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Wild edible trees and shrubs in the semi-arid lowlands of Southern Ethiopia

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Abstract

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The study was conducted in Benna Tsemay district, South Omo Zone of the Southern Nations', Nationalities' and Peoples' Region (SNNPR) of Ethiopia, to identify and document wild edible trees and shrubs and to assess their role in household food security. Ethno-botanical data were collected using a semi-structured questionnaire, key informant interview, group discussion and vegetation inventory. A total of 30 wild edible trees and shrubs were identified and documented, of which 15 species (50%) have a supplementary role in household food security, three species (10%) are used to fill the seasonal food shortage and 12 species (40%) have an emergency role. In addition to food, four species are used to generate income for households. The density of wild edible trees and shrubs varied with altitude, the average number being 25 trees or shrubs ha^{-1} in the lower altitudinal zones (500–600 m a.s.l.) and 312 in mid-altitudinal zones (1200–1500 m a.s.l.). The harvestable edible materials also varied from site to site, with average quantities of 85 and 382 kg ha^{-1} for the lowlands and mid-altitudinal zones, respectively. Expansion of agriculture (25%), fire hazards (21.7%) and overgrazing (18%) were the major threats to the existence of wild edible trees and shrubs in the study area. The study indicated that wild edible plants are valuable resources for improving food and nutritional security and income of households living in dryland areas. Thus, more research is needed to assess their nutritional value and economic as well as ecological contributions.

Keywords: Ethno-botany, Food security, Indigenous knowledge, Benna, Tsemay, South Omo

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Introduction

Rural people derive a significant proportion of their food and energy requirements from various indigenous trees and shrubs, which are not cultivated (Nair, 1989). Wild food plants are plants with edible parts that grow naturally on farmland, fallow or uncultivated land (Ruffo *et al.*, 2002; Zemede Asfaw & Mesfin Tadesse, 2005; Getachew Addis, 2009; Demel Teketay *et al*., 2010). They are relevant to household food security and nutrition in some rural areas, particularly in the drylands, to supplement the staple food, to fill seasonal food shortages, and as emergency food during famine (Amare Getahun, 1974; FAO, 1989; 2003; Guinand & Dechassa Lemessa, 2000; Teshome Soromessa & Sebsebe Demissew, 2002).

These wild plants can supplement nutritional requirements, especially vitamins and micronutrients. Analysis of some wild food plants demonstrates that, in many cases, their nutritional quality is comparable to— and may be superior to— domesticated varieties (Getachew Addis *et al*., 2005; Kebu Balemie & Fassil Kebebew, 2006). Income and employment can be obtained from the sale or exchange of their fruits, leaves, juice and local drinks. Moreover, the indigenous species are adapted to the local culture and environment, and therefore propagate and grow easily, with few requirements for external inputs such as fertiliser and pesticides. Thus they can easily be integrated into sustainable farming systems (Ruffo *et al*., 2002).

For many years, the importance of wild edible plants in the subsistence agriculture of developing countries, as a food supplement or a means of survival during drought and famine, has been overlooked. Although many wild food plants are used by the majority of the rural population, they are still not as appreciated or valued as are some cultivated food plants, such as mango, orange, cabbage and banana (Bell, 1995; Guinand & Dechassa Lemessa, 2000; Ruffo *et al*., 2002; Demel Teketay *et al*., 2010).

Traditional knowledge of wild plants in Africa is in danger of being lost, as habits, value systems and the natural environment change. There is a widespread decline in knowledge about wild food plants, especially among young people and urban dwellers. Therefore, to preserve this knowledge, which potentially is highly valuable for future generations, it needs to be recorded systematically (FAO, 1996; Zemede Asfaw & Mesfin Tadesse, 2005; Tigist Wondimu *et al*., 2006; Demel Teketay *et al*., 2010).

In Ethiopia, where more than 80% of the population is rural, people have depended on their traditional knowledge for the utilisation of plants in their surroundings. Despite the wider role of wild edible plants in rural communities, their contribution, management and utilisation are not exhaustively documented. This is particularly true of the drylands of Benna Tsemay district in Southern Ethiopia.

The present study was, therefore, designed to answer the following research questions: *(a)* what wild edible trees and shrubs are there in the area, *(b)* what part do wild edible trees and shrubs play in household food security, *(c)* what traditional knowledge and skill is there regarding the management and utilisation of wild edible trees and shrubs, and *(d)* what is the production potential of those edible trees and shrubs?

The aims of this study were to document indigenous knowledge related to the use and management of wild edible trees and shrubs and to assess the constraints and potentials for their better exploitation in the future.

Materials and Methods

The study area

The study was conducted in Benna Tsemay District of the South Omo Administrative Zone, in the Southern Nations', Nationalities' and Peoples' Regional State (SNNPRS) of Ethiopia (Figure 1). The District is situated

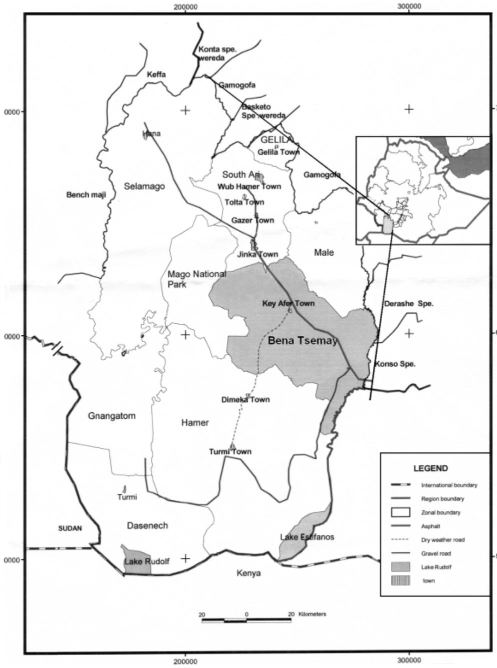

Figure 1. Geographical location of Benna Tsemay District, South Omo Zone, Southern Ethiopia (Source: BOFED, 2008).

between 5.11º–5.70º N latitude and 36.20º–37.04º E longitude (BOFED, 2007). The area receives bimodal rainfall; the first peak, from mid-March to the end of April, is important for crop production, and the second peak, from mid-October to the beginning of November, is short and important only for pasture. The altitude ranges between 500–1500 m a.s.l. The lower altitude, below 700 m a.s.l., is inhabited by the Tsemay ethnic group, while the area above 1000 m a.s.l. is predominantly inhabited by the Benna ethnic group. The annual average rainfall varies between 400–920 mm. The mean annual temperature ranges between 17.6–27.5 ºC. The diurnal maximum temperature in the plains of Weyto in the Tsemay area can exceed 42 ºC (SIM-Alduba, unpublished report). The major soil types of the area are Eutric fluvisols (in the flat lands of the Tsemay), and Eutric and Chromic cambisols (in the rolling plateau of the Benna area). According to Teshome Soromessa *et al.* (2004), the district has substantial vegetation resources, particularly the *Combretum-Terminalia* and *Acacia-Commiphora* woodlands, which are also used as rangelands and common property resources of the whole community.

The human population of the district is 55,590, of whom 28,087 are male and 27,503 female (CSA, 2007). The two dominant ethnic groups, Benna and Tsemay, comprise 27,022 (48.6%) and 20,046 (36.1%) of the population, respectively, while the remaining 8,522 (15.3%) are from other ethnic groups. As regards the livestock population, there are *ca.* 179,918 head of cattle, 82,178 goats, 28,494 sheep, 18,885 donkeys and 80,000 traditional beehives (CSA, 2007).

Methods of data collection

Socio-economic survey

The socio-economic survey involved various data collection techniques, such as semi-structured questionnaires, focus-group discussions and field observations. For the questionnaire survey, six *Kebeles* or Peasant Association (PAs) were selected out of 28, on the basis of vegetation cover, altitudinal range and ethnic composition (Table 1). Ten households from each *Kebele* were randomly selected for the survey, in total 60 sample households. The sample households constitute about 10% of the total population in the *Kebeles*.

In addition to the household interviews, information was collected from 30 key informants (five per *Kebele*) and six group discussions (one per *Kebele*). This information provided an overview of the socio-economic and biophysical environment of the sites, and served to cross-check the data collected from households.

Table 1. *Selected kebeles, their vegetation type, altitude and dominant ethnic groups*

Kebele	Vegetation type	Mean altitude, m	Ethnic group
Shalla-kyyuo	Desert and semi-desert scrubland	500	Tsemay
Luka	*Acacia–Commiphora* woodland	600	Tsemay
Alduba	*Combretum–Terminalia* woodland	1250	Benna
Shabba	*Combretum–Terminalia* woodland	1400	Benna
Olka-kibo	*Combretum–Terminalia* woodland	1500	Benna
Kako	*Combretum–Terminalia* woodland	1300	Benna

A semi-structured questionnaire was developed, and interviews were conducted with the selected households. Data were collected on the role of wild edible trees and shrubs in food security, production potential per tree and utilisation practices, and on plant parts. Other uses of the trees and shrubs, traditional management practices and major threats to these wild edible species, were identified through interviews and field observations.

Vegetation inventory

An inventory was made of the wild edible trees and shrubs, to obtain information on the type of trees and shrubs, their density per hectare and the production potential of edible materials per tree and per hectare. The term ‘shrub’ in this paper is used to describe woody perennial plants that remain low and produce multiple shoots from the base, while ‘trees’ refers to woody perennial plants that produce one main trunk or bole and a more or less distinct and elevated crown (Huxley & van Houten, 1997). The inventory was conducted by systematic transect sampling. In each *kebele*, two parallel transect lines were laid out 500 m apart, with quadrats at an interval of 600 m. Each transect had two 40×40 m (1600 m^2) or 20×20 m (400 m^2) quadrats, depending on the vegetation cover, i.e., 40×40 m for the sparse vegetation of the lower altitudes (< 700 m a.s.l.) and 20×20 m for the dense vegetation in the mid-altitudes (>1000 m a.s.l.). Therefore, four quadrats were laid out in each *kebele*, in total 24 quadrats for the whole study. Of these, eight quadrats had an area of 1600 m^2 each, and the remaining 16 were each of 400 m^2.

On each plot, all trees and shrubs were documented by their vernacular name, later converted to the scientific name by means of a tree identification manual. Unfortunately, some species were not identified at field level: For such species, plant specimens were collected, mounted, labelled and submitted to the National Herbarium at Addis Ababa University for identification.

The density of wild edible trees and shrubs on each plot was expressed by counting stems and converting the number to a per hectare basis. Data on the estimated quantity of edible products expected from each plant were collected by interviewing the harvesters. According to Pancel (1993), the quantity of edible parts expected from each plant species of a certain size class can be estimated by asking the same question of a number of harvesters. Following this method, 15 harvesters in total were interviewed, to obtain a reasonable estimate of the yield of edible parts of the various trees and shrubs on each plot. The result obtained was then averaged and converted to a per hectare basis.

Data analysis

The data collected were analyzed by means of descriptive statistics, with Microsoft Excel and SPSS (Statistical Package for Social Sciences, version 13).

Results and discussion

Wild edible trees and shrubs in Benna Tsemay district

The plant species of the study area are generally diverse and serve different purposes to the communities. Among them, a total of 30 wild edible trees and shrubs, belonging to 25 genera and 19 families, were identified (Table 2, overleaf). The Capparidaceae and Tiliaceae families had the highest proportion of edible wild trees and shrubs, with four and three species, respectively. A study conducted in the Kara and Kwego area of Southern Ethiopia (Tilahun Teklehaimanot & Mirutse Giday, 2010) has also indicated that these families had the highest number of edible plants. The diversity of edible trees and shrubs was higher in the altitudinal range 1200–1550 m a.s.l., as compared to the lower altitudes (500–700 m a.s.l.). The difference in species diversity is mainly due to differences in agroecological zones, which in turn depend on the soil, temperature, and rainfall that are determining factors for survival and growth of species.

Most of the identified trees and shrubs are reported to be edible elsewhere in Ethiopia and other parts of Africa. In an ethnobotanical study in Derashe and Kucha district of Southern Ethiopia, Kebu Balemie & Fasil Kebebew (2006) recorded 10 of the wild edible plant species reported in the present study, while a study undertaken in Tanzania (Ruffo *et al.*, 2002), indicated the use of 16 of the wild edible trees and shrubs (see also Amare Getahun, 1974; Teshome Soromessa & Sebsebe Demissew, 2002; Zemede Asfaw & Mesfin Tadesse, 2005; Getachew Addis *et al.*, 2005; Tigist Wondimu *et al.*, 2006; Getachew Addis, 2009; Tilahun Teklehaimanot & Mirutse Giday, 2010).

Role of wild edible trees and shrubs in household food security

Wild food plants could be grouped into three categories on the basis of their consumption pattern. These include those consumed: *(a)* during periods of ample food production to supplement the staple food, *(b)* to fill the gap of seasonal food shortage and *(c)* during famine. In addition to their food value, some species of wild edible plants have other economic values.

(a) Supplementary role of wild edible trees and shrubs

This study showed that, of the 30 identified wild edible tree and shrub species, 15 (50%) are used to supplement the regular food supply (Table 2; Appendix 1). The majority of these species are found in the Benna area. According to the informants, the selection of these edible plants is based on simplicity of processing, good taste, time of availability and low labour requirement. This is in agreement with earlier studies, which indicated that wild food usually is considered as an addition to farmers' daily food consumption pattern (UP, 2000; Guinand & Dechassa Lemessa, 2000). Bell (1995) also noted that wild plants are incorporated in the normal livelihood strategies of many rural people who are pastoralists, shifting cultivators, sedentary farmers or hunter-gatherers.

(b) Seasonal role of wild edible trees and shrubs

Wild edible trees and shrubs are used by many agropastoralists in the study area to fill the food gap. Of the 30 edible trees and shrubs, three (10%) are used to fill the gap of seasonal food shortage (Table 2; Appendix 2). These trees and shrubs regenerate their leaves after the first shower of rain. The survey

Table 2. *List of wild edible trees & shrubs in the two altitudinal zones of the study area*

Scientific name	Family	Edible part	Role in food security	Degree of distribution	
				500–850 m a.s.l.	850–1550 m a.s.l.
Balanites aegyptiaca (L.) Del.	Balanitaceae	Fr, Lf	SS	xx	xx
Balanites rotundifolia (van Tilghem) Blatter	Balanitaceae	Fr	SP	xxx	x
Borassum aethiopum Mart.	Arecaceae	Fr	EM	x	0
Boscia angustiifolia A. Rich.	Capparidaceae	Se	EM	0	x
Canthium pseudosetiflorum Bridson	Rubiaceae	Fr	SP	x	xxx
Carissa spinarum L.	Apocynaceae	Fr	SP	0	xx
Cleome monophylla L.	Capparidaceae	Lf	SS	0	xxx
Crateva adansonii DC.	Capparidaceae	Fr	SP	0	x
Diospyros mespiliformis Hochst. ex A. DC.	Ebenaceae	Fr	EM	0	x
Euclea divinorum Hiern.	Ebenaceae	Fr	EM	x	x
Ficus sur Forssk.	Moraceae	Fr	EM	x	x
Ficus vasta Forssk.	Moraceae	Fr	EM	x	x
Flacourtia indica (Burm.f.) Merr.	Flacourtiaceae	Fr	EM	x	xxx
Grewia tenax (Forssk.) Fiori	Tiliaceae	Fr	SP	0	x
Grewia velutina (Forssk.) Vahl.	Tiliaceae	Fr	EM	0	x
Grewia villosa Willd.	Tiliaceae	Se	SP	0	x
Lannea schimperi (Hochst. ex A. Rich.)	Anacardiaceae	Fr	EM	0	xx
Leucas glabrata (Vahl) Sm in Rees.	Lamiaceae	Fr	EM	0	xx
Meyna tetraphylla (Schweinf. ex Hiern) Robyns	Rubiaceae	Fr	SP	xx	x
Opuntia ficus-indica (L.) Miller	Cactaceae	Fr	SP	0	x
Piliostigma thonningii (Schum.) Milne-Redh.	Fabaceae	Se	EM	0	xx
Psydrax schimperiana (A. Rich.) Bridson	Rubiaceae	Fr	SP	0	xx
Rhus quartiniana A. Rich.	Anacardiaceae	Se	SP	0	xx
Salvadora persica L.	Salvadoraceae	Fr	SP	0	x
Sclerocarya birrea (A. Rich.) Hochst	Anacardiaceae	Fr	SP	x	xx
Securidaca longepedunculata Fresen	Polygalaceae	Lf	SS	0	xx
Senna singueana (Del.) Lock	Fabaceae	Fr	EM	0	xx
Tamarindus indica L.	Fabaceae	Fr	SP	x	xx
Ximenia americana L.	Olacaceae	Fr	SP	xx	xx
Ziziphus mucronata Willd.	Rhamnaceae	Fr	SP	o	xx

Key: a) *Edible parts:* Fr=Fruit; Lf=Leaf; Se=Seed
b) *Degree of distribution:* 0=none; x=rare; xx=Intermediate; xxx=large-scale
c) *Role in food security* SP=Supplementary; SS=Seasonal EM=Emergency

showed that the Benna ethnic group predominantly use *Cleome monophylla* L. and *Securidaca longepedunculata* Fresen, but the Tsemay consume *Balanites aegyptiaca* (L.) Del. and some herbaceous weeds to fill the gap of seasonal food shortage. This difference between ethnic groups is mainly due to the wider distribution of the species in their respective localities.

Wild plants play a critical part in food security in arid and semi-arid environments. Since dry and rainy seasons are sharply separated in these areas, agriculture is restricted to specific periods of the year, thus leaving wide intervals with limited options for food production. In such periods, food reserves are reduced or may be exhausted, and wild food plants then become a critical food security resource. Wild food plants represent an untapped resource, with the potential to improve nutrition in arid and semi-arid lands. They play a role analogous to that of vegetable crops in humid and sub-humid areas (FAO, 2003; Getachew Addis *et al*., 2005). According to UP (2000), wild leafy vegetables, cabbage and tuberous plants are consumed to fill the gap after the first rain, when farmers prepare their fields.

(c) Emergency role of wild edible trees and shrubs.

Of the recorded wild edible trees and shrubs, 12 species (40%) are consumed during famine (Table 2; Appendix 3). Famine foods are used only when preferred alternatives are not available, and in situations where chronic food shortage prevails (Amare Getahun, 1974; Guinand & Dechassa Lemessa, 2000; Kebu Balemie & Fassil Kebebew, 2006). The agropastoralists of both ethnic groups reported that shortage of food is the major problem in the area, and that the consumption of wild food plants ranked second as a coping mechanism for surviving during famine (Table 3). Famine occurs in the area because of recurrent drought; thus, most of the annual food plants die off, while only perennial plants survive. Since most non-cultivated plants are perennial, they form the most important diet for starving people in the area.

Income-generating role of wild edible trees and shrubs

In addition to their use for household consumption, the identified wild edible trees and shrubs are marketable, and provide an opportunity to supplement household incomes in the study area. According to Kebu Balemie & Fassil Kebebew (2006), income derived

Table 3. Respondents' ranking of disaster-coping mechanisms (n = 60)

Disaster-coping mechanism	***Kebele* (Site)**							**Rank**
	Luka	**Shalla Kyayo**	**Alduba**	**Shaba**	**Olika Kibo**	**Kako**	**Total**	
Sale of small ruminants (goats & sheep) to purchase grain	4	2	3	4	3	2	18	**1**
Consumption of wild edible plants	3	4	2	1	1	2	13	**2**
Slaughtering small ruminants for meat	1	2	2	1	2	1	9	**3**
Collection and sale of firewood and charcoal	0	0	1	2	1	3	7	**4**
Migration to other areas to look for water and grass for animals	1	1	1	1	1	0	5	**5**
Begging food from relatives and friends	0	0	1	1	1	1	4	**6**
Collection and sale of incense	1	1	0	0	0	0	2	**7**
Slaughtering male cattle for consumption	0	0	0	0	1	0	1	**8**
Migration to other areas to look for employment as day-labourers	0	0	0	0	0	1	1	**8**
Total	**10**	**10**	**10**	**10**	**10**	**10**	**60**	

N.B. Each respondent was asked to mention only one of the most important coping mechanisms the household exercises from the sale of wild plant is of particular importance to the poorer households, which must supplement food production with cash in order to meet their basic needs. This was truly observed in the study area, where some of the wild edible plants were sold in the local market to support household incomes (Table 4). A study conducted in Tanzania (Ruffo *et al.*, 2002) and other parts of Ethiopia (Getachew Addis *et al.*, 2005) also revealed that the sale of wild food plants supplements low farm returns, and contributes additional income to households.

Table 4. *List of marketable, wild edible trees and shrubs*

Scientific name	No. of respondents	Rank
Menya tetraphylla (Schweinf. ex Hiern) Robyns	26	1
Balanites rotundifolia (Van Tilghem) Blatter	19	2
Opuntia ficus-indica (L.) Miller	8	3
Sclerocarya birrea (A. Rich.) Hochst	7	4

Density of wild edible trees and shrubs

The density of wild edible trees and shrubs in the study area varied from site to site. In the mid-altitude woodlands of Alduba *kebele*, the density of edible trees and shrubs was 312 stems ha^{-1}, whereas it was only 25 stems ha^{-1} in the lowlands of Shalla *kebele* (Table 5). The density of wild edible trees and shrubs increased with altitude, as did that of the other trees and shrubs.

Production potential of wild edible trees and shrubs

The total harvestable yield per hectare of edible materials varied from site to site, with values ranging between 85–382 kg ha^{-1} (Table 5). The yield of edible materials also varied with the type and age of the species. According to respondents, the quantity of harvestable material per tree is generally small. For instance, the species *Crateva adansonii* DC. does not produce more than seven fruits (1.5 kg) per production cycle, and *Salvadora persica* L. also does not produce more than 3 kg per production cycle. According to the community, this low production potential is the major limitation of some wild edible trees and shrubs, as has also been reported elsewhere (Guinand & Dechassa Lemessa, 2000). It is, therefore, advisable to initiate selection and breeding programmes for such species, to increase production. The harvestable yield increased with altitude. This is attributed to the high density of edible trees and shrubs, which increases with altitude, resulting in a higher yield of harvestable material per unit area of land, as was also reported by Becker (1983).

Table 5. *Density and estimated yield of wild, edible trees and shrubs*

Kebele	Altitude (m a.s.l.)	Total no. of trees and shrubs/plot	No. of edible trees and shrubs/plot	Density of edible trees and shrubs ha^{-1}	Total prod/ha (kg)
Shalla	500	45	16	25	85.00
Luka	600	89	43	67	155.00
Alduba	1250	130	50	312	173.00
Shaba	1400	171	28	175	219.18
Olka kibo	1500	183	45	281	381.79
Kako	1300	165	29	181	193.03

Utilisation practices of wild edible trees and shrubs by the Benna and Tsemay community

Of the collected wild edible trees and shrubs, trees comprised 18 species (60%), and the remaining 12 species (40%) were shrubs. This result as regards growth form is in agreement with the ethnobotanical study of wild edible plants in Kara and Kwego (Tilahun Teklehaimanot & Mirutse Giday, 2010), but disagrees with the report from Derashe and Kucha District (Kebu Balemie & Fassil Kebebew, 2006), which revealed that wild edible materials are largely collected from shrubs. These differences could be attributed to the composition of the dominant species in the respective localities. The proportional abundance of wild edible trees and shrubs in the landuse system was, in decreasing order, open woodland (40%), dense woodland (33%) and cultivated land (17%) (Appendix 4). In some cases, these plants are semi-domesticated, because the local people manage them in ways that ensure their conservation and regular availability, even occasionally cultivating them.

