-1 in lowering the temperature and increasing the relative humidity in the cooling chamber environments might have greatly contributed to an increased efficiency (Pal *et al*., 1997; Roy, 1988).

The lower slope of regression line equation than the other two chambers (Figure 2) also revealed the superiority of structure-1. The rate of change in physiological loss in weight per unit change of holding time was almost twice in structure-3 and structure-2 as compared to structure-1. The coefficient of determination (R^2) values showed the strong linear relationship between physiological loss in weight and progress in holding time. Structure-1 recorded significantly ($p \leq 0.05$) lower physiological loss in weight (9.75%) for sweet oranges even after 35 days of storage as compared to the 21st day of storage in structure-2 (9.41%) and (12.53%) in structure-3 (Table 5). This clearly indicated the superiority of structure-1 over the other structures for storage of sweet orange fruits

Table 5. Effect of cooling chambers on physiological loss in weight, total soluble solid and volume of juice of sweet orange fruits over storage period

S. No.	Cooling chambers/ Storage period	Quality parameters		
		PLW (%)	TSS (°B)	Juice (ml/kg)
1	Structure-1 0-day	0.00	8.36	571.6
2	Structure-1 7th-day	3.06	8.36	562.0
3	Structure-1 14th-day	3.77	8.76	543.6
4	Structure-1 21st-day	7.25	8.89	519.8
5	Structure-1 28th-day	8.72	9.28	508.7
6	Structure-1 35th-day	9.75	9.73	479.2
7	Structure-1 38th-day**	11.40	9.97	463.9
8	Structure-2 0-day	0.00	8.36	571.6
9	Structure-2 7th-day	3.16	8.62	522.2
10	Structure-2 14th-day	4.32	8.97	512.6
11	Structure-2 21st-day	9.41	9.04	486.6
12	Structure-2 28th-day**	11.43	9.65	467.8
13	Structure-3 0-day	0.00	8.36	571.6
14	Structure-3 7th-day	4.02	8.90	520.3
15	Structure-3 14th-day	6.52	9.10	494.0
16	Structure-3 21st-day**	12.53	9.42	456.4
	Test	*	*	*
	S.Em (±)	0.62	0.13	8.44
	CD (α=0.05)	1.80	0.37	24.31
	CV (%)	18.10	2.51	2.83

**Significance at 5% probability level. **Indicate threshold level of physiological loss in weight in each Cooling chamber. PLW = Physiological loss in weight TSS = Total soluble solids*

Further, the fact that there were significant differences in effective holding times indicated that structure-1 could effectively store sweet orange fruits twenty days and fourteen days longer than structure-3 and structure-2, respectively (Table 5 and Figure 3). Here again, the superiority of structure-1 in extending the shelf life could be attributed to the low temperature and high relative humidity obtained. The effective holding time observed also well compared with respect to the storage of sweet orange fruits using non-renewable energy sources to accomplish double the holding time (Burdon, 1997; Toledo, 1991). In view of this and the fact that structure-1 uses zero-energy in extending the shelf life of the commodities appears to be significant. The results presented in Figure 3 also explain that physiological loss in weight was found to be higher in structure-3 and structure-2 than structure-1.

Based on threshold physiological loss in weight values of sweet orange fruits, least holding time (less than three weeks) was recorded in structure-3 and slightly beyond three weeks in structure-2 (Table 5). This further substantiated the utility of structure-1 for increasing the effective holding time to five weeks using no energy. This will have immense practical advantage for short-term storage of the commodity in remote rural areas by small and marginal farmers as well as by urban and semi-urban retailers not having access to energy sources.

3.3. Total Soluble Solids (°Brix)

There was a gradual increase in total soluble solids content of mangoes and sweet oranges studied over the holding time irrespective of the cooling chambers/structures used. This suggested the progress of ripening and senescence processes. In mango, it was observed that the rate of increment in total soluble solids under the influence of structure-1 was significantly ($p \leq 0.05$) lower on the 6th day of storage as compared to structure-2 and-3 (Table 4). This clearly brought out the superiority of structure-1 in slowing down of ripening process and extending the storability of mango over structure-2 and-3. The efficiency of structure-1 in slowing down ripening process could be attributed to the significant lowering of temperature and increase of relative humidity as compared to that of structure-3 (Tables 2 and 3). Similar views have been expressed by other works (Wasker *et al.,* 1993).

The rate of increase in total soluble solids content of sweet orange under the influence of structure-1 was significantly ($p \leq 0.05$) lower than structure-2 and-3 on the same day of holding i.e., twenty-first day of storage (Table 5). To determine the effective holding time, based on the threshold level of physiological loss in weight maximum total soluble solids was recorded on the 35th day of storage in structure-1 as compared to the 21st day in structure-3. Thus, structure-1 could provide incremental storage benefit of 14 days over structure-3. This is quite significant from the marketing point of view for both the farmers and retailers. Based on this analogy, structure-2 was also significantly less efficient than structure-1 as maximum total soluble solids content was recorded on the 28th day of storage providing one week less time as compared to structure-1 (Table 5).

3.4. Juice Content

The juice content of fruits and succulent of vegetables which is an important factor influencing the quality, generally decreased with the progress of storage (Wasker *et al.,* 1993; Wasker *et al.,* 1999). In the present study, mango fruits stored under structure-1 storage recorded significantly ($p \leq 0.05$) higher juice content (6.74%) at twelve days of storage over that of structure 3 at the 6th day though the fruits, based on physiological loss in weight criteria had crossed the threshold level (Table 4). This could probably be attributed to the low temperature and high relative humidity effects as factor of desiccation influencing water vapor pressure in the commodity (Thomson, 1985; 1992). In case of structure-2, the differences in juice content, however, was not significant ($p \leq 0.05$) except for the effective holding time, which is also an important criterion of shelf life.

Structure-1 significantly ($p \leq 0.05$) influenced juice content of sweet orange fruits also, over holding times. The juice content of sweet orange after 35 days of storage in structure-1 was comparable to those in structure-3 on the 14th day of storage (Table 5). Thus, structure-1 offered a potential advantage of almost three weeks an important consideration in the marketability of the commodity. The superiority of structure-1 in this regard could be explained in light of the possible influence of low temperature and high relative humidity in lowering the water vapor pressure of the fruits which is a factor in maintaining the juice content (Thomson, 1985; 1992; Wills *et al.*, 1998**).**

4. Conclusion

Structure-1 constructed from the factory pressed burnt clay performed best in extending the shelf life of mango and sweet-orange because of low temperature and high relative humidity over Structure-2 constructed from locally molded mud block and Structure-3 constructed from wood. It is made from easily available materials and this may be scaled up with commercialization in order to suit the high demand from fruit growing community in different parts of Ethiopia. However, its adoption is limited to the area where water is not scarce to constantly keep the sand of interspaces moist.

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Enclosures to Enhance Woody Species Diversity in The Dry Lands of Eastern Tigray, Ethiopia

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Abstract: Vegetation and soil seed banks were studied in exclosures and unprotected areas, to investigate the role of exclosures in the rehabilitation of degraded drylands. Woody vegetation was assessed in fifty plots in exclosures and 30 in unprotected areas, each measuring 20 × 20 m². Twenty-seven woody species representing eighteen families were observed in exclosures and fourteen woody species representing twelve families were recorded in open area. Higher abundance, density and basal area were found in the exclosure. An expanding population structure in exclosure, and obstructed population structure in open area, showed favorable succession in the set-aside area. In both cases, woody species were absent in the soil seed bank.

Keywords: Degradation; Natural Regeneration; Rehabilitation; Soil Seed Bank

1. Introduction

Deforestation has been a major problem for quite a long time with serious consequences to Ethiopia. These consequences include decline or loss of biodiversity, degradation of land and water bodies, possible negative effects on the local, regional and global climatic conditions as well as negative impacts on the welfare of human beings. Effects of deforestation have been great and continue unabated. At the close of the twentieth century, the country found itself undergoing rapid and complete deforestation/devegetation in some places. Forest clearances for crop cultivation, unsustainable exploitation of wood for timber, construction and fuel, overgrazing and civil unrest are among the main causes of deforestation in Ethiopia. Thus, at present, small remnant forests, woodlands or shrublands have become restricted to inaccessible areas such as hillsides, mountaintops, and around churches, monasteries, mosques or graveyards, particularly in the northern parts of the country. Larger forest relics are only found in the southern parts of the country.

One of the regions, which has fallen victim to the land degradation problem in the northern parts of the country, is Tigray. In Tigray, the severely degraded lands can be typically characterized by heavily eroded or nutrient deficient soils, hydrological instability, reduced primary productivity and loss of biological diversity. The floral, faunal and microbial diversity of these areas could be reduced, to the extent that they might be changed into wastelands. Past reforestation/afforestation programs in such areas have been unsuccessful due to either total failure or low survival rate of planted species. Several major factors such as unavailability or low availability of propagules, low soil nutrient availability, absence of fungal/bacterial root symbionts or unsuitability of the microhabitats for plant establishment in general and seasonal drought (Verma *et al*., 1999) may be attributed to such failures.

To circumvent these problems, communities have started to limit interference of people and domestic animals in certain degraded areas (hereafter referred to as exclosures) with the hope of preventing further degradation and promoting their re-vegetation. The main objective of establishing such exclosures is to improve the overall ecological conditions of degraded areas so that they can provide better socio-economic benefits to the local communities. Establishing exclosures is considered advantageous since it is a quick, cheap and a lenient method for the rehabilitation of degraded lands (Bendz, 1986).

It has become a common phenomenon to observe acceleration of plant, but also animal, diversity with time, after the establishment of exclosures. In areas where they have been established, particularly in the northern parts of the country, set-aside areas are among the green spots with considerable woody species diversity (Tefera, 2001). At some places, the local people report that species disappeared in the past have been restored as a result of the exclosures. For instance, in some parts of eastern Tigray, species that had long disappeared from the areas (e.g. *Olea europaea* subsp. *cuspidata* and *Juniperus procera*) re-appeared, densities and diversities of the flora (particularly grasses) and fauna increased, the level of soil erosion decreased, and

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even springs started to flow after exclosures were established (personal observation).

The Bureau of Agriculture and Natural Resources and other development organizations in Tigray have started to avert the land degradation process in the region through massive efforts on soil and water conservation activities, including the establishment of exclosures, with the active involvement of the local communities. Already, some of the degraded areas have become re-vegetated within just a few years (Medanie, 1997), and it is strongly hoped that the current momentum of restoration of the vegetation would continue leading to rehabilitation of the degraded lands, which would in turn offer the desired socio-economic benefits as well as environmental services.

Despite the fact that exclosures have proved instrumental in the re-vegetation/rehabilitation of degraded lands, knowledge on the diversity, sources of propagules and status of regeneration of the developing flora are lacking. Hence, this study was conducted with the aim of studying the diversity, i.e. species richness and evenness of woody species, investigating the soil seed bank as a possible indicator of the actual or potential source of propagules for the developing flora, and assessing the regeneration status of woody species found in one of the oldest exclosures established in Tigray.

2. Materials and Methods

2.1. Description of the Study Area

2.1.1. Geographical Location, Area and Population

The study was conducted in Aynalem within Wukro district situated 30 km north of Mekelle, Eastern Zone of Tigray. The site is geographically located at 39° 50' – 39° 60' E and 13° 70' – 13° 81' N, and covers a total area of 7133 ha. It has five villages and 1800 households, of which 500 inhabit in the actual study area known as Hawza village. The total population in the study area is 3000. In Hawza village, two sites of similar characteristics were selected for the study at a locality known as Ziban Serawat. One site, covering a total area of 58 ha, has been closed for eight years while the other site, covering a total area of 52 ha, has been used for grazing.

2.1.2. Rainfall, Temperature and Length of Growing Period

Aynalem Tabia is a dry area with an average annual rainfall ranging from 500 to 600 mm·yr^{-1} (NMSA, 2002), although variability of rainfall from year to year is very considerable. The rainy season is mainly between June and September. The average annual temperature at the study site ranges from 15 to 18° C. It belongs to the Weinadega traditional agro-climatological zone characterised by a hot to warm semi-arid climate. The length of the growing period varies from 75 to 90 days. However, secondary spring rains locally called 'Belg' cause a separate but unreliable growing period, which lasts for 45-65 days.

2.1.3. Geology and Relief

The study area is found between the Mekelle and Adigrat plateau. The topography in the study area is mainly mountain plateau with undulating terrain. The Adigrat plateau lies between 2500-2700 m and is formed on Antalo limestone. The Axum, Mekelle and Sekota plateau lies between 2000 and 2500 m and is formed on cretaceous shale, limestone and sandstone (TFAP, 1996). The area has an altitude that ranges from 1900 to 2200 m and a slope that ranges between 5 and 20%.

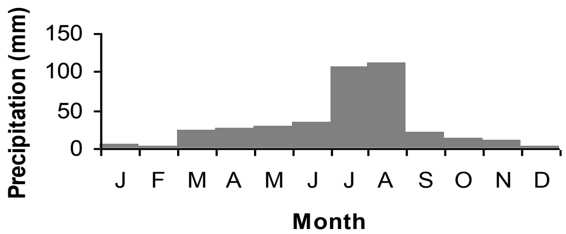
2.1.4. Soils

In the eastern part of the region, where the study area is located, the soils are mostly developed under arid conditions where the weathering process is slow; as a result very shallow lithosols are developed (TFAP, 1996). The locally named soils, such as 'Tsaeda Baehel' and 'Walka', belong to these soil types. Cambisols are also dominant in the arable areas of the study site.

2.1.5. Land Use and Land Cover

The intensively cultivated land covers a large portion of the study area. Practically all the land is opened-up for cropping and grazing livestock. Hardly any vegetation cover is seen in the arable lands except in exclosures and some fallow areas of the previous cropping season. Almost about 80% of the land is under crop cultivation during the cropping season. There are no perennial crops that could cover the major part of the study area. The remaining land is either fallow land used as unimproved pasture or very difficult terrain and not suitable for agriculture. There is high shortage of grazing land, which leads to overstocking during the growing season. After crop harvesting, livestock is allowed into the croplands for grazing. This cycle leaves very extensive areas completely bare by the middle of the dry season, which leads to wind erosion and water erosion during the onset of the next rainy season.

The eastern zone, far worse than other zones, is the most degraded part of the region and almost devoid of vegetation (Tesfaye, 1996). As community forestry practices there are different area exclosures established since 1993, and community tree nurseries managed by the communities. Dispersed trees on croplands, trees and shrubs in home gardens, improved fallow, trees and shrubs on terraces, protection of waterways and gullies, living fences as well as trees and shrubs on pastures are the major agroforestry practices. Some of the woody species found in these practices are *Faidherbia albida, Acacia etbaica, Eucalyptus* spp., *Cordia africana, Schinus molle, Euphorbia* spp., *Optuntia ficus-indica, Agave sisalana*, etc. In this study, plant nomenclature follows Friiss (1992) and the Flora of Ethiopia (Edwards *et al.*, 1995; Hedberg *et al.*, 1995).



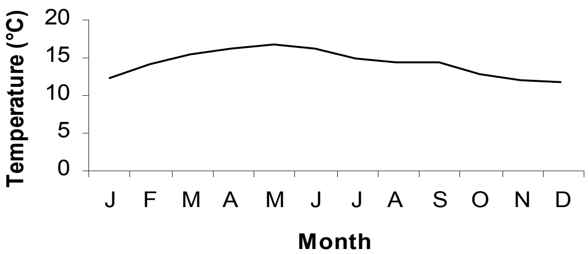


Figure 1. Mean monthly precipitation and temperature for Mekelle town (1991- 2001)

3. Methods

3.1. Species Abundance, Density and Diversity

To determine the species composition, abundance, density and diversity of woody plants, line transects were laid out parallel to each other and with a north to south orientation in the exclosure and open grazing land. The distance between two consecutive parallel transect lines was 200 m. Along the transect lines, sample quadrats measuring 20 m × 20 m (400 m^2) were laid down at 50 m intervals from each other. The quadrats were marked using plastic ribbon and four wooden pegs. A total of 50 and 30 quadrats were established in the exclosure and open grazing land, respectively. More quadrats were sampled in the exclosure since the variability was much higher than in the grazing land. In each quadrat the following measurements were made: (I) the identity of all woody plants was determined and the total number as well as height of individuals (using a graduated stick) of each species were recorded; (II) the diameters of saplings and trees were measured just above the ground (basal diameter) and at 0.5 m height, respectively using a calliper and diameter tape. For regenerated seedlings (height < 0.5 m), only their number was recorded. Individual woody categorization was made as height < 0.5 m and dbh < 2.5 cm for seedlings, h > 0.5 m and dbh < 5 cm for saplings and h > 0.5 m and dbh > 5 cm for trees. For species that were difficult to identify in the field, herbarium specimens were collected, pressed, dried and transported to the National Herbarium in the Department of Biology, Addis Ababa University, for proper identification.

3.2. Ground Cover of Herbs

To estimate the abundance of herbaceous species in the exclosure and open grazing land, a small plot measuring 4 m × 4 m (16 m^2) was placed in the middle of each of the quadrats described above. In this plot, the proportion of cover by each herbaceous species was estimated visually (Sutherland, 2000).

3.3. Regeneration Status

Examination of the population structure of plants, employing either height or diameter classes, has been used to provide a rough idea about the status of regeneration of woody plants (Tamrat, 1994; Peter, 1996; Demel, 1998; Getachew, 1999; Mekuria *et al.*, 1999; Tadesse *et al.*, 2000; Tefera, 2001; Alemnew, 2001; Feyera *et al.*, 2002). To assess the regeneration status of woody plants, through examination of their population structures, all individuals encountered in the quadrats were grouped arbitrarily into: (i) height classes: < 0.5 m (seedlings), 0.5 - 3 m (saplings) and > 3 m (trees); and (ii) diameter classes: < 2.5 cm, 2.5 - 5 cm and > 5 cm. The categorization considers the life form and taxonomic structure. Then, histograms were drawn to see the population structure of a few of the woody plants.

3.4. Soil Seed Banks

The assessment of soil seed banks from both sites was carried out mid-December. Considering the size of the study area samples were taken to represent the main floristic vegetation types. The quadrats used to record composition, height and diameter of woody plants along the line transects were used to collect soil samples for seed bank analyses (Mekuria *et al.*, 1999; Lyarru, 1999; Tefera, 2001). In each of the quadrats, five plots measuring 15 cm × 15 cm were laid out, one at the center and the other four at the four corners. From each plot, three soil layers of three cm thickness each, i.e. a total depth of nine centimetres, were collected using a knife and spoon. Then, similar layers from these five plots within a quadrat were mixed to form a composite sample in order to reduce variability within the quadrats. The composite sample for each soil layer was again divided into five equal parts among which one was selected randomly as a working soil sample (Tefera , 2001). A total of 240 soil samples, i.e. 150 from the exclosure and 90 from the open grazing land, were collected. The soil samples were transported daily from the sites to a safe storing place in Wukro town. Then, the soil samples were transported to the Forestry Research Center (FRC) where they were sieved to recover seeds of woody plants. Four sieve sizes, i.e. 1 mm, 1.6 mm, 2 mm and 3.15 mm, were selected assuming the seed sizes of the different species are within these ranges. Viability of seeds recovered by sieving was determined by cutting tests (Demel and Granstrom, 1995) after which they were identified. The sieved soils were then transported to the Ethiopian Agricultural Research Organisation (EARO) headquarters where they were incubated in a glasshouse to stimulate germination of seeds. In the glasshouse, the soil samples were spread as thinly as possible on plastic trays and watered every day. Seedlings started germinating from the soil samples within a week. The seedlings were identified, counted and removed. Those that were difficult to identify were transplanted into polythene bags filled with a soil medium and left to grow until they let themselves for identification. Those difficult to identify were categorized as unidentified species. Thus, soil sieving together with seedling emergence method was used to assess the status of the soil seed banks.

3.5. Data Analysis

The sum of all species encountered in the quadrats of both the exclosure and open area was used to determine the species richness in the study site. Similarly, the abundance, basal area, Important Value Index (IVI) of each woody species, and the diversity values of woody plants in the exclosure and open area were calculated using diversity indices, species richness, evenness and heterogeneity (Krebs, 1999; Magurran, 1996). In addition to the different indices used a one-way ANOVA test was employed to test the significance of differences.

To assess the ground cover of herbaceous species in the exclosure and open area, the proportions of cover of all herbs in each plot were categorized into ground cover classes (Heinz, 1972). To understand the regeneration status of woody plants and some important tree species a histogram was constructed using frequency distribution of diameter and height classes of different arbitrary classes. The seed bank was analyzed by studying the woody species composition, density of seeds in the soil and horizontal and vertical distribution of seeds (Demel and Granström, 1995).

4. Results and Discussion

4.1. Composition of Woody Species

The total number of woody plant species recorded in the study area, in both the exclosure and open grazing area, was 39, among which 31 were naturally growing species and eight were planted. In the exclosure 27 plant species representing 18 families were recorded. Out of the total woody species encountered in the study quadrats, 37% were trees, 52% shrubs and the rest were woody herbs. In the open grazing area, 14 species were recorded representing 12 families. Here, trees constituted 50% of the total woody species and shrubs 50%. About 14 species were recorded both in the exclosure and open area while 13 species were found only in the exclosure area.

The three most abundant species in the exclosure were *Acacia etbaica, Leucas oligocephala,* and *Oncoba spinosa* (Table 1). Of all the species *A. etbaica* represented about 64% of the total abundance. Similarly, *A. etbaica, Euclea racemosa* subsp. *schimperi* and *Leucas oligocephala*, were the abundant species in the open area (Table 2). *A. etbaica* was the most dominant species (60%).

The composition of the woody vegetation in exclosures of degraded land depends largely on the time since closure, the original vegetation and past disturbance history. The climatic and edaphic conditions could also have a significant effect on the type of species appearing. More time for the exclosure to establish leads to a greater richness in plant communities (Pielou, 1975). Woody species appearance in exclosures indicates a long period of protection, allowing regeneration of shrubs and trees, exemplified in Ethiopia (Kebrom, 2001; Tefera, 2001) and in Eritrea (Medaine, 1997).

The vegetation composed by the woody species and the ground cover of herbaceous species was denser in the exclosure than in the open area. The difference in density was significantly greater for the herbaceous than for the woody species (p=0.01). This indicates that the disturbance in the open area was mainly due to the high grazing intensity throughout the year.

Acacia etbaica was the most dominant species in both the exclosure and open area. The same result was also found in Sekota by Tefera (2001). The importance value index is higher in the open area than in the exclosure, while basal area and density is higher for this species in the exclosure (P=0.01). Hence the species occupies more space in relation to other species in the open area than the exclosure. The dominance of *A. etbaica* could be because the site was originally dominated by this species (history of the site and reports office of agriculture of the site). Even though the area was changed into agricultural land, farmers left important woody species while clearing for shade, fuelwood and to put crop residues, especially trees with an umbrella crown and shorter in height. *Acacia etbaica* is also a pioneer species; such species are more dominant in disturbed sites (Denslow, 1987), taking advantage of primary succession.

The Importance Value Index (IVI) gives a realistic value of dominance. According to the IVI *Acacia etbaica, Aloe berhana, Euclea racemosa* subsp. *schimperi*, *Leucas oligocephala* and *Carissa edulis* are the most dominant species in the exclosure. On the other hand, *Acacia etbaica, Euclea racemosa* subsp. *schimperi, Leucas oligocephala, and Echinopis hispidus* are the most dominant species in the open area. The higher IVI value of these species is related to the higher basal area, abundance, density and frequency distribution they have. Abundance of woody species indicates the future recovery of the open area would be successful if it became closed.

Table 1. Abundance (AB), density (DE), frequency (FR), basal area (BA) and Importance Value Index (IVI) of woody plants sampled in an exclosure in northeast Ethiopia

No.	Species	Family	Life Form	AB	DE	FR	BA	IVI
1	*Acacia etbaica* Schweinf.	Fabaceae	Tree	1724	862	100	20,46	59,34
2	*Leucas oligocephala* (Vahl)Smith	Lamiaceae	Shrub	327	163,5	6	0,01	4,51
3	*Oncoba spinosa* Forrsk**.**	Flacourtiaceae	Shrub	104	52	26	0,19	3,32
4	*Taverniera abyssinica* A. Rich.	Fabaceae	Shrub	81	40,5	12	0,13	2,01
5	*Echinopis hispidus* O.hoffm.	Asteraceae	Woody herb	68	34	20	0,20	2,48
6	*Rhus vulgaris* Meikle.	Anacardiaceae	Tree	56	28	2	0,00	0,84
7	*Carissa edulis* Vahl.	Apocynaceae	Tree	52	26	38	0,14	3,40
8	*Euclea racemosa* subsp. *schimperi (*A.DC.) Dandy.	Ebenaceae	Shrub	47	23,5	74	0,07	5,64
9	*Senna singueana* (Del.) Lack**.**	Caesalpiniaceae	Shrub	46	23	28	0,13	2,64
10	*Maytenus senegalensis* (Lam.) Exell	Celastraceae	Shrub or tree	27	13,5	24	0,17	2,19
11	*Aloe berhana* Tad.	Aloaceae	Woody herb	24	12	70	0,33	5,47
12	*Jasminum abysinicum* Pax	Oleaceae	Shrub	22	11	2	0,00	0,41
13	*Tsamo (Vernacular name)*	Unidentified	Shrub	20	10	14	0,01	1,20
14	*Opuntia ficus-indica* (L.) Mill	Cactaceae	Bush	13	6,5	8	0,00	0,70
15	*Meriandra bengalensis* (Konig ex Roxb.) Benth	Lamiaceae	Shrub	13	6,5	2	0,00	0,30
16	*Rhus glutinosa* A.Rich.	Anacardiaceae	Shrub or tree	11	5,5	32	0,04	2,33
17	*Showha (Vernacular name*)	Unidentified	Shrub	5	2,5	2	0,00	0,20
18	*Maytenus arbutifolia* (A. Rich.) Wilczek.	Celastraceae	Shrub	3	1,5	4	0,00	0,31
19	*Asparagus africanus* Lam.	Asparagaceae	Shrub	3	1,5	2	0,01	0,18
20	*Agave sisalana* Perr.	Agavaceae	Woody herb	3	1,5	2	0,00	0,18
21	*Ehretia cymosa* Thonn.	Boraginaceae	Shrub or tree	2	1	6	0,00	0,43
22	*Grewia ferruginea* A.Rich	Tiliaceae	Shrub or tree	2	1	2	0,00	0,16
23	*Osyris quadripartita* Decn.	Santalaceae	Tree	2	1	4	0,00	0,29
24	*Commiphora africana* (A.Rich.) Engl.	Burseraceae	Tree	1	0,5	6	0,03	0,45
25	*Withania somnifera* (L.) Dunal	Solanaceae	Shrub	1	0,5	8	0,01	0,56
26	*Indigofera arrecta* Hochst.ex A.Rich.	Fabaceae	Shrub	1	0,5	2	0,02	0,18
27	*Ziziphus spina-christi* (L.) Desf.	Rhamnaceae	Tree	1	0,5	4	0,01	0,29
	Total			2659	1329,5	500	21,96	99,99

The greater variability of abundance of species distribution in the exclosure could be because of the special niche requirement (Pielou, 1975), the time of immigration of the species may be recent and the need for special micro-site requirements for regeneration. The difference in species abundance distribution in non-exclosure areas could be attributed to the excessive disturbance, overgrazing and special palatable characteristic of the species.

The basal area distribution for the exclosure indicates the contribution of each diameter class to the total basal area is considerable and smaller diameter class individuals have a higher contribution to the total basal area indicating early succession. Whereas, in the open area, the higher basal area is contributed through big individual classes indicating the open area is in its oldest stage or in poor reproduction condition (Figure 2). The greater difference in basal area between the exclosure and open area could be due to the high number of multi-stemmed trees in the exclosures, leading to bigger diameters. The heights of the majority of trees in both sites are almost the same, indicating that both sites probably have equal site quality (Figure 3).

4.2. Diversity

Exclosures show a positive impact on density but they didn’t show a positive impact on diversity (Table 3).

Results from the calculation of diversity indices reveal that there is higher diversity of woody species in the open area than the exclosure (P=0.05).

Table 2. Abundance (AB), density (DE), frequency (FR), basal area (BA) and Importance Value Index (IVI) of woody plants sampled in unprotected grazing land in northeast Ethiopia

No.	Species	Family	Life form	AB	DE	FR	BA	IVI
1	*Acacia etbaica* Schweinf.	Mimosaceae	Tree	455	379,2	100	9,35	85,1
2	*Euclea racemosa* subsp. *schimperi (*A.DC.) Dandy	Ebenaceae	Shrub	72	60,0	8	0,00	3,2
3	*Leucas oligocephala* (Vahl) Smith	Lamiaceae	Shrub	47	39,2	20	0,04	2,4
4	*Echinopis hispidus* O.Hoffm.	Asteraceae	Woody herb	42	35,0	14	0,00	1,9
5	*Aloe berhana* Tad.	Aloaceae	Woody herb	35	29,2	24	0,01	1,6
6	*Maytenus senegalensis (*Lam.) Exell.	Celastraceae	Shrub or tree	24	20,0	14	0,00	1,1
7	*Oncoba spinosa* Forrsk.	Flacourtiaceae	Shrub	17	14,2	10	0,00	0,8
8	*Carissa edulis* Vahl.	Apocynaceae	Tree	16	13,3	26	0,00	0,7
9	*Rhus glutinosa* A.Rich.	Anacardiaceae	Shrub or tree	15	12,5	6	0,00	0,7
10	*Rhus vulgaris* Meikle.	Anacardiaceae	Tree	10	8,3	32	0,04	0,7
11	*Senna singueana* (Del.) Lack	Caesalpiniaceae	Shrub	5	4,2	10	0,11	1,0
12	*Jasminum abyssinicum* Pax.	Oleaceae	Shrub	5	4,2	30	0,06	0,6
13	*Ehretia cymosa* Thonn	Boraginaceae	Shrub or tree	2	1,7	2	0,00	0,1
14	*Osyris quadripartita* Decn.	Santalaceae	Tree	1	0,8	2	0,00	0,0
	Total			746	621,7	298	9,62	100,0

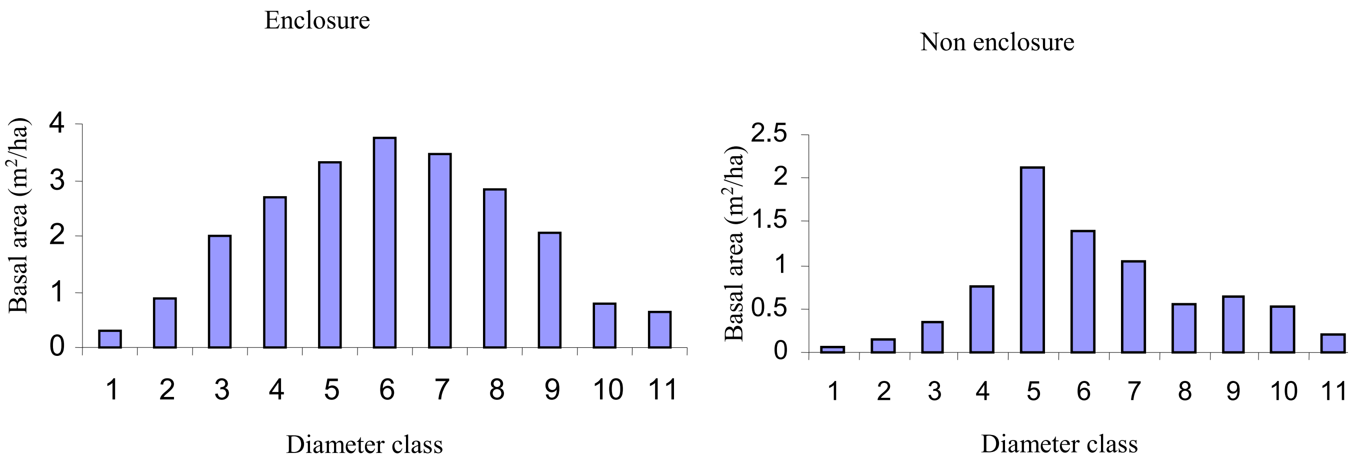


Figure 2. Basal area (m^2/ha) distribution of all woody species: Diameter class (cm): 1 < 5 cm, 2 = 5-10, 3 = 10-15, 4 = 15-20, 5 = 20-25, 6 = 25-30, 7 = 30-35, 8 = 35-40, 9 = 40-45, 10 = 45-50, 11 = >50 cm

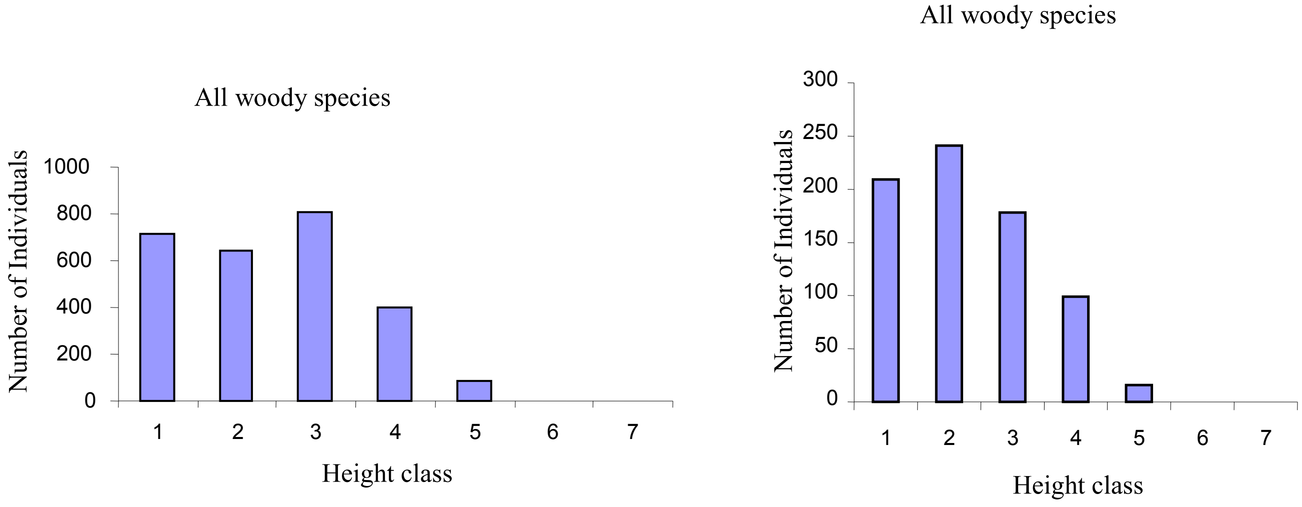


Figure 3. Frequency distribution of height classes (m) for all woody species of exclosures and non-exclosures: Height class 1 = <0.5m, 2 = 0.5-1, 3 = 1-1.5, 4 = 1.5-2, 5 = 2-2.5, 6 = 2.5-3, 7 = >3m.