The parts of wild edible trees and shrubs consumed include fruit, seed and leaf. Fruits are the dominant edible parts (80%) consumed by both ethnic groups (Table 2; Appendix 4). The dominance of fruits as edible parts has also been reported in most previous studies undertaken in Ethiopia (see Zemede Asfaw & Mesfin Tadesse, 2005; Getachew Addis *et al*., 2005; Kebu Balemie & Fassil Kebebew, 2006; Tilahun Teklehaymanot & Mirutse Giday, 2010). Contrary to this finding, Mohammed Ali *et al*. (2008) reported that leaves and stems are the most widely used parts of wild edible trees and shrubs in the West Bank of Palestine. This difference might be due to variation in the available species, and culture of the communities with respect to food preference and preparation.

As regards the mode of consumption, 23 species (76.7%) are consumed raw or without further processing, five species (16.7%) are consumed cooked or roasted and two species (6.7%) are consumed either fresh or cooked (Appendix 4). This result is in agreement with the findings of previous studies conducted in Southern Ethiopia (Guinand & Dechassa Lemessa, 2000; Kebu Balemie & Fassil Kebebew, 2006). Most of the wild edible trees and shrubs that require further processing are consumed as emergency food, at a time of chronic food shortage. On the other hand, the respondents indicated that some of these edible plants are poisonous if consumed raw. One such example is the edible fruit of *Boscia angustifolia* A. Rich., which must be cooked for a long time, because it is poisonous if eaten raw (Appendix 4).

Traditional management practices and threats to wild edible trees and shrubs

The woodlands and their resources are the common property of the community in the study area. However, there are certain restrictions on their use, which is controlled by the council of elders. For instance, the cutting for firewood of big trees, as well as edible and medicinal trees and shrubs, is forbidden. On the other hand, the keeping of individual beehive-hanging trees, which pass from father to son, is a common tradition and management practice of both ethnic groups (Table 6).

The Tsemay ethnic group protect their resources against the collection of edible materials by other tribes. They collect these wild edible materials first from communal land, then from their farmland. This is because there are few alternative ways of obtaining food in the area, owing to the harsh climate. This result is consistent with the finding of Wubalem Tadesse *et al*. (2007), who reported that the

Table 6. *Traditional management practices for wild edible plants*

Traditional management	Number of respondents	
	Benna (n = 40)	Tsemay (n = 20)
Retain trees and shrubs when opening up new farmland	16	4
Prevent the use of trees and shrubs by other tribes	0	6
Collect from communal land before farmland	0	3
No cutting of wild edible and medicinal trees	24	5
Clearing the ground under the canopy to facilitate collection of fallen fruits	0	2

development of non-timber forest products (NTFPs) is a key to the sustained management and development of drylands which, owing to their harsh climate, have few alternative means of livelihood.

Wild edible trees and shrubs in the study area face some challenges that threaten their existence. According to the respondents, the expansion of agriculture is the major threat, followed by the fire hazard (Table 7). Over time, the community is changing from a pastoral, to an agropastoral way of life. The major form of agriculture practised by the community is shifting cultivation, which requires the clearing of natural vegetation to open up new farmland. Also, agropastoralists set fire to the woodlands to create fresh grazing and to eliminate parasites and pests. These practices adversely affect wild edible trees and shrubs, leading to a reduced food supply. The challenges facing wild edible plants have also been reported in previous studies (Guinand & Dechassa Lemessa, 2000; Tigist Wondimu *et al*., 2006). Hence, strategies should be designed to protect and domesticate these plants for future use.

Conclusions

The Benna Tsemay community of Southern Ethiopia faces chronic food shortages because of the harsh environment of the area. These food shortages are partly compensated for by the collection of wild edible materials from communal woodlands, and farms. Little is known about these wild edible trees and shrubs, their nutritional value, their production level, the possibility of storage or possible long-term side effects, such as toxicity.

The analysis of household interviews showed that wild edible materials collected

Table 7. *Threats to wild edible and medicinal trees and shrubs*

Threats	No. of respondents		Respondents (%)	Rank
	Benna	Tsemay		
Expansion of agriculture	12	3	25.0	1
Fire hazards	7	6	21.7	2
Overgrazing	7	4	18.3	3
Construction of new road	6	2	13.3	4
Drought	2	5	11.7	5
Collection of firewood and construction materials	6	-	10.0	6
Total	40	20	100	

from trees and shrubs make a major contribution to the dietary intake of the community, either in times of seasonal food shortage, to fill a gap and supplement staple food in normal times, and for use as emergency food during famine. In addition to the household food supply, edible parts are collected from some species of trees and shrubs, and sold in the local market to generate income. In general, these results indicate that wild edible trees and shrubs should be given due consideration when strategies are developed to fight food insecurity and to improve rural livelihood. The following suggestions and recommendations are presented for the better utilisation and conservation of wild edible trees and shrubs in the study area:

- Promote wild edible plants as valuable resources to improve household food security, nutrition and income, especially for households living in the study area or other dry or marginal areas.

- Incorporate wild food plants in agricultural development programmes, placing special emphasis on their nutritional value and production potential.

- More research should be carried out on the nutritional value of wild edible plants.

- Propagation and domestication of wild food plants should be started through the efforts of governmental and non-governmental organisations.

- *In-situ* conservation of edible trees and shrubs should be enhanced through the participation of the local community.

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***Appendix* 1.** Rank of edible trees and shrubs having a supplementary role in household food security

Scientific name	Ethnic group		Proportion (%)	Rank
	Benna (*n* = 40)	Tsemay (*n* = 20)		
Balanites rotundifolia (Van Tilghem) Blatter	4	8	20.0	1
Meyna teterphylla (Schweinf. ex Hiern) Robyns	8	3	18.3	2
Canthium pseudosetiflorum Bridson	5	1	10.0	3
Sclerocarya birrea (A. Rich.) Hochst	4	2	10.0	3
Rhus quartiniana A. Rich.	4	-	6.7	4
Tamarindus indica L.	3	1	6.7	4
Ziziphus mucronata Willd.	3	-	5.0	5
Salvadora persica L.	1	2	5.0	5
Crateva adansonii DC.	2	-	3.3	6
Grewia villosa Willd.	1	1	3.3	6
Ximenia americana L.	1	1	3.3	6
Grewia tenax (Forssk.) Fiori	1	1	3.3	6
Opuntia ficus-indica (L.) Miller	1	-	1.7	7
Psydrax schimperiana (A. Rich.) Bridson	1	-	1.7	7
Carsia spinarum L.	1	-	1.7	7

***Appendix* 2.** Major trees and shrubs having a seasonal role in household food security

Scientific name	Benna (*n* = 40)		Tsemay (*n* = 20)	
	No. of respondents	Proportion (%)	No. of respondents	Proportion (%)
Cleome monophylla L.	21	52.5	-	-
Securidaca longepedunculata Fresen	14	35.0	-	-
Balanites aegyptiaca (L.) Del.	5	12.5	20	100

Appendix 3. Rank of trees and shrubs used in emergency in the study area

Scientific name	No. of respondents		Total	Rank
	Benna (*n* = 40)	Tsemay (*n* = 20)		
Flacourtia indica (Burm.f.) Merr.	6	6	12	**1**
Ficus vasta Forssk.	5	1	6	**2**
Ficus sur Forssk.	6	0	6	**2**
Euclea divinorum Hiern.	1	4	5	**3**
Piliostigma thonningii (Schum.) Milne-Redh.	2	3	5	**3**
Diospyros mespiliformis Hochst. ex A. DC.	4	1	5	**3**
Grewia velutina (Forssk.) Vahl.	5	0	5	**3**
Senna singueana (Del.) Lock	5	0	5	**3**
Leucas glabrata (Vahl) Sm in Rees.	2	2	4	**4**
Borassus aethiopum Mart.	3	0	3	**5**
Boscia angustifolia A. Rich.	0	2	2	**6**
Lannea schimperi (Hochst. ex A. Rich.)	1	1	2	**6**

***Appendix* 4.** Utilisation practices of wild edible trees and shrubs

Scientific name	Growth form	Parts used	Utilisation practices	Habitat	Other uses
Balanites aegyptiaca (L.) Del.	tree	fruit and leaf	The ripe fruits are collected and the pulp eaten; the seeds are discarded. The newly grown leaves are also collected and cooked then consumed with other food, like vegetables	Open woodland	Shade
Balanites rotundifolia (Van Tilghem) Blatter	tree	fruit	The ripe fruits are collected either from the ground or picked from the tree and the pulps of the fruits eaten and the seed dried and stored. The dry seeds are cooked and mixed with cooked maize seed and consumed, or the fruit is cooked and used as juice. The seed is sold at local markets	Open woodland	Shade
Borassus aethiopum Mart.	tree	fruit	The fruit is collected from the ground or tree; the flour is consumed	Dense woodland	Construction
Boscia angustifolia A. Rich.	shrub	seed	The seeds are collected and cooked for a long time, then eaten	Farmland	Shade
Canthium pseudosentiflorum Bridson	shrub	fruit	Ripe red fruit are collected from the shrub and eaten raw. The fruits are very sweet, people collect in competition with wild animals	Dense woodland	Bee forage
Carissa spinarum L.	shrub	fruit	The fruits are collected directly and the pulp eaten fresh	Dense woodland	Medicine
Cleome monophylla L.	tree	leaf	The small leaves are collected and cooked and consumed like cabbage together with other food	Farmland	Bee forage
Crateva adansonii DC.	shrub	fruit	The ripe fruits are collected and consumed raw	Open woodland	Shade
Diospyros mespilifomis Hochst. ex A. DC.	shrub	fruit	The fruits are collected and eaten raw	Open woodland	Shade
Euclea divinorum Hiern.	shrub	fruit	The ripe fruit is collected and consumed raw	Open woodland	Medicine
Ficus sur Forssk.	tree	fruit	Ripe fruits are collected either from the tree or the ground, dried and ground and the flour is consumed in various dishes	Open woodland	Bee forage
Ficus vasta Forssk.	tree	fruit	The ripe fruits are collected from the ground or tree and consumed raw or the flour of the seeds is cooked and consumed	Open woodland	Bee forage

Appendix **4.** *continued*

Scientific name	Growth form	Parts used	Utilisation practices	Ecological niches	Other uses
Flacourtia indica (Burm.f.) Merr.	tree	fruit	Ripe fruit are collected from the tree and eaten raw	Dense woodland	Bee forage
Grewia tenax (Forssk.) Fiori	tree	fruit	The red ripe fruits are collected and eaten fresh. It is very sweet, but unripe fruit creates stomach dryness	Shrubland	Fodder
Grewia velutina (Forssk.) Vahl.	tree	fruit	The ripe reddish brown fruit are collected and the pulp is eaten raw	Dense woodland	Bee forage
Grewia villosa Willd.	tree	seed	The dry pod is collected, the pod is removed and the seed consumed raw	Dense woodland	Bee forage
Lannea schimperi (Hochst. ex A. Rich.)	tree	fruit	The ripe red fruits are collected from the tree and consumed directly fresh	Farmland	Construction
Lecus glabrata (Vahl) Sm in Rees.	shrub	fruit	Ripe fruits are collected and eaten raw	Open woodland	Firewood
Meyna tetraphylla (Schweinf. ex Hiern) Robyns	shrub	fruit	Fruits are collected from the shrub and the pulps consumed. The fruits are also marketable	Farmland	Firewood
Opuntia ficus-indica (L.) Miller	shrub	fruit	The yellow fruits are collected and consumed raw by removing the pulp	Farmland	Fence
Piliostigma thonningii (Schum.) Milne-Redh.	tree	seed	The brown pod is collected, the pod is removed and the seed consumed raw	Open woodland	Shade
Psydrax schimperiana (A. Rich.) Bridson	tree	fruit	The ripe black fruits are collected directly from the tree and consumed raw	Dense woodland	Firewood
Rhus quartiniana A. Rich.	shrub	seed	The seeds are eaten raw after removing the pulp	Open woodland	Bee forage
Salvadora persica L.	shrub	fruit	Ripe red fruit are collected by hand squeezed in water and drunk as juice	Shrubland	Medicine
Sclerocarya birrea (A. Rich.) Hochst	tree	fruit	The yellow ripe fruit are collected and consumed raw	Dense woodland	For hanging beehives
Securidaca longepedunculata Fresen	tree	leaf	Leaves are cooked and eaten together with any food.	Dense woodland	For hanging beehives
Senna singueana (Del.) Lock	shrub	fruit	Ripe red fruits are collected and eaten fresh	Open woodland	Fodder
Tamarindus indica L.	tree	fruit	Ripe dark brown pods are collected from the tree and the pulp is consumed. The pulp is also squeezed in water and drunk as juice	Open woodland	Medicine
Ximenia americana L.	shrub	fruit	The ripe fruits are collected and consumed raw	Shrubland	Medicine
Ziziphus mucronata Willd.	tree	fruit	Ripe fruits are collected from the tree and consumed raw	Open woodland	Fodder

Nutrient composition and effect of processing on antinutritional factors and mineral bioavailability of cultivated *amochi* in Ethiopia

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Abstract

Andargachew Gedebo, Admasu Tsegaye, Girma Akalu, Bjørnstad Å. & Appelgren M. 2011. Nutrient composition and effect of processing on antinutritional factors and mineral bioavailability of cultivated *amochi* in Ethiopia. *Journal of Science and Development* 1(1) 2011, 21-29. ISSN 2222-5722.

Amochi (*Arisaema schimperianum* Schott) is an important off-season tuber crop in Southern Ethiopia. Uncooked *amochi* is irritating in contact with the skin. Proximate contents, antinutritional factors (oxalate and phytate) and effects of processing (cooking and fermentation) on antinutritional factors and mineral availability were determined for *amochi* cultivars using established methods of the AOAC. The ranges of proximate contents from five cultivars were: moisture 65.25–85.37%, fat 0.10–0.15%, protein 0.56–1.13%, crude fibre 0.59–0.70%, ash 0.88–1.03%, carbohydrate 12.60–33.16% and caloric value 52.70–133.56 kcal/100 g dry matter per wet tuber mass. The differences between cultivars were significant ($p < 0.05$), although the overall levels of fat and protein were low. The carbohydrate and caloric values indicated that *amochi* could be a valuable food crop if supplemented with animal or plant protein. For antinutrient determination, four cultivars were analysed as raw, cooked and cooked after five days' fermentation. *Amochi* tubers had high oxalate levels and low phytate levels. Cooking resulted in reduction of oxalate and phytate levels. Further significant reduction occurred when the tubers were cooked after fermentation. These reductions were coupled with an increase in the levels of Fe, Zn and Ca. Cultivars differed significantly in their levels of phytate but not of oxalate. High levels of oxalate might have been the cause of skin irritation. *Amochi* meal preparation should follow extended fermentation and cooking. Effects of different heat and fermentation processes, and environmental factors such as season, soil and water conditions on *amochi* oxalate levels should be determined.

Keywords: *Arisaema schimperianum,* cooking; fermentation; oxalate; phytate; proximate analysis

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Introduction

Root and tuber crops are dominant staple foods in Southern Ethiopia. *Arisaema schimperianum* Schott, locally '*amochi*' or '*kolto*' in S. Ethiopia, is an herbaceous plant grown for its edible tubers. Because of the frequent occurrence of drought in the region, much attention has been paid to high yielding drought-tolerant crops such as enset (*Ensete ventricosum*), and recently also to new tuber crops such as *amochi*.

Amochi grows in various habitats, along roadsides, farm edges, in forests and on agricultural lands. It was long considered as a weed. Whenever there is a food shortage, *amochi* is harvested from all such habitats and consumed as food. While the larger tubers are harvested, small offsets remain in the soil and serve as propagules in subsequent seasons (Gedebo *et al*., 2007). *Amochi* currently is one of the most important root crops in some of the villages of Dita and Chencha, administrative sub-zones of S. Ethiopia. The plant grows during the off-season, January–June, and is harvested between June and September. In these months, *amochi* is a common component of the villagers' diet (Gedebo *et al*., 2006).

Preparation of *amochi* comprises washing and crushing of tubers between millstones. Following crushing, it can be cooked as various local dishes, immediately or after a period of fermentation under anaerobic conditions, usually buried underground. *Amochi* is irritating in contact with the skin, making food preparation very difficult (Gedebo *et al*., 2006). The irritation may be due to the presence of antinutritional factors in the edible portion. The term 'antinutritional factors' usually refers to natural products, such as oxalate and phytate, which reduce nutrient utilization, food intake or both (Sefa-Dedeh & Agyir-Sackey, 2004). A high content of calcium oxalate crystals has been implicated in the irritation caused by coco-yam (Sefa-Dedeh & Agyir-Sackey, 2004). Oxalate usually tends to precipitate calcium as calcium oxalate crystals, and makes it unavailable for use by the body (Oke, 1967). Phytate is a storage form of phosphorus, found in some plant seeds and in many roots and tubers (Dipak & Mukherjee, 1986). There are reports that phytic acid has the potential to bind Ca, Zn, Fe and other minerals, thereby reducing their availability in the body (Sefa-Dedeh & Agyir-Sackey, 2004; Davis & Olpin, 1979). In many crops it has been found that cooking and fermentation reduce the level of such anti-nutritional factors (Sefa-Dedeh & Agyir-Sackey, 2004; Oke, 1967).

One of the bases for food quality is the balance between the nutrient and antinutrient composition. Since *amochi* is not yet widely known as a food crop, except in S. Ethiopia during the past two decades (Gedebo *et al*., 2007), information on its nutritional properties has not yet been included in the food composition table for use in Ethiopia (Gobezie *et al*., 1997). To our knowledge, there are no reports on the nutrient composition of cultivated *amochi*. The purpose of the present study was therefore to determine: (1) proximate composition, (2) antinutritional factors, (3) the effect of processing on antinutritional factors and mineral bioavailability of *amochi* cultivars, and (4) the causes of irritation by *amochi*.

Materials and Methods

General sample preparation

Fresh tuberous roots of five *amochi* cultivars considered important by the farming community of Mesho (6°15.231'N lat., 37°34.401'E long.) and Dalbansa (6°11.348' N lat., 37°29.484' E long.) villages, owing to their yield ability and general adaptability (Gedebo et al., 2007) were harvested from the agricultural research station of Chencha. From each cultivar, 20 plants were randomly harvested. The cultivars were referred to by their local name; '*Maze*', '*Dashare*', '*Oge*', '*Kalazo*' and '*Bondare*'. After harvesting, the tubers were washed in tap-water to remove all soil, dried in air to remove external moisture, and weighed. The tubers were then placed in polyethylene bags and transported in an ice-box to the laboratory in Addis Ababa (Ethiopian Health and Nutrition Research Laboratory, EHNRL) within 24 h of harvesting. In the EHNRL laboratory, the samples were kept at –20 °C until analysed.

Proximate analysis

Before analysis, the samples were thawed for 5 h at room temperature and shredded in a food processor. The proximate composition of protein, crude fibre, crude fat, ash and moisture content of the edible portions of the five duplicate *amochi* samples was determined according to the methods of the Association of Official Analytical Chemists (AOAC, 1990). The moisture content was determined from 10-g samples of shredded material by drying to constant mass at 92 °C; the crude protein content was determined by the micro-Kjeldahl method (%protein = %N×6.25). The crude fat content was determined using diethyl ether in a Soxhlet extraction apparatus, and the crude fibre content by dilute acid and alkali hydrolysis. The carbohydrate content was estimated by difference.

The energy value was calculated using Atwater factors (values for crude protein, fat and carbohydrates were multiplied by 4, 9 and 4, respectively, and the results summed).

Processing for antinutritional factor determination

For the determination of antinutritional factors, tubers of four cultivars *Maze*, *Dashare*, *Oge* and *Kalazo* were considered (material of *Bonde* was insufficient). The tubers were thawed at room temperature for 5 h. After diseased and non-edible parts had been removed, all samples were shredded in a food processor. The blend was then divided into three portions in preparation for three processing levels: 'unfermented and uncooked', 'unfermented and cooked', and 'fermented and cooked'.

Unfermented and uncooked: After storage at –20 °C for five days, the blends were thawed for 5 h at room temperature and analysed.

Unfermented and cooked: After storage at –20 °C for five days, the blends were thawed for 5 h at room temperature, cooked, then analysed.

Fermented and cooked: The blend was set to ferment for five days, cooked, then analysed.

Fermentation

Fermentation was carried out by imitating the traditional process used for *amochi* by the farming community of Mesho village, in the Chencha administrative sub-zone of S. Ethiopia. Freshly blended samples were kept in a sieve for 5 h, to allow leaching of free liquid from the blend. Traditionally, this is done in a porous bamboo container. The liquid was discarded and the semi-solid residue was placed in a bowl, wrapped in enset leaves. The bowl was covered with a cotton towel and closed with a lid. The traditional method is to make a hole in the ground, into which the blended *amochi* is placed, wrapped in enset leaves and made air-tight with layers of stone on top. The bowl containing the sample was kept at room temperature for five days. In traditional practice, the duration varies from two days to several months, depending on food availability (Gedebo *et al*., 2007).

Cooking

The cooking process also imitated the *amochi* cooking procedures of the farming community of Mesho village. Well-known traditional dishes of *amochi* are bread and porridge (Gedebo *et al*., 2007). In the present experiment, bread only was considered; therefore, 'cooking' refers to baking bread. The dough was laid flat between enset leaves on an *injera*-making (*injera*: Ethiopian flat bread made from *teff* — *Eragrostis tef*) electric hotplate, preheated for 15 min to bring it to working temperature. The dough was baked for 36 min; it was turned every 12 min during the first 24 min, and every 6 min during the last 12 min. After 36 min the bread was removed from the baking plate and cooled for 1 h on a flat plate made of straw, and kept in a refrigerator at 4 °C until analysed.

Determination of phytate and oxalate

For phytate determination, the method described by Haug and Lantzsch (Haug & Lantzsch, 1983) was applied to 0.5 g of dried, ground sample. The analysis was performed in duplicate. The oxalate in *amochi* tubers was separated into two fractions: 2 g of finely ground sample was extracted with 100 ml of boiling, deionised water for 30 min., filtered and adjusted to 200 ml. The residue of the hot water extract was further extracted with 150 ml boiling 1*N* HCl for 30 min., adjusted to 200 ml, and filtered. The oxalate concentration in the two fractions was determined as outlined in AOAC (1990) by $KMnO_4$ titration. The analysis was done in duplicate, and the results calculated and expressed on a dry-mass basis.

Determination of minerals

Duplicate aliquots (500 mg) from each of the dried, powdered samples were weighed, then wet-ashed by refluxing overnight at 150 °C with 15 ml of concentrated HNO_3 and 2.0 ml of 70% $HClO_4$. The samples were dried at 120 °C and the residue was dissolved in 10 ml of 4.0*N* HNO3 – 1% $HClO_4$. The mineral content of each sample was determined by means of an automated atomic absorption spectrophotometer (Pye Unicam Model SP 191, Cambridge), as outlined in AOAC (1990), for the specific minerals Fe, Zn and Ca. The mineral contents of the samples were quantified against standard solutions of known concentration, which were analysed simultaneously.

Statistical analysis

The sample analyses for all components were carried out in duplicate and the means and the standard deviations were calculated. One-way Analysis of Variance (ANOVA) was carried out by Tukey's method, to compare the mean values from proximate components of cultivars. For two-way ANOVA (cultivar *vs*. process), the General Linear Model (GLM) procedure with Tukey's method of multiple comparison was used. The analysis was done using MINITAB release 14.

Results and discussion

The proximate content ranges obtained for the five *amochi* cultivars were: moisture 65.25–85.37%, fat 0.10–0.15%, protein 0.56–1.13%, crude fibre 0.59–0.70%, ash 0.88–1.03%, carbohydrate 12.60–33.16% and caloric value 52.70–133.56 kcal/100g dry matter (Table 1).

In the light of the high moisture content found, *amochi* cultivars have substantial levels of carbohydrates, and caloric value showed significant differences ($P<0.05$) between them (Table 1). A daily energy requirement of 2500–3000 kcal has been reported for adults (Bingham, 1978). To obtain from any of these cultivars an energy value of 2750 kcal per day, which is within the range reported by Bingham (Bingham, 1978), an adult would need to consume 2059 g of cultivar *Maze*, 2217 g of cultivar *Dashare*, 3032 g of cultivar *Oge*, 2261 g of cultivar *Kalazo* and 5218 g of cultivar *Bondare*. An intake of up to 1000 g day^{-1} would provide 1335, 1240, 906, 1216 and 520 kcal from cultivars *Maze*, *Dashare*, *Oge*, *Kalazo* and *Bondare*, respectively. From these values, it is evident that, with the exception of *Bondare*, the cultivars would meet the FAO (1973) recommended range of 800–1200 kcal, if they were consumed at 1000 g day^{-1}.

There were significant differences ($p<0.05$) in protein and fat contents among the five *amochi* cultivars. However, the difference may not be of practical importance, as the general level of protein and fat in the cultivars is very low (Table 1). The low level of plant proteins found in all of the analysed cultivars does not justify the use of *amochi* as a sole protein source in diets. The low protein levels in *amochi* would require dietary supplementation with animal protein, or complementary proteins from cereals and legumes, especially in diets intended for children and pregnant women.

The level of phytate under the three cooking processes of the *amochi* cultivars is shown in Table 2 (overleaf).

Unfermented and uncooked (raw) samples had the highest levels of phytate (24.76 mg/100g). Cooking brought about a significant ($P<0.05$) decrease in phytic acid content, compared to the uncooked control (Table 2). Similarly, cooking has been reported to decrease phytic acid content in peas (Bishnoi *et al.*, 1994) and pearl millet (Sharma & Kapoor, 1996). Since phytic acid is known to be heat-resistant, the reduction of the phytic acid level

Table 1. *Proximate nutrient composition of cultivated amochi cultivars from Chencha administrative sub-zone of S. Ethiopia*

Vernacular name	Moisture (%)	Fat (%)	Protein (%)	Crude fibre (%)	Ash (%)	Carbohydrate (%)	Caloric value (Kcal/100 g)
Maze	65.25±0.03^{e}	0.12±0.00^{ab}	0.56±0.00^{e}	0.6±0.01^{b}	0.91±0.02^{c}	33.16±0.02^{a}	133.56±0.02^{a}
Dashare	67.59±0.06^{d}	0.14±0.00^{ab}	0.88±0.00^{c}	0.7±0.02^{a}	0.88±0.01^{c}	30.51±0.01^{b}	124.02±0.02^{b}
Oge	75.82±0.07^{b}	0.13±0.00^{ab}	1.13±0.01^{a}	0.64±0.00^{b}	1.03±0.01^{a}	21.89±0.01^{d}	90.69±0.00^{d}
Kalazo	68.11±0.02^{c}	0.15±0.01^{a}	0.81±0.02^{d}	0.65±0.00^{b}	1.02±0.00^{a}	29.91±0.02^{c}	121.63±0.02^{c}
Bondare	85.37±0.14^{a}	0.1±0.01^{bc}	0.94±0.01^{b}	0.59±0.00^{b}	0.99±0.01^{b}	12.6±0.01^{e}	52.7±0.07^{e}

Note: Each value in the table is the mean of two determinations ± SD. Caloric values were determined on a dry-mass basis. Means not followed by the same letters in the same column were significantly different ($P<0.05$).

Table 2. *The phytate content (mg/100 g dry basis) of cultivated amochi cultivars from Chencha administrative sub-zone of S. Ethiopia, under different cooking processes*

Cooking process	Amochi cultivar				Cooking process mean
	Maze	Dashare	Oge	Kalazo	
Unfermented, uncooked	17.81±0.01	19.70±0.01	29.51±0.02	32.01±0.01	**24.76^{a}**
Unfermented, cooked	15.50±0.00	19.01±0.01	28.21±0.01	30.00±0.01	**23.18^{b}**
Fermented , cooked	8.81±0.02	10.00±0.01	22.71±0.02	24.61±0.01	**16.53^{c}**
Cultivar mean	**14.04^{d}**	**16.24^{c}**	**26.81^{b}**	**28.87^{a}**	

Note: Values in the body of the table are means of two determinations ± SD. Process means with the same letters were not significantly different (p >0.05). Cultivar means with the same letters were not significantly different (p >0.05).

in the cooked samples may not be due to destruction of the compound, but may rather be due to its ability to complex with protein and minerals (Bishnoi *et al*., 1994). The phytate reduction may, therefore, only be apparent. The further reduction of the phytic acid content after cooking was significant (P<0.05) in samples given five days' natural fermentation. Fermented and cooked samples had a 33% reduction of the phytic acid content. Such an effect of fermentation has been reported for food mixtures (Sharma & Kapoor, 1996). The reduction in phytic acid content may have partly been due to phytase activity, which is known to be affected by a wide range of microflora (Sharma & Kapoor, 1996) in the fermentation process.

The complexing of phytic acid with nutritionally essential minerals such as Ca, Fe and Zn, has been suggested to be responsible for its antinutritional activity (Davis & Olpin, 1979; Sindhu & Khetarpaul, 2003). In the present study, the reduction in the levels of phytic acid with cooking, and more evidently with cooking after fermentation, appeared to be coupled with the increase in the levels of Fe, Zn and Ca (Table 3, opposite). The increase in the levels of the minerals could be due to their release from complexes with phytic acid. However, the levels of phytate found in the edible portions of *amochi* are much lower than the phytate content of many nutritionally important food crops (Phillippy *et al*., 2004; Dintzis *et al*., 1992). The nutritional significance of phytate levels in *amochi* is, therefore, negligible.

The level of oxalate found in the *amochi* cultivars (23.42 g/100 g dry mass, Table 4) is much higher than that reported for most crop species. For example, Jiru and Urga (Jiru & Urga, 1995) reported the total oxalate content of some vegetables in Ethiopia: beetroot, cabbage, carrot, kale, lettuce, potato, sweet potato, spinach, and Swiss chard, where spinach had the highest value (9793.7 mg/100 g dry mass). Kansal and Pahwa (Kelsay & Pratter, 1983) also reported that spinach contained a very high amount of oxalate (11 g/ 100 g). *Amochi* appears to be the crop with the highest content of oxalate so far known.

The observed high levels of oxalate in *amochi* cultivars might have both nutritional and health significance. This is because oxalic acid usually forms a strong bond with various minerals, such as Na, K, Mg and Ca, resulting in oxalate salts (Jiru & Urga, 1995). Because of this, some vegetables, even if they are rich in Ca, are not so nutritionally, owing to high levels of oxalates. For example, the high levels of Ca in spinach were shown to be unavailable for absorption, owing to the

Table 3. *Mineral composition of cultivated amochi cultivars from Chencha administrative sub-zone of S. Ethiopia, under different cooking processes*

Mineral mg/100g	Cooking process	Amochi cultivar				Process mean
		Maze	Dashare	Oge	Kalazo	
Fe	Unfermented, uncooked	2.88±0.00	4.48±0.01	2.40±0.01	4.14±0.01	**3.48[b]**
	Unfermented, cooked	3.98±0.01	9.78±0.00	3.87±0.01	5.42±0.01	**5.76[a]**
	Fermented, cooked	4.97±1.41	9.96±0.26	5.40±2.14	5.68±0.35	**6.57[a]**
	Cultivar mean	**3.94[b]**	**8.07[a]**	**3.89[b]**	**5.08[b]**	
Zn	Unfermented, uncooked	2.13±0.01	2.55±0.01	3.04±0.01	1.47±0.01	**2.30[b]**
	Unfermented, cooked	2.53±0.01	3.13±0.01	3.13±0.00	3.87±0.01	**2.89[ab]**
	Fermented, cooked	2.88±0.01	2.87±0.01	5.67±0.01	2.08±0.00	**3.37[a]**
	Cultivar mean	**2.51[b]**	**2.83[b]**	**4.19[a]**	**1.86[b]**	
Ca	Unfermented, uncooked	43.04±0.01	72.32±0.01	46.38±0.02	42.77±0.01	**51.12[b]**
	Unfermented, cooked	59.75±0.03	81.27±0.02	61.95±0.01	59.07±0.01	**65.51[a]**
	Fermented, cooked	57.72±0.01	90.46±0.01	74.11±0.02	58.63±0.01	**70.23[a]**
	Cultivar mean	**53.50[c]**	**81.35[a]**	**60.81[b]**	**53.49[c]**	

Note: Values in the body of the table are means of two determinations ± SD. For each mineral, process means with the same letters were not significantly different (p >0.05). For each mineral, cultivar means with the same letters were not significantly different (p >0.05).

Table 4. *The oxalate content (g/100 g dry basis) of cultivated amochi cultivars from Chencha administrative sub-zone of S. Ethiopia, under different cooking processes*

Cooking process	Amochi cultivar				Cooking process mean
	Maze	Dashare	Oge	Kalazo	
Unfermented, uncooked	24.27±0.00	23.09±0.00	23.98±0.00	22.35±0.00	**23.42[a]**
Unfermented, cooked	15.12.±0.70	13.17±0.71	11.49±0.71	13.02±0.71	**13.20[b]**
Fermented, cooked	4.56.±0.00	7.20±0.00	5.96±0.00	10.07±0.00	**6.95[c]**
Cultivar mean	**14.65[a]**	**14.48[a]**	**13.81[a]**	**15.15[a]**	

Note: Each value in the table is the mean of two determinations ± SD. Process means with the same letters were not significantly different (p >0.05). Similarly, cultivar means with the same letters were not significantly different (p >0.05).

formation of calcium oxalate (Jiru & Urga, 1995; Weaver *et al*., 1987). The presence of spinach in a meal could reduce the availability of Ca even from other foodstuffs consumed during the same meal (Kelsay & Pratter, 1983).

Calcium oxalate is particularly water-insoluble and has a tendency to precipitate (or solidify) in the kidneys or in the urinary tract, to form calcium oxalate crystals. Coe et al. (1992) reported that 80% of all kidney stones were composed of calcium oxalate, alone or surrounding a calcium phosphate core. Thus, attempts to prevent calcium stones have focused on reducing calcium and oxalate urinary concentrations, by reducing the rate of urinary excretion of both calcium and oxalate, as well as by increasing urine volume (Coe et al., 1992).

Cooking resulted in a significant reduction (P<0.05) in oxalate content (Table 4). Such reduction of oxalate through cooking has also been reported for African yam bean (Onyeike & Omubo-Dede, 2002) and cocoyam (Akban & Umoh, 2004; Fasset, 1973; Vilyakon & Standal, 1989). Cooking following five days' natural fermentation resulted in a more pronounced reduction of oxalate in *amochi*. If such a significant reduction is obtained after five days' fermentation, we hope that extended fermentation would do more.

The *amochi* cultivars did not differ significantly in their oxalate content. However, the amount of oxalate in crop plants depends not only on the plant cultivars, but also on the season, soil nutrients and local soil-water conditions where they grow (Singh & Saxena, 1973). Since *amochi*-growing farmers usually have an extended harvesting time, from June to September, future studies should consider the influence of these environmental factors.

Amochi is irritating in contact with the skin, which makes food preparation very troublesome (Gedebo *et al*., 2006). Since it has been shown that the presence of oxalate in crop plants produces irritation (Safa-Dedeh & Agyir-Sackey, 2004; Osisiogu *et al*., 1974), we suggest that the observed high levels of oxalate in *amochi* (Table 4) could be the likely cause of the irritation. In tropical root crops, calcium oxalate is present as fine needle-like crystals. The presence of these crystals has been considered as either a source of or a contributor to the acridity, which initiates irritation and swelling of mouth and throat (Holloway *et al*., 1989). As cooking following natural fermentation for only five days resulted in such a significant reduction in the levels of oxalate, we suggest that *amochi* meal preparation should follow extended fermentation. Future studies in this regard should consider determining the optimum duration of fermentation.

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Toposequence in Gununo Area, Southern Ethiopia

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Abstract

Sheleme Beyene 2011. Characterization of Soils along a Toposequence in Gununo Area, Southern Ethiopia. *Journal of Science and Development* 1(1) 2011, 31-41. ISSN 2222-5722.

Six soil profiles of different landscapes, representing convex crest, top-slope, mid-slope and depression, were studied along a toposequence, to assess the influence of topography and management practice on soil characteristics in the Gununo area of S. Ethiopia. The soil profiles on the convex crest, at the low side of the terrace on mid-slope and depression had deep, dark surface layers as compared to the others, and the continuous deposition of soil material on the depression had led to lithological discontinuity. Clay migration and coatings were observed in the subsurface layers of the pedons, except in the pedon in the depression. Generally, the soil structure was angular to sub-angular blocky with varying grades. The dry consistency of the soils in the surface layers was by and large slightly hard, whereas the moist consistency was invariably friable. The wet consistency indicated various degrees of stickiness and plasticity. The soils were slightly to moderately acidic (pH <6.4), with CEC ranging from 21.3 to 44 $cmol_c\ kg^{-1}$ and high in exchangeable Mg on the surface layers. The organic C and total N were low to medium, although the C:N ratio was almost optimal. The available P of the surface layers was low to very low (2.2–4.6 mg kg^{-1}), except for the soils of the pedon on the convex crest, which had 7.8 mg P kg^{-1}, whereas exchangeable K contents were below the critical limit in some of the pedons. The results revealed that slope and management practices influenced soil properties, suggesting the need for development and/or adoption of appropriate management options for varying slope gradients.

Keywords: toposequence, pedon, slope position, soil characteristics

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Introduction

Agriculture, accounting for about 45% of GDP and 85% of total employment, is the dominant sector in the national economy of Ethiopia (CSA, 2010). This sector is, however, beset by several natural and anthropogenic factors that adversely affect its productivity (Ahmed, 2002; Woldeamlak, 2003). Increasing population pressure expanded farming from gently sloping surfaces in the highlands to steeper slopes and marginal lands (Azene, 1997; Demel, 2001) which in turn have brought disturbance to the ecosystems, particularly soils, that are the determinant factors of agricultural production and productivity. Assessment of soil quality with respect to landuse types and management practices is therefore crucial for sustainable agriculture.

All soils are naturally variable; their properties changing across the landscape and vertically down the soil profile (Brubaker *et al.*, 1993; Brady & Weil, 2002). Soils commonly occur in groups, each member of the group occupying a characteristic and different sequential topographical position from top to bottom of a slope, termed as *toposequence*. When the same sequence occurs as a mirror image on similar parent material, the two toposequences are called a *catena* (Buol *et al.*, 2003). The prevalence of differences in soil properties along a landscape affects not only patterns of plant production but also litter production and decomposition. Soil properties such as clay, sand and pH (Ovalles & Collins, 1986) and organic matter (Miller *et al.*, 1988; Pierson & Mulla, 1990; Bhatti *et al.*, 1991) correlate highly with landscape position. Soil properties can also vary with landuse and management systems. Land management and its various uses for crop production in mountain areas influence runoff and erosion, which in turn result in varying physicochemical properties of the soils under cultivation and grazing lands (Belayneh, 2009).

Gununo area, in Southern Nations', Nationalities' and Peoples' Regional State (SNNPRS) of Ethiopia, is densely populated (400–600 km^{-2}), with very small farm size (averaging 0.25 ha per farming family). Intensive cultivation in this area, with subsequent removal of plant residues, has resulted in severe degradation of soil fertility. Subdivision of the fields into several plots for various purposes (field crops and vegetable production, enset (*Ensete ventricosum*) and coffee (*Coffea arabica*) plantation, and for tethering animals) has led to different soil fertility gradients and has complicated management. The decline in soil fertility is exacerbated by soil erosion, which is aggravated by steep slopes, poor vegetation cover and continuous cropping. Thus, different points along the slope require different management practices. The present study was therefore carried out to assess the morphological, physical and chemical properties of the soils under different landuse systems along the toposequence, and to generate data for management options.

Materials and Methods

The study was conducted at Gununo, in Wolaita Zone of the SNNPRS of Ethiopia. The study site is situated 30 km W of Sodo town at 6º56´ N lat., 37º39´ E long., at altitudes between 1880 and 1960 m above sea level (m asl). The area receives a mean annual rainfall of 1350 mm and has a mean annual air temperature of 18.5 ºC. The main crops grown in the area are cereals such as *teff (Eragrostis tef),* maize *(Zea mays),* wheat *(Triticum aestivum)*, barley *(Hordeum vulgare*); pulses such as faba bean (*Vicia faba),* field pea (*Pisum sativum*), haricot bean (*Phaseolus vulgaris*); and root and tuber crops such as potato (*Solanum tuberosum*), sweet potato *(Ipomea batatas)* and enset (*Ensete ventricosum*).

Six soil profile pits were excavated at different slope gradients on various positions of the landscape, representing convex crest, topslope, mid-slope and depression. Pedon 1 was located on convex crest, 2 and 3 were on topslope, 4 and 5 were on mid-slope, whereas Pedon 6 was in a depression. Pedons 1 and 6 were on grass cover; Pedons 2 and 3–5 were on maize and wheat fields, respectively. The soil profiles were described *in situ* following Guidelines for Soil Profile Description (FAO, 1990), and samples collected from identified genetic horizons. The samples were processed and analysed for physicochemical properties, following standard laboratory procedures.

Particle-size distribution was determined by the modified hydrometer sedimentation method, and soil pH in H_2O using a 1:2.5 soil to solution ratio (Van Reeuwijk, 1993). The organic carbon was analyzed by the wet combustion method of Walkley and Black (Van Ranst *et al.*, 1999), total nitrogen (N_{tot}) by the Kjeldahl wet digestion and distillation procedure (Bremner & Mulvaney, 1982), and available phosphorus by the 0.5*M* sodium bicarbonate extraction (pH 8.5) method (Olsen & Sommers, 1982). The CEC and exchangeable bases were determined by the 1*M*-ammonium acetate (pH 7) method (Van Reeu-wijk, 1993), and base saturation (BS) was computed.

Results and Discussion

Site characteristics

The site characteristics of the six pedons indicated differences in slope, permeability and extent of erosion (Table 1, overleaf). Pedons 2 and 3 were on slopes of 18% and 9%, respectively, whereas the remaining pedons were on gentle slopes (2–4%). The physiography ranged from convex plateau to undulating slope and depression, showing nil erosion in the depression (Pedon 6) to moderate erosion at the mid-slope position (Pedon 2 and 3), on a basaltic landform with well-drained soils, except in the depression (Pedon 6), which was of alluvial parent material and poorly drained.

Morphological features

The morphological descriptions of the pedons (Table 2 overleaf, opposite) showed that all the profiles had deep soils, while those on convex crest (Pedon 1) and depression (Pedon 6) had deeper and darker surface layers as compared to the others. These might be attributed to relatively low removal of surface soil by water erosion at the convex crest (plain with 2% slope), and continuous deposition of soil material in the depression, resulting in lithological discontinuity in the latter, as indicated by the abrupt change in textural class within the profile (Table 3). The greatest depth to the B horizon was, however, recorded on Pedon 5, situated on the lower side of the terrace, this indicates accumulation of materials originating in topographically higher pedons. Mulugeta Demis (2006) found a deeper A-horizon in pedons in lower slope positions, as compared to those on the upper and middle slopes. Mulugeta Demis explained that the greatest erodibility was associated with upper-slope positions, where soils tended to be shallow, coarse, poorly leached and low in organic matter, whereas low erodibility was found in lower-slope positions with deep, organic-rich and leached soils.

The soil colour of the surface layers varied from 2.5YR to 10YR, although the moist soil colour of the same layers invariably indi-

Table 1. *Site characteristics of the pedons*

Pedon	Geographical position		Altitude (m asl)	Physiography	Slope (%)	Permeability	Drainage	Erosion	Landuse	Parent material
	N Lat.	E Long.								
1	06°56.34´	37°39.80´	1960	Convex plateau	2	Moderately rapid	Well drained	Slight	Grassland	Basalt
2	06°56.32´	37°39.50´	1930	Undulating, upper slope	18	Moderately rapid	Well drained	Moderate	Cropped for maize	Basalt
3	06°56.29´	37°39.95´	1925	Undulating, upper slope	9	Moderately rapid	Well drained	Moderate	Cropped for wheat	Basalt
4	06°56.25´	37°39.54´	1920	Undulating, middle slope	3	Moderately rapid	Well drained	Slight	Cropped for wheat	Basalt
5	06°56.34´	37°39.60´	1910	Undulating, middle slope	4	Moderately rapid	Well drained	Slight	Cropped for wheat	Basalt
6	06°56.57´	37°39.29´	1880	Depression	2	Moderately slow	Poorly drained	Nil	Grassland	Alluvium

[1:] C = Clay; CL = Clay loam; SiL = Silt loam

cated a lower value, chroma or both (Table 2). The decrease in value and chroma could be attributed to the influence of soil moisture on the reflection of light and purity of the colour, respectively. Light absorption increases when the soil is wet, hence the soil colour value decreases. Similarly, purity of the spectral colour decreases with absorption of moisture by the soil, resulting in reduction of the chroma. The determination of soil colour revealed that all the soils were well drained, except Pedon 6, where mottles were prevalent throughout the profile, indicating imperfect drainage conditions due to repeated wetting and drying.

Except in Pedon 6, which consisted of contrasting materials deposited by water at different times, the field soil texture as estimated by the feel method below the surface layers invariably became finer (Table 2), owing to clay migration, which was confirmed by clay coatings observed in the subsurface layers of the pedons. The soil structure was generally angular to sub-angular blocky of various degrees, except in the surface layer of Pedon 4 and in the subsurface horizon of the depression Pedon, which had granular and single-grain structure, respectively. The size of the peds generally increased with depth due to an increase in clay content, as explained by Brady & Weil (2002). The dry consistency of the surface soil was by and large slightly hard, whereas the moist consistency was invariably friable, indicating a high rate of water absorption. The wet consistency revealed various grades of stickiness and plasticity.

Particle-size distribution

The textural class of the soils did not vary under different landuse systems, indicating that mineral particles in a soil are not readily subject to change by management practices (Prasad & Power, 1997). The texture of the subsurface horizons, except Pedon 6, became finer with depth, due to migration of clay from surface to lower horizons (Table 3). It was also evident in the progressive decrease in the silt:clay ratio with depth of pedons. The low silt-to-clay ratios in the subsoil layers also indicate that the soils are at an advanced stage of development (Abayneh, 2005), and confirm the existence of clay migration in the pedons.