This is because the Shannon diversity index is highly influenced by the number of dominant and rare species present. The dominance for *A. etbaica* is 64 % for the exclosure while 60 % in the open area. The species diversity of the open areas was found to be higher than the closed areas in Eritrea by Medanie (1997) and in Tanzania by Mwalayosi (2000). The Simpson measure of evenness also shows a higher value for the open area. This is because of the relative abundance of each species. The more the relative abundance of species differs, the lower the evenness is (Avena, 2000). On the other hand, the species richness in the exclosure is higher than in the open area. The average number of species per plot is also higher in the closed area than in the open areas, indicating more diversity in the exclosure. The two measures of richness (Margalefs and Menhicks index) are higher for the exclosure. The two diversity indices used to estimate the total number of species did not estimate precisely. This is because the number of species represented by 1 and 2 individuals affects the indices.

4.3. Ground Cover of Herbs

The ground cover is much better in the exclosure than in the open area, thus supporting further regeneration because of better soil conditions and microclimate (Table 4).

4.4. Regeneration Status

In the exclosure the diameter distribution of the community of all woody species shows an inverted J shape (Figure 4), with more abundant individuals in the lower diameter classes. It indicates active and uniform regeneration. 45% of the individuals had a diameter distribution of less than 5 cm. The most abundant species (*Acacia etbaica*) also has an inverted J-distribution. About 50% of its population has a diameter less than 5 cm. Others like *Leucas oligocephala, Euclea racemosa* subsp. *schimperi* and *Maytenus senegalensis* also have an expanding type of population structure. *Rhus vulgaris* shows an obstructed type of population structure and has low numbers of individuals in the lower diameter classes. The percent of seedling, sapling and trees for the exclosure was 60%, 20% and 19% respectively.

The diameter distribution for the non-exclosure also shows an inverted J shape (Figure 5). The percent of seedlings, saplings and trees was 27%, 58% and 15% respectively. *Acacia etbaica*, the most abundant species in the non-exclosure shows more individuals in the middle, and less in the lower diameter classes indicating the inability to reach higher diameter classes.

There is no problem of regeneration but the regenerated seedlings have been trampled by the free grazing animals. Species like *Maytenus senegalensis* and *Euclea racemosa* subsp. *schimperi* had more gaps in the distribution. Mature trees and seedlings are limited. It shows a more disturbed regeneration pattern. There was very low abundance of tree seedling individuals in the lower diameter classes of the non-exclosure and much dominated with shrubs of middle diameter class.

The population structure helps to study the regeneration pattern of a species (Swamy *et al*. 2000). The major species in the exclosure such as *Acacia etbaica* and *Leucas oligocephala* are represented by high seedling proportion. These species could have seeds that are easily germinating and match their seed dispersal to the rainy season (Demel , 1996). The high proportion of seedlings in the exclosure showed the potential for the restoration of a woody community. A lower proportion of seedlings of the same species in the open area were less promising.

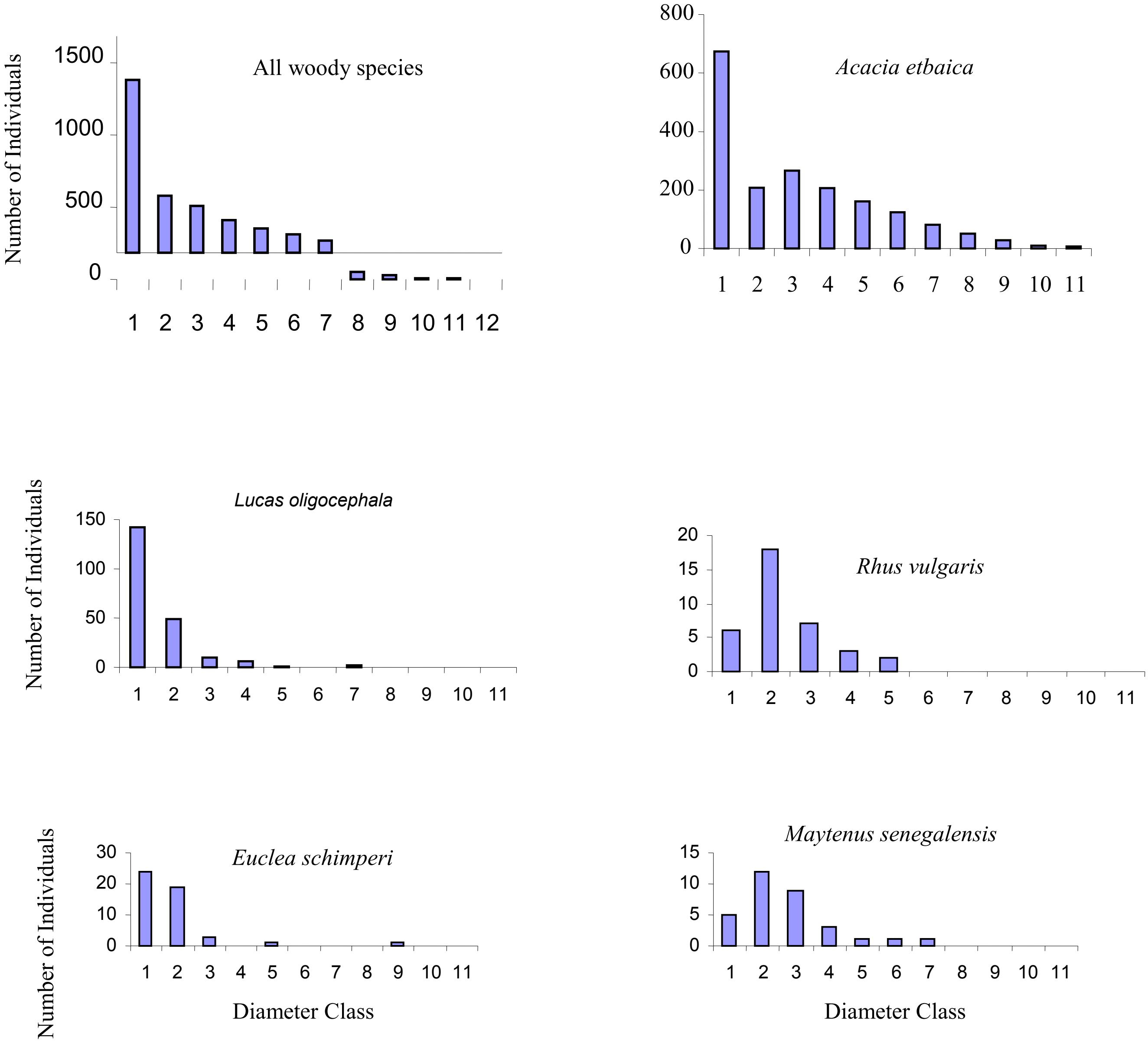


Figure 4. Diameter class (cm) distribution of all woody plants encountered in all plots of the exclosure and some major woody plants. Diameter class: 1 < 5 cm, 2 = 5-10, 3 = 10-15, 4 = 15-20, 5 = 20-25, 6 = 25-30, 7 = 30-35, 8 = 35-40, 9 = 40-45, 10 =45-50, 11 = >50 cm

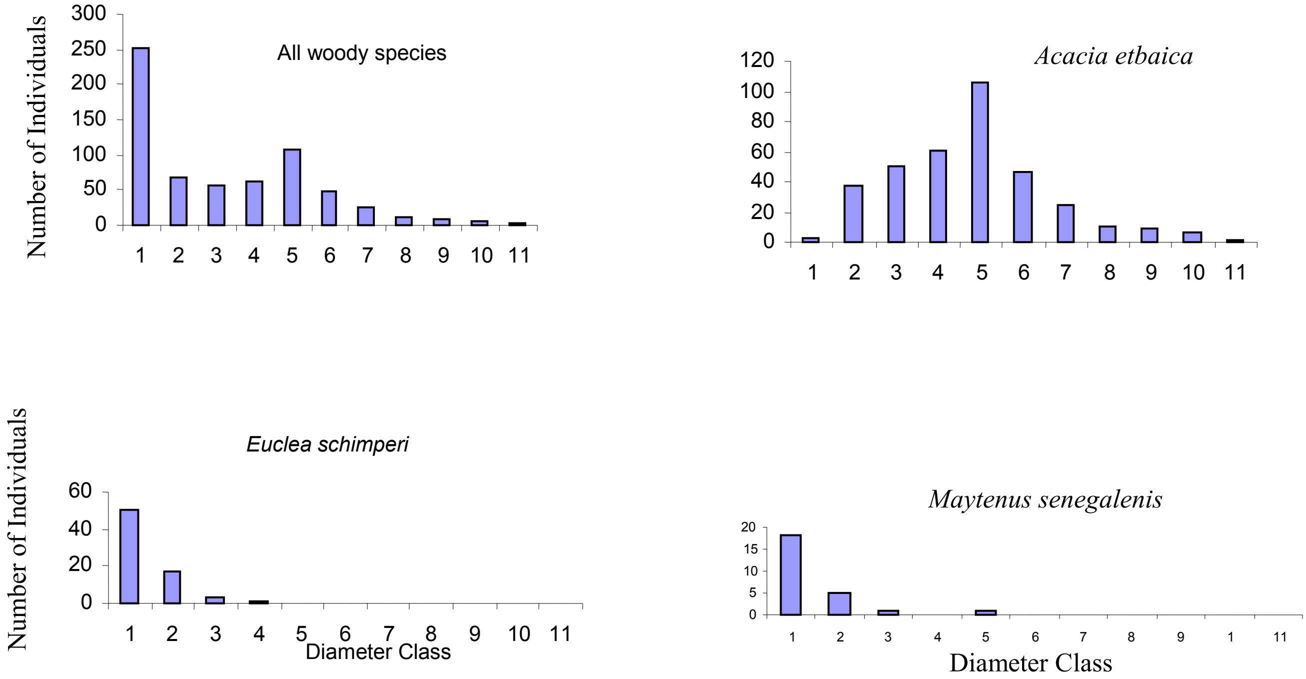


Figure 5. Diameter class (cm) distribution of all woody plants encountered in all plots of non-exclosures and some of the major woody plants. Diameter classes: 1 < 5cm, 2 = 5-10, 3 = 10-15, 4 = 15-20, 5 = 20-25, 6 = 25-30, 7 = 30-35, 8 = 35-40, 9 = 40-45, 10 = 45-50, 11 = >50 cm

Table 3. A summary of diversity indices of woody species for exclosures and non-exclosures

Diversity index	Value for exclosure	Value for non-exclosure
Number of individuals (N)	2659	746
Species Richness		
Observed number of species (S)	27	14
Chaos index (C)	29	14
Jack knife index (J)	32	15
Margalefs index (Dmg)	3.29	1.96
Menhicks index	0.524	0.512
Species Evenness		
Shannon evenness (E)	0.455	0.573
Berger Parker diversity (1/d)	1.562	1.640
Species Heterogeneity		
Shannon (H’)	1.468	1.514
Simpson (1/D)	2.272	2.548

Table 4. Ground Cover Class: 1 = 1-25% (poor cover), 2 = 26-50% (thin cover), 3 = 51-75% (intermediate), 3 = 76-100% (good covers)

Site	Ground Cover Classes			
	1	2	3	4
Exclosure	0	1 (2%)	3 (6%)	46 (92%)
Open Area	5 (16.7%)	17 (56.6%)	5 (16.7%)	3 (10%)

Since the exclosure is protected from interference, there is a high probability of growing to the next diameter class, which gives a sound population structure. The most dominant *Acacia etbaica* also shows an inverted J- shape distribution. The high proportion of seedlings shows a self-maintaining population structure implying the probability of being the main species in the recovery of the woody community.

In the open area *A. etbaica*, the dominant species, contributes much to the community structure, but has a discontinuous type of population distribution with a higher frequency of middle class diameters. The low proportion of seedlings is probably because of grazing or trampling and shows that the open area has a lower potential for rehabilitation than the exclosure. Cutting for fuelwood may decrease the probability to recruitment to higher diameter classes.

The less common species *Euclea racemosa* subsp. *schimperi* and *Leucas oligocephala* in the exclosure occur mostly as bushes with a high number of individuals at the lower classes, even more so for *Euclea racemosa* subsp. *schimperi* than in the open area. Trees in higher diameter classes occur irregularly or are missing. This pattern indicates a good reproduction but a bad recruitment to bigger trees in both the exclosure and the open area. Bigger trees of *Euclea racemosa* subsp. *schimperi* may be cut, since the species is important for ceremonies. Species like *Maytenus senegalensis*, and *Rhus vulgaris* shows a discontinuous or periodic recruitment. The distribution indicates that the number of seedlings may be sufficient to maintain the population. Bigger trees of these less common species might be remnants from the previous vegetation.

The exclosure has a sound type of regeneration, represented both by the community structure and individual species population structure. The unprotected area shows a more obstructed type of structure, mainly indicated by the dominant species. These revealed that the high level of protection in the exclosure helps the regeneration of woody species.

4.5. Composition and Density of Soil Seed Banks

A total of 29 herbaceous species (data from germination and sieving combined) was obtained from the top 9 cm in the soil seed banks of both land uses. 29 herbaceous species belong to the exclosure and 23 species were found in the open area. There were no woody species obtained from the soil seed bank, all seeds found were herbaceous. There is also a very low number of woody species in studies made in the northern part of Ethiopia by Tefera (2001), Kebrom and Tesfaye (2000) and Kebrom (2001) as compared to other areas studied in afromontane and rift valley biotopes by Demel (1997), Feyera (1998) and Mekuria (1999). The lack of woody seeds could be related to the high level of degradation and erosion in the northernmost part of the country, as the seed bank density is negatively affected by erosion (Bergston, 1993; Granström, 1986). Woody plants generally have low seed numbers (Demel and Granstrom, 1995) and are short lived in the soil (Demel , 1997). Instead most woody seeds germinate soon after rain indicating that they rely on a seedling bank. This is a common regeneration strategy probably appropriate for tropical woody species as seed losses can be expected for many reasons (Jerry, 1992). *Acacia etbaica* sets its seeds in line with the rainy season and seems to have a strategy of a seedling bank rather than a seed bank. The reason why no seeds were found in the soil seed bank either for the dominant species *Acacia etbaica* or the other woody species in the exclosure could be that the soil seed bank was collected at the end of the dry season, when all seeds had germinated. For the open area a lack of seedlings is probably not due to a lack of seeds, it is more likely that they disappear after germination through grazing and trampling. There are probably also other reasons why seeds can be missing like predation. Loss of acacia seeds through predation was reported by (Leck *et al.*,1994). High seed number of herbaceous and grass species both in the exclosure and the unprotected area may link to a prolonged dry season, which helps with the accumulation of dormant seeds.

The total number of seeds recovered was 1663 for the exclosure (sample area = 11250 cm^2) and 924 for the open area (sample area = 6750 cm^2) up to a depth of 9 cm. Many of the seeds in both the exclosure and open area were recovered from sieving. Only 6% are obtained from incubation. The total number of viable seeds obtained both from sieving and incubation shows a seed bank density of about 1479/m^2 for the exclosure and 1369/ m^2 for the unprotected area to a depth of 9 cm. That is comparable with investigations in dry tropical ecosystems that have revealed 48-1890 seeds/m^2 (Garwood, 1989) and 8-67 species. The lower densities are found in drier areas.

The density of species decreased with depth in both land uses. High seed density in the upper portion of the soil seed bank indicates that the contribution of the standing vegetation is recent, since seeds in the superficial layer can be assumed to form part of that seasons seed input (Lyarru, 1996). It is interesting and cannot be easily explained why the soil seed bank in the two land-uses were almost the same and at the same time the ground cover of herbs differed substantially between the two land-uses.

The diversity of the seeds in the exclosure is higher (Shannon's H' = 2.1) than the open area (Shannon's H' = 2.0). The diversity decreases with depth in both land uses. Sørensen's index of similarity between the soil seed bank of exclosure and open area was 0.70. The similarity of the seed bank between the two land uses is higher than the similarity between the standing vegetation of exclosure and open area. The similarities in species diversity of herbaceous species soil seed banks between the enclosed and open area and the high level of similarity index between the standing vegetation in the exclosure and in the open area indicate that the open area, if closed, still has a chance to rehabilitate in the same way as the closed area.

Even though no woody species were found in the exclosures and open area, the possible contribution of the soil seed bank for the process of regeneration shouldn't be ruled out (Kebrom, 2001). The high number of herbaceous and grass species found through sieving and incubation from the seed bank shows its role in providing vegetative protection cover that could help in reducing degradation through erosion. For successful woody vegetation reestablishment, however, the seed and seedling banks may require the supplementary planting of seedlings (Tesfaye and Kebrom, 2000).

5. Conclusion

The vegetation in the exclosure has a significantly higher woody vegetation density than the corresponding open area. Exclosures show a positive impact on density but they didn't show a positive impact on diversity. The ground cover is much better in the exclosure than in the open area, thus supporting further regeneration because of better soil conditions and microclimate. The main reason for not finding woody seeds in the soil seed bank both in the exclosure and open area is related to the high level of degradation in the area. Therefore, recruitment from the soil seed bank is doubtful if not impossible. The dominance of the seed bank by herbaceous species indicates that the area is at the early stage of succession.