Table 2. *Morphological description of the pedons*

P*	Depth (cm)	Horizon	Boundary[1]	Colour Dry	Colour Moist	Field textural class [2]	Structure [3]	Consistency [4]	Roots [5]	Special features, if any [6,7]
1.	0–50	A	C,S	10YR3/3	10YR 3/2	CL	WE,FI,SB	SHA,FR,SST,SPL	M,Fi	-
	50–113	B1	G,S	-	2.5YR 3/3	C	WE,FI,AB	FR,SST,SPL	M,Me	-
	113–220	B2	G,S	-	2.5YR 3/4	C	WE,ME,AB	FR,SST,SPL	F,Fi	F,F,SF,P[6]
	220–300*	B3	-	-	2.5YR 3/4	C	WE,ME,AB	FR,SST,SPL	-	F,F,SF,P[6]
2.	0–20	Ap	C,S	2.5 YR 3/4	2.5YR 2.5/4	CL	WE,FI,SB	HA,FR,SST,SPL	F,Me	-
	20–47	Bt1	G,S	-	2.5YR 2.5/3	CL	MO,ME,SB	FR,SST,SPL	F,Fi	F,F,C,P[6]
	47–86	Bt2	G,S	-	10R 3/3	C	MO,ME,AB	FR,SST,SPL	F,Me	F,F,C,P[6]
	86–200	Bt3	-	-	10R 3/4	C	WE,ME,AB	FR,SST,SPL	F,Me	C,F,C,P[6]
3.	0–25	Ap	C,S	5YR4/4	2.5YR 3/2	SiCL	WE,FI,SB	SHA,FR,SST,SPL	M,Fi	-
	25–63	Bt1	G,S	-	2.5YR 3/4	CL	MO,ME,AB	FR,SST,SPL	C,Me	-
	63–118	Bt2	G,S	-	2.5YR 3/3	C	MO,FI,SB	FR,SST,SPL	M,Fi	F,F,C,P[6]
	118–200*	Bt3	-	-	10YR 3/4	C	MO,ME,SB	FR,ST,PL	-	F,F,C,P[6]
4.	0–15	Ap	C,S	7.5YR 2.5/3	2.5YR 2.5/1	CL	WE,ME,GR	SHA,FR,SST,SPL	M,Me	-
	15–58	AB	C,S	-	10YR 2/1	C	WE,ME,SB	FR,ST,PL	M,Me	-
	58–100	Bt1	G,S	-	2.5YR 2/4	C	WE,ME,SB	FR,ST,PL	F,Fi	F,F,C,P[6]
	100–200*	Bt2	-	-	10YR 3/3	C	WE,ME,SB	FR,SST,SPL	V,Fi	F,F,C,P[6]
5.	0–20	Ap	C,S	5YR4/4	5YR 3/2	CL	WE,FI,AB	SHA,FR,SST,SPL	M,Fi	-
	20–52	A11	C,S	-	5YR 3/3	CL	WE,FI,AB	FR,SST,SPL	C,Fi	-
	52–70	A12	G,S	-	5 YR 2.5/2	C	WE,FI,AB	FR,SST,SPL	F,Fi	-
	70–105	AB	C,S	-	2.5YR 3/1	C	WE,ME,AB	FR,ST,PL	F,Fi	F,F,C,P[6]
	105–200*	B	-	-	2.5YR 3/4	C	WE,ME,AB	FR,ST,PL	-	F,F,C,P[6]
6.	0–40	A	G,S	7.5YR 4/4	2.5YR 2.5/3	C	WE,FI,AB	SHA,FR,SST,SPL	C,Fi	F,M,F,RY[7]
	40–95	Bt	A,S	-	5YR 2.5/2	C	WE,FI,AB	FR,ST,PL	M,Fi	V,M,F,YE[7]
	95–150	E	A,S	-	10YR 4/4	S	SG	LO,NST,NPL	M,Fi	-
	150–190	2Bth1	C,S	-	7.5YR 2.5/3	C	WE,FI,AB	FR,ST,SPL	M,Fi	M,F,F,YE[7]
	190–200*	2Bts2	-	-	5YR 3/4	C	WE,ME,AB	FR,ST,PL	C,Fi	M,F,F,YE[7]

P* = Pedon

1: A=Abrupt; C= Clear; G= Gradual; S= Smooth

2: C= Clay; CL= Clay loam; SiCL= Silt clay loam; S= Sand

3: WE=Weak; MO=Moderate; FI=Fine; ME=Medium; AB= Angular blocky; SB=Sub-angular blocky; GR= Granular; SG= Single grain

4: LO=Loose; SHA=Slightly hard; HA=Hard; FR=Friable; NST=Non sticky; SST=Slightly sticky; ST=Sticky; NPL=Non plastic; SPL=Slightly plastic; PL=Plastic

5: V=Very few; F=Few; C=Common; M=Many; Fi=Fine; Me=Medium

6: F,F,SF,P=Few, Faint, Shiny faces, Pedfaces; F,F,C,P=Few, Faint, Clay, Pedfaces; C,F,C,P=Common, Faint,Clay, Pedfaces

7: F,M,F,RY=Few, Medium, Faint, Reddish yellow; V,M,F,YE=Very few, Medium, faint, Yellow; M,F,F,YE=Many, Fine, Faint, Yellow mottles.

Table 3. *Particle-size distribution of the soils*

Pedon	Depth (cm)	Particle-size distribution (%)			Textural class[1]	Silt/clay
		Sand	Silt	Clay		
1.	0–50	28	40	32	CL	1.25
	50–113	18	16	66	C	0.24
	113–220	12	8	80	C	0.10
	220–300$^+$	22	14	64	C	0.22
2.	0–20	40	32	28	CL	1.14
	20–47	18	22	60	C	0.37
	47–86	18	16	66	C	0.24
	86–200$^+$	10	12	78	C	0.15
3.	0–25	27	44	29	CL	2.00
	25–63	26	30	44	C	0.68
	63–118	14	22	64	C	0.34
	118–200$^+$	10	10	80	C	0.12
4.	0–15	30	42	28	CL	1.50
	15–58	28	40	32	CL	1.25
	58–100	14	20	66	C	0.30
	100–200$^+$	10	8	82	C	0.10
5.	0–20	30	36	34	CL	1.06
	20–52	32	32	36	CL	1.12
	52–70	26	32	42	C	0.76
	70–105	28	30	42	C	0.71
	105–200$^+$	14	33	53	C	0.65
6.	0–40	20	36	44	C	0.82
	40–95	26	32	42	C	0.86
	95–150	32	54	14	SiL	3.86
	150–190	26	26	48	C	0.54
	190–300$^+$	36	20	44	C	0.45

[1]: C = Clay; CL = Clay loam; SiL = Silt loam

The presence of an appreciable amount of the silt fraction in the surface soils could increase the water-absorbing ability of the respective soils, and facilitate a longer period of soil-water retention for plant utilisation.

Chemical properties of soils

The soil pH values within the profiles ranged from slightly to moderately acidic, and the pH values of Pedons 1–3 varied widely between the surface and subsurface layers (Table 4). The wide variation in pH values in these pedons might be due to difference in landuse, existing micro-climate and associated chemical environment. The pH level was slightly higher under the grassland than in the cultivated fields. Previous reports have also indicated that soil reaction can be influenced by various anthropogenic and natural activities (Rowell, 1994; Miller & Donahue, 1995; Brady & Weil, 2002). Relatively lower pH values in the pedons of the cultivated fields, as compared to those under grassland, might be due to depletion of basic cations in the crop harvest, and leaching. Gebeyaw (2007) also found lower pH values in cultivated land as compared to grassland, and attributed this to a high rate of organic matter oxidation, which produces organic acids and provides H-ions to the soil solution, and thereby reduces soil pH values.

The exchangeable cations in all the soils were in the order of Mg > Ca > K > Na throughout the profile, except for Pedon 6, where Ca dominated over Mg in the first two surface horizons (Table 4). This virtually indicates the dominance of Mg-bearing minerals in the weathering environment, the soil's being at relatively older stage of development, or both. Along the toposequence, the maximum value of exchangeable Mg (20.9 $cmol_c$ kg^{-1}) in the surface layer of Pedon 1 reconfirms the occurrence of Mg-rich source material. The Ca and Mg contents were above their critical limits for agricultural land; hence deficiencies of these elements would not be expected in the soils. The ratio of Ca:Mg was, however, very low, indicating that Mg could interfere with the uptake of Ca (Havlin *et al.,* 1999). On the other hand, the exchangeable K content was below the critical level of 0.38 $cmol_c$ kg^{-1} (Landon, 1991) in two of the middle-slope topographic positions and in the depression pedons. In line with the present finding, Wondwosen (2008) also reported that K is a potentially limiting nutrient for supporting good crop growth in Alfisols of the neighboring district.

The cation exchange capacity (CEC) of the soils across the surface and subsurface layers varied between 21.3 $cmol_c$ kg^{-1} (the surface layer of Pedon 6) and 44 $cmol_c$ kg^{-1} (the subsurface 70–105 cm depth of Pedon 5), which could be rated as medium to high (Landon, 1991). The soils of the topographic high showed relatively higher CEC in the two surface horizons as compared to those on middle slopes, whereas that of the alluvial soil was the lowest (Table 4). The magnitude of total exchangeable basic cations followed the same trend. This was in contrast to the normal principle of basic cations' distribution. However, the data suggest that the immediate weathering products on the topographic high would have been of basic nature, as observed in basaltic soils (Heluf & Mishra, 2005). On further transformation, the exchange sites might have been occupied by other cations such as H and Al in the weathering environment. The dominant clay mineral in basaltic soils is smectite or inter-stratified minerals, including corrensite and attapulgite (palygorskite). The relatively low CEC in some of the soil profiles could be attributed to the formation of interstratified clay minerals. The base saturation varied widely, and was found to be lowest under the upper slope positions with high slope gradients.

The organic C content of the soils was low (Landon, 1991), and consistently decreased with depth, as compared to the subsoil horizons in the respective profiles. A similar trend was noted for the distribution of total nitrogen (N_{tot}; Table 5), which was also in the low to medium range (Havlin *et al.,* 1999). Organic C and N_{tot} contents were not influenced by landuse systems, possibly due to the complete removal of crop residues, and continuous heavy grazing in the case of grasslands. The C:N ratio was optimal, indicating the mineralization stage of soils and the availability of N to plants. The low content of organic C and N_{tot} could be attributed to the effects of intensive cultivation, which aggravated the oxidation of organic C. Previous findings also revealed that cultivation of land results in the reduction of organic C and N_{tot} (Saikh *et al.,* 1998; Wakene & Heluf, 2003).

The amount of available P was higher in the surface layers as compared to the subsoils in all but Pedon 6 (Table 5). However, the available P content in all the soils was very low to low (Havlin *et al.,* 1999) except in the surface layer of Pedon 1, indicating that P availability is the most limiting factor for crop production. The low availability of P might be due to the inherent P deficiency of the soils and the fixation of P with Fe and Al, as the soils are acidic in reaction. Previous reports (Kelsa *et al.,* 1998; Mulugeta Demis, 2006; Alemayehu, 2007; Tigist, 2007) have con-

Table 4. *Chemical properties of the soils*

Pedon	Depth (cm)	pH-H_2O (1:2.5)	Exchangeable cations and CEC($cmol_c\,kg^{-1}$)						Base Saturation (%)
			Na	K	Ca	Mg	TEB	CEC	
1.	0–50	6.1	0.19	0.80	11.13	20.90	33.0	40.4	82
	50–113	6.4	0.25	1.55	4.64	26.2	32.6	40.6	80
	113–220	5.7	0.21	1.24	2.59	8.15	12.2	34.8	35
	220–300+	5.5	0.19	0.75	1.90	3.70	6.53	32.0	20
2.	0–20	5.7	0.15	0.34	7.19	10.1	17.7	39.4	45
	20–47	4.7	0.14	0.31	6.89	9.0	16.3	37.0	44
	47–86	4.8	0.18	0.39	4.68	9.5	14.8	36.0	41
	86–200+	4.5	0.15	0.51	3.13	12.1	15.9	35.0	45
3.	0–25	5.3	0.16	0.69	4.14	6.7	13.7	38.0	36
	25–63	4.7	0.18	0.43	2.74	6.1	9.4	37.4	25
	63–118	4.5	0.28	0.52	2.49	5.5	8.8	36.4	24
	118–200+	6.0	0.28	0.45	2.09	5.0	7.8	33.4	23
4.	0–15	5.4	0.16	0.31	8.03	13.7	22.2	37.0	60
	15–58	5.8	0.26	0.29	9.13	24.0	33.7	39.0	86
	58–100	5.7	0.22	0.43	4.34	18.2	23.2	36.8	63
	100–200+	5.3	0.25	0.54	5.19	20.1	26.0	39.4	66
5.	0–20	5.4	0.19	0.42	5.29	11.9	17.8	35.4	50
	20–52	5.3	0.14	0.32	5.24	12.3	18.0	36.0	50
	52–70	5.6	0.15	0.32	6.74	21.6	28.8	38.0	76
	70–105	5.7	0.18	0.42	5.84	24.1	30.5	44.0	69
	105–200+	5.8	0.20	0.64	4.69	26.9	32.4	39.0	83
6.	0–40	6.1	0.17	0.24	6.00	3.7	10.1	21.3	47
	40–95	6.2	0.17	0.39	8.41	4.2	13.2	32.0	41
	95–150	6.0	0.15	0.31	8.03	10.5	19.0	35.0	54
	150–190	6.3	0.24	0.27	9.13	11.5	20.7	37.0	56
	190–300+	6.3	0.21	0.43	8.34	12.2	21.2	36.8	58

TEB = Total exchangeable bases

firmed that the available P content of most soils in the region is low, and that P fertiliser application is required for optimum crop production.

Conclusions

The differences in landuse systems, grassland and cultivated, resulted in varying physico-chemical properties of the soils. The variations in soil characteristics observed in the studied four (Pedons 2–5) of the six pedons were due to differences in slope and soil management. Soil Pedon 5 was located on mid-slope, but at the lower side of a terrace, where soil materials removed from upslopes were continuously deposited. The subsequent accumulation of materials resulted in the development of a thick A horizon, indicating the role of soil conservation practices in soil development and characteristics. The soils are low in organic C, N_{tot} and available P content, hence integrated plant-nutrient management, together with soil conservation practices, should be employed to ensure sustainable crop production at the site.

Table 5. *Organic carbon, total nitrogen and available phosphorus of the soils*

Pedon	Depth (cm)	Organic carbon (%)	Total nitrogen (%)	Carbon : nitrogen ratio	Available P (mg kg^{-1})
1.	0–50	1.68	0.175	10	7.80
	50–113	0.65	0.080	8	2.20
	113–220	0.55	0.070	8	1.00
	220–300$^+$	0.39	0.042	9	1.40
2.	0–20	1.56	0.175	9	3.20
	20–47	1.15	0.133	9	0.80
	47–86	0.94	0.119	8	1.00
	86–200$^+$	0.64	0.084	8	1.00
3.	0–25	1.42	0.133	11	2.40
	25–63	1.12	0.126	9	0.40
	63–118	0.77	0.106	7	0.60
	118–200$^+$	0.58	0.084	7	0.80
4.	0–15	1.59	0.175	9	4.60
	15–58	1.59	0.161	10	1.40
	58–100	0.53	0.042	13	1.80
	100–200$^+$	0.47	0.098	5	1.40
5.	0–20	1.47	0.154	10	3.00
	20–52	1.38	0.133	10	2.20
	52–70	1.32	0.119	11	0.60
	70–105	1.14	0.119	10	0.80
	105–200$^+$	0.63	0.091	7	0.60
6.	0–40	1.27	0.147	9	2.20
	40–95	1.18	0.110	11	1.20
	95–150	0.42	0.042	10	1.00
	150–190	0.74	0.091	8	2.40
	190–300$^+$	0.76	0.063	12	3.80

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The effect of cropland fallowing on soil nutrient restoration in the Bale Mountains, Ethiopia

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Abstract

Fantaw Yimer & Abdu Abdelkadir 2011. The Effect of Cropland Fallowing on Soil Nutrient Restoration in the Bale Mountains, Ethiopia. *Journal of Science and Development* 1(1) 2011, 43-51.

Fallowing is considered an important management practice in maintaining soil productivity. This study investigated the level to which traditional cropland fallowing restored soil fertility in the Bale Mountains of Ethiopia. It included a comparison among a three-year fallow, cropland and natural forest. A total of 36 surface soil samples (3 altitudinal ranges×3 landuse types×4 soil samples from 0–0.20 m depth) were collected and analysed for soil organic carbon, total nitrogen, exchangeable bases, cation exchange capacity (CEC) and percentage base saturation (PBS). Results showed that soil organic carbon content ($p<0.001$) and total N ($p=0.001$) were significantly higher in the fallow land and natural forest than in cropland. Except for exchangeable Mg^{2+} and Ca^{2+}, the differences in exchangeable bases were significant with landuse types. Exchangeable K^+ was higher in the fallow land than in cropland soils. Cation exchange capacity and PBS also showed significant variation with landuse type ($p<0.001$ and $p=0.004$, respectively) and altitudinal ranges ($p<0.001$ and $p=0.006$, respectively). The overall mean CEC was higher in the natural forest and fallow land than in cropland. The CEC in fallow land was strongly related to the soil organic carbon ($r^2 = 0.84$, $p<0.001$). The nutrient build-up and rise in CEC and PBS in soil within the three-year fallow period could be due to the addition of soil organic matter.

Keywords: Degraded land; Cropland fallowing; Nutrient restoration; Soil fertility recovery

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Introduction

'Fallow', the resting state of an agricultural field (Szott *et al.*, 1999), is a soil conservation and soil improvement technique (Grisley & Mwesigwa, 1994), which is important for maintaining and restoring soil fertility over wide areas of the world (Ruthenberg, 1980; Loomis, 1984; Sánchez, 1995; Büttner & Hauser, 2003). Many farmers in the tropics still use fallows as part of their farming system. Fallowing replenishes nutrients removed by crops, reduces erosion and leaching, and maintains better soil physical and biological conditions (Adejuwon & Adesina, 1990; Juo *et al.*, 1995; Sánchez, 1995; Szott & Palm, 1996; Barrios & Cobo, 2004; Tian *et al.*, 2005). However, fallow periods throughout the tropics have become progressively shorter, as a result of pressure on land**,** arising from human population growth (Grisley & Mwesigwa, 1994; Mendazo-Vega & Messing, 2005). A shorter fallow period means that there is less opportunity for the land to restore its fertility status, as well as an increase in net soil nutrient loss; and less crop residue and animal manure remain on the fields (Solomon, 1994). This shortening of traditional fallows, combined with little or no use of fertilisers, has had negative consequences for agricultural productivity and agro-ecosystem functioning in the tropics (Szott *et al.*, 1999).

Despite some reported reservations regarding fallowing (Abubaker, 1996), it has long been seen as one of the systems for maintaining soil fertility (Greenland, 1975). Research information is available for many tropical areas on the extent to which fallowing helps restore soil fertility (Juo & Lal, 1977; Szott *et al.*, 1999; Barrios *et al.*, 2005; Mendazo-Vega & Messing, 2005; Bruun *et al.*, 2006).

Earlier research (Yimer *et al.*, 2007, 2008a) established that cropland soils in the Bale Mountains have shown a decline in organic carbon and total nitrogen (N_{tot}) contents by 30.9 and 32.1%, respectively. There are also reports of a decline in exchangeable cations, CEC, and a reduction in infiltration rate (Yimer *et al.*, 2008a, 2008b) after conversion of native forest into cultivated land. Soil nutrient levels were severely depleted and crop yields declined during the cropping cycle. This was primarily attributed to low nutrient contents, resulting from a negative nutrient budget, *i.e.* when more soil nutrients are removed from the system by leaching, gaseous losses, soil erosion and through crop off-take ('nutrient mining'), than are returned to the soil in the form of crop residues (Sanchez, 1995; Barrios & Cobo, 2004).

On the steep slopes of the Bale Mountains, research into traditional cropland fallowing is lacking, and there is no information on the extent to which fallowing helps protect the land and restore soil nutrients. Effective management of agricultural land for sustained production relies on knowledge of the fluxes and losses of nutrients during cropping and fallowing. Therefore, the aim of this paper is to evaluate the extent to which nutrient-mined sites under cropland are replenished and their fertility restored through traditional cropland fallowing practice.

Materials and methods

Study site

The study was carried out on the southern slope of the Bale Mountains National Park (BMNP), 60 km south of Goba town, Ethiopia (Figure 1). The BMNP is situated between 6º29´–7º10´ N lat., and between 39º28´–39º58´ E long. The altitudinal range of the study site is 3000–3200 m above sea level (m asl). The mean annual precipitation is 1064 mm, of which 66% falls partly during summer and partly during autumn. The mean annual temperature ranges between 13.3 °C–14.1 °C.

Geologically, the area consists of rocks of

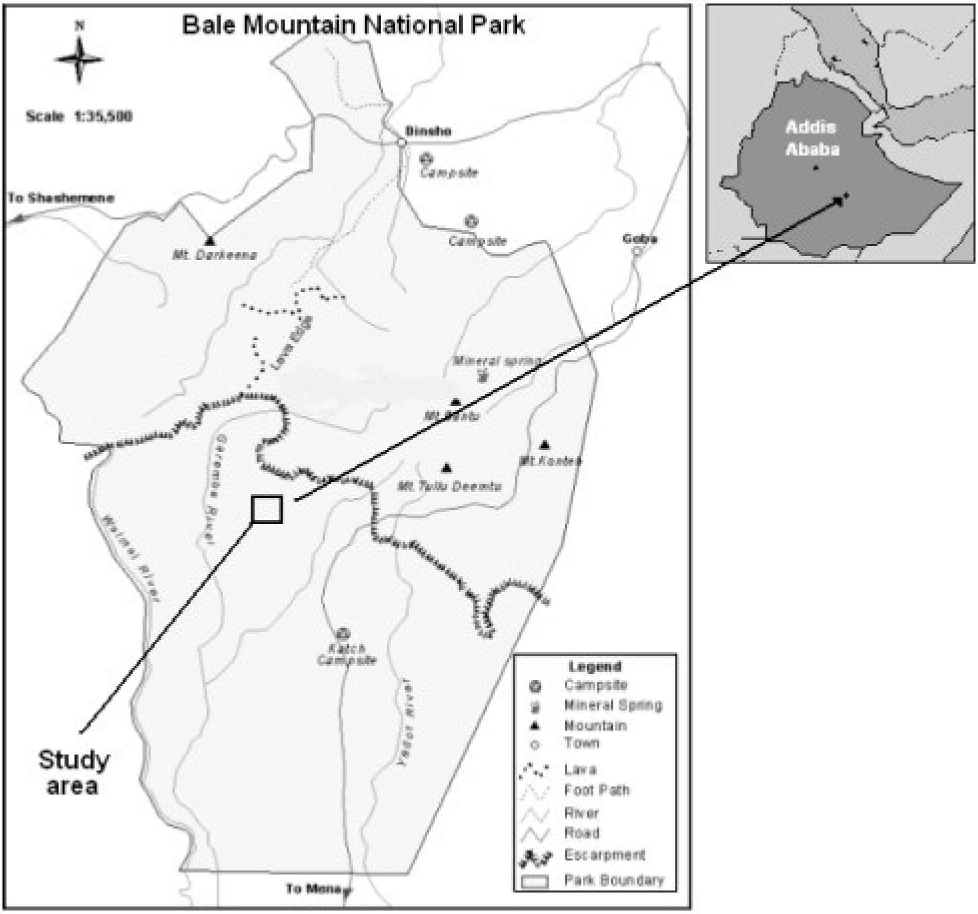

Figure 1. Map showing location of the study area.

Table 1. *Soil textural fractions (%) and bulk density (B.d., cm^{-3}) in relation to altitudinal range and landuse type (mean ± SE) at 5% probability level*

Treatment	**Soil property**			
	Sand	Silt	Clay	B.d.
Altitudinal range				
Lower	53.8 (± 1.3)	38.5 (± 0.7)	7.7 (± 1.3)	0.9 (± 0.04)
Middle	53.7 (± 2.2)	38.5 (± 1.6)	7.8 (± 1.1)	0.9 (± 0.03)
Upper	53.7 (± 2.0)	42.2 (± 1.4)	4.2 (± 0.6)	0.7 (± 0.03)
Landuse type				
Cropland	50.3 (± 1.8)	41.8 (± 1.4)	7.8 (± 0.9)	0.92 (± 0.03)
Cropland-fallow	54.0 (± 1.1)	41.3 (± 1.0)	4.7 (± 0.5)	0.88 (± 0.04)
Native forest	56.8 (± 2.0)	36.0 (± 1.1)	7.2 (± 1.6)	0.80 (± 0.05)

volcanic origin, welded with volcanic ash materials (Mohr, 1971; Berhe *et al.*, 1987), weathered to mainly black to very dark brown sandy loam to loam in the surface soil, and sandy loam to loam–clay loam in the subsurface soils (Yimer *et al.*, 2006b). In an earlier reconnaissance study, Andisols were considered to be the most prevalent soil in the higher parts of the Bale Mountains (Weinert & Mazurek, 1984). Andisols have a unique combination of physical and chemical properties (*e.g.* low bulk density, large variable charge, large water storage capacity, high phosphate retention and high accumulation of organic matter (Shoji *et al.*, 1993; Delvaux *et al.*, 2004; Yimer *et al.*, 2006a). Both the surface and subsurface horizons are very friable to friable at moist moisture content; not sticky to slightly sticky and slightly plastic (wet) (Yimer *et al.*, 2006b). Selected surface-soil properties are presented in Table 1. The natural vegetation is dominated by *Schefflera abyssinica* and *Hagenia abyssinica,* and the understorey consists of small trees and shrubs such as *Brucea antidysenterica, Cassipoourea malosana, Rubus apetalus, Dombeya torrida, Allophyllus abyssinicus, Rapanea simensis, Euphorbia dumalis, Vernonia urticifolica* and *Echinops macrochaltus* (Nigatu & Tadesse 1989).