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Vegetation Composition, Biomass Production, Carrying Capacity and Grassland Types in Odolla Area of Shinile Zone, Eastern Ethiopia

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Abstract: A study was conducted to characterize vegetation composition and grassland types as well as to estimate biomass production and carrying capacity of the rangeland in Ordolla areas of Shinile zone, eastern Ethiopia in October 2004. The Ordolla grasslands covered 22,621ha on alluvial plain composed of sand and silt texture and clay in minor cases in small hydromorophic depressions. Seventeen vegetation types are identified in Orodolla areas based on soil types, vegetation structure and density, and drainage pattern described using LANDSAT image and geographical map of the area. The dominant grass species were *Cynodon dactylon, Cynodon nlemfuensis, Eragrostis cilianensis, Cenchrus ciliaris, Andropogon greenwayii, Brachiaria leersiodes, Setaria pumila* and *Sorghum arundinaceum*. *Acacia tortilis*, *Acacia nilotica, Acacia mellifera* and *Acacia seyal* were the most dominant shrubs with scattered *Caddaba rotundifolia, Caddaba furmisa*, *Seddera bagshawei, Tamarix nilotica, Dobera glabra* and abundant *Parthenium hysterophorus, Cissus rotundifolia and C. quadrangularis*. The grass biomass estimated in enclosed site near Ordolla village was 4.5 t DM/ha/yr and the total grass biomass produced in Ordolla rangeland was estimated around 27 534 t DM/year. The theoretical, dry and wet seasons carrying capacities were 0.16, 0.06 and 0.09 TLU/ha, respectively. There were good grazing lands in hydromorphic depression and well drained facets in Ordolla areas but the palatable grasses, trees and shrubs are decreasing due to overgrazing, runoff and drought and replaced by *Parthenium, Calotropis, Solanum* and Xanthium species, which are invader category of the plant community, indicating overgrazing and rangeland degradation.

Keywords: Biomass Production; Carrying Capacity; Grassland Types; Grazing Lands; Vegetation Composition

1. Introduction

The rangeland of Ethiopia covers about 60% of the total area (about 62 million ha) of which 88% receive less than 600 mm rainfall per year, and is the major source of livestock feed (BLPDP, 2004; PFE, 2004). The pastoral areas of Ethiopia are located around the peripheries almost surrounding the central mass below 1500 masl on degraded shallow soils and fallow lands, which cannot be successfully cropped because of physical constraints (Alemu and Lemma, 1991; Alemayehu, 1998)). They are characterized by lowland plains and have relatively harsh climate with low, unreliable and erratic rainfall and high temperature (Coppock, 1994). The grasslands include sparse vegetation of grasses, bushes, shrubs, small trees and bare land with low level of surface water. The pastoral areas are sparsely human populated and are occupied by temporary and seasonal settlements with semi nomadic pastoral transhumant mode of life (Coppock, 1994).

The Somali Region in Ethiopia is one of the pastoral areas of the country covering about 285,000 km^2 and is divided into 9 administrative zones with 52 districts and the people depend on pastoral activity and in some extent agro pastoral agriculture (SORPARI, 2003). Evaluation and monitoring of rangelands is a useful strategy to document the capacity of the rangeland that could accommodate a given number of livestock species and to develop proper interventions for future pasture utilisation. The vegetation compositions of rangelands vary depending on topography, climate and soil fertility (Coppock, 1994). The current study was designed to characterize vegetation composition and grassland types as well as to estimate biomass production and carrying capacity of the rangeland in Ordolla areas of Shinile zone, eastern Ethiopia in which information is lacking for designing and implementing range and natural resources management and development interventions.

2. Materials and Methods

2.1. General Description of the Study Area

Ordolla is found in Shinile zone of the Somali Regional State of Ethiopia, 25 km north of Errer town and 12km west of Aydora and 15-20 km south of Azbuli at an elevation of 820 m, receiving 400-500 mm rainfall per annum with high temperature through out the day. The study covered an area 227km^2, about 22,651 ha of land. Ordolla area is classified as recent and pleistocene alluvium undifferentiated geologically and the soil is continental sediments including alluvium, aeolian deposits and eluvium differentiated

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into lacustrine deposits (Corra, 1993). There is wide alluvium expanding plain stripped by fast moving hydrographical net south of Errer in the direction of Awash Valley and Djibouti.

Ordolla Kebele (peasant Adminstration) and most of the settlements are located along the main Ordolla River that joins Asbuli river to the west, 20 km to the north of Ordolla. On east side, the biggest river is found crossing Aydora Kebele, coming from Tebi and Sedeti mountains and all the rivers in Ordolla areas are seasonal and do not have permanent flood. The hydro net, in addition of these main rivers, presented plenty of tributary rivers, hydromorphic veins and progressive gullies created by soil erosion (Map 1). The range land was mainly open grassland covered by short growth cycle annual vegetation which was originally predominant compared to woody stratus. Woody stratus was found in the southern part of the area on sandy soils near the hills surrounding Errer district but decreasing bit by bit when going to the north due to heavy grazing. The rangeland was mainly opened grassland covered by annual vegetation (Map 2).

2.2. Study Procedures

Vegetation and grassland characterization was done by interpretation and primary zoning of LANDSAT image based on the appearance of images and using GPS by clustering and delineation of similar grasslands and vegetation types together and taking samples of representative points to be surveyed. Twelve aerial photographs available for the area issued from the Ethiopian Mapping Agency (1: 50000) (edited 1999), Asbuli and Aydora topo maps (1:50000) (1999) and Dire Dawa geological map (1: 250000) (1985) were used during the field work (Map 1). During the field survey, visits were made to each representative grassland priory identified on LANDSAT image and moving to each site using GPS for validation in early October 2004. The latitude, longitude and altitude of the grasslands identified on the map were read on a hand held GPS during the fieldwork. The data include location, soil type, grazing land exploitation and grassland types, percentage of vegetation cover, grazing lands and barren soil, proportion of grasses, shrubs and trees and range and soil degradation.

2.3. Vegetation Composition, Biomass Production and Carrying Capacity

In the long rainy season of 2004, five half-hectare (50m x 100m) pasture sites were enclosed in all direction around Ordolla village on degraded rangeland dominated by weeds and barren soil to sensitize livestock herders and authorities about the impact of overgrazing and to estimate vegetation composition and potential biomass production. For biomass yield estimation of the vegetation inside the enclosure, four samples of 1m x 1m quadrates in each site, a total of 20 samples were taken randomly, in which all the herbaceous species were cut at full maturity. All the plant species inside the quadrat were harvested and weighed and samples dried in an Oven at 65^0C for 72 h to constant weight for dry matter yield determination (Tarawali *et al*., 1995). In addition, in each grassland types and in the enclosures, all plant species were listed and identified on site primarily based on their morphological, structural and floristic characteristics while unknown species were collected for further identification at Haramaya University Herbarium in comparison with preserved specimens and using taxonomic keys (FAO, 1989; Hedberg and Edward, 1989; Sylvia, 1995).

In Ordolla areas, the rainfall pattern allows two vegetation growth cycles per year. The first rainy period called “Gu” which is the shortest one from mid-March to mid-May and “Karan” is the long rainy season from July to September. The enclosure biomass yield from the five random sites and 20 samples across Ordolla areas represented the Karan vegetation growth only, which is the main biomass production period. The Gu vegetation growth has not been assessed but elders in the community considers that the vegetation growth in Gu period is roughly half of the Karan season due to short and small rainfall even if the limitation in exactly estimating the biomass in Gu period is clear. Thus, the total vegetation productivity of the area was obtained by adding the GU season production onto the Karan season biomass production.

Estimation of livestock numbers grazing in Ordolla areas was done through community interview on average number of animals per household and number of household heads for each Kebele settlements and the TLU conversion factors for cattle, sheep and goats, donkey and camel which are 0.7, 0.1, 0.5 and 1, respectively (ILCA, 1990). The theoretical carrying capacity (CC) of a given grazing area is calculated as $CC = (B*K)/PD \times 6.25$ (Stoddart, 1976)**,** in which B is the biomass edible in kg DM/ha, K is the animal use ratio which varies between 0.1 and 0.9 but usually 0.3 is considered as the grazing lands has limit for pasture regeneration properly and PD is the period duration in days and 6.25 is kg of DM consumed by one TLU/day. The pasture available for livestock is only for 3 to 4 months in Ordolla areas and the two rainy seasons are separated by a short dry spell resulting in creating two short vegetation growth cycles which limits the amount and duration of biomass production. During this dry spell the pastoralists move and displace their cattle by remaining sheep and goats and donkey. Therefore, the CC adapted to the transhumant condition for cattle in Ordolla areas was calculated for two short rainy seasons.

Five composite soil samples of each 1 kg were collected from hydromorphic veins, upper sandy areas and eroded gullies separately which constitute a total of 15 samples. A composite sample was prepared at each sampling site for texture, pH (Bouyoucos, 1962), organic matter (Walkley and Black, 1934), total N (Jackson, 1970), available P, exchangeable K, Ca, Mg and Na (Olsen et al., 1954). Electrical conductivity was determined using sodium saturation ratio (SAR) as $[Na+]/\sqrt{1/2}\{[Ca^{2+}] + [Mg^{2+}]$ (Van Reev Wijk, 1992) and the results of the soil test are presented in Table 1 and 2.

3. Results and Discussion

3.1. Grassland Distributions

Seventeen grassland types are identified (Map 2) in Ordola areas based on soil type, vegetation structure and species composition according to vegetation classification of Pratt and Guwyanne (1977). The detail description of each grass land is indicated in Table 3 but some unique characteristics of each grassland type are discussed in brief as follows:

3.1.1. Barren Land with Scarce *Caddaba rotundifolia* and Restricted Pockets of Mixed Perennial and Annual Herbaceous (ORD 1)

The grassland was covered by barren land (95%) with scattered shrubs (1%) and perennial grasses (4%). The dominant shrub was *Caddaba rotundifolia* and rare *Seddera bagshawei* and *Cissus quadrangularis* and the grass species were *Brachiaria leersioides* and *Dactyloctenium scindicum.*

3.1.2. *Acacia nubica* Open Shrub Land (ORD 2)

It was open shrub vegetation composed of *Acacia nubica* syn. Oerfota and rare Caddaba with 40 and 10% canopy cover, respectively, and some weeds along the shallow gullies.

3.1.3. Bushed Grassland Altered by Invading Species in Lower Hydromorphic Valley (ORD 3)

It was bushed grassland covered 40% by shrubs and 50 by various perennial grasses and 10% barren land. The grass species were Cynodon, *Setaria pumila* and *B. leersioides* and *C. rotundifolia* and some *S. bagshawei* and *A. nubica* were also found. The grassland was cinvaded by *Xanthium strumarium*, *Solanum somalense* and *Parthenium hysterophorus*.

3.1.4. Tributary Riverbanks of Open Shrub-Land Dominated by Acacia Species and Annual Vegetation (ORD 4)

It was open shrub grassland in riverbanks and hydromorphic valleys with barren land (50%), shrubs (45%) and 5% herbaceous vegetation. *Acacia tortilis* covered 40%, *A. nubica* (2%) and *C. rotundifolia* (1%) and no grasses.

Table 1. Soil physical and chemical characteristics in Ordolla areas of Shinile zone, eastern Ethiopia

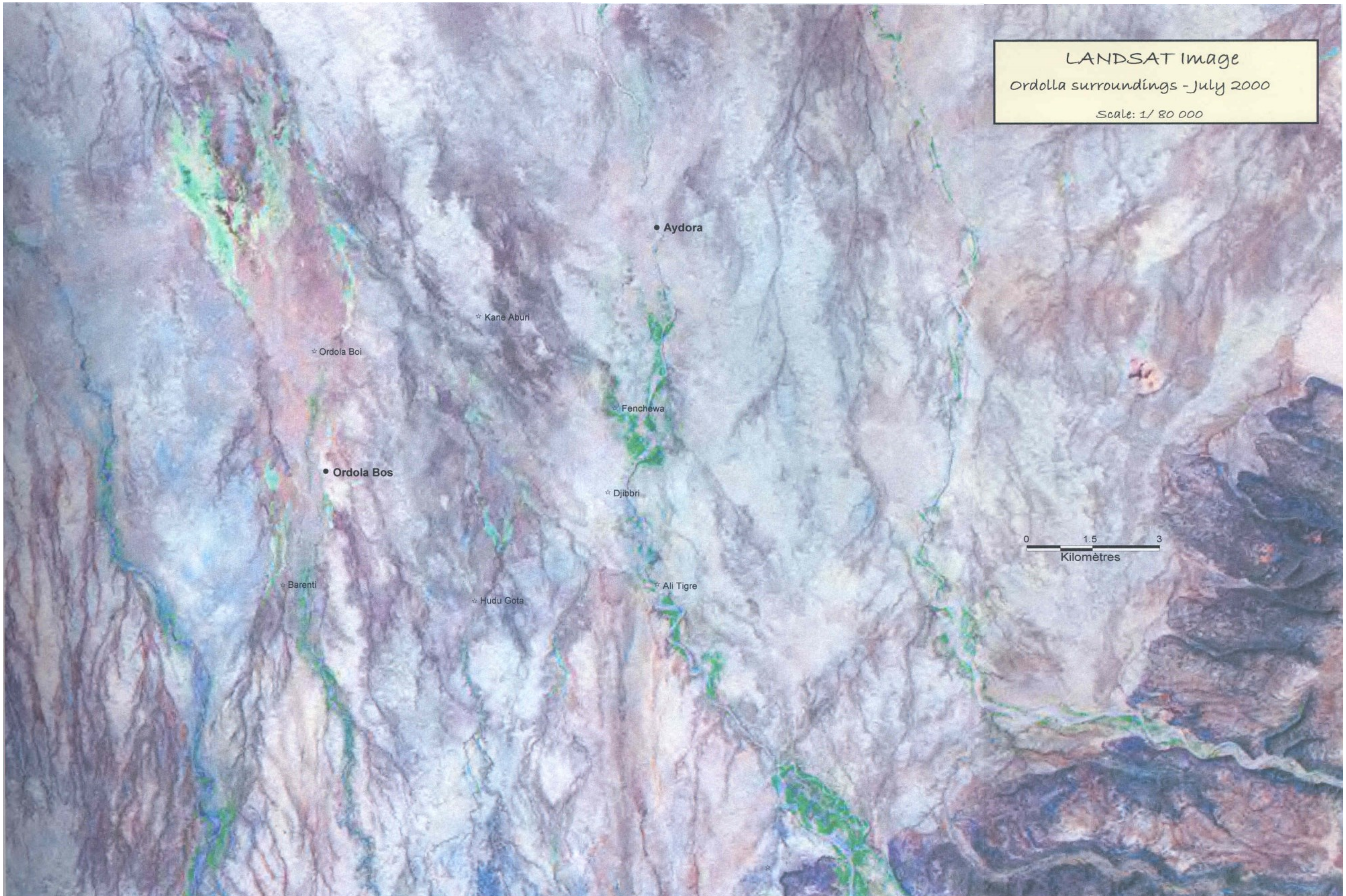
Description of the sampled area	Texture (%)			pH-H_2O (1: 2.5)	OM (%)	Tot N (%)	EC (1: 2.5)
	Sand	Silt	Clay				
Experimental enclosure (hydromorphic vein.)	27.12	36	36.88	7.86	1.53	0.06	0.27
Experimental enclosure (upper sandy part)	63.12	20	16.88	7.94	0.54	0.02	0.21
Erosive gulley (degraded banks)	87.12	2	10.88	7.89	0.25	0.01	0.13

OM= Organic matter; EC=Eelectrical conductivity; Tot N = Total nitrogen

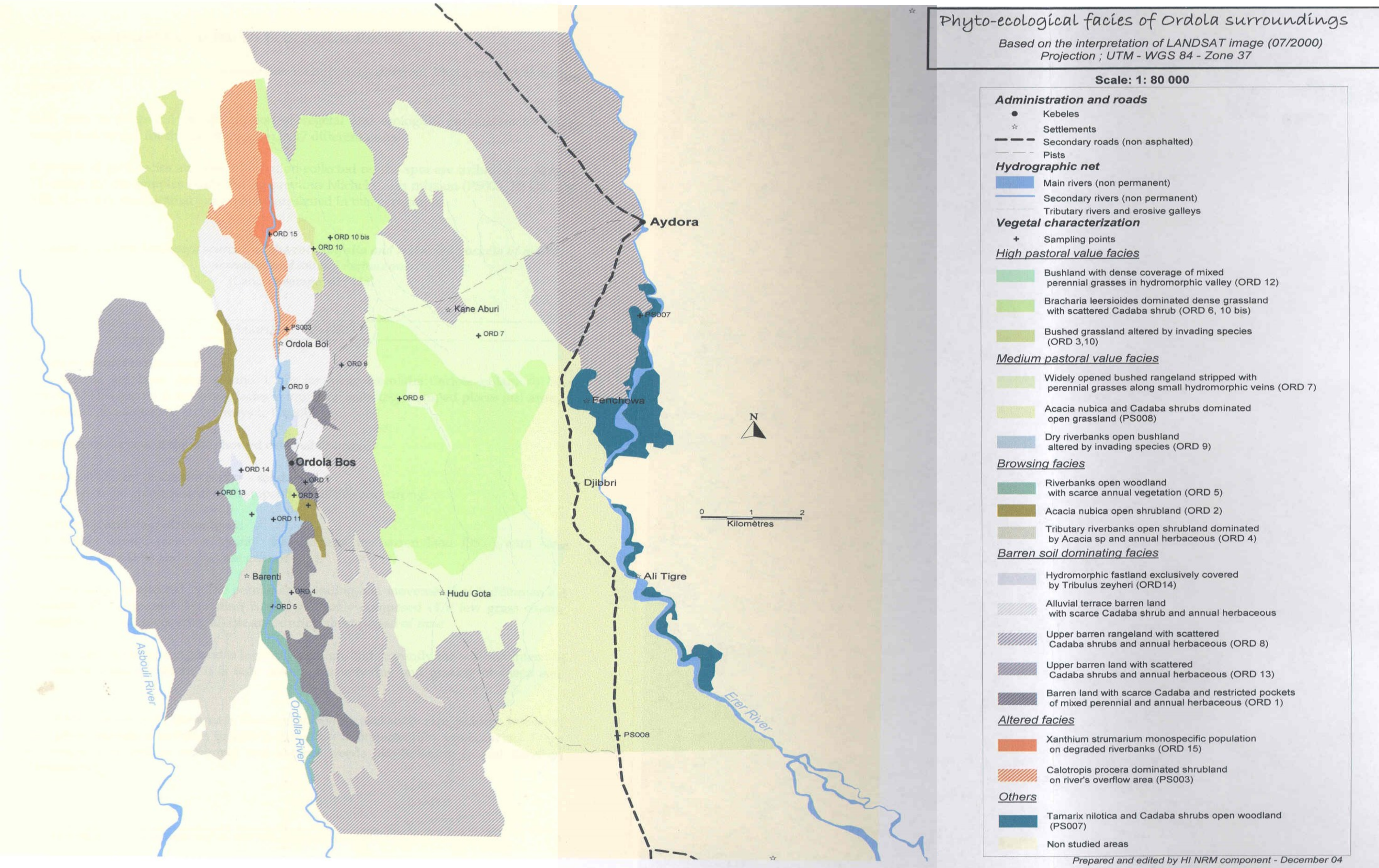
Table 2. Some soil macro nutrients in Ordolla areas of Shinile zone, eastern Ethiopia