The traditional farming system in the higher areas of the Bale Mountains is mainly based on continuous cultivation, followed by three to four years of fallowing to restore soil nutrients. Barley, the major food crop, is cultivated below 3300 m asl and may extend far above that level, depending on the soil and slope. Grazing is carried out mainly on the communal pastures.

Soil sampling & laboratory analyses

Three elevation ranges: lower, middle and upper, with an interval of 50 m between 3000 and 3150 m asl altitude, were designated. In each elevation range, three landuse types were selected: natural forest, cropland (cultivated for three consecutive years, and at the time of sampling, covered with barley), and fallow land (abandoned for three years). Four soil pits were sited in each landuse type, taking into account similarities in the physiographic conditions, such as landscape position and slope. A total of 36 surface soil samples (3 altitudinal ranges×3 treatments×4 soil samples from 0–0.2 m soil depth) were collected for laboratory analysis.

Samples for chemical analysis were passed through a 2-mm soil sieve. SOC was determined according to the Walkley and Black method (Schnitzer, 1982). N_{tot} was measured following the Kjeldahl method (Bremner & Mulvaney, 1982). Soil pH was measured with combined electrodes in a 1:2.5 soil to water suspension. Exchangeable base cations were extracted with 1*N* ammonium acetate at pH 7. Ca and Mg were determined by atomic-absorption spectrophotometry, while Na and K were analysed by flame-emission spectrophotometry (Black *et al.*, 1965). Cation exchange capacity (CEC) was estimated titrimetrically by distillation of ammonium displaced by Na (Chapman, 1965). Percentage base saturation (PBS) was calculated by dividing the sum of the charge equivalents of the exchangeable base cations (Ca^{2+}, Mg^{2+}, K^+ and Na^+) by the CEC of the soil, and multiplying by 100. The data were then grouped according to the landuse and elevation ranges. Statistical differences were tested using two-way analysis of variance (ANOVA), following the General Linear Model (GLM) procedure of SPSS version 12.0.1 for Windows (Julie, 2001). Tukey's Honest Significance Difference (HSD) test was used for mean separation, when the analysis of variance showed statistically significant differences ($p<0.05$).

Results

Soil organic carbon & total nitrogen

Soil organic carbon and N_{tot} (p=0.001) concentrations varied significantly with landuse types and altitudinal ranges (p<0.001, Table 2). The significantly lowest SOC occurred in cropland, while N_{tot} showed the highest increase in the native forest (Table 3). Irrespective of the landuse types, SOC and N_{tot} contents were significantly higher in the upper than in the middle and lower elevation ranges (Table 3). The C/N ratios varied greatly with respect to landuse type (p=0.042) and altitudinal range (p=0.010).

Exchangeable cations

Except for exchangeable Mg^{2+} and Ca^{2+}, the differences were significant with landuse type (Tables 3 and 4). However, the combined interaction effects were significant for all base cations in relation to landuse type (Table 4). Exchangeable Na^{+} was low in cropland and high in natural forest, followed by the fallow land. Irrespective of landuse, significantly higher concentrations of Na^{+} and Ca^{2+} were observed in the middle than in the lower and upper altitudinal ranges. Exchangeable K^{+} was higher in the fallow land than in cropland soils (Table 3).

Cation exchange capacity (CEC) & percentage base saturation (PBS)

CEC and PBS varied significantly with landuse type (p<0.001 and p=0.004, respectively) and altitudinal range (p<0.001 and p=0.006, respectively (Tables 3, 4 overleaf). The overall mean CEC was higher in the natural forest and fallow land than in cropland (Table 3). Irrespective of land use, CEC was significantly higher in the upper than in the middle and lower altitudinal ranges. CEC in fallow land was strongly related to the soil organic carbon (r^2 = 0.84, p<0.001). PBS in the fallow-land soils showed a significant linear relationship with some selected soil properties.

Discussion

Our findings indicate that cropland fallowing significantly improved and restored soil organic carbon by 28.6%, suggesting that organic matter buildup during the fallow period partly replaced organic matter lost during the cropping period. This could be explained by

Table 2. *Summary of Two-Way ANOVA results for soil organic carbon content (%), N_{tot} (%) and carbon-nitrogen (C:N) ratios of the top 0.2 m soil depth, in relation to altitudinal range and landuse type*

Source of Variation		SOC		T – N		C-N ratios	
	d.f.	MS	P-val.	MS	P-val.	MS	P-val.
Landuse (LU)	2	9.383	<0.001	0.084	0.001	13.722	0.042
Altitudinal range (AR)	2	33.193	<0.001	0.126	<0.001	20.789	0.010
LU × AR	4	0.364	0.729	0.010	0.346	3.434	0.479
Error	27	0.714		0.009		3.827	

Table 3. *Soil organic carbon (%), N_{tot} (%), Carbon-nitrogen (C:N) ratios, Exchangeable cations ($cmol_c$ kg^{-1}), CEC ($cmol_c$ kg^{-1}) and percentage base saturation (PBS) of the top 0.2 m soil depth, in relation to altitudinal range and landuse type (mean ±SE). Means followed by the same letter(s) for each variable in relation to altitudinal range and land use type are not significantly different (p = 0.05)*

Variables	**Altitudinal range**			**Landuse type**		
	Lower	Middle	Upper	Cropland	Fallow	Native forest
SOC	4.85 (±0.35) ^{a}	5.36 (±0.32) ^{a}	7.95 (±0.27) ^{b}	5.04 (±0.52) ^{a}	6.48 (± 0.46) ^{b}	6.65 (±0.42) ^{b}
TN	0.54 (±0.03) ^{a}	0.60 (±0.03) ^{a}	0.74 (±0.04) ^{b}	0.55 (±0.04) ^{a}	0.60 (±0.03) ^{a}	0.72 (±0.04) ^{b}
C/N	9.00 (±0.40) ^{a}	8.94 (±0.37) ^{a}	11.25 (±0.90) ^{b}	8.92 (±0.48) ^{a}	10.94 (±0.92) ^{b}	9.33 (±0.36) ^{ab}
Na	0.11 (±0.03) ^{a}	0.33 (±0.06) ^{b}	0.15 (±0.05) ^{a}	0.06 (±0.02) ^{a}	0.26 (± 0.02) ^{b}	0.27 (±0.08) ^{b}
K	1.33 (±0.35) ^{a}	1.58 (±0.32) ^{a}	1.04 (±0.28) ^{a}	0.84 (±0.23) ^{a}	1.69 (± 0.35) ^{b}	1.42 (±0.33) ^{ab}
Ca	8.54 (±1.39) ^{a}	12.91 (±1.58) ^{b}	11.16 (±1.42) ^{ab}	10.35 (± 1.26) ^{a}	11.99 (± 1.19) ^{a}	10.27 (± 2.04) ^{a}
Mg	3.61 (±0.48) ^{a}	4.18 (±0.48) ^{a}	4.36 (±0.56) ^{a}	3.24 (±0.31) ^{a}	4.30 (± 0.49) ^{a}	4.60 (±0.61) ^{a}
CEC	35.83 (±2.56) ^{a}	39.86 (±2.68) ^{a}	47.36 (±2.69) ^{b}	30.78 (± 1.69) ^{a}	43.73 (± 1.89) ^{b}	48.53 (± 2.33) ^{b}
PBS	37.99 (±4.66) ^{a}	49.11 (±5.61) ^{b}	34.86 (±3.16) ^{a}	47.83 (± 5.30) ^{b}	41.62 (± 3.74) ^{ab}	32.50 (± 4.53) ^{a}

the progressive accumulation and decay of the aboveground herbaceous vegetation and root biomass (Samaké *et al.* 2005), and probably by the effects of crop residues left after harvest. Unfortunately, the absence of SOC measures before and after cropping, together with unknown actual above- and belowground litter inputs, does not allow us to explain the SOC increase between the fallow and cropland. The decrease in SOC under cultivation usually is the result of a combination of increased mineralization, because of increased soil temperature and a low input of fresh organic materials returned to the soil. Studies carried out under various tropical climates reported that short-term fallow (<4 years) was not able to increase soil organic carbon content significantly (Masse *et al.*, 2004).

Changes in N_{tot} were less variable than changes observed in SOC in cropland and fallow-land soils. Accumulation of SOC content was higher at higher elevations, which may be attributed to slow litter decomposition, confounded by low temperature conditions. With a decrease in temperature with altitude, a lower decomposition rate is to be expected at the higher altitudes (Samaké *et al.*, 2005, Yimer *et al.*, 2006).

The results presented above also showed that cropland-fallowing brought about significant enrichment of the soils with respect to exchangeable Na^+, K^+, and CEC. The changes in CEC due to fallowing are remarkable. CEC concentrations across all landuse types varied significantly, due to differences in the amounts of soil organic carbon. When the fairly low clay content is taken into consideration, it is clear that the contribution made to CEC by organic substances is critical. The cation exchange capacity, which is used to describe soil fertility (Roder *et al.*, 1995), was higher by 29.6% in soils under fallow as compared to cropland, which most likely is attributable to the increase in the amount of organic carbon during fallowing. This finding has important implications, because it suggests that soil CEC is not likely to be significantly increased, except by improving the organic matter (carbon) content of the soil. The percentage base saturation of the studied soils was significantly higher in the croplands

Table 4. Summary of Two-Way ANOVA results for soil pH (H_2O), exchangeable cations ($cmol_c\ kg^{-1}$)), CEC ($cmol_c\ kg^{-1}$) and percentage base saturation in the top 0.2 m soil depth, in relation to altitudinal range and landuse type

Source of variation		pH		Na		K		Ca		Mg		CEC		PBS	
	d.f.	MS	P-val	MS	P-val	MS	P-val	MS	P-val	MS	P-val	MS	P-val	MS	P-val
Landuse (LU)	2	0.610	0.019	0.159	<0.001	2.288	0.036	11.295	0.542	6.134	0.076	1011.719	<0.001	713.801	0.004
Altitudinal range (AR)	2	0.324	0.105	0.154	<0.001	0.893	0.249	57.925	0.056	1.849	0.435	410.858	<0.001	672.677	0.006
LU × AR	4	1.204	<0.001	0.074	0.001	4.794	<0.001	85.889	0.005	7.774	0.018	30.014	0.297	1011.318	<0.001
Error	27	0.132		0.012		0.610		18.000		2.155		23.166		106.037	

than in fallow and native forests. Base cations stored in wood and shrubs are released at burning, and replace hydrogen at the exchange sites of the soil, increasing the base saturation. Moreover, the fewer exchange sites with smaller amounts of organic matter and more base cations, also leads to higher base saturation (Yimer *et al.* 2008a).

Conclusions

The positive effect of cropland fallowing on soil organic carbon content, exchangeable K^+ and CEC obtained in the present study confirmed that cropland fallowing still needs to be considered as an important and essential management practice for soil-nutrient restoration in the Bale Mountains. However, successful restoration of soil nutrients normally requires a long fallow period, because the loss of nutrients during the cultivation phase can no longer be restored by short fallow periods. Thus, it is suggested that an appropriate alternative technology (*e.g.* planted fallow with suitable tree species) should be considered, which would have wider acceptance by the farmers, and have a potential to generate additional products and bring immediate benefits while replenishing soil-nutrient stocks.

As fallow becomes more relevant, because of the need to maintain and restore soil productivity, it is also necessary to understand the dynamics of soil properties and associated crop productivity under such traditional fallowing practices. Therefore, an understanding of the rationale behind this cultivation practice and dynamics is a necessary step towards assisting farmers to develop their system in productive and environmentally sound directions.

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Effect of dietary protein concentration on feed intake, body mass gain and carcass traits of Rhode Island Red chicken

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Abstract

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The effect of dietary crude protein (CP) concentration on dry-matter intake (DMI), body mass gain (BWG) and carcass traits of Rhode Island Red (RIR) chicken was determined through a 12-week feeding trial (10–93 days of age) in southern Ethiopia. Diets were formulated to contain 140 (T1), 160 (T2), 180 (T3), 200 (T4) and 220 (T5) g CP kg^{-1} DM from maize, wheat bran, soybean, sunflower cake, Niger seed (*Guizotia abyssinica*) cake, salt, rear premix, lysine and methionine. ME (14.36–14.84 kJ kg^{-1} DM) and other nutrients in diets were similar. Ten chicks were randomly distributed to each of four replicates of five treatment diets in a completely randomized design. Chicks were raised in groups, and the feed offer and refusal measured daily. Body mass was measured weekly. At the beginning of the experiment, four male (1 per replicate) and four female (1 per replicate) chicks whose body mass was closest to the mean body mass of their respective groups and sexes, were selected per treatment, fasted for 12 h, weighed, slaughtered and parts of the carcass weighed. Differences in DMI and BWG of chicks fed different levels of dietary CP were not significant. Diet T2 was as efficient as the higher CP diets but more efficient than T1 in DM utilization. Chicks fed on diet T2 had significantly ($P<0.05$) higher total non-edible offal (TNEO) than those fed on T1, and TNEO of chicks fed on diets T3, T4 and T5 were in between. Differences in carcass mass were not significant ($P<0.05$) among treatment groups. Chicks fed on diet T1 had significantly ($P<0.05$) higher dressing percentage than those on diets T3 and T5, but similar to those on diets T2 and T4. The highest net return was from diet T2, but it was close to T1. Mortality of chicks was observed only in T1 (2.5%) and T5 (12.5%). The results suggest that 160 g CP kg^{-1} DM is optimum for growing RIR chicks in tropical climates from 10–93 days of age.

Keywords: Dietary crude protein, carcass traits, feed efficiency, Rhodes Island Red chicken

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Introduction

Feed cost represents 65–75% of the total cost of intensive poultry production, depending mainly on the relative costs of feed constituents, labour, housing and miscellaneous items in particular situations (Gopalakrishnan & Lal, 2004). The optimal use of protein is essential in any feeding system, because protein supplements are usually much more expensive than energy feeds, and wasteful usage increases the cost of production. Excess protein if fed may increase elimination of N in faeces and urine, which has environmental implications (Church & Kellems, 2002). Therefore, economically as well as nutritionally it is imperative that balanced diets should be provided during the brooding, rearing and laying stages (Gopalakrishnan & Lal, 2004).

Although the National Research Council (NRC, 2003) recommended a feeding standard for chicken, this has not been totally practical in the tropics, for obvious reasons of environmental differences and type and quality of available feed ingredients. Furlan *et al.* (2004) reported that, in tropical areas, the feeding of high-protein diets to broilers was not recommended, because among dietary nutrients, protein has the highest heat increment. Consequently, for many years low-protein diets were recommended, to decrease the amount of heat produced and its harmful effects on birds' performance. On the other hand, when low feed intake of heat-stressed birds is associated with low-protein content of diets, there is a reduction in amino-acid intake. Moreover, the specific nutrient requirements of dual-purpose breeds have not been adequately researched (Blake, 2008). The aim of this study was thus to determine the level of protein for optimum growth and carcass yield of Rhode Island Red chicken under Ethiopian conditions.

Materials and methods

The study area

A feeding trial with Rhode Island Red (RIR) chicks was conducted at Wolaita Soddo Poultry Husbandry Centre (Southern Ethiopia), situated 400 km SW of the capital, Addis Ababa. The area is between 6.72º–6.99ºN lat. and 37.61º–37.88ºE long., 1884 m above sea level. Rainfall is bimodal. Mean annual rainfall is between 1201–1600 mm, and mean annual temperature is 22–24 ºC.

Experimental feed

The coarse feed ingredients were first ground in a feed mill; then all ingredients were thoroughly and uniformly mixed. Soybean meal, sunflower seed cake and Niger seed (*Guizotia abyssinica*) cake were the major protein sources used in the formulation of different protein concentrations. The level of protein in the diets was increased from 140.3 to 220.0 g kg^{-1} DM, by replacing maize and wheat bran with roasted soybean, sunflower seed cake and Niger seed cake. The calculated energy, crude fibre, Ca and P contents of the treatment diets were closely similar (Table 3). The proportion of feed ingredients and the nutrient composition of the experimental diets are given in Tables 1 and 2.

Management of experimental animals

Experimental rooms were cleaned with water and detergent, then disinfected with for-

Table 1. *The proportion of feed ingredients used in experimental diets*

	Treatment diets				
Ingredients, g kg^{-1}	T1	T2	T3	T4	T5
Maize (white)	387.0	362.0	308.0	297.0	250.0
Wheat bran	333.0	240.0	187.5	80.0	25.0
Soybean (roasted)	50.0	113.0	197.0	283.0	375.0
Niger seed cake	95.0	140.0	160.0	180.0	185.0
Sunflower seed cake	105.0	115.0	117.5	130.0	135.0
Limestone[a]	20.0	20.0	20.0	20.0	20.0
Salt	5.0	5.0	5.0	5.0	5.0
Rear premix[b]	4.0	4.0	4.0	4.0	4.0
Lysine	0.5	0.5	0.5	0.5	0.5
Methionine	0.5	0.5	0.5	0.5	0.5
Total	**1000**	**1000**	**1000**	**1000**	**1000**

Note
a) Limestone contains 35% Ca (Boushy & Van der Poel, 2000)
b) Rear premix contents per kg: ash 655 g, crude protein 135 g, crude fat 2 g, crude fibre 9 g, lysine 90 g, methionine 20 g, threonine 5 g, Ca 100 g, Na 135 g, Chloride 230 g, Cu 3000 mg, Fe 4000 mg Mn 6000 mg, Zn 5000 mg, Co 20 mg, I 80 mg, Se 15 mg, vitamin A 1,000,000 if, vitamin D3 200,000 if, vitamin E 1500 mg (Pre-Mervo, Utrecht. EXPVALK)

malin (37%, v/v) two weeks before the experimental chicks were housed. Feeding and watering troughs were cleaned with water and detergent twice a week during the trial. Each replicate of ten chicks was housed in a pen constructed from wood and wire mesh, with 1×1.5 m floor space. Sawdust was spread on the floor of pens to a depth of 5 cm.

In total, 250 unsexed day-old RIR chicks were purchased from Bonga Poultry Husbandry Centre (Southern Ethiopia) and electrically brooded at Wolaita Soddo Poultry Husbandry Centre for nine days. Then, after weak chicks had been discarded, 200 chicks were randomly divided into 20 replicates of ten chicks each, with initial body mass of 52±0.5 g. Finally, four replicates were randomly assigned to each of the five treatment diets (Table 3). Chicks were vaccinated against Newcastle disease at 7 and 21 days of age, and against infectious bursal disease (Gumboro) at 14 and 28 days of age. The drug COCOBAN was used to prevent and treat coccidiosis. Mortality was recorded throughout the entire experimental period.

Known amounts of experimental diets were offered daily in two equal portions, in the morning and afternoon. The daily offer of each group was increased by 10% above the previous day's offer. Water was available at all times. Daily feed refused at each pen was collected, weighed and recorded before the daily feed was offered at 08:00 h. The chicks were weighed at the beginning, every week during the trial and at the end of the experiment. Weighing took place in the morning before feed was offered.

Measurement of carcass characteristics

At the end of the experiment, two chicks (1 male + 1 female) from each replicate (8 chicks/treatment), whose body mass was closest to the mean body mass of their respective

Table 2. *Chemical composition of feed ingredients used in the experimental diets*

	Feed ingredients				
Nutrients, g kg^{-1} DM	Maize (white)	Wheat bran	Soybean (roasted)	Niger seed cake	Sunflower seed cake
Dry matter	877.4	886.0	922.2	935.6	947.3
Mineral matter	16.0	43.5	57.5	108.0	58.6
Crude fibre	29.0	155.6	81.2	265.6	272.3
Crude protein	86.5	140.1	310.8	282.4	293.3
Nitrogen-free extract	835.0	612.0	326.0	271.0	302.8
Fat	33.0	48.0	223.3	72.5	73.0
Calcium	0.62	4.5	2.8	6.0	3.1
Phosphorus	3.5	8.1	6.7	6.9	6.7
Amino-acids[a]					
Methionine	1.8	2.3	6.2	3.1	8.0
Lysine	2.6	6.1	26.9	9.0	12.4
Cystine	1.8	3.2	6.6	3.4	6.4
Threonine	4.0	4.9	14.1	7.9	12.9
Tryptophan	1.0	2.0	5.1	-	4.1
Isoleucine	4.0	5.8	15.6	8.6	14.3
Leucine	11.0	10.7	27.5	13.4	22.2
Phenylalanine	5.0	6.4	17.8	8.7	16.6
Tyrosine	-	4.5	13.4	3.5	9.1

Note
a) Amino acid content of feed ingredients (as fed basis) was obtained according to Tacon (1987), Lauridsen et al. (2004) and Perry et al. (2004). DM=dry matter

groups and sexes, were selected. The chicks were identified by means of a leg band, and were starved for 12 h to allow emptying of the gut to minimize influence of digesta on live body mass at slaughter. Each bird was weighed and immediately killed by severing the jugular vein. Blood was completely drained onto a dish, and weighed. The bodies were then scalded for one minute and feathers manually plucked. Feather mass was taken to be slaughter body mass minus carcass body mass without feathers and blood. Edible offal (liver, skin and gizzard) and non-edible offal (shank + claws, head, lungs, heart, spleen, pancreas, digestive organs) were weighed and recorded. The carcass was further apportioned into commercially important parts (two drumsticks, two thighs, two wings, back and breast), and weighed. The dressing percentage was calculated as (commercial carcass body mass / slaughter body mass) × 100. Gizzard, skin and liver are edible offal in Ethiopia, and these added to the commercial carcass were used to calculate another version of dressing percentage.

Data analysis

Data obtained on DM intake, body mass gain, DM conversion ratio and measurement of carcass traits, were subjected to ANOVA using the General Linear Model (GLM) procedure of SPSS version 13 using the following model: $Y_{ijk} = \mu + A_i + S_j/A_i + e_{ijk}$; where, Y_{ijk} = individual values of the dependent variables; μ = grand mean of the response variable; A_i = the effect of the *i*th crude protein level (*i*=1, 2, 3, 4, 5) on the dependent variable S_j/A_i = the effect of the *j*th replicate (*j*=1, 2, 3, 4) under the *i*th crude protein level and e_{ijk}= random variation in the response of individual chick. Means were separated using Duncan's multiple range test. Treatment differences were considered significant at the P<0.05 level.

Results and discussion

Chemical composition of feeds

The chemical composition of feed ingredients is presented in Table 3. The rations were formulated to have five levels of protein between 140.3 and 220.0 g kg^{-1} DM, by replacing maize and wheat bran with the protein supplements roasted soybean, sunflower seed cake and noug seed cake. The energy, crude fibre, C and P contents of the treatment diets were close to one another.

Dry-matter intake, growth performance and dry-matter conversion ratio

The influence of dietary crude protein (CP) level on the DM intake of Rhode Island Red chicks fed for 12 weeks is presented in Table 4. The mean daily DM consumption of the chicks fed the different treatment diets did not differ significantly (P>0.05). This probably was related to the closely similar energy content of the diets (Melesse, 2007), or possibly the palatability of the diets was not affected by CP levels (Pond *et al.*, 2005). This result is in agreement with the reports of Kamran *et al.* (2000) and Oyedeji *et al.* (2005), that dietary CP level did not significantly (P>0.05) affect the feed intake of chicken. In disagreement with the result of the present study, Urdaneta-Rincón & Leeson (2008) reported that chicks fed on low CP diet (170 g kg^{-1} DM) had significantly lower (P<0.05) feed intake than chicks fed dietary CP ranging between 190–250 g kg^{-1} DM. Pfeffer *et al.* (2000) reported that, when broiler chicks were fed diets containing 225, 210, 190, 172, 153 g CP kg^{-1} DM, more feed was consumed (P<0.05) by chicks fed on the lowest CP diet, possibly because chicks were not able to meet their CP and other nutrient requirements with small intake. Jiang *et al.* (2005) reported that increasing dietary essential amino-acids above NRC in fact caused a significant linear reduction in feed intake, possibly because chicks were able to meet their amino-acids, CP and other nutrient requirements with small intake.

The mean daily body mass gain of the chicks fed the five treatment diets did not differ significantly (P>0.05). The protein sources used in the study were of good quality plant protein sources, and the combination of these protein feeds might have complemented each other, and could have met the minimum amino-acid demand of the chicks (Perry *et al.*, 2004); also, the demand for amino-acids might have been satisfied by the addition of critical amino-acids (lysine and methionine) to the diets (Sainsbury, 2000).

The results of the present study agree with those of other studies, which indicated that reduction of dietary CP to 16% did not significantly affect the body mass gain of growing chicken. Oyedeji *et al.* (2005) concluded

Table 3. *Nutrient composition of the experimental diets*

Nutrient composition [a]	Treatment diets				
	T1	T2	T3	T4	T5
Dry matter (DM), g kg-1	921.5	908.5	920.0	924.0	926.0
Crude protein, g kg-1 DM	140.3	160.2	180.4	200.4	220.0
ME, MJ kg-1 DM [b]	14.36	14.48	14.60	14.72	14.84
Crude fibre, g kg-1 DM	115.3	115.5	119.0	118.7	119.6
Calcium, g kg-1 DM	9.5	9.6	9.7	9.6	9.7
Total Phosphorus, g kg-1 DM	5.2	5.2	5.3	5.3	5.4
Methionine, g kg-1 DM	3.2	3.6	4.0	4.4	4.8
Lysine, g kg-1 DM	6.9	8.4	10.3	12.3	14.3
Cystine, g kg-1 DM	2.8	3.1	3.5	3.8	4.2
Threonine, g kg-1 DM	5.5	6.3	7.2	8.1	9.1
Tryptophan, g kg-1 DM	1.6	1.7	2.0	2.3	2.6
Isoleucine, g kg-1 DM	6.0	6.9	7.8	8.9	9.9
Leucine, g kg-1 DM	11.6	12.9	14.4	16.0	17.7
Phenylalanine, g kg-1 DM	6.9	7.8	8.9	10.1	11.2
Tyrosine, g kg-1 DM	3.2	3.8	4.8	5.6	6.7

Note

a) calculated according to information in Table 2.

b) ME = Metabolizable energy (kcal kg^{-1} DM) = 3951 + 54.40 fat – 88.70 crude fibre – 40.80 ash (Wiseman, 1987)

DM = dry matter; T1 = maize (387.0 g kg^{-1}) + wheat bran (333.0 g kg^{-1}) + roasted soybean (50 g kg^{-1}) + Niger seed cake (95.0 g kg^{-1}) + sunflower seed cake (105.0 g kg^{-1}) + limestone (20.0 g kg^{-1}) + salt (5.0 g kg^{-1}) + rear premix (4.0 g kg^{-1}) + lysine (0.5 g kg^{-1}) + methionine (0.5 g kg^{-1}); T2 = maize (362.0 g kg^{-1}) + wheat bran (240.0 g kg^{-1}) + roasted soybean (113.0 g kg^{-1}) + Niger seed cake (140.0 g kg^{-1}) + sunflower seed cake (115.0 g kg^{-1}) and same amounts of limestone, salt, rear premix, lysine and methionine as in T1; T3 = maize (308.0 g kg^{-1}) + wheat bran (187.5 g kg^{-1}) + roasted soybean (197.0 g kg^{-1}) + Niger seed cake (160.0 g kg^{-1}) + sunflower seed cake (117.5 g kg-1) and same amounts of limestone, salt, rear premix, lysine and methionine as in T1; T4 = maize (297.0 g kg^{-1}) + wheat bran (80.0 g kg^{-1}) + roasted soybean (283.0 g kg^{-1}) + Niger seed cake (180.0 g kg^{-1}) + sunflower seed cake (130.0 g kg^{-1}) and same amounts of limestone, salt, rear premix, lysine and methionine as in T1; T5 = maize (250.0 g kg^{-1}) + wheat bran (25.0 g kg^{-1}) + roasted soybean (375.0 g kg^{-1}) + Niger seed cake (185.0 g kg^{-1}) + sunflower seed cake (135.0 g kg^{-1}) and same amounts of limestone, salt, rear premix, lysine and methionine as in T1.

that a single diet of 180 g CP kg^{-1} DM fed to chicks from 0 to 8 weeks of age would be most suitable and convenient, rather than feeding differing CP contents during the brooding period. The authors also reported that the different feeding regimes did not significantly (P>0.05) affect the body mass gain of growing broilers. Kamran *et al.* (2000) suggested that, when diets were supplemented with critical amino-acids, dietary CP level could be reduced from 230 to 200 g CP kg^{-1} DM during the starter period, without any harmful effect on broiler performance. Pfeffer *et al.* (2000) reported that the feeding of broiler chicks on five diets containing 225 (control), 210, 190, 172, 153 g CP kg^{-1}, supplemented with essential amino-acids, resulted in no significant (P>0.05) influence on body mass gain.

Table 4. *Dry-matter intake, body mass gain and feed efficiency of Rhode Island Red chicks fed on different levels of dietary crude protein*

	Treatment diets					
Parameters	T1	T2	T3	T4	T5	SEM
Total dry-matter intake, g/chick	3401	3344	3473	3391	3299	118
Dry-matter intake, g/chick/d	40.49	39.82	41.35	40.37	39.29	1.40
Initial body mass, g/chick	51.73	51.75	51.75	51.78	51.78	0.48
Final body mass, g/chick	750	806	838	842	827	30.98
Total body mass gain, g/chick	698	754	786	791	775	30.92
Body mass gain, g/chick/d	8.31	8.98	9.36	9.42	9.23	0.37
Dry-matter conversion ratio	4.88^b	4.43^a	4.42^a	4.30^a	4.26^a	0.10

Notes
Means within the same row with different superscript letters are significantly different at P<0.05.
For composition of diets T1-T5, see Note to Table 3.

Although differences were not statistically significant, the daily body mass gain of chicks tended to increase linearly as the level of dietary CP increased from 140 up to 200 g CP kg^{-1} DM, then started to decline (Table 3). The difference in the trend of body mass gain increment was widest between 140 and 160 g CP kg^{-1} DM, but it was narrower between 180 and 200 g CP kg^{-1} DM, and became negative between 200 and 220 g CP kg^{-1} DM (Table 4).

Results for the dry-matter conversion ratio (DMCR), expressed as grams of daily dry-matter intake per gram of body-mass gain of the chicks fed on the treatment diets, indicated that chicks on the diet containing 140 g CP kg^{-1} DM required a significantly (P<0.05) larger amount of feed per unit of body mass gain, than those on other treatment diets. However, differences in DMCR among other treatments were not significant (P>0.05). This might be due to a lower concentration of amino acid per unit of DM in the 140 g CP kg^{-1} diet than in the other treatment diets, because the rest of the treatment diets contain larger amount of soybean with a good amino-acid profile, to achieve the same level of gain with the same amount of DM consumed. In agreement with the results of the present study, Pfeffer *et al.* (2000) reported that broiler chicks fed 153 g CP kg^{-1} diets had a poorer (P<0.05) feed-conversion efficiency. In disagreement with the results of the present study, the reduction of dietary CP to 16% did not significantly affect (P>0.05) the feed conversion ratio (Faria *et al.*, 2005; Kamran *et al.*, 2000; Kerr & Kidd, 1999; Oyedeji *et al.*, 2005).

Effect on carcass traits

Data on carcass traits of RIR chicks fed on different levels of dietary protein are presented in Table 5. Differences in slaughter body mass of chicks among treatment groups were not statistically significant (P>0.05). Total non-edible offal (TNEO) included feathers, blood, head, shank and claw, esophagus, crop, proventriculus, spleen, pancreas, kidney, heart, lung and intestines; and Total edible offal (TEO) included skin, gizzard and liver (Tera, 2007). Chicks on T1 had significantly (P<0.05) lower TNEO than those on T2.

Chicks on T3, T4 and T5 fell in between. Chicks on T1 and T2 had significantly (P<0.05) higher TEO than chicks on T3, T4 and T5. Total edible carcass (TEC) was calculated by adding the gizzard, skin and liver to back, drumsticks, thighs, wings and breast. Differences in TEC mass were not significant (P>0.05) among the feeding groups.

Dressing percentage, calculated from TEC, was affected by treatment. Chicks on T1 had a similar dressing percentage to those on T2 and T4, but had a significantly (P<0.05) higher dressing percentage than chicks on T3 and T5, presumably due to greater yield of skin of chicks on T1 (P<0.05) than those on T3 and T5. Hai and Blaha (2000) reported that reduction of dietary CP from 23 to 20% did not reduce the dressing percentage. The overall mean dressing percentage, including TEO as part of the carcass, was 63.1%. In agreement with this, Dana (1999) reported a similar dressing percentage (63%) for RIR hens kept on choice feeding of energy or protein feeds under intensive and semi-intensive management conditions in the central highlands of Ethiopia. Tera (2007) also reported that RIR chicks fed a diet containing about 200 g CP kg^{-1} DM had a dressing percentage of 56%.

Differences in dressing percentages calculated excluding TEO were, however, insignificant (P>0.05). The overall mean dressing percentage was 53.1%. In close agreement with the results of the present study, Tera (2007) reported a 55.6% dressing percentage for RIR chicks fed diets containing fish meal as a protein source. Contrary to the result of the present study, Maigualema & Gernat (2003) and Scanes *et al*. (2004) reported 70% dressing percentage for Arbor Acres × Arbor Acres Glastonbury broilers, probably due to breed differences.

There was no significant (P>0.05) difference among different treatment diets in commercial carcass yield In agreement with this, Hai & Blaha (2000) reported that reduction of dietary CP from 23 to 20% had no negative effect on the muscle proportion in live body mass. Nawaz *et al.* (2006) also reported that carcass mass did not vary significantly (P>0.05) between broiler chicks fed 160, 170 and 180 g CP kg^{-1} DM with 3000 kcal kg^{-1} ME, and 180, 190 and 200 g CP kg^{-1} DM with 3200 kcal kg^{-1} ME. Pfeffer *et al.* (2000) reported a similar result, that broiler chicks fed five iso-energetic (13MJ kg^{-1}) diets containing 225 (control), 210, 190, 172, 153 g CP kg^{-1} DM, and supplemented with essential amino-acids, exhibited no significant (P >0.05) influence on the relative body mass of various carcass cuts. As opposed to the results of the present study, Faria *et al.* (2005) and Zarate *et al.* (2003) observed a significant (P<0.05) decrease in carcass responses of broilers fed on a low CP diet. Kamran *et al.* (2004), however, reported higher carcass mass at 200 g CP kg^{-1} DM than at 230 g CP kg^{-1} DM, when low protein diets were supplemented with essential amino-acids in an ideal amino-acid pattern. The reason why carcass mass of chicks was not significantly affected by CP level may be that the lowest CP diet was sufficient for the synthesis of non-essential amino-acids, and thus RIR chicks fed on the low CP diet had low voluntary feed intake (Bregendahl *et al.*, 2002).

Economic analysis

As revealed by partial budget analysis of the economics of the operation, the level of dietary CP in the diet of growing RIR chicks moderately affects net return. Net return increased as the level of dietary CP increased from 140 to 160 g CP kg^{-1} DM, and decreased from then on. The highest net return was thus obtained from 160 g kg^{-1} DM dietary CP (Table 6).

Table 5. *Carcass characteristics of RIR chicken fed with different levels of dietary protein*

Variables, g/head	Treatment diets					
	T1	T2	T3	T4	T5	SE
Slaughter mass	740	809	710	778	736	39
Blood	21.5^{b}	16.8^{ab}	14.3^{a}	17.9^{ab}	19.1^{b}	1.5
Feather	31^{a}	55^{b}	54.1^{b}	48.6^{ab}	48.5^{ab}	6.1
Head	35.5^{a}	42.5^{b}	37.1^{ab}	39.6^{ab}	39.5^{ab}	1.9
Skin	39.5^{c}	37.1^{bc}	27^{a}	32.6^{abc}	31^{ab}	2.5
Shank	39.5	40.4	35.9	38.6	36.3	2.5
Heart	4.4	4.4	4.1	4.8	4	0.37
Liver	17.5	18	17.1	19.6	18.4	1.1
Gizzard	24.9	26	21.4	22.5	24.3	1.4
Lung	6.6	5.6	4.8	5.1	5	0.7
Kidney	6	6	5.4	5.9	6.8	0.59
Small intestine	32^{ab}	33^{ab}	31^{a}	37^{b}	38^{b}	2.2
Large intestine	15^{a}	16^{ab}	14^{a}	18^{b}	17^{ab}	0.96
Pancreas	2^{ab}	2.6^{b}	1.8^{a}	2^{ab}	1.9^{a}	0.22
Spleen	2.1	2.6	1.8	2.4	2	0.19
Proventriculus	4.8^{a}	5.3^{a}	4.9^{a}	6.9^{b}	5.4^{a}	0.36
Crop	4.8^{a}	5.6^{a}	6.6^{a}	6.3^{a}	5.3^{a}	0.74
Esophagus	5.9	7	5.6	6.8	5.8	0.50
Drumstick	64.1	69.8	61.5	66.8	63.1	3.7
Thigh	78.6	80.6	71.8	78.3	72.6	4.9
Wing	59.1	63.5	53.1	60.4	54.6	4.0
Back	82.9	87.4	77.4	84.8	78.4	6.6
Breast	108	133	113	129	117	7.8
TNEO	212^{a}	283^{b}	221^{ab}	240^{ab}	234^{ab}	19.7
TEO	81.87^{b}	81.13^{b}	65.50^{a}	74.75^{ab}	73.63^{ab}	3.76
TEC	475	516	442	494	458	27.1
Dressing % [1)]	64.19^{b}	63.69^{ab}	62.22^{a}	63.55^{ab}	61.93^{a}	1.08
Carcass mass	393	435	377	419	385	26.3
Dressing % [2)]	53.11	53.63	52.96	53.87	51.89	1.09

Notes
Means within the same row with different superscript letters are significantly different ($P<0.05$)
GM=Grand mean, 1) Dressing % with total edible offal, 2) Dressing % without total edible offal.
For composition of diets T1–T5, see Note to Table 3.

Table 6. *Partial budget analysis of treatment diets*

Items	Treatment diets				
	T1	T2	T3	T4	T5
Total feed consumed, kg/chick	3.40	3.34	3.47	3.39	3.30
Final mass of chick, kg/head	0.75	0.81	0.84	0.84	0.83
Cost of feed, ETB/kg	3.20	3.80	4.50	5.30	6.10
Total cost of feed consumed, ETB (TVC)	10.88	12.69	15.62	17.97	20.13
Sale of chicks, ETB/head (GR)	35.00	37.00	39.00	39.00	39.00
Net return (GR–TVC), ETB	24.12	24.31	23.38	21.03	18.87

Notes
GR = Gross Revenue; TVC = Total Variable Cost; 1 ETB = 0.077 USD in March 2009.
For composition of diets T1–T5, see Note to Table 3.

Conclusions

The overall results of the present study revealed that RIR chicks fed diets with crude protein content of 160 g kg^{-1} DM were similar in body mass gain, feed efficiency and important economic carcass traits, to chicks fed higher levels of dietary CP; mortality was nil and net return highest. Therefore, feeding RIR chicks with 160 g CP kg^{-1} DM from early life up to 93 days of age is recommended for areas with similar climatic conditions to Wolaita, Southern Ethiopia.

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Effects of storage duration and hydro-priming on seed germination and vigour of Common vetch

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Abstract

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The possibility for prolonged ambient seed storage, and the role of seed hydro-priming were studied in Common vetch (*Vicia sativa* L.) in the laboratory and greenhouse. Seeds stored for zero, one, two, and three years under ambient conditions at Kulumsa, Ethiopia, were soaked in distilled water for 24 h at 20±1°C and subsequently surface-dried at room temperature for *ca*. 6 h. Part of the seeds from the four storage durations was maintained unprimed, and was compared with hydro-primed seeds. Effects of ambient storage duration and hydro-priming, including their interactions, were significant (P<0.01) for all parameters considered. There was no significant reduction in germination percentage, speed of germination, and emergence index of seeds stored for up to two years, as compared to freshly harvested seeds. Despite its negative influence on germination percentage and some vigour parameters that depend on seed age, hydro-priming improved the speed of germination in all age groups, root length and Vigour Index-I of aged seed lots, and emergence index for zero and one-year storage duration. Therefore, Common vetch seeds can be stored under the ambient conditions of a tropical highland environment for about two years without significant loss in germination percentage and emergence index. The positive influences of hydro-priming on speed of germination and emergence index could be an opportunity to be considered in over-sowing studies with vetch on native pastures.

Keywords: Emergence, over-sowing, *Vicia sativa* L., tropical. ISSN 2222-5722.

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Introduction

Common vetch (*Vicia sativa* L.) is an annual legume commonly cultivated in the semiarid regions of Mediterranean countries. Varieties with forage production potential in pure stands and in association with small cereals, and for over-sowing of native pastures, are being promoted for use in the highlands of Ethiopia (KARC, 2007). Seed production of vetches in Ethiopia is limited, mainly because of fluctuating demand, which necessitates unforeseen long-term seed storage under adverse conditions.

Effects of adverse storage conditions on the seed vigour of various crop species have been well documented (Hopkinson & English, 2005; Ouzouline *et al.*, 2009). When stored under prevailing temperature and humidity conditions, seeds of many plant species lose viability and vigour within a short time, except for legume seeds with impermeable seed coats (Cupic *et al.*, 2005). Vigour loss is associated with biochemical losses associated with seed ageing (Murthy *et al.*, 2003). However, published data on the viability and vigour of Common vetch seeds after prolonged storage are scarce (Pita *et al.*, 2005).

Hydro-priming is one of the techniques used to improve the germination and vigour of seeds (Harris, 1996; Harris *et al.*, 1999). Hydro-priming improved the field performance of barley and chickpea (Rashid *et al.*, 2006; Ghassemi-Golezami *et al.*, 2008). However, Abush Tesfaye & Modi (2009) reported that hydro-priming negatively influences the normal germination of dry bean. Dehydration damage and loss of nutrients from large-seeded legumes accounted for the low performance of hydro-primed seeds. On the other hand, hydro-priming is reported to improve seed and seedling performance in wheat (Giri & Schellinger, 2003), sunflower (Hussain *et al.*, 2006), maize (Dezfuli *et al.*, 2008), and soybean (Mohammadi, 2009), whereas reports are rarely available on the role of hydro-priming on seed vigour of forage species, vetch seeds in particular. Therefore, the present study was carried out to investigate the effects of prolonged storage under the ambient conditions of a tropical highland environment, and to evaluate the potential role of hydro-priming in the germination and vigour of Common vetch seeds for over-sowing of native pastures.

Materials and Methods

Two sets of experiments were carried out in 2009, under laboratory and greenhouse conditions at Kulumsa Agricultural Research Centre, Ethiopia. The first set involved the testing of germination percentage and seedling growth (root length, shoot length, seedling dry mass); the second set involved the testing of speed of germination and emergence index. A 4×2 factorial combination, comprising four storage durations and two priming treatments, was laid out in a completely randomised design with four replications.

Seeds of Common vetch (*Vicia sativa* L.), variety IG-62786, produced at Kulumsa Agricultural Research Centre, Ethiopia, in the years 2008, 2007, 2006, and 2005, were stored for zero, one, two, and three years, respectively, under ambient conditions at temperatures of 6–28 °C, and relative humidity of 40–

85%. Seed moisture content at harvest of the four seed lots was between 10–11%.

In the laboratory, seeds were hydro-primed by complete-immersion soaking in distilled water, and incubated for 24 h at 20±1°C. The seeds then were surface-dried on blotting paper for *ca*. 6 h at room temperature. Part of a seed lot was kept unprimed. Note that the hydro-priming treatment was performed separately for the two sets of experiments, but with the same procedure.

The germination percentage was evaluated by taking 400 seeds (in four replications) per treatment, according to the ISTA (2005) rules. Seeds were placed in plastic boxes filled (up to 3 cm) with moistened fine sand (0.05–0.85 mm), and the boxes were placed in a cement-concrete germination room until the final counts were taken after 14 days. The temperature of the room was adjusted to 20±1°C.

After the final count in the standard germination test, seedling growth rate was assessed by measuring root and shoot lengths and seedling dry mass, on 10 normal seedlings per replicate randomly taken from the standard germination test. The means were computed.

Ten randomly selected seedlings were washed with running tap water, cut free from their cotyledons, placed in envelopes, then oven-dried at 80±1°C for 24 h, for determination of seedling dry mass, as suggested by Fiala (1987). Since the seedlings were obtained from the standard germination test, their age was 14 days after planting.

The speed of germination was measured in four replicates of 25 seeds from each treatment. Seeds were placed on double-layered Whatman #101 filter paper in 90-mm diameter Petri dishes, and kept in an incubator at 20±1°C for 20 days, until no further germination took place. Each day, normally germinated seeds (with radicles emerged more than 5 mm out of the seed coat) were removed, until seed germination had ceased. An index was calculated as follows:

Speed of Germination = $\Sigma(G_t / D_t)$,

where G_t is the number of germinated seeds on day t and D_t is the number of days after planting when the germinated seeds were counted.

The emergence index was recorded in a greenhouse, on seedlings grown in pots filled with untreated agricultural soil. To simulate field conditions, no temperature or humidity control was applied in the greenhouse during the study period. From every replicate of a treatment, 25 seeds were placed in rows, and covered with 3 cm of soil. The soil was then packed gently and pots were placed in a watering bath, to supply water from below the pots whenever needed. This was intended to avoid disturbing seed placement by watering from above. Daily emergence was counted, and continued until constant readings were obtained. The emergence index was calculated as $\Sigma (E_t / D_t)$, where E_t is the number of seedlings emerged, D_t is the number of days after planting when the seedlings were counted (Yang *et al.,* 2005).

Percentage values were arcsin transformed and analysed by means of the SAS Systems for Windows, Version 9 (SAS Institute Inc., 2002).

Results and Discussion

With one exception, germination percentage, root length, Vigour Index-I, seedling dry mass, Vigour Index-II, shoot length, speed of germination, and emergence index of Common vetch seeds were significantly ($P<0.01$) influenced by duration of storage, hydro-priming, and by their interaction (Table 1). The effect of hydro-priming on Vigour Index-I was non-significant. Since the interaction effects were highly significant for all traits investigated, the results and discussion are mainly based on the interactions.