Description of the sampled area	Available P (ppm)	Exch. Na	Exch. K	Exch. Ca	Exch. Mg
		Com0c kg^{-1} soil			
Experimental enclosure (hydromorphic vein.)	5.12	0.37	1.40	43.73	4.92
Experimental enclosure (upper sandy part)	4.45	0.38	0.67	33.37	2.92
Erosive gulley (degraded banks)	3.20	0.23	0.29	25.36	1.70

Exch = Exchangeable; P = Phosphorus; Na = Sodium; K = Potassium; Mg = Magnesium



Map 1. LANDSAT Image of Ordolla surroundings, Somali Regional State, eastern Ethiopia



Map 2 Phyto-ecological grasslands of Ordolla areas in Shinile zone of Somali Regional State, eastern Ethiopia

3.1.5. Riverbanks Open Woodland with Scarce Annual Vegetation (ORD 5)

The grassland covered 40% barren soil and 40-45% woody vegetation especially *Acacia seyal* (10%) and grouped *C. rotundifolia* (20%) and few *Balanites aegyptiaca* along the riverbanks with 10 % *T. zeyheri* but no perennial grasses.

3.1.6. *B. leersioides* Dominated Dense Grassland with Scattered *C. rotundifolia* Shrub (ORD 6)

It was typical grassland 80% covered by perennial grasses with *C. rotundifolia* (15%) and 5% barren soil and the grass species was *B. leersioides* (70%) and *Cynodon* species (10%). Next to this grassland, about 4-5 km far from Ordolla village to the north east direction there was grassland represented by ORD 10 BIS dominated by *B. leersioides* (70%) and *Dichantium annulatum (5%),* Cyperus species (10%) and *Caddaba glandulosa* (15%).

3.1.7. Widely Opened Bushed Rangeland Striped with Perennial Grasses along Small Hydromorphic Veins (ORD 7)

This grassland was composed of two sub-grasslands: the long veins formed due to hydromorphic conditions and presented various perennial and annual grass mixed with weeds and the interfluves between hydromorphic veins were the upper land with dry and barren soil covered by scattered *C. rotundifolia* and *T. zeyheri*.

3.1.8. Upper Barren Rangeland with Scattered *C. rotundifolia* and Annual Vegetation (ORD 8)

It was covered 95% by barren land and 5% *C. rotundifolia canopy cover*. *T. Zeyheri* was only covering most of the barren land during the rainy season.

3.1.9. Dry Riverbanks Open Bush Land Altered by Invading Species (ORD 9)

The vegetation was covered by *C. rotundifolia* with 40% canopy cover, grouped in big and full pockets but it was increasing in size. The vegetation area was covered with 40% barren soil and the rest 20 and 20% covered with herbaceous layer and *X. strumarium*, respectively.

3.1.10. Bushed Grassland Altered by Invading Species in Lower Hydromorphic Valley (ORD 10)

It was covered 90% vegetation and 10% barren land and the vegetations were *C. rotundifolia* (20%) and *S. bagshawei,* stunted *Acacia seyal and* mixture of *B. leersioides* and *Cynodon nlemfuensis* (20%) and it was coveed by *Xanthium strumarium* (20%), *Parthenium hysterophorus* (20%) and Solanum species (10%).

3.1.11. Bush Land with Dense Coverage of Mixed Perennial Grasses in Hydromorphic Valley (ORD 12)

It represented the highest productive vegetation covered by shrubs and perennial grasses (80%). It was divided into two parts: the central one where the vegetation coverage was around 100% of which *D. annulatum*, *B. leersiodes* and *Ischaemum afrum cover* 50% and *A. seyal* and *C. rotundifolia* covered the remaining 50% canopy cover and the peripheral part of this vein was covered by *B. leersioides* and *C. rotundifolia* with 20 and 40 canopy cover, respectively.

3.1.12. Upper Barren Land with Scattered *C. rotundifolia* Shrub and Annual Herbaceous on Gravelled Soil (ORD 13)

The vegetation was covered 90% by barren soil and 5 to 10% scattered *C. rotundifolia.*

3.1.13. Hydromorphic Fast Land Covered by *Tribulus zeryheri* (ORD 14)

The vegetation was highly influenced by hydromorphic condition and covered only by barren soil without grasses but it was covered by *T. zeyheri* during the rainy season.

3.1.14. *Xanthium strumarium* Monospecific Formation on Degraded Riverbanks (ORD 15)

The vegetation area was characterized by 30% barren soil land and exclusively covered 65% by *X. strumarium* and 5% by *C. procera* but no herbaceous species at all.

3.1.15. *Calotropis procera* Dominated Shrub Land on River Overflow Area (ORD 15)

The vegetation was dominated by tall and densely populated *C. procera*, followed by *X. strumarium*, *Amaranthus hybridus*, *S. somalense* and *P. hysterophorus,* respectively.

3.1.16. Alluvial Terrace Barren Land with Scarce *Caddaba* Shrub and Annual Vegetation

This vegetation was dominated 15% by *Caddaba* species and 85% by barren land and some pockets of *T. zeyheri*.

3.1.17. Acacia and *Caddaba* Dominated Open Vegetation (PS 008)

This vegetation was characterized by distinct patches of *A.oerfota*, *C. rotundifolia* and *T. nilotica* and the presence of rare *Barleria eranthemoides*, *Lasiocorys abyssinica*, *C. quadrangularis* and stunted *Panicum coloratum*, *Chrysopogon plumulosus* and *Eragrostis cilianensis*.

3.1.18. *Tamarix nilotica* and Caddaba Dominated Open Vegetation (PS 007)

It was characterized by distinct patches of *C. rotundifolia* and *T. nilotica* and the presence of rare *Aerva jsvanica, L. abyssinica, Solanum indicum, S. somalense*, and *Abutilon figarianum*, *Cissus quadrangularis* and some stunt *P. coloratum, C. plumulosus, Setaria pumila, E. cilianensis* and *Dactyloctenium scindicum*.

3.2. Ranking of Vegetation Types

The grassland types were ranked into six pastoral values (Map 3) based on area coverage of palatable species mainly perennial grasses, species diversity and productivity of the pasture follows: -

3.2.1. High Pastoral Value Grassland

It covered 3 275 ha (14.4%) representing the best pastures of the area including pure vegetation (ORD 6), the mixed vegetation (ORD 10) and the very productive grass and bush mixed land (ORD 12). These are the most productive rangelands because of more than 80% perennial vegetation coverage. Moreover, this vegetation was mainly composed of dense perennial grass carpet (ORD 6 and 10) except in the small over trampled part (central part of hydromorphic veins, depressions-ORD 10).

3.2.2. Medium Pastoral Value Grassland

It covered 5 361 ha (23.6%) of Ordolla area and it included the hydromorphic vein vegetation (ORD 7), the close alluvial terrace (ORD 9) and the open shrub and vegetation (PS008). They were areas where some perennial and annual mixed grasses and weeds species were found in relatively dense coverage (ORD 7 and more weeds in ORD 9). It also included the PS008 grassland where only annual grasses and *T. zeyheri* were found but constituted an interesting potential area by its wide coverage and the presence of some *Acacia* shrubs. However, these rangelands have quite lower pastoral interest than the first group, as the vegetation coverage was limited to restricted areas (hydromorphic veins) or pockets (PS008).

3.2.3. Preferred Shrubs Dominated Grassland

It covered 1 561 ha (almost 6.9 %) of Ordolla area and included all woody grasslands dominated by *A. nubica* syn oerfota, along the tributary riverbeds. The herbaceous coverage was absent or limited (ORD 2, 4, 5) and mainly composed of *T. zeyheri* and some rare annual grasses in secondary erosive gullies. These grasslands have limited potential due to the absence of grass and even herbaceous species but have pastoral interest as they constitute an important browse for camels.

3.2.4. Barren Soil Dominated Grassland

It occupied 11 418 ha (almost 50.4%) of Ordolla area representing ORD 1, 8, 13, 14 and the wide terrace. The contribution of these grasslands to grazing was very low to null as they were covered by more than 90% barren soil and 10% by *Caddaba* shrubs. Some of the barren soil was completely sterile, but remaining wide areas covered by *T. Zeheri*, the only vegetation growing for few weeks. Due to its short-lived behaviour of *T. Zeheri*, it is partially grazed by camels before blooming. Therefore, these grasslands are not considered as significant grazing lands.

3.2.5. Altered and Degraded Grassland

This grassland covered 606 ha (almost 2.7%) of Ordolla area representing grasslands invaded by *C. procera (*PS003) and *X. strumarium (*ORD 15) where they were forming pure colony. These grasslands were located along the river, where trampling by animals during watering and do not have interest for animal grazing since there are no perennial grasses and preferred browse species.

3.2.6. *T. nilotica* Formation

It covered 400 ha (almost 1.8%) of Ordolla area. This vegetation (PS007) was isolated as it was pure population of *T. nilotica.* Moreover, it does have small value for grazing since there is no herbaceous species for animals.

3.3. Grazing Land Categorization

According to the ranking done, the grazing areas in Ordolla surroundings are categorized by considering the surveyed areas as a whole, based on the palatability of herbaceous vegetations (proportion of perennial grasses, shrubs and invaders available), total vegetal coverage and barren soil as follows:

1. Good and permanent grazing which represents only 15% of the surveyed area (grasslands of the first ranked group)
2. Complementary grazing lands, which represent additional 30% (medium pastoral value + browsing grassland), wide areas dominated by low productive barren soil as well as taking probably low part on livestock grazing
3. About 55% of the rangeland can be considered as non-grazing areas (barren soil dominated grassland + altered grassland + Tamarix colony) due to their limited values and it does have low value for livestock grazing or browsing.

3.4. Vegetation Composition, Biomass Production and Carrying Capacity

After enclosing the pasture, the difference between the inside and outside on vegetation composition was very clear and demonstrative. Although the place was looking degraded, barren, sandy and invaded by weeds, the grasses grown showed an unforeseen diversity and density. By protecting seasonal grazing, essential grass species has grown up, flowered and set seeds with in short period demonstrating high capacity of regeneration and presence of good soil seed bank. Moreover, it was impressive for herders to observe the grasses at full maturity as grasses were continuously grazed even up to the roots in the unprotected area. This showed that the area has good potential and capacity to support different livestock species if properly managed. The main grass species observed in the enclosure were *Cynodon dactylon, Cynodon nlemfuensis, Andropogon greenwayii, Brachiaria leersiodes, Setaria pumula* and *Cenchrus ciliaris* in order of abundance and rarely *Cyprus involucratus* Table 3. Enclosures are good sources of biodiversity of grass and shrub vegetations as indicated by different authors (Blench and Sommer, 1999; Emiru, 2002). The grasses are naturally palatable and important for livestock feeding and the height of these grasses reached around 25-50 cm. Similar research findings are reported by many authors in other parts of Ethiopia (Coppock, 1994; Baars, 1996; Ayana and Baars, 2000; Lema, 2001; Amsalu and Baars, 2002; Alemayehu, 2004; Yihalem, 2004; Yvan and Tessema, 2005).

Biomass produced measured inside the enclosure during the main rainy season was 4.5 t DM/ha. This biomass yield was obtained in the Karan rainy season (July to September) only herbaceous species due to the absence of trees and shrubs in the enclosure. The total grazing land annual biomass production in Ordolla areas may be estimated as 4.5 + 2.25 = 6.75 t DM/ha/year by taking the two short rainy seasons. This figure is comparable to most managed natural pasture (Tessema, 2005) and even higher than most of the communally grazed pasture in Ethiopia as reported by many authors (Coppock, 1994; Ayana and Baars, 2000; Lema, 2001; Amsalu and Baars, 2002). The productivity estimation for high pastoral value grazing lands, with no grass cover was 3 275 ha * 6.75 t DM/ha = 22 106 t DM/year and for medium pastoral value grazing lands, with 15% herbaceous cover was 5 361 ha * 0.15 * 6.75 t DM/ha = 5 428 t DM/year, and the total annual biomass produced by different grazing lands in Ordolla areas was estimated to be around 27 534 t DM/year.

For the 390 households in twelve settlements in the Ordolla areas, the number of different animal species was estimated as follows: shoats 39 340, cattle 11 396, camels 3 293 and donkey 315, total of 54 344 heads of mixed livestock or 15 361.7 TLU (Table 4). According to the estimated biomass production of the pasture and available livestock species in TLU, the carrying capacity of the rangeland in Ordola areas would be estimated as 0.16 TLU/ha/year (27 534 000 * 0.3/365 * 6.25) or 6.25 ha grazing land for 1 TLU or 1 camel or 10 shoats without affecting vegetation composition and pasture productivity. The estimated carrying capacity of Ordolla areas with respect to transhumant pastoral condition was 0.06 and 0.09 TLU/ha in dry (5 months) and in wet seasons (7 months), respectively.

4. Conclusions

In general, large proportion of Ordolla rangelands was barren land without herbaceous vegetation except some scattered shrubs and trees. Seventeen grassland types were identified in Ordola areas. Vegetation composition, grassland types and other phyto ecological characteristics of other districts of Shinile zone near Ordola area has been reported by Corra (1993). The dominant grass species in Ordolla areas were *C. dactylon, C. nlemfuensis, E. cilianensis, C. ciliaris, A. greenwayii, B. leersiodes, S. pumila* and *Sorghum arundinaceum*. *A. tortilis*, *A. nilotica, A. mellifera* and *A. seyal* were the most dominant shrubs with scattered *C. rotundifolia, C. furmosa*, *S. bagshawei, T. nilotica, D. glabra* and abundant *P. hysterophorus, C. rotundifolia and C. quadrangularis.* The grass biomass estimated in enclosure near Ordolla village was 4.5 t DM/ha/yr and total annual biomass produced in Ordolla rangeland was around 27 534 t DM/year. The theoretical and transhumant context carrying capacities of Ordolla rangeland in dry and wet seasons were 0.16, 0.06 and 0.09 TLU/ha, respectively without affecting the pasture. There were good grazing lands in hydromorphic depression in Ordolla areas but the palatable grasses, trees and shrubs are decreasing due to overgrazing, runoff and drought and replaced by *Parthenium, Calotropis, Solanum* and Xanthium species, which are invader plant species and replaced palatable plants (decreasers and increasers mainly perennial grasses) indicating overgrazing and rangeland degradation as observed in most parts of Ethiopia.

5. Acknowledgment

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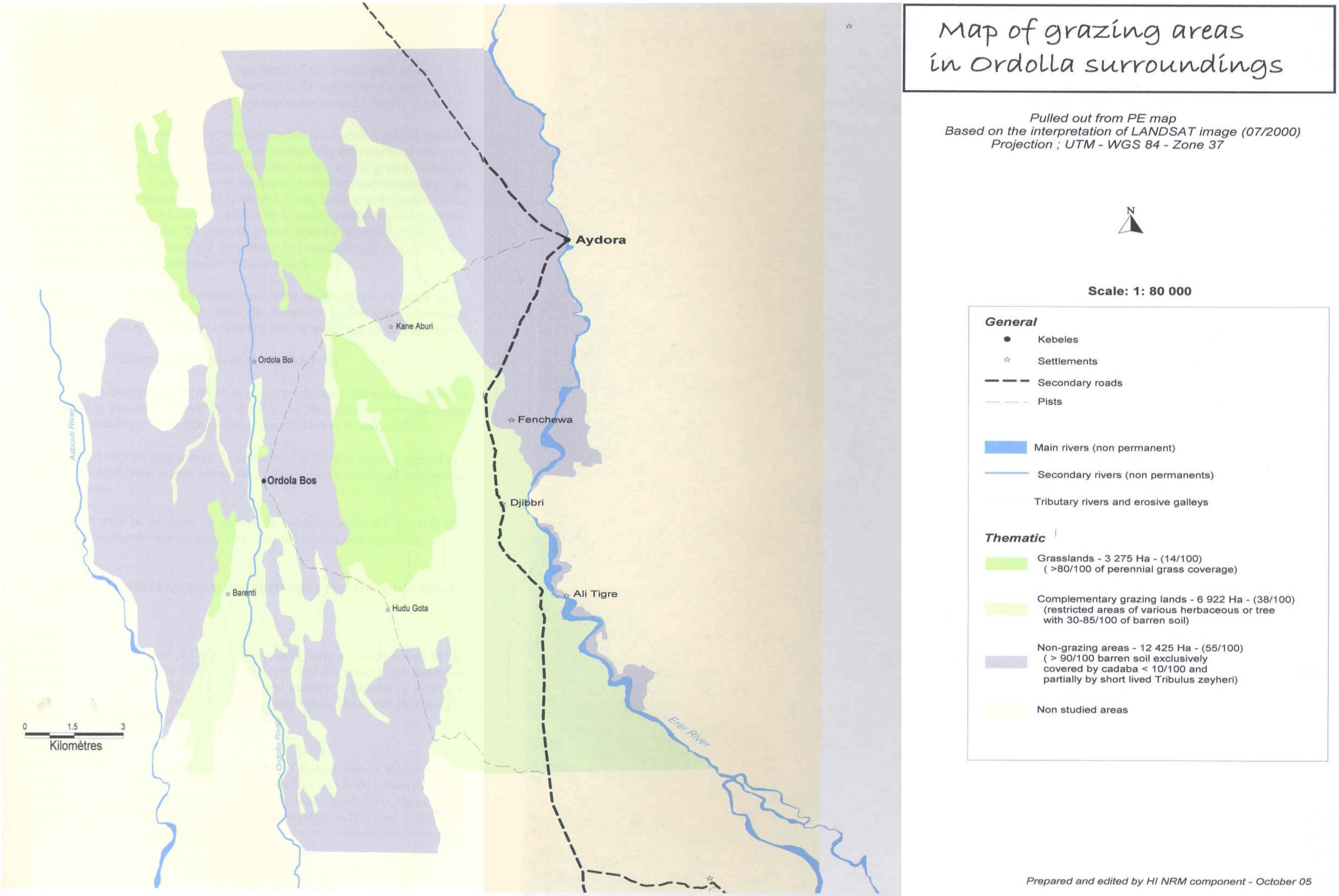
Table 3. Description of different grassland types in Ordolla areas of Shinile zone, eastern Ethiopia

Vegetation types code	Vegetation type descriptions								
	Area covered (ha)	Altitud (masl)	Proportion of		Drainage pattern	Estimated field texture	Hypochloride Test	Vegetation	
			Vegetation	Barren soil				Use level	Pastoral interest
ORD1	417	827	5	95	External	Silty sand	Strong efferscence	High to very high	Quasi in existent
ORD2	147	823	50	50	External	Silty	Strong efferscence	Very high	Low
ORD3	486	808	90	10	External	Silty	Strong efferscence	Medium	Very high
ORD10	-	800	90	10	External	Silty	Strong efferscence	Low	Very high
ORD4	1208	824	50	50	External	Silty clay	Strong efferscence	High	High to very high
ORD5	207	-	60	40	External	Silty clay	Strong efferscence	Very high	Low
ORD6	2604	800	95	5	external	Sand silty	Strong efferscence	Low	Very high
ORD10B15	-	790	95	5	External	Sand silty	Strong efferscence	Low	Very high
ORD7	2891	804	10	90	External	Clay	Strong efferscence	High	Low
ORD8	7160	802	5	95	External	Silty clay	Strong efferscence	Very high	Low
ORD9	279	800	60	40	External	Silty sand	Strong efferscence	Very high	low
ORD12	133	814	80	20	External	Clay silt	Strong efferscence	Medium	Very high
ORD13	2505	822	10	90	external	Sandy clay	Strong efferscence	In existent	Very low
ORD14	20	-	5	95	External	Silty-clay	Strong efferscence	Very high	Very low
ORD15	103	817	70	30	External	Silty loam	Strong efferscence	Very high	in existent
ORD5 & 9	1317	-	20	80	External	Silty	Strong efferscence	Very high	Low to null
PS008	2243	863	40	60	External	-	Strong efferscence	High	Low
PS007	400	802	35	65	External	Clay	Strong efferscence	High	Low

Table 4. Vegetation composition of Ordolla areas of Shinile zone, eastern Ethiopia

Caesalpiniodeae	Gramineae	Convolvulaceae
Cassia italica (Mill.)	*Andropogon greenwayii* Napper	*Seddera bagshawei* Rendel
Senna Alexandria (L.) Link	*Brachiaria leersioides* (Hochst.) Stapf	*Seddera hallieri* Engl. and Pilgr
Tamarindus indica L.	*Cenchrus ciliaris* L.	*Seddera latifolia* Steud.
Papilionoideae	*Chryspogon plumulosus* Hochst.	Cactaceae
Crotalaria spinosa Benth	*Cynodon dactylon* (L.) pers	*Opuntia ficus* indica
Indigofera amorphoides	*Cynodon nlemfuensis* Vanderyst	Cyperaceae
Salvadoraceae	*Dactyloctenium scindicum* Boiss	*Cyprus involucratus* Rottb.
Dobera glabra (Forsk.) Juss.	*Eragrostis cilianensis (*All.) Link	Euphorbiaceae
Mimosoideae	*Setaria pumila* (Poir.) Roem.	*Euphorbia tirucali* L.
Acacia horrida (L.) Willd Subsp.	*Sorghum arundinaceum* (Willd). Stapf	Solanaceae
Acacia mellifera (Vahl) Benth	*Sporobulus ioclades* (Tri.) Nees	*Datura stramonium* L.
Acacia nilotica (L. Del. Subsp.	Tamaricaceae	*Solanum indicum* L.
*Acacia senega*l (L.) Willd.	*Tamarix nilotica* (Ehrenb.) Bunge	*Solanum somalense* Franchet
Acacia seyal Del. Var. seyal	Tiliaceae	Vitaceae
Acacia tortilis (Forssk.) Hayne	*Grewia bicolour* Juss	*Cissus qudrangularis* L.
Balanitaceae	*Grewia erythraea* Schweinf.	*Cisus rotundifolia* (Forssk.) Vahl
Balanites aegyptica (L.) Del	*Grewia tenax* (Forssk.) Fiori	Amaranthaceae
Balanites glabra Mildbr.	*Grewia villosa* Willd	*Amaranthus hybridus* L.
Capparaceae	Salvadoraceae	Compositeae
Caddaba farinose Forssk.	*Dobera glabra* (Forsk.) Juss.	*Parthenium hysterophorus*
Caddaba glandulosa Forssk.	Convolvulaceae	*Vernonia cinerascens* Sch. Bip.
Caddaba heterotricha Stocks.	*Seddera bagshawei* Rendel	*Xanthium strumarium* auc. Non L.
Caddaba rotundifolia Forssk	*Seddera hallieri* Engl. And Pilgr	Verbenaceae
	Seddera latifolia Steud.	*Lantana camara* L.



Map 3 Types of grazing lands in Ordolla areas of Shinile zone, Somali region, eastern Ethiopia

Table 5. Average and total of number of livestock species in Ordolla areas of Shinile zone, eastern Ethiopia

	Number of livestock species per household (HH)							
	Poor group (70%)		Medium group (15%)		Better off group (15%)		Total heads	TLU
Cattle	0-7	273 HH	20-40	58 HH	100-200	58 HH	11396	7977
Shoats	30-50		60-120		300-500		39340	3934
Camel	0-5		15-30		80-120		3293	3293
			Total				54344	15361.7

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Characterization and Fertility Status of the Soils of Ayehu Research Substation, Northwestern Highlands of Ethiopia

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Abstract: The pedogenic properties and fertility status of the soils at Ayehu Substation of the Amhara Region Agricultural Research Institute were studied both in the field and through laboratory analysis. On the basis of *in situ* description of two soil profiles and laboratory analysis, the soils of the study site qualified for the Nitisol soil group as per the FAO/UNESCO Soil Grouping System. The soils were moderately acidic in reaction and silty clay to clay in texture. The pedons exhibited increasing clay contents with depth qualifying for argillic (Bt) horizons. The surface horizons of both pedons revealed the lowest and the bottom (Bt3) horizons indicate the highest bulk density values. The consistent increase of bulk density with depth is apparently due to the decreasing level of organic carbon (OC) with depth from 2.6 to 0.6% in pedon 1 and from 2.8 to 1.1% in pedon 2. The lowest total porosity (44.2%) was observed in the Bt3 horizon of pedon 1 and the highest (55.2%) in the composite surface soil collected around pedon 2. Throughout the depths of the two pedons and surface soil samples, pH (H_2O) values were higher than pH (KCl) resulting in positive ΔpH values and indicating the presence of variable charge clay surfaces. The subsoil horizons showed lower values of cation exchange capacity (CEC) and percentage base saturation suggesting intensive weathering and presence of 1:1 (kaolinitic) clay minerals. The quantity of exchangeable Na was trace whilst appreciable amount of exchangeable K was available in both pedons. The surface horizons contained high exchangeable Ca and Mg to the extent that the sum of these bases occupied over 83% of the CEC in both pedons. In accordance with OC, total N decreased with depth from 0.19 to 0.05% in pedon 1 and from 0.22 to 0.10% in pedon 2. The highest contents of Olsen P (3.21 mg l^{-1}) and Bray P (4.40 mg l^{-1}) were obtained in the surface horizon of pedon 1 and both showed decreasing trends with depth in the two pedons. Application of increasing rates of P fertilizer increased both the Olsen and Bray II P consistently, while applied rates of N did not bring significant change in soil total N content.

Keywords: Ayehu Area; Bray II Available P; Nitisols; Olsen Available P; Pedon

1. Introduction

Soil and water resources and the methods of their exploitation on sustainable basis dictate food production and ultimately human survival. The regions of highest food production have been those with favorable climate, relatively fertile soils, and an adequate supply of water. The success of soil management to maintain soil quality depends on understanding the soil characteristics and the responses of soils to agricultural use and management practices over time (Wakene and Heluf, 2003; Mohammed *et al*., 2005). Land use and management influence most of the agriculturally relevant soil morphological, physical, chemical and biological characteristics (Martel and Mackenzie, 1980; Kang, 1993; Saikh *et al.*, 1998a, 1998b; Wakene and Heluf, 2003).

The soils of the Ethiopian highlands are highly variable, varying greatly in their inherent natural characteristics and productive capacities. This is attributed to the extremely rugged terrain, widely varying topography and mountainous landscape which further govern the variations in regional geomorphologies, soil parent materials, soil toposequences, agroecological zones (climate), land use and types of plant and animal lives in a given area. As a result, many soil types differing from each other in their morphological, physical, chemical, mineralogical, and biological properties occur on a given landscape along a toposequence (Mishra *et al.*, 2004; Mohammed *et al.*, 2005). The fertility, water holding capacity, susceptibility to erosion and potential productivity of these soil types differ from each other significantly. Therefore, soil characterization and classification which provide with knowledge on soil properties are vital in designing appropriate management strategies in agriculture and natural resources for sustainable development.

Soil fertility declines when its nutrient content diminishes, and its quality to meet plant requirements is lowered. Soil nutrient depletion in smallholding farming systems is recognized as a causal force leading to food insecurity and rural poverty in Africa (Smaling *et al.*, 1997; FAO, 2001). Declining soil fertility has also been stressed to be the fundamental impediment to agricultural development and the major reason for the slow growth in food production in Ethiopia (Asfaw *et al.*, 1997). As a result, greater emphasis has been given to examination of nutrient cycles and budgets at scales ranging from farm to regional levels. However, successful examinations of nutrient cycles and budgets necessitate data of inherent soil physicochemical properties and fertility status as the existing soil quality (stock) is the basis for such examination. Generally, the

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available scientific information on soil characteristics and fertility depletion and its consequences on agricultural productivity and the livelihoods of small-scale farming communities in sub-Saharan countries has contributed to the development and implementation of strategies for soil fertility replenishment in developing countries.

The first criterion in making a valid fertilizer recommendation is to know the soil test level of the specific nutrient in the soil. Successful soil test method should be able to predict whether or not a response is expected as well as the magnitude of that response. Since environmental conditions, soils and crops vary from place to place, it is necessary to select a suitable soil test method for each local condition. However, in Ethiopia, a few indicative P calibration studies have been carried out. Tekalign and Haque (1991) reported that the Olsen method estimated plant available P reliably on contrasting soil types indicating that the method is of more general application on wider range of soils than in calcareous soils for which it was first recommended.

Thus, understanding the physicochemical characteristics and the fertility status of a given soil play a vital role in designing appropriate management strategies for enhancing productivity of the agricultural sector and sustainable utilization of natural resources. Hence, in order to generate such information at and around the Ayehu Research Substation in the northwestern Ethiopia, this study was undertaken to characterize the soils of the study area on the basis of some selected physicochemical properties and reveal their fertility status.

2. Materials and Methods

2.1. Description of the Study Area

The study was conducted at the experimental and seed multiplication site of the Ayehu Research Substation of Adet Agricultural Research Center in the Amhara National Regional State, Ethiopia. The Ayehu Research Substation is located in Ankasha District (Fig. 1) at about 435 and 30 km distances, in the north direction (Finote Selam-Bahir Dar Road), from Addis Ababa city and Kesa town, respectively. It is situated at 11^0 20' N latitude and 37^0 25' E longitude and an altitude of 1900 m above sea level (masl). The rainy season covers from April to November and maximum rain is received in the months of June, July, August and September. According to the weather data recorded at the Ayehu meteorological station, the average annual rainfall is 1100 mm, and the mean maximum and mean minimum temperatures are 30.6 and 13.6 ^oC, respectively (data taken from Ayehu meteorological station). The area is characterized by a subhumid tropical climate and falls under the tepid to cool moist mid highlands (M2) agroecological zone.

The study area lies on an upland landform that is predominantly characterized by almost flat to gently undulating topography. A larger proportion of the study area and the surroundings fall in the slope ranges of nearly level (0.5-1.0%) to gently slopping (2.0-5.0%) with a slope aspect of northwest direction. Basalt is the dominant parent material from which the soils at and around the study area have been formed through *in situ* weathering. The soils at the study area are generally highly weathered, very deep and moderately well to well drained. Intensive rainfed cultivation of annual field crops mainly cereal crops constitute the land use in the area. The dominant crops grown in the area are maize (*Zea mays)*, wheat (*Triticum spp.*), teff (*Eragrostis tef*) and hot pepper (*Capsicum frutescence*).

A field experiment involving fertilization of wheat crop with factorial combinations of five levels of N (0, 23, 46, 69 and 92 kg N ha^{-1}) and five levels of P (0, 10, 20, 30 and 40 kg P ha^{-1}) fertilizers was also conducted on the site where Pedon 1 was characterized during the time of profile study. The objectives of the study were to determine the effects of N and P fertilizers on yield, yield components and nutrient uptake of wheat and to reveal the residual effects of these fertilizers on soil N and available P contents. The full dose of P fertilizer was applied as triple super phosphate (20% P) at planting, while N was split applied (half of the dose at planting and half at 30 days after planting) as Urea: 46% N).

2.2. Soil Sampling

Two representative soil profile pits of 2 m width x 2 m length and 2 m depth were excavated based on site survey and preliminary inspection of the auger-sampled soil samples. The soil profiles were described for their morphological properties according to the FAO guidelines (FAO, 1990) and samples were taken from all identified horizons for characterization of selected physical and chemical properties (particle size distribution, bulk density, particle density, porosity, pH, organic matter, total N, available P, CEC and exchangeable cations) through laboratory analysis. In addition to the soil profile samples, six composite surface soil samples (0-30 cm depth) were collected from representative spots of the entire experimental plot and the fields nearby the two pedons for laboratory analysis of the above indicated soil physicochemical properties before planting. Similarly, surface soil samples at the same depth were collected from each plot after crop harvest and finally bulked by replication to obtain one representative composite sample per treatment for determination of soil P and N contents. Undisturbed duplicate soil samples were taken using core sampler from the surface layer of the experimental field and from every horizon of the two pedons for the determination of bulk density.