Germination percentage

Mean germination percentage of unprimed seeds remained between 93–100 % for the first three seed-storage durations (Figure 1). The maximum germination percentage was recorded in unprimed seeds after one year's storage. The increase in germination percentage of Common vetch seeds with increased seed age could be attributed to the seed-coat characteristics of legumes. It is well documented that the exposure of legume seeds to adverse storage conditions can contribute to the softening of the impermeable seed coat, and improve the germination potential of seeds by enhancing gas and water uptake (Cupic *et al*., 2005). These authors reported an improved germination percentage in alfalfa seeds after four years' storage under ambient conditions. The present study has shown that storage of Common vetch seeds for up to two years under ambient conditions in a tropical highland environment may not adversely affect germination percentage.

The effect of hydro-priming on germination percentage was significantly negative for

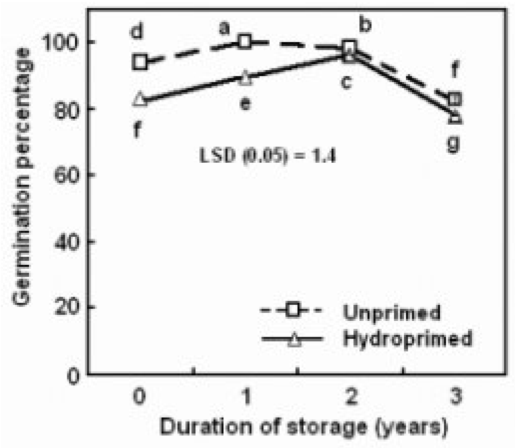

Figure 1. Germination percentage (%) of Common vetch seeds as affected by duration of seed storage and hydro-priming; means ±SE. Different letters show a significant difference at 0.05 level.

Table 1. *Analysis of variance for effects of duration of seed storage and hydro-priming on germination and vigour of Common vetch seeds*

Sources of Variation	DF	Germination (%)	Root length (cm)	Vigour Index-I	Shoot length (cm)	Seedling dry mass (mg)	Vigour Index-II	Speed of Germination	Emergence Index
Duration of storage	3	454.0**	4.7**	11035.4**	46.6**	0.2**	5256.7*	10.9**	69.1**
Hydro-priming	1	406.1**	2.2**	864.2ns	66.5**	0.5**	10099.8	92.3**	68.2**
Interaction	3	39.2**	7.1**	80881.9**	218.5**	0.3**	3536.8*	3.9**	28.9**
Error	24	0.90	0.20	1416.60	0.95	0.01	69.9	0.29	3.12
CV %		**2.2**	**5.1**	**4.9**	**5.7**	**4.6**	**4.8**	**6.0**	**7.1**
Mean		**90.1(67.4)**	**8.6**	**772.8**	**17.1**	**1.9**	**174.9**	**10.0**	**24.8**
R^2		**0.99**	**0.89**	**0.89**	**0.97**	**0.91**	**0.96**	**0.95**	**0.83**

Note: *Significant at 0.05 level; **Significant at 0.01 level; ns non-significant.

seeds from all storage durations (Figure 1). The reduction in germination percentage of hydro-primed seeds could be attributed to dehydration damage and nutrient leakage. When hydro-primed seeds were surface-dried for nearly 6 h at room temperature, dehydration damage to the embryo column may have occurred, hence there was an increase in the number of abnormal seedlings at the expense of normal germination. This result is in agreement with that of Abush Tesfaye & Modi (2009), where dehydration treatment of hydro-primed seeds reduced the percentage of normal germination in dry bean.

Seedling root length and vigour

The mean root length of unprimed seeds decreased as the duration of storage increased, up to two years (Figure 2). The superior root growth of unprimed, freshly harvested seeds could indicate that they have better initial nutrient reserves (proteins, lipids, starch) which, through storage under adverse conditions, were gradually depleted in the older seed lots. Earlier reports have shown that storage under adverse conditions could cause depletion of important nutrient reserves (Murthy *et al.*, 2003). The root length of unprimed seeds from the lot stored for three years was greater, but still was inferior to that of freshly harvested seeds.

Hydro-priming remarkably improved the root length of seedlings from one-, two- and three-year-old seed lots (Figure 1). Previous studies in *Zea mays* L. indicated positive influences of hydro-priming on radicle length (Dezfuli *et al.*, 2008). Better performance in root length of hydroprimed seeds could be attributed to earlier mobilisation of major nutrient reserves. Freshly harvested seeds, however, were negatively influenced by hydro-priming; this could be due to nutrient leakage, *cf.* Abush Tesfaye & Modi (2009).

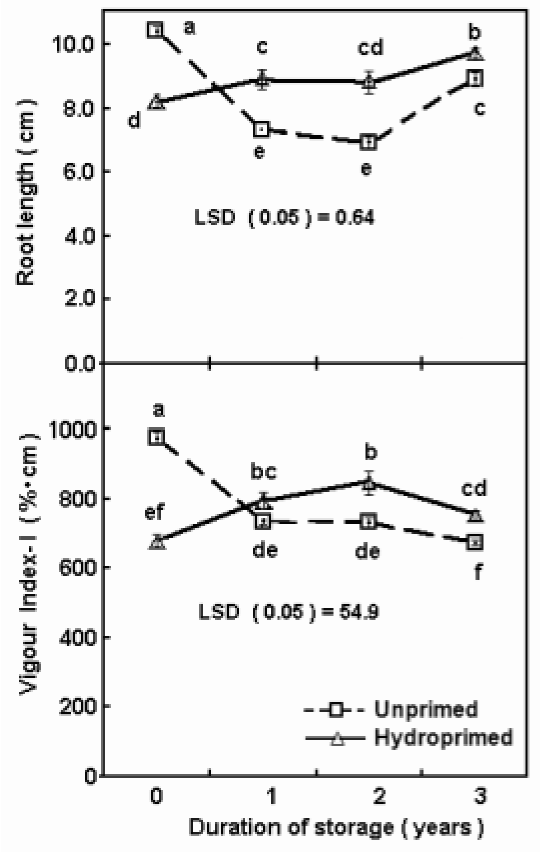

Figure 2. Root length and Vigour Index-I of Common vetch seeds as affected by duration of seed storage and hydro-priming; means ±SE. Different letters show a significant difference at 0.05 level.

Vigour Index-I (multiple of root length and germination percentage) indicated that unprimed, freshly harvested seeds were more vigorous at all durations of storage, than the remaining seed lots, including hydro-primed seeds (Figure 2). The vigour of unprimed seeds declined as seed age increased, up to three years. Murthy *et al.* (2003) reported a decline in vigour of *Vigna radiata* (L.) Wilczek as the seed-storage period increased from zero to several days. These authors indicated that loss of seed vigour was associated with biochemical deterioration during seed ageing. Hydro-priming improved seed vigour in older seed lots, indicating that there was faster rehabilitation of intracellular structures after the hydro-priming treatment.

Seedling dry mass and seedling vigour

Seedling dry mass of unprimed controls significantly decreased as seed storage duration increased (Figure 3). Vigour Index-II (multiple of seedling dry mass and germination percentage) results, however, indicated that unprimed seeds at storage durations of zero and one year were equally vigorous. Our result agrees with that of Makawi & van Gastel (2006), who reported a reduction in seedling dry mass after different periods of accelerated ageing treatment on seeds of different varieties of lentil (*Lens culinaris* Medikus). In our study, except for seeds stored for two years, hydro-priming negatively influenced seedling dry mass and seedling vigour at all storage durations.

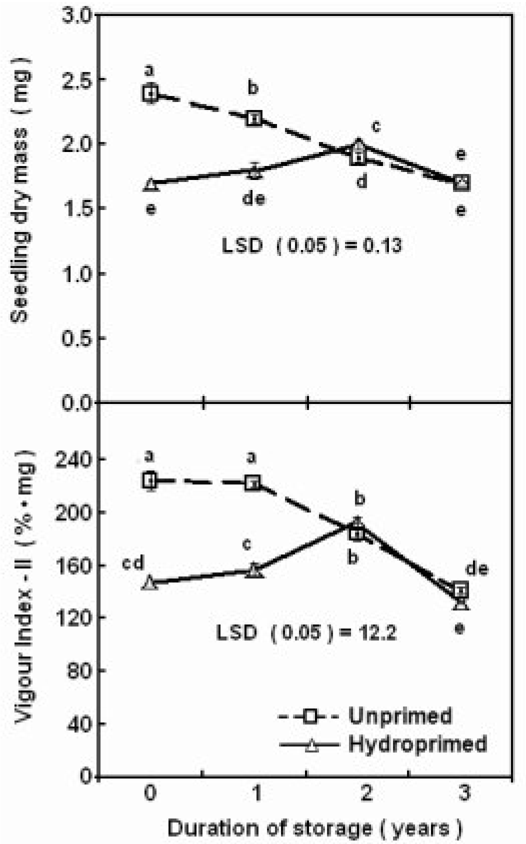

Figure 3. Seedling dry mass and Vigour Index-II of Common vetch seeds as affected by duration of seed storage and hydro-priming; means ±SE. Different letters show a significant difference at 0.05 level.

Shoot length

Shoot length of unprimed seeds was considerably higher for seed lots stored for one and two years, as compared to freshly harvested and three-year-old seed lots (Figure 4). This could be due to a higher germination capacity of the stored seed lots, which resulted in normal seedlings with longer shoots. Hydro-primed seeds of freshly harvested lots showed a significant improvement in shoot length, as compared to the unprimed control. Shoot length of seeds stored for one year was negatively influenced by hydro-priming.

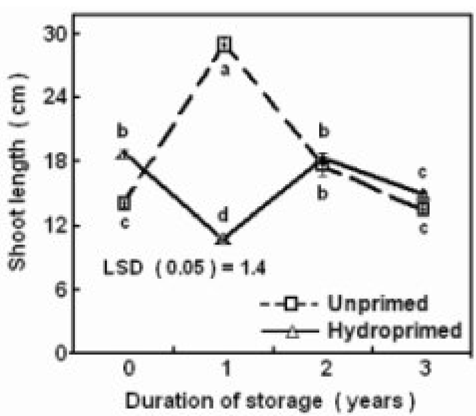

Figure 4. Seedling shoot length of Common vetch seeds as affected by duration of seed storage and hydro-primingmeans ±SE. Different letters show a significant difference at 0.05 level.

Speed of germination and emergence index

Speed of germination of unprimed seeds was not affected by storing seeds for up to two years under ambient conditions, whereas emergence index increased as seed-storage

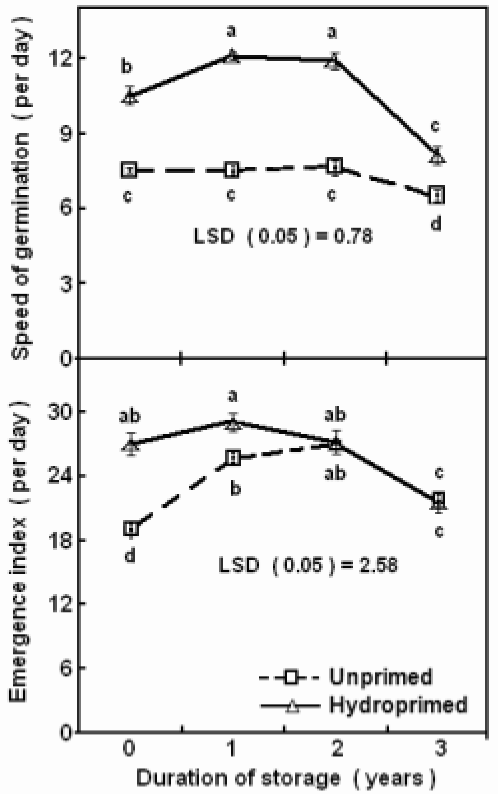

Figure 5. Speed of germination and seedling emergence index of Common vetch seeds as affected by duration of seed storage and hydro-priming; means ±SE. Different letters show a significant difference at 0.05 level.

duration increased, up to two years (Figure 5). Speed of germination, unlike germination percentage, seedling dry mass and shoot length, was significantly improved by hydro-priming at all durations of storage. For zero and one year's storage, emergence index was also improved by the hydro-priming of Common vetch seeds. Our results agree with those of Giri & Shillinger (2003) and Mohammadi (2009), who reported that hydro-priming significantly improved seedling emergence in wheat, and speed of germination in soybean. A faster rate of germination of hydro-primed seeds could be attributed to enhanced repair of the intra-cellular architecture, and mobilisation of hydrolytic enzymes required for visible germination to occur (Bewley, 1997).

Association of traits

The relationship between emergence index and vigour parameters such as speed of germination, Vigour Index-I and root length, was significant (Table 2). Germination percentage was positively related to emergence index, but the association was not statistically significant. The associations of speed of germination and root length with emergence index were strong (r = 0.70, and r = –0.65, respectively). Our results concerning the strong and positive association of emergence index with speed of germination is in agreement with the findings of Wang *et al.* (2004) for Purple vetch (*Vicia benghalensis* L.) and alfalfa (*Medicago sativa* L.). Those authors also reported a negative relationship between field emergence and root length, but it was weak and not statistically significant. The strong and negative association of root length with seedling emergence index observed in our study is, however, not tenable and calls for further investigation.

In conclusion, there was no significant reduction in germination percentage, speed of germination, and emergence index of Common vetch seeds stored for up to two years, as compared to freshly harvested seeds. Despite its negative influence on germination percentage and some vigour parameters that depend on seed age, hydro-priming improved the speed of germination of all age groups, root length and Vigour Index-I of aged seed lots, and emergence index at zero and one-year storage durations. Therefore, Common vetch seeds can be stored under the ambient conditions of a tropical highland environment for about two years without significant loss of germination percentage and emergence index. Since hydro-priming improved emergence index at the zero and one-year storage durations, this finding can be considered in the context of over-sowing of native pastures,

Table 2. *Pearson correlation coefficients of germination percentage, root length, Vigour Index-I, seedling dry mass, Vigour Index-II, shoot length, speed of germination, and emergence index of Common vetch seeds*

Parameter	Germination (%)	Root length (cm)	Vigour Index-I	Seedling dry mass (mg)	Vigour Index-II	Shoot length (cm)	Speed of Germination	Emergence Index
GP †	1.00							
RL	−0.57**	1.00						
VI_I	0.06	0.76**	1.00					
DW	0.67**	0.14	0.66**	1.00				
VI_II	0.85**	−0.11	0.52**	0.95**	1.00			
SL	0.70**	−0.61**	−0.31	0.42*	0.51**	1.00		
GS	−0.11	0.06	0.11	−0.21	−0.14	−0.20	1.00	
EI	0.28	−0.65**	−0.47**	−0.32	−0.09	0.20	0.70**	1.00

Note: *Significant at 0.05 level; **Significant at 0.01 level. †GP = Germination percentage, RL = Root length (cm), Vigour Index-I, DW = Seedling dry mass (mg), Vigour Index-II, SL = Shoot length (cm), GS = Speed of germination, EI = Emergence Index.

after further investigation of its applicability under harsher field conditions.

Our study has, however, several limitations that call for further investigation. First, the study involved a single variety, and lacks information on genotypic effects on responses to seed ageing, as well as to hydro-priming treatment. Moreover, the hydro-priming treatment was based only on a 24-h duration; shorter durations may need to be evaluated.

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Grain yield and malting quality of barley in relation to nitrogen application at mid- and high altitude in Northwest Ethiopia

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Abstract

Minale Liben, Alemayehu Assefa & Tilahun Tadesse 2011. Grain yield and malting quality of barley in relation to nitrogen application at mid- and high altitude in Northwest Ethiopia. *Journal of Science and Development* 1(1), 2011. 75-88. ISSN 2222-5722.

In the main cropping seasons of 2006-2007, a two-year field experiment on the response of malting barley varieties to nitrogen (N) application was conducted on nitosols of the Laie-Gaint, Gozamen and Yilmana-Denssa areas of northwestern Ethiopia. The aim was to determine the optimum N application rate for malting barley production. The experiment was a complete factorial arrangement in RCB with three replications. It consisted of 12 factorial combinations of four N rates (46, 69, 92, 115 kg N ha^{-1}), and three recently released malting barley varieties (HB-52, HB-1533 and Miscale-21). A blanket application of 46 kg ha^{-1} P (as P_2O_5) was applied across all treatments at the time of sowing. Grain yield and its protein content in all locations increased almost linearly as the N rate increased. Based on the findings of the experiment, it is recommended that fertiliser rates of 115/46 kg N/P_2O_5 ha^{-1} for HB-52, and 92/46 kg N/P_2O_5 ha^{-1} for Miscale-21, are economically optimum rates, with an acceptable grain quality standard in the Laie-Gaint, Yilmana-Denssa and Gozamen areas. For variety HB-1533, fertiliser rates of 92 kg N ha^{-1} and 115 kg N ha^{-1} are recommended, with acceptable grain quality in the Laie-Gaint and Gozamen areas, respectively. It is not recommended to grow the variety HB-1533 in the Yilmana-Denssa area, owing to its high protein content. Selection of appropriate varieties for different localities was also found to be crucial for maintaining the grain quality of malting barley at its standard level.

Keywords: Nitrogen application rates, Malting barley varieties, Protein content, Nitosols.

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Introduction

Barley (*Hordeum vulgare*) is one of the most important cereal crops, mainly grown by smallholder farmers at mid- and high altitudes in NW Ethiopia, predominantly between 2200–3000 m a.s.l (Asmare *et al.*, 1998.). Malting barley is used for preparing alcoholic beverages, mainly beer. ORDA (2008b) estimated that about 15,945 tons of malting barley is produced annually in Ethiopia. By contrast, the combined annual malting barley consumption of the six breweries in the country, was estimated at 48,330 tons, which is expected to double owing to the expansion of the existing breweries. Most of the demand for malt is met through imports, which account for 69% of the total annual requirement (ORDA, 2008a).

To satisfy the ever-increasing demand for raw materials by the beverage industry, and to ensure dependable and higher cash returns to the farmers, expansion of the malting barley production area is very important. Immense potential areas are available for malting barley production to meet the national demand. However, its production has not expanded, and productivity at farm level has remained low. One reason for the low productivity of the crop is the poor soil fertility of farmland, which is aggravated by continuous cropping, overgrazing, high soil erosion and removal of field-crop residues, without any soil amelioration. Nitrogen is deficient in most Ethiopian highland soils (Taye *et al.*, 1996). Particularly at farmers' level, an increase in crop production must achieve a high yield per unit area, which will require the application of improved technologies. Fertiliser application is a lead practice in the introduction of improved technologies for increasing crop yield.

Quality requirements for malting barley are fairly strict, and directly related to processing efficiency and product quality in the malting and brewing industries. Important characteristics for malting quality include grain protein concentration, grain size, malt extract and diastatic power (Henry, 1990). Grain protein content depends on soil fertility, and, more specifically, on the availability of N in the soil and in the plant for its conversion into grain protein. Excessively higher protein content is undesirable, because of the strong inverse correlation between protein and carbohydrate content; thus high protein content leads to a low malt extract level (Fox *et al.*, 2003). Grain N content is a determining factor of malt quality; high grain N content not only means lower carbohydrate content and lower malt extract level, but also makes the barley more difficult to modify, causing problems for the maltster. The preferred grain N level is not greater than 1.6–1.8% (Atherton *et al.*, 1984). Grain size is also an important malting quality parameter, because small grain contains less carbohydrate, and leads to a low malt extract level (Zhao *et al.*, 2006).

A high N application rate significantly increases grain yield, grain protein and grain N content, and decreases kernel weight and kernel plumpness. Split application of N at the anthesis stage of the crop also increases grain protein (Eagles *et al.*, 1995). Recommendations for an optimum level of N fertiliser, which ensures optimum grain yield without affecting the necessary malting barley qualities, are needed. Cultivars differ in malting quality characteristics, and are also influenced by environmental factors, including N nutrition (Weston *et al.*, 1993). Therefore, the identification of appropriate varieties of malting barley and the use of appropriate production practices are critical to the production of quality malting barley. Malting barley varieties have been released nationally. However, there are no studies on the interaction between N fertiliser rate and different malting barley varieties under different environmental conditions in the major barley-growing areas of the country. The present investigation was conducted with the aim of recommending appropriate malting barley varieties, with their respective optimum level of N fertiliser, for the major barley-growing areas of northwestern Ethiopia.

Materials and Methods

The study areas

The experiment was carried out on nitosols in three localities: Laie-Gaint (South Gondar), Yilmana-Denssa (West Gojam) and Gozamen (East Gojam) districts of NW Ethiopia during the main cropping season (May–October) of two consecutive years (2006 and 2007). The altitudes of the experimental areas are 3000, 2600 and 2240 m a.s.l. for Laie-Gaint, Gozamen and Yilmana-Denssa, respectively. The mean total annual rainfall (which mainly falls in the cropping season) is 1060 mm at Laie-Gaint, 1318 mm at Gozamen and 1133 mm at Yilmana-Denssa. The rainfall pattern of the areas is unimodal; the effective rainy period extends from May to October, with the peak during July. Mean monthly maximum and minimum temperatures are 18.3 and 8.0 °C at Laie-Gaint, 22.8 and 10.4 °C at Gozamen and 26.0 and 9.7 °C at Yilmana-Denssa, respectively (Table 1).

The experiment was conducted at 12 representative sites in total; five in Laie-Gaint, two in Gozamen and five in Yilmana-Denssa. The cropping pattern of the experimental areas is dominated by cereal crops. Pre-sowing soil samples were collected from each site, to estimate fertility status. A composite soil sample was taken at 0–20 cm, and analysed for its content of total nitrogen (N), pH, Organic Carbon (OC), Organic Matter (OM) and available phosphorus (P).

Treatments and experimental design

The experimental treatment consisted of 12 factorial combinations of three recently released malting barley varieties (HB-52, HB-1533 and Miscale-21), and four N rates (46, 69, 92 and 115 kg ha^{-1}). The treatments were laid out in a randomised complete block design (RCBD), in a complete factorial arrangement with three replications. Forty-six kg ha^{-1} of P (as P_2O_5) was applied across all treatments as a blanket application at the time of planting. The N application was split, half of the N being applied at sowing and the remaining half at the tillering stage of the crop. The sources of N and P were urea and DAP, respectively. Malting barley seed was broadcast-sown at a rate of 125 kg ha^{-1}. The gross plot was 5×4 m (20 m^2), and the net plot 4×3 m (12 m^2), respectively. Land preparation and time of sowing were according to the farmers' practice. The sowing date ranged between early and mid-June in both experimental years.

Data collection and analysis

Data were collected on grain yield, plant height, thousand-kernel weight, and hectolitre weight. The height of five randomly selected plants in each plot was measured, and average plant height was calculated. Analysis of variance was undertaken for all collected data by means of SAS statistical software. The Duncan multiple-range test was employed for

Table 1. *Total precipitation during the growing season and mean temperature averaged over the years 1998–2004*

Location	Total precipitation mm	Mean temperature °C	
		Max.	Min.
Laie-Gaint	897	17.5	8.3
Gozamen	1146	21.0	10.8
Yilmana-Denssa	1042	24.6	11.5

mean comparisons among treatments. A grain sample was taken at one representative site of each location for determination of grain protein content. The grain N content was analyzed by the Kjeldahl method, and the result was multiplied by 5.7 to obtain the grain protein content. The agronomic efficiency (AE) of applied N was also computed, as kg grain produced per kg N added.

The mean grain yield data were reduced by 10% to adjust the yield to the farmers' management conditions, and subjected to partial budget and sensitivity analysis (CIMMYT, 1988). The average market price of malting barley grain for the three months December–February during the experimental periods of 2006 and 2007 was used. The cost of urea fertiliser was considered as a variable cost for the economic analysis. The cost varied for each treatment, and treatments were ranked in order of ascending variable cost. Dominance analysis was used to eliminate those treatments which cost more, but which produced a lower net benefit, than the next lowest-cost treatment. The marginal rate of return (MRR) was calculated for each non-dominated treatment, and a minimum acceptable MRR of 100% was assumed (CIMMYT, 1988). A sensitivity analysis was made on the basis of the assumption that the cost of the fertiliser may increase by 50%, while simultaneously the grain price increases by 20% (Table 2).