2.3. Analysis of Soil Physical and Chemical Properties

The surface and profile soil samples collected from the study area were air dried and crushed to pass through 2 mm sieve for the analysis of pH, particle size distribution, CEC, exchangeable cations, available P, organic matter and total nitrogen. Soil color (dry and moist) was determined using the Munsell soil color chart in the field. Particle size distribution was analyzed by the modified Bouyoucos hydrometer method (Bouyoucos, 1962). Bulk density was estimated from

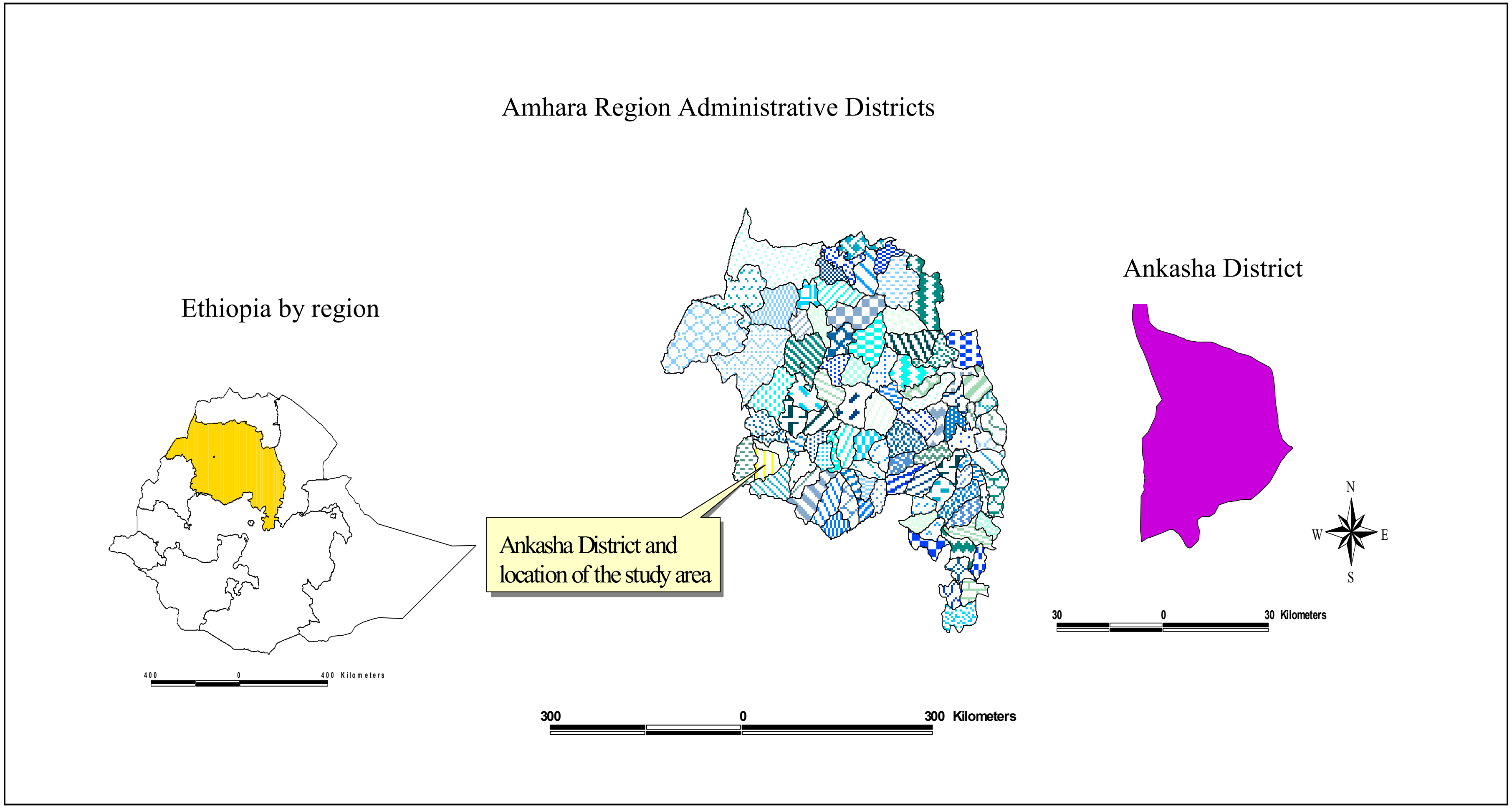

Figure 1. Location map of the Ayehu Research Substation within the Ankasha District

undisturbed soil samples collected using core sampler from every identified genetic horizon and surface layers. Particle density was determined by the pycnometer method (Blake, 1965) and finally calculated as the mass of the solid particles per unit volume of the soil solids. Total porosity was estimated from the values of bulk density (Db) and particle density (Dp) as:

$$\text{Total porosity (\%)} = \left(1 - \frac{Db}{Dp}\right) \times 100$$

The pH of the soil was measured potentiometrically using a pH meter in the supernatant suspension of 1:2.5 soil to liquid ratio of water and 1 M KCl solution and ΔpH was determined by subtracting soil pH (KCl) from soil pH (H_2O). Cation exchange capacity (CEC) of the soil was determined by the ammonium acetate (pH 7.0) method whereby ammonium ion was replaced by Na from percolating sodium chloride solution (Chapman, 1965) and reported as CEC. Exchangeable bases were extracted with 1 M ammonium acetate at pH 7.0. Exchangeable Ca and Mg were measured from the extract with atomic absorption spectrophotometer while exchangeable K and Na were determined from the same extract with flame photometer. Percent base saturation was determined as the percentage of total exchangeable bases to the CEC of the soil. Organic carbon content was determined following the wet digestion method as described by Walkley and Black (1934), whereas the Kjeldahl procedure was followed for the determination of total nitrogen as described by Jackson (1970). Available P was determined using both the Olsen (Olsen *et al.*, 1954) and Bray II (Bray and Kurtz, 1945) extraction methods. The absorbance of available P extracted by both methods was measured using spectrophotometer after color development.

3. Results and Discussion

3.1. Soil Site and Morphological Features

There was not much difference in the characteristics of the sites on which the two pedons were excavated. Accordingly, the majority of the areas represented by both of the pedons studied were cultivated for maize, wheat, triticale and other field crops. The site where pedon 1 was located is very gently sloping (1.0-2.0% slope) with slight to moderate sheet erosion. On the other hand, the site of pedon 2 is gently sloping (2.0-5.0% slope) affected by moderate sheet and slight rill erosion. Similarly, the soils on both sites were developed from basalt parent material and both were very deep (> 200 cm) and moderately well to well drained.

The surface layers (0-25 and 0-20 cm) of the soils represented by pedons 1 and 2, respectively, were dark reddish brown (5YR 3/3 and 5YR 5/4) in color when dry and dark brown (7.5YR 3/2 and 5YR 3/4) when moist (Table 1). In the subsurface horizons, there was no variation in dry soil color (5YR 3/4 to 5YR 4/6) in pedon 1 while it varied from 5YR 5/4 to 2.5YR 4/6 in pedon 2. Similarly, the moist soil color of the subsoil layers varied from 5YR 3/4 (Bt1) to 2.5YR 4/6 (Bt3) in pedon 1 and from 5YR 3/4 (Bt1) to 2.5YR 4/3 (Bt3) in pedon 2. The soil structure was weak, fine granular at the surface and weak, fine and medium subangular blocky in the Bt1 horizons of both pedons (Table 1). In the Bt2 horizons, the structure of pedon 1 changed to moderate, medium subangular blocky while that of the Bt3 of both pedons had moderate, fine angular blocky structure. The roots observed in the surface horizon of pedon 1 were common, fine and medium while that of pedon 2 were many, medium and coarse which decreased progressively with depth to none in the Bt3 horizons of both pedons.

The soils represented by both profiles were very deep as the total depth of both profiles was greater than 200 cm. The thicknesses of the Ap horizons were 25 cm in pedon 1 and 20 cm in pedon 2. The subsoil horizons showed a progressive increase in thickness with profile depth in both pedons. Accordingly, the boundary of the surface horizons which was described to be abrupt and smooth in both pedons changed to gradual and smooth in pedon 1 and to gradual to clear and smooth in pedon 2 in their subsoil horizons (Table 1).

The soil consistence of the top soils were soft (dry), very friable (moist) and slightly sticky and slightly plastic (wet) in pedon 1 and soft (dry), friable (moist) and sticky and plastic (wet) in pedon 2. These changed to slightly hard to hard and very hard (dry), friable to firm (moist) and sticky and plastic (wet) in the subsoil layers of both profiles (Table 1). The shiny faces observed in the ped faces of the Bt2 and Bt3 horizons of both pedons exhibited the presence of nitic properties which is considered as one of the major diagnostic characteristics of the Nitisols major soil group (FAO, 1998).

3.2. Soil Physical Properties

The surface layers (0-25 and 0-20 cm) of pedons 1 and 2, respectively, and the surface soils represented by both soil profiles were silty clay in texture. However, the subsoil horizons of both pedons were clayey in texture (Table 2). Both pedons exhibited high levels of clay accumulation in the subsoil horizons. There was no marked difference in particle density between the two pedons and the surface soil samples. The highest soil particle density (2.51 g cm^{-3}) was noted at the Bt3 horizons of the two pedons, whilst the lowest (2.45 g cm^{-3}) was recorded at the surface horizon of pedon 2 (Table 2). The lowest bulk density values were recorded at the surface horizons.

The results obtained from this study are in agreement with Brady and Weil (2002) who indicated that the bulk density increased with increasing soil depth and the highest bulk density occurred at the C-horizon. Wakene and Heluf (2003) also reported highest bulk density values at the bottom layers of the Cambisol and Nitisol profiles under the farmer's field and on the virgin land, respectively, in Bako area of Ethiopia. However, the same authors reported the highest bulk density value in the surface layer of the Alisol profile of the area that was under intensively cultivated research field for over three decades. The increasing bulk density with soil profile depth in the present study is apparently due to the lower content of organic matter, which was 0.61% in the Bt3 as compared to 2.60 - 2.80% in the surface horizon (Table 3). Besides to the low organic matter, less aggregation and root penetration and compaction

Table 1. Morphological features and classification of Ayehu area soils

Depth (cm)	Horizon	Boun-dary*	Color		Structure	Consistence*			Root
			Dry	Moist		dry	moist	wet	
Pedon 1: Nitisols									
0-25	Ap	as	5YR 3/3	7.5YR 3/2	Weak, fine granular	s	vfr	sssp	Common, fine & medium
25-50	Bt1	gs	5YR 3/4	5YR 3/4	Weak, fine and medium subangular blocky	h	fr	sp	Few, fine
50-100	Bt2	gs	5YR 4/6	5YR 4/3	Moderate, medium subangular blocky	h	fi	sp	Very few, very fine
$100\text{-}200^{+}$	Bt3	-	5YR 4/3	2.5YR 4/6	Moderate, Fine angular blocky	vh	fi	sp	None
Pedon 2: Nitisols									
0-20	Ap	as	5YR 5/4	5YR 3/4	Weak, fine granular	s	fr	sp	Many, medium & coarse
20-50	Bt1	gs	5YR 5/4	5YR 3/4	Weak , fine and medium subangular blocky	sh	fr	sp	Few, fine and medium
50-130	Bt2	cs	2.5YR 4/6	2.5YR 3/6	Weak, fine & medium subangular blocky	h	fi	sp	Few, very fine
$130\text{-}200^{+}$	Bt3	-	2.5YR 4/6	2.5YR 4/3	Moderate, fine angular blocky	h	fi	sp	None

**as = Abrupt and smooth; gs = Gradual and smooth; cs = Clear and smooth; s = Soft; h = Hard; vh = Very hard; sh = Slightly hard; vfr = Very friable; fr = Friable; fi = firm; sp = Sticky and plastic; sssp = Slightly sticky and slightly plastic*

Table 2. Soil physical properties

Depth (cm)	Horizon	Particle size distribution (%)			Textural class	Particle density (g cm^{-3})	Bulk density (g cm^{-3})	Porosity (%)
		Sand	Silt	Clay				
Pedon 1: Nitisols								
0-25	Ap	3.0	57.0	40.0	Silty clay	2.48	1.23	50.4
25-50	Bt1	4.0	24.0	72.0	Clay	2.50	1.30	48.0
50-100	Bt2	4.0	20.0	76.0	Clay	2.50	1.30	48.0
100-200+	Bt3	3.0	19.0	78.0	Clay	2.51	1.40	44.2
Pedon 2: Nitisols								
0-20	Ap	2.0	54.0	44.0	Silty clay	2.45	1.21	50.6
20-50	Bt1	2.0	30.0	68.0	Clay	2.50	1.37	45.2
50-130	Bt2	3.0	20.0	77.0	Clay	2.51	1.33	47.0
130-200+	Bt3	2.0	22.0	76.0	Clay	2.51	1.38	45.0
Surface soil samples nearby Pedon 1 including the experimental plot								
0-30	-	4.0	46.0	50.0	Silty clay	2.50	1.12	55.2
0-30	-	3.0	47.0	50.0	Silty clay	2.49	1.23	50.6
0-30	-	4.0	48.0	48.0	Silty clay	2.50	1.19	52.4
Mean	-	3.7	47.0	49.3	Silty clay	2.50	1.18	52.7
Composite surface soil samples nearby Pedon 2								
0-30	-	2.0	45.0	53.0	Silty clay	2.50	1.17	53.2
0-30	-	3.0	43.0	54.0	Silty clay	2.50	1.14	54.4
0-30	-	4.0	44.0	52.0	Silty clay	2.50	1.13	54.8
Mean	-	3.0	44.0	53.0	Silty clay	2.50	1.15	54.1

caused by the weight of the overlying layers have contributed to the increasing bulk density with depth (Brady and Weil, 2002). In contrast to bulk density, the lowest total porosity (44.2%) was observed at the Bt3 horizon of pedon 1 followed by 45.0% at the Bt3 horizon of pedon 2 and the highest (55.2%) was recorded on the composite surface soil sample collected around pedon 1 (Table 2). This low total porosity was also the reflection of low organic matter content in the subsurface horizons and due to compaction caused by the weight of the soil in the overlying horizons.

3.3. Soil Chemical Properties

Throughout the horizons of the two pedons and in the composite surface soil samples, pH (H_2O) was higher than pH (KCl) (Table 3). Consequently, ΔpH values remained positive, which is an indication of variable charge clay surfaces. Sahlemedhin (1999) also reported results in which the values of pH (H_2O) were higher than pH (KCl) in soils dominated with layer silicate minerals, whereas in the soils dominated by amorphous mineral and oxides of iron and aluminum, the proportion of pH dependent charges was very high and the pH (KCl) values were higher than that of pH (H_2O). Considering the pH (KCl) values, all of the horizons except the Bt3 (pH 5.1) of profile 1 were strongly acidic (pH < 5.0) throughout the depths of the pedons and the composite surface soils. The soil pH (H_2O) values of both soil pedons and the composite surface soil were in the range of 5-6, which is considered as moderately acidic reaction class (Brady and Weil, 2002).

The organic carbon (Table 3) contents were in the range of 2.4 to 2.9% across the surface layers of the pedons and the composite surface soils around the pedons. In both pedons, organic carbon was the highest in the surface soils and decreased rapidly and consistently with profile depths. The organic carbon contents of both pedons and the surface soils fall under moderate based on the ratings of soil test values established by Tekalign *et al.* (1991). The distribution of the total soil N contents among the pedons and the surface soils (0.19-0.22%) is almost similar to the organic carbon and are also considered as moderate as per the ratings of same. The C: N ratios of the surface soil layers of both pedons and the average values of the composite surface soil samples varied from 12.2 to 13.7 (Table 3) and these were within the normal ranges for average mineral soils. The relatively higher values of C: N ratios in some of the subsoil layers suggest low rate of organic matter decomposition and indicate lower rate of mineralization of organic N.

The CEC and total exchangeable bases decreased consistently from the surface to the subsurface horizons except for the Bt3 horizon of pedon 2 (Table 3). The decrease in CEC with depth could be due to the strong association between organic carbon and CEC, as organic matter content also decreased with depth in both pedons. The subsoil horizons showed relatively lower values of CEC and percentage base saturation values lower than 50% suggesting high intensity of weathering and the presence of 1:1 (kaolinitic) type minerals. Exchangeable Na contents of the soils under the two profiles and the surface soil samples were trace. Exchangeable K decreased almost consistently from the surface to the subsurface horizons on pedon 1, whereas an appreciable amount of K was recorded in both profiles which made the result in agreement with the common observation that Ethiopian soils are rich in K. Moreover, based on the ratings of Tekalign *et al.* (1991), which sets that soils consisting of exchangeable K values greater than 0.77 cmol(+) kg^{-1} as high in K, the soils of the study area were high to very high in exchangeable K.

In both pedons, the highest values of exchangeable Ca were recorded in the surface horizons (Table 3). Similarly, exchangeable Mg was highest in the surface layers of the pedons, and hence exchangeable Ca and Mg occupied 84% and 90% of the CEC in pedon 1 and pedon 2, respectively. The distribution of exchangeable Ca and Mg showed inconsistency with depth in both pedons. Relatively lower Ca and Mg concentrations were recorded on the composite surface soil samples analyzed compared to that of the surface layers of the pedons. Considering the results of the composite surface soil samples, soil exchangeable Ca is in the range of medium (5-8 cmol(+) kg^{-1}) and Mg is rated as high (0.67-1.50 cmol(+) kg^{-1}) as per the rating suggested by Tekalign *et al.* (1991).

The percent base saturation values throughout the two pedons and composite surface soil samples were less than 50%. This could be due to the high rainfall and intensive cultivation in the study area that enhanced loss of basic cations through leaching and crop harvest (Singh *et al.*, 1995; Saikh *et al.*, 1998b). Higher organic carbon concentrations were recorded in the surface horizons as compared to the lower depths of the soil profiles. Similarly, the amount of total nitrogen decreased consistently with depth throughout the two pedons (Table 3). Considering the surface soil layers, the highest organic carbon (2.8%) and total nitrogen (0.22%) were obtained in Pedon 2 (Table 3).

3.4. Soil Classification

The morphological, physical, and chemical properties of pedons 1 and 2 suggest that the soils under both soil profiles qualify the FAO (1998) criteria for classification as Nitisols. According to the FAO (1998), Nitisols are reddish brown soils with nitic properties on the exposed surfaces and exhibit shiny, lustrous ped faces. In both pedons, the soil structure of the Bt horizons ranged from moderate, medium subangular blocky to moderate, fine angular blocky structure. The horizon boundaries were abrupt and smooth in the surface horizons. These changed to gradual and smooth in Pedon 1 and to gradual to clear and smooth in Pedon 2 in their subsoil horizons. The contents of clay throughout the pedons were greater than 30% and increased considerably with increasing depth from 40 to 78% in Pedon 1 and from 44 to 77% in Pedon 2 indicating translocation of clay from the surface soil and its accumulation in the subsoil layers. The Munsell moist color values and chromas were also 5 and 4 or less, respectively. The diagnostic properties and the physicochemical properties suggested the classification of these soils into Nitisols group (FAO, 1998). The shiny ped faces (pressure faces) observed in the Bt2 and Bt3 horizons of both pedons clearly indicate the existence of Nitic properties which is a major diagnostic property for their classification as Nitisols at a reference

Table 3. Chemical properties of soils in Ayehu area

Depth (cm)	pH (1:2.5)		ΔpH	AvP (mg l^{-1})*		TN (%)	OC (%)	C: N ratio	CEC and exchangeable bases (cmol(+) kg^{-1})						PBS (%)
	H_2O	KCl		Olsen	Bray				CEC	Na	K	Ca	Mg	TEB	
Pedon 1: Nitisols															
0-25	5.88	4.77	1.11	3.21	4.40	0.19	2.6	13.70	33.5	trace	2.66	10.36	3.55	16.57	49.46
25-50	5.56	4.29	1.27	1.80	3.80	0.10	1.5	15.00	29.5	trace	1.90	6.22	2.42	10.54	37.33
50-100	5.70	4.52	1.18	2.13	3.80	0.07	1.0	14.30	27.9	trace	0.72	7.73	2.64	11.09	39.75
100-200+	5.75	5.10	0.65	1.91	3.40	0.05	0.6	12.00	22.9	trace	0.68	6.35	3.00	10.33	45.10
Pedon 2: Nitisols															
0-20	5.55	4.53	1.02	2.35	4.01	0.22	2.8	12.70	33.1	trace	1.52	10.6	2.90	15.02	45.38
20-50	5.46	4.34	1.12	2.36	3.40	0.09	1.9	21.10	26.9	trace	0.76	7.16	1.90	9.82	36.50
50-130	4.89	4.31	0.58	0.19	2.80	0.07	1.3	18.60	19.9	trace	1.29	0.82	1.31	3.42	17.19
130-200+	5.35	4.40	0.95	0.43	4.00	0.10	1.1	11.00	26.1	trace	2.05	5.32	2.60	9.97	38.20
Composite surface soils nearby Pedon 1 including the experimental plot															
0-30	5.81	4.81	1.00	2.58	4.24	0.22	2.9	13.18	29.5	trace	2.81	5.90	1.01	9.72	32.95
0-30	5.89	4.80	1.09	2.33	4.22	0.22	2.7	12.27	28.7	trace	2.97	5.80	0.98	9.75	33.97
0-30	6.00	4.83	1.17	2.95	4.18	0.22	2.8	12.73	28.9	trace	0.53	5.40	0.87	6.80	23.53
Mean	5.90	4.81	1.09	2.62	4.21	0.22	2.8	12.73	29.0	trace	2.10	5.70	0.95	8.76	32.55
Composite surface soil samples nearby Pedon 2															
0-30	5.99	4.78	1.21	2.33	4.20	0.21	2.4	11.43	24.7	trace	1.60	6.00	1.10	8.70	35.22
0-30	5.81	4.75	1.06	2.34	4.22	0.21	2.6	12.38	22.7	trace	2.21	6.00	1.00	9.21	40.57
0-30	6.01	4.72	1.29	2.64	4.21	0.21	2.7	12.86	29.1	trace	2.13	5.42	1.05	8.60	29.55
Mean	5.94	4.75	1.19	2.44	4.21	0.21	2.6	12.22	25.5	trace	1.98	5.81	1.05	8.84	35.11

**AvP = Available P; TN = Total N, OC = Organic carbon; CEC = Cation exchange capacity; TEB = Total exchangeable bases; PBS = Percent base saturation* group level. Moreover, the percentage base saturation throughout the depths of both soil profiles was below 50%. This property suggests that the soils further qualify to be classified as Dystric Nitisols at the second level of classification of the FAO system (FAO, 1998).

3.5. Native and Residual Soil Phosphorus

The Olsen extractable P of the soils in the study area was very low (< 5 ppm) as per the ratings of Olsen *et al.* (1954). Similarly, the Bray II extractable P was low (< 3 ppm) as described by Olsen and Dean (1965). The highest concentrations of Olsen extractable phosphorus (3.21 ppm) and Bray II extractable phosphorus (4.40 ppm) were obtained in the surface horizon of pedon 1 (Table 3). Available P values are still lower in the composite surface soil samples of the cultivated fields near the two pedons. Generally, both the Olsen and Bray II extractable P values of the soils are far below the critical soil test P levels for most crop plants as reported by Tekalign and Haque (1991) for Ethiopian soils. This low soil test levels of available P may be due to the inherently low P levels of the soil or due its high P fixation capacity caused by the strongly acidic (pH KCl) and moderately acidic (pH H_2O) soil reactions.

The results of the Olsen and Bray II extractable soil P determined on soil samples collected from every treatment combination at harvest are presented in Table 4. The main effects of increasing levels of applied N fertilizer on soil P extracted by both methods were not consistent although the Bray II P tended to increase while the Olsen P showed a decreasing trend with increasing applied N rates. Considering the main effect of applied N, the highest values of Bray II (5.16 kg ha^{-1}) and Olsen (4.32 kg ha^{-1}) extractable soil P were obtained with the application of N at 46 and 0 kg ha^{-1}, respectively. Nevertheless, without applied P, increasing the levels of N fertilizer from 0 to 92 kg ha^{-1} increased consistently the Bray II P from 2.80-4.80 kg ha^{-1} and the Olsen P from 1.65-2.53 kg ha^{-1} (Table 4).

On the contrary, application of P fertilizer increased both the Olsen and Bray II extractable available soil P consistently (Table 4). Averaged across all levels of applied N fertilizer rates, the Bray II extractable soil P increased from 3.84 to 5.64 kg ha^{-1} and Olsen P from 2.15 to 4.26 kg ha^{-1} when the rate of applied P fertilizer increased from 0 to 40 kg P ha^{-1}. In the absence of applied N fertilizer, the Bray II extractable soil P increased consistently from 2.80-6.20 kg ha^{-1} with the increment of P fertilizer rate from 0 to 30 kg P ha^{-1} whereas the Olsen P increased from 1.65-8.02 kg ha^{-1} when the rate of applied P fertilizer increased from 0 to 40 kg P ha^{-1} (Table 4). The increment of both Bray II and Olsen extractable soil P with increasing applied rates of P fertilizer indicates that the crop recovery of applied P was low and a considerable amount of the applied phosphorus fertilizer has been left in the soil as a residual P.

Table 4. Effects of increasing levels of N and P application on Olsen and Bray II available P contents of the soil

Applied N (kg ha^{-1})	Applied P (kg ha^{-1})					Mean
	0	10	20	30	40	
			Bray II available P (mg l^{-1})			
0	2.80	3.20	5.00	6.20	5.00	4.44
23	3.60	4.40	4.60	5.00	4.60	4.44
46	4.00	4.80	4.00	5.40	7.60	5.16
69	4.00	4.20	5.60	5.40	6.00	5.04
92	4.80	3.80	4.60	5.00	5.00	4.64
Mean	3.84	4.08	4.76	5.40	5.64	4.74
Applied N (kg ha^{-1})	Applied P (kg ha^{-1})					Mean
	0	10	20	30	40	
			Olsen available P (mg l^{-1})			
0	1.65	2.01	4.21	5.74	8.02	4.32
23	1.92	2.66	2.39	3.44	2.65	2.61
46	2.16	3.41	2.52	3.74	3.83	3.13
69	2.50	2.15	3.45	2.95	3.78	2.97
92	2.53	4.63	2.72	3.26	3.01	3.23
Mean	2.15	2.97	3.06	3.82	4.26	3.25

4. Conclusion

Examination of the pedons revealed that the soils exhibited high levels of clay accumulation with increasing depth and silty clay to clay in texture. The reddish brown and red soil characteristics with nitic properties on the exposed surfaces having shiny, lustrous ped faces and their chemical properties lead to the classification of this soil into Nitisol. In both pedons, the lowest bulk density values were recorded at the surface horizons. Higher values of pH (H_2O), available P (Bray II), total N, organic matter, CEC, total exchangeable bases and percentage base saturation were observed in the surface soil horizons and the composite surface soil samples than in the subsurface horizons of the pedons.

The Olsen and Bray II soil test P values revealed that the soils of the study area are very low and low, respectively, and are far below the critical soil test P values for most crop plants as per the results of similar studies under Ethiopian conditions. Similarly, the organic carbon and total N status of the soils are moderate whereas exchangeable Ca is medium, Mg is high and K is high to very high. Application of P fertilizer increased both the Olsen and Bray II extractable soil available P consistently. This further indicates that crop recovery of applied P fertilizer in one season is low and therefore much of the applied P remains in the soil as available form of P for subsequent use by crop plants. Apparently, the results of this study provide basic information and baseline data for further research and development efforts in soil fertility management for sustainable utilization of the soil resources in the area. However, further detailed study and analysis should be carried out on the soils around Ayehu in order to supplement the results of this specific location and one year study so that sound conclusions can be drawn and recommendations made.

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Registration of *Chercher* and *Haramaya*: Common Bean Varieties for Production in Eastern Ethiopia

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Abstract: Two common bean (*Phaselus vulgaris L.*) varieties: *Chercher* (STTT-165-96) and *Haramaya* (G-843) developed by the Haramaya University were released for production in the highlands of Hararghe and similar agro-ecologies in 2005 and 2006, respectively. These varieties were selected and evaluated at 12 environments (locations x years) in eastern Ethiopia between 1998 and 2001. The varieties were described in their phenological and seed characters, yield performance, disease reaction, quality aspect, and adaptation, and compared with the standard and local checks. The varieties have indeterminate bush type growth habit and preferable seed size and color, stable and high yield (1.7 tons ha^{-1} for *Chercher* and 2.8 tons ha^{-1} for *Haramaya*) across environments, resistance reactions to major fungal and bacterial diseases, and superior canning (*Chercher*) and food qualities.

Keyword: *Chercher*; Common Bean; *Haramaya*; Variety Registration

1. Introduction

Chercher (STTT-165-96) and *Haramaya* (G-843) are common bean (*Phaseolus vulgaris L.*) varieties released in 2005 and 2006 respectively, by the Haramaya University (HU). *Chercher* is navy (white) bean type. They were among CIAT/ECABREN breeding lines that had been introduced to Ethiopia and evaluated in preliminary observation nurseries in 1996 and advanced observation nurseries in 1997 at Haramaya Research Center. The official release of the varieties to bean producing areas in eastern and western Hararghe was approved by the Ethiopian National Variety Release Committee in accordance with the national variety release and registration policy of the country. Breeder and foundation seed is maintained by HU. In describing these varieties, descriptions of new common bean varieties used by Grafton *et al.* (1993), Kelly *et al.* (1994) and Saindom *et al.* (1996) were adopted.

2. Evaluation

Chercher and *Haramaya* were tested under Regional Variety Trial at 12 environments (locations x years) in eastern Ethiopia between the years 1998 and 2001. *Chercher* was evaluated along with *Mexican-142* (G-11239) and *Awash-1* (Extrico-23) as standard checks. On-farm evaluation was conducted during 2004 at 10 sites, with *Melka Awash-98* (PAN-182) as new standard check at altitudes ranging from 1650-2200 meter above sea level.

Haramaya was evaluated along with *Roba-1* (A-176) as standard and *Red Wolaita* as local checks. On-farm evaluation was conducted during 2005 at 8 sites with *Zebra* (GX-1175-3) as the new standard check. The sites represent common bean production environment with altitude range of 1700-2200 meters above sea level.

3. Varieties Characters

Chercher is a tall and an erect variety of an indeterminate bush (type IIa) growth habit. It has thick stem and branches, with vigorous up right growth, thus resistant to lodging. The canopy height ranges from 36-50 cm depending on the environment. The average days-to-flowering after emergence is 52 and maturity is 105 days (Table 1). On average, it produces 25 pods per plant. The pods are straight and nearly round in shape; medium in size with average dimensions of length (9 cm), width (9.4 mm), and thickness (6.8 mm) at maturity. The variety on average produces 5 seeds per pod. The seeds are white (navy types) and nearly elliptical, with dimensions of length (10 mm), width (6.5 mm), and thickness (5.3 mm). The average weight of 100-seeds is 20.4 g, which is greater by 20% than that of *Melka Awash- 98*.

Haramaya is characterized by its indeterminate prostrate (type IIIb) growth habit. The variety flowers 52 days after emergence and matures in 99 days (Table 1). The pods are green before maturity, are round in shape and of medium size. Each pod produces on average 4 seeds.The seeds belong to the cream (*mulatinho*) market class, with a prominent yellow color of the hillary ring. The plump, shiny seeds on average weigh 33 g per 100-seeds, which is greater by 83%, 74% and 14% than those of *Roba-1*, *Red Wolaita*, and *Zebra*, respectively.

4. Yield Performance

Chercher has shown superior yield performance across environments (2-3 tons ha^{-1}) without fertilization; exceeding *Awash-1* by 30% and *Mexican-142* by 10% but similar with *Melka-Awash 98*. It gave a maximum yield of 3.3 tons ha^{-1} at one location (average of 3 years), which indicated its increasing response to potential environments receiving adequate rainfall and having fertile soils.

Hararmaya is well adapted to the environments in

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eastern Ethiopia receiving a well distributed average annul rainfall of greater than 650 mm. Grain yield ranged between 1.7 tons ha^{-1} at low rainfall receiving areas and 3.8 tons ha^{-1} at areas receiving high rainfall and having fertile soils without fertilization. The average yield is 2.8 tons ha^{-1}, exceeding *Roba-1* by 50% and *Red Wolaita* by 48%. On-farmers' fields higher yield advantages of 71%, 41%, and 15% over *Roba-1*, *Red Wolaita*, and *Zebra,* respectively, have been recorded.

5. Reaction to Diseases

On the standard rating scale of 1-9, 1 being highly resistant and 9 highly susceptible, *Chercher* scored a mean of 2 for bean rust (*Uromyces appendiculatus*), angular leaf spot (*Phaeoisariopsis griseola*) and halo blight (*Pseudomonas syringae pv. phaseolicola*), and 3 for anthracnose (*Colletotricum lindemuthianum*) and common bacterial blight (*Xanthomonas campestris pv. phaseoli*) (Table 1). *Haramaya* scored 1 for angular leaf spot and anthracnose, 2 for halo blight and rust, and 3 for common bacterial blight (Table 2). The varieties are resistant to the major common bean diseases. The resistance reaction of the varieties could be integrated with other disease management methods such as seed treatment, growing in intercropping, and managing infested debris.

Table 1. Mean agronomic characters and disease reactions of *Chercher* (STTT-165-96), *Haramaya* (G-843) and their check varieties in multilocation trial

Variety	Agronomic character			Disease reaction[1]				
	DF	DM	YI (t ha^{-1})	RU	ANT	ALS	HB	CBB
Chercher	52	105	1.7	2.3	2.7	1.7	1.9	3.5
Mexican-142[2]	56	108	1.5	5.0	2.8	1.3	2.2	3.7
Awash-1[2]	56	108	1.3	2.3	2.8	2.0	1.9	3.4
Haramaya	52	99	2.8	2.0	1.3	1.0	1.6	2.8
Roba-1[3]	58	102	1.4	1.3	1.6	1.0	2.0	2.6
Red Wolaita[3]	54	102	1.4	4.0	4.0	1.3	2.3	4.0

[1] Disease score based on 1-9 scale where 1 is highly resistant and 9 is highly susceptible.
DF = days to flowering; DM = days to maturity; YI = yield; RU = rust; ANT = anthracnose; ALS = angular leaf spot; HB = halo blight; CBB = common bacterial blight
[2] check varieties for Chercher.
[3] check varieties for Haramaya.

6. Quality Test

Canning quality test conducted at Lodato Gennaro and C.S.P.A Industrie Conserve Alimentari, Italy indicated that *Chercher* was the best in its canning quality, being the lightest in processed bean color and the softest in firmness, compared to the current *Melka Awash-98*, the standard check. In a quality test conducted at HU food science laboratory, *Chercher* was found fast soaked with 100% soakability and 2.1 hydration index compared to 89% soakability and 1.9 hydration index for *Melka Awash-98*. Average crude protein and ash contents of *Chercher* raw dry seeds are 25.7% and 4.7%, respectively, which is about the same with the standard variety.

Haramaya is preferred by producers and consumers for its attractive seed physical characteristics (color, size, shape and plumpness). It is also preferred for its suitability for preparing different local dishes (in the form of boiled grain, *shummo*) and for sauce making. *Haramaya* was found 100% soakable with mean cooking time of 30 minutes.

7. Adaptation

Chercher and *Haramaya* are released for production in eastern and western Hararghe, eastern Ethiopia, preferably for areas receiving a well distributed total annual rainfall of greater than 650 mm. However, the varieties can be extended to other regions of similar agro-ecologies after adaptation trials. The upright growth habit and good pod clearance character of *Chercher* would make it suitable for production under intercropping and irrigation in all potential regions of Ethiopia. On highly fertile soils with relatively better rainfall receiving, *Haramaya* often shows excessive vegetative growth, and needs a wider spacing than the recommended 40 cm inter-row and 10 cm inter-plant spacing. Depending on fertility and cropping system (sole cropping versus intercropping) seed rate of 50-60 kg ha^{-1} could be used. The varieties can be planted in early April in spring season, *Belg* and in early July in summer season, *Meher*.

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