Table 2. *The mean cost (Ethiopian Birr, ETB) of input and the price of raw barley grain at the experimental locations during the experimental periods*

Cost of input and price of output	**Current market situation**	**Assumption for sensitivity analysis**
Cost of urea fertiliser (ETB kg^{-1})	3.74	5.61
Price of grain (ETB kg^{-1})	3.81	4.57

Results and Discussion

According to the fertility classification of Landon (1991), the soil analysis of the locations shows that the soils of the experimental sites were acidic, with low pH, low to medium content of Organic Carbon (OC), medium content of available P and low total N content (Table 3).

The ANOVA results for the grain yield for each site within the three locations are shown in Table 4. The grain yield of malting barley exhibited statistically significant differences in response to N rate at almost all sites of the locations. In the Laie-Gaint area, two of the five sites, and in the Yilmana-Denssa area, all sites except one, showed significant differences in grain yield between varieties, whereas in the Gozamen area, none of the sites exhibited a significant yield difference due to variety. The interaction Variety×Nitrogen (V×N) showed non-significant differences in grain yield at almost all sites of the locations. The mean grain yield obtained from application of the lowest N rate (46 kg ha^{-1}) ranged between 1155–2612 kg ha^{-1} at Laie-Gaint, 285–1285 kg ha^{-1} at Yilmana-Denssa, and 1003–1249 kg ha^{-1} in the Gozamen area. The high yield potential of the sites is manifested in the application of the highest N rates (92 and 115 kg ha^{-1}). The highest mean yield ranged from 2394–5832 kg ha^{-1} at Laie-Gaint, 1965–2729 kg ha^{-1} at Yilmana-Denssa and 1823–2467 kg ha^{-1} at Gozamen (Table 4).

Table 3. *Mean value of important soil parameters, as measured on soil sample taken just before sowing at the experimental locations*

Location	Total N %	O.C. %	O.M. %	Available P ppm	pH
Laie-Gaint	0.22	2.12	3.65	9.5	4.94
Gozamen	0.18	1.52	2.62	10.1	4.68
Yilmana-Denssa	0.17	1.59	2.74	6.37	5.08

Table 4. *Results of analysis of variance for grain yield of individual sites at the three locations*

Source of variation	Laie-Gaient					Yilmana-Denssa					Gozamen	
	Site-1	Site-2	Site-3	Site-4	Site-5	Site-1	Site-2	Site-3	Site-4	Site-5	Site-1	Site-2
Variety (V)	*	*	NS	NS	NS	NS	*	**	**	**	NS	NS
Nitrogen (N)	**	NS	*	*	NS	*	NS	**	*	*	**	*
V×N	*	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS
Lowest mean yield	2612	2569	1169	1155	2612	1285	933	320	285	613	1003	1249
V×N for lowest yield	V2×N1	V2×N1	V3×N1	V2×N1	V2×N1	V1×N2	V1×N1	V1×N1	V1×N1	V1×N1	V1×N1	V1×N1
Highest mean yield	5832	4442	3229	2394	3430	2641	2729	2218	1965	2174	1823	2467
V×N for highest yield	V3×N3	V3×N4	V1×N4	V1×N2	V3×N3	V2×N3	V3×N2	V3×N4	V2×N4	V1×N4	V2×N4	V2×N4
CV %	19.58	26.08	30.42	24.90	29.08	24.5	28.8	22.4	24.6	25.7	20.08	30.5

The results of the combined analysis of variance (across the experimental sites at each locality) for grain yield, plant height, thousand-kernel weight and hectolitre weight are shown in Table 5. Site, variety, N and their interactions significantly affected most crop parameters in all of the locations, with the exception of the Site×N (S×N) interaction in the Laie-Gaint area. A significant Site×N interaction effect in other locations suggests that heterogeneity among the sites in initial soil N levels may have exerted a differential effect on the response of the crop to N application. It has been reported that the N-use efficiency of a crop is enhanced as a result of important soil factors that may affect available P, soil moisture and the nature and amount of clay in the soil (Desta, 1988).

Grain yield increased almost linearly in response to applied N in all the locations. The increase was 31, 48 and 80% at Laie-Gaint, Gozamen and Yilmana-Denssa, respectively, as the N application rate increased from 46 to 115 kg ha^{-1}. The agronomic efficiency of applied N was 12 for the first interval (*i.e.* from 46 to 69 kg N ha^{-1}), 15.3 for the second interval (69 to 92 kg N ha^{-1}) and 4.5 for the third interval (92 to 115 kg N ha^{-1}) in the Laie-Gaint area. Similarly, the AE was 14.3, 11.8, 12.0 in the Yilmana-Denssa area and 8.9, 7.1, 10.7 in the Gozamen area for the first, second and third intervals, respectively (Figure 1). The varieties responded differently at these three locations. The variety HB-52 gave the highest yield at Laie-Gaint, whereas HB-1533 and Miscale-21 did so at Gozamen and Yilmana-Denssa, respectively. The highest mean grain yield, 3437 kg ha^{-1} at Laie-Gaint, 2072 kg ha^{-1} at Yilmana-Denssa and 2145 kg ha^{-1} at Gozamen, were obtained from the respective variety with the application of the highest N rate (Table 6). There was an increase of 62%, 185% and 91% over the lower rate at Laie-Gaint, Yilmana-Denssa and Gozamen, respectively. Among the locations, the lowest grain yield was recorded in the Yilmana-Denssa area, which might be due to the relatively higher temperature there (Table 1), compared to the other two locations.Schelling *et al.* (2003) stated that temperature had the strongest influence on the duration of grain filling; yield reductions between 4.1 and 5.7% have been calculated for every 1°C increase in the diurnal mean temperature.

Plant height increased in all varieties and in all locations as N rates increased (Figure 2 and 3). Variety Miscale-21 had the greatest plant height, compared to the other varieties (Figure 2). The greatest and least plant height among the locations was recorded at Laie-Gaint and Yilmana-Denssa, respectively (Figure 3). The record plant height (110.6 cm) was from the variety Miscale-21 at the highest N application rate in the Laie-Gaint area. Plant height is strongly correlated with grain yield, and showed a similar trend in all locations. The correlation across locations, as indicated in Figure 4, was positive and significant ($P = 0.0001$).

Thousand-kernel weight and hectolitre weight are more affected by variety than by the N application rate. As the N application rate increased, thousand-kernel weight increased in the Laie-Gaint and Yilmana-Denssa areas. The highest thousand-kernel weight was recorded in varieties HB-1533 and Miscale-21, as compared to HB-52, at all locations (Table 7). According to the Ethiopian quality standard, the acceptable grain size (thousand-kernel weight) and test weight (hectolitre weight) for raw barley are in the range 25–35 g and 48–62, respectively (EQSA, 2006). The results of the present experiment exhibited an acceptable thousand-kernel weight and hectolitre weight in all varieties for all N application rates at all locations (Tables 7 and 8).

Table 5. *Results of combined analysis of variance for all measured crop parameters at the three locations*

Source of Variation	Laie-Gaint				Yilmana-Denssa				Gozamen			
	Grain yield kg ha^{-1}	Plant height cm	Thousand-kernel wt g	Hectolitre wt	Grain yield kg ha^{-1}	Plant height cm	Thousand-kernel wt g	Hectolitre wt	Grain yield kg ha^{-1}	Plant height cm	Thousand-kernel wt g	Hectolitre wt
Site (S)	**	**	**	**	**	**	**	**	NS	*	*	-
Variety (V)	**	**	**	**	**	**	**	**	*	**	**	*
V×S	NS	**	**	NS	*	**	**	**	NS	**	*	-
Nitrogen (N)	**	**	*	NS	**	**	**	*	**	**	NS	NS
N×S	NS	NS	NS	NS	*	*	NS	NS	NS	*	NS	-
V×N	*	*	*	NS	*	*	*	*	*	*	NS	NS
V×N×S	*	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	-
Lowest value	2124	82.5	39.3	63.3	728	64.7	31.4	61.5	1126	76.2	31.3	57.8
Highest value	3437	110.6	43.5	68.3	2072	92.2	40.9	64.5	2145	95.0	38.7	63.2
V×N for highest value	V2×N4	V3×N4	V3×N4	V3×N4	V3×N4	V3×N4	V3×N4	V3×N4	V2×N4	V3×N3	V2×N4	V3 x N4
CV %	25.94	6.71	6.62	4.74	26.51	9.45	6.66	2.93	31.07	6.76	8.06	4.16

Note: *, ** significant difference at 5%, 1% probability levels, respectively NS-Non-significant
V1= HB-52 V2 = HB-1533 V3 = Miscale-21 N1 = 46 kg N ha^{-1} N2 = 69 kg N ha^{-1} N3 = 92 kg N ha^{-1} N4 = 115 kg N ha^{-1}

Table 6. *Effect of N application rate on the grain yield of malting barley varieties at the three locations*

N (kg ha^{-1})	Laie-Gaint				Gozamen				Yilmana-Denssa			
	HB-52	HB-1533	Miscale-21	Mean	HB-52	HB-1533	Miscale-21	Mean	HB-52	HB-1533	Miscale-21	Mean
46	2555	2124	2496	2391	1126	1561	1183	1290	728	982	1575	1095
69	2838	2354	2810	2667	1421	1574	1492	1495	1148	1336	1786	1423
92	3050	2794	3211	3018	1520	1813	1879	1737	1441	1657	1986	1695
115	3437	2832	3097	3122	1652	2145	1914	1904	1890	1950	2072	1971
Mean	2970	2526	2904		1370	1773	1617		1302	1481	1855	
	V	N	V×N		V	N	V×N		V	N	V×N	
Std Err	93.76	108.27	187.53		100.6	116.2	201.3		52.9	61.1	105.8	
LSD (0.05)	262.8	303.4	525.6		289.9	331.2	573.7		148.3	171.2	296.6	

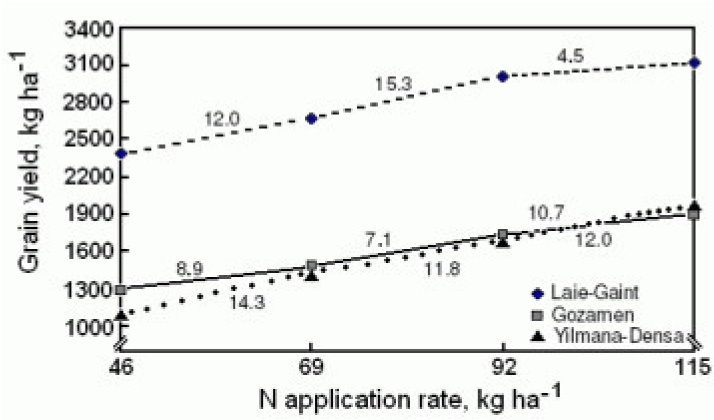

Figure 1. Grain yield response and agronomic efficiency of malt barley to N application rates in the three localities.

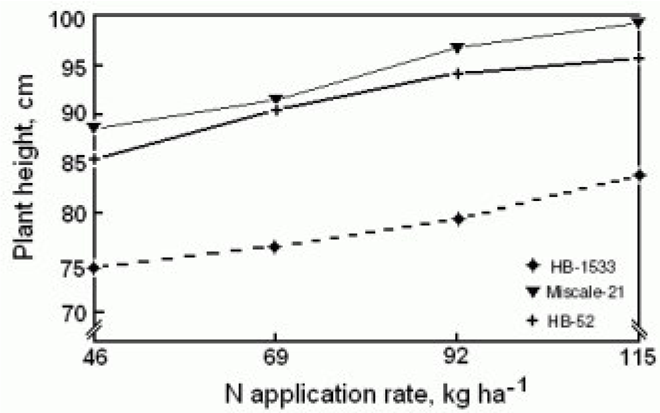

Figure 2. Plant height response of malt barley varieties to N application rates across the localities.

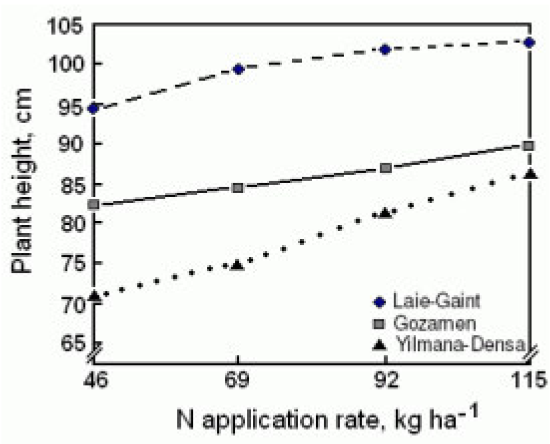

Figure 3. The overall plant height response of malt barley to N application rates in different localities.

Grain protein content increased with higher N application rates in all varieties at all locations (Table 9). For variety HB-52, grain protein content ranged from 8.9% in Gozamen with the application of 46 kg N ha^{-1}, to 11.8% in Laie-Gaint, at the highest N rate (115 kg N ha^{-1}). For variety HB-1533, grain protein content ranged from 9.4% in Gozamen at 46 kg N ha^{-1}, to 13.3% in Yilmana-Denssa at 92 kg N ha^{-1}, whereas for variety Miscale-21 the range was from 8.9% in Gozamen, at 46 kg N ha^{-1}, to 11.3% in Yilmana-Denssa, at 92 kg N ha^{-1}. Grain

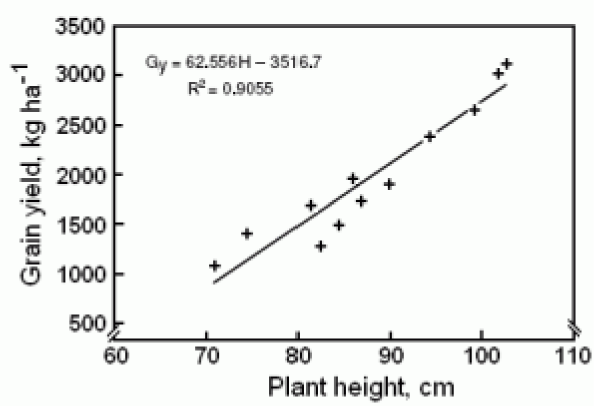

Figure 4. The relationship between grain yield (G_y) and plant height (H) of malt barley across the localities.

protein content was highest in variety HB-1533 as compared to the other two varieties. According to the Ethiopian standards authority, the raw barley quality standards for malt have a protein level between 9–12%**.** The results of the experiment showed that all varieties, except HB-1533 at the highest N rate (115 kg N ha^{-1}), gave a grain protein content within the acceptable range in the Laie-Gaint area. In the Gozamen area, all varieties, except at the lowest rate (46 kg N ha^{-1}) for HB-52 and Miscale-21, had a grain protein content within the acceptable range. By contrast, in Yilmana-Denssa, HB-52 and Miscale-21 exhibited an acceptable grain protein content at all N application rates, but HB-1533 did not do so, owing to its high protein content (Table 9). The superior protein content of the grain in Yilmana-Denssa was possibly due to the high temperature in that area, as compared to the other locations (Table 1). Eagles *et al.* (1995), Savin & Nicolas (1996) and Wallwork *et al.* (1998) indicated that high temperatures during grain-filling appear to reduce grain quality in malting barley, owing to the reduction in starch accumulation and the increase in the N% of the grain. Savin *et al.* (1996) also stated that high temperature reduced the amount of 'maltable' grain, by reducing grain size and increasing the screening percentage, and reduced malt extract by 3–7%, which represents a large decrease for the malting industry.

The results of the partial budget analysis (Tables 10, 11, 12) revealed that the economically optimum fertiliser application rate varies in relation to the varieties and locations. Since grain quality is the major concern of this paper, the economical application rates that are within the acceptable level of grain protein content, thousand-kernel weight and hectolitre-weight, are to be selected. For varieties HB-52 and Miscale-21, the fertiliser rates 115 and 92 kg N ha^{-1}, respectively, are economical rates, with acceptable grain quality at all locations. For variety HB-1533, fertiliser rates of 92 kg N ha^{-1} and 115 kg N ha^{-1} were economical rates, with acceptable grain quality in the Laie-Gaint and Gozamen areas, respectively. In the Yilmana-Denssa area, none of the fertiliser rates for variety HB-1533 was optimum for retaining the desired grain quality. The protein content of HB-1533 in the Yilmana-Denssa area was beyond the limit, and none of the N application rates gave a grain protein content within the acceptable range. Moreover, an economic sensitivity analysis was carried out to test the sensitivity of the recommended fertiliser rates to changes in input cost and output price. The economically optimum rates remain profitably recommendable even under worst cost and price assumptions at all the tested locations.

Table 7. *Effect of N application rate on thousand-kernel weight of malting barley varieties at the three locations*

	Laie-Gaint				Gozamen				Yilmana-Denssa			
N (kg ha^{-1})	HB-52	HB-1533	Miscale-21	Mean	HB-52	HB-1533	Miscale-21	Mean	HB-52	HB-1533	Miscale-21	Mean
46	39.3	40.8	42.4	40.8	31.3	36.0	35.7	34.4	31.4	36.1	39.2	35.4
69	39.8	41.6	41.8	41.1	32.0	36.5	37.6	35.4	32.2	37.3	39.2	36.2
92	39.6	42.1	42.2	41.3	29.4	37.5	36.6	34.5	32.2	38.3	39.8	36.8
115	40.9	43.5	43.4	42.6	30.4	38.7	36.9	35.3	33.7	40.4	40.9	38.3
Mean	39.9	42.0	42.4		30.8	37.2	36.7		32.4	38.0	39.8	
	V	N	V×N		V	N	V×N		V	N	V×N	
StdErr	0.35	0.40	0.70		0.57	0.66	1.14		0.31	0.36	0.63	
LSD (0.05)	0.99	1.14	2.10		1.64	NS	3.27		0.88	1.02	1.76	

Table 8. *Effect of N application rate on hectolitre weight of malting barley varieties at the three locations*

	Laie-Gaint				Gozamen				Yilmana-Denssa			
N (kg ha^{-1})	HB-52	HB-1533	Miscale-21	Mean	HB-52	HB-1533	Miscale-21	Mean	HB-52	HB-1533	Miscale-21	Mean
46	66.7	63.4	65.9	65.4	60.3	59.3	59.9	59.8	61.9	61.5	63.1	62.2
69	66.4	63.3	65.9	65.2	60.5	58.9	63.2	60.9	62.0	61.9	62.3	62.1
92	66.7	63.4	65.1	65.1	57.8	62.0	62.5	60.7	61.7	60.2	63.9	62.6
115	67.0	64.2	68.3	66.5	58.5	62.0	63.2	61.2	62.9	63.5	64.5	63.6
Mean	66.7	63.6	66.4		59.3	60.8	62.2		62.1	62.2	63.5	
	V	N	V×N		V	N	V×N		V	N	V×N	
StdErr	0.40	0.46	0.80		0.73	0.84	1.45		0.23	0.27	0.47	
LSD (0.05)	1.63	NS	NS		2.13	NS	NS		0.66	0.76	1.32	

Table 9. *Grain protein content of malting barley varieties as influenced by N application rate at the three localities*

Treatments	Protein content %		
	Laie-Gaint	Gozamen	Yilmana-Denssa
HB-52 + 46 N/46 P_2O_5 ha^{-1}	9.4	8.9	10.1
HB-52 + 69 N/46 P_2O_5 ha^{-1}	9.4	9.4	10.8
HB-52 + 92 N/46 P_2O_5 ha^{-1}	10.3	9.4	10.2
HB-52 + 115 N/46 P_2O_5 ha^{-1}	11.8	10.1	10.8
HB-1533 + 46 N/46 P_2O_5 ha^{-1}	10.6	9.4	12.8
HB-1533 + 69 N/46 P_2O_5 ha^{-1}	11.2	10.6	12.9
HB-1533 + 92 N/46 P_2O_5 ha^{-1}	11.5	10.9	13.3
HB-1533 + 115 N/46 P_2O_5 ha^{-1}	12.3	11.7	12.4
Miscale-21 + 46 N/46 P_2O_5 ha^{-1}	9.7	8.8	10.6
Miscale-21 + 69 N/46 P_2O_5 ha^{-1}	10.2	9.0	10.8
Miscale-21 + 92 N/46 P_2O_5 ha^{-1}	10.9	9.4	11.3
Miscale-21 + 115 N/46 P_2O_5 ha^{-1}	10.8	9.9	10.3

Table 10. *Results of the economic analysis of N application rate on the grain yield of malting barley in the Laie-Gaint area*

Variety	N rates kg ha^{-1}	Economic analysis			Sensitivity economic analysis		
		TVC (ETB)	NB (ETB)	MRR (%)	TVC (ETB)	NB (ETB)	MRR (%)
HB-52	46	227.6	8533.5		335.3	10173.4	
	69	414.6	9316.9	418.9	610.8	11061.9	322.5
	92	601.6	9856.8	288.7	886.3	11658.3	216.5
	115	788.6	10996.9	609.6	1161.8	12974.5	477.8
HB-1533	46	227.6	7055.6		335.3	8400.7	
	69	414.6	7657.2	321.7	610.8	9071.2	243.4
	92	601.6	8979.0	706.8	886.3	10605.4	556.9
	115	788.6	8922.3 **D**		1161.8	10486.2 **D**	
Miscale-21	46	227.6	8331.2		335.3	9930.7	
	69	414.6	9220.9	475.8	610.8	10946.7	368.8
	92	601.6	10408.9	635.3	886.3	12320.5	498.7
	115	788.6	9831.0 **D**		1161.8	11576.1 **D**	

Note: TVC= Total Variable Cost, NB= Net Benefit, MRR= Marginal Rate of Return, D= Dominated treatment. Values in Ethiopian Birr (ETB).

Table 11. *Results of the economic analysis of N fertiliser application rate on the grain yield of malting barley in the Yilmana-Denssa area*

Variety	N rates kg ha^{-1}	Economic analysis			Sensitivity economic analysis		
		TVC (ETB)	NB (ETB)	MRR (%)	TVC (ETB)	NB (ETB)	MRR (%)
HB-52	46	227.6	2303.0		335.3	2700.1	
	69	414.6	3521.9	651.8	610.8	4110.9	512.1
	92	601.6	4339.6	437.3	886.3	5040.5	337.4
	115	788.6	5692.2	723.3	1161.8	6611.7	570.3
HB-1533	46	227.6	3139.7		335.3	3703.6	
	69	414.6	4166.5	549.1	610.8	4884.1	428.5
	92	601.6	5080.2	488.6	886.3	5928.9	379.2
	115	788.6	5897.9	437.3	1161.8	6858.5	337.4
Miscale-21	46	227.6	5173.1		335.3	6142.6	
	69	414.6	5709.6	286.9	610.8	6735.0	215.0
	92	601.6	6208.4	266.7	886.3	7282.1	198.6
	115	788.6	6316.3	57.7	1161.8	7360.3	28.4

Note: TVC= Total Variable Cost, NB= Net Benefit, MRR= Marginal Rate of Return, D= Dominated treatment. Values in Ethiopian Birr (ETB).

Table 12. *Results of the economic analysis of N fertiliser application rate on the grain yield of malting barley in the Gozamen area*

Variety	N rates kg ha^{-1}	Economic analysis			Sensitivity economic analysis		
		TVC (ETB)	NB (ETB)	MRR (%)	TVC (ETB)	NB (ETB)	MRR (%)
HB-52	46	227.6	3633.4		335.3	4295.9	
	69	414.6	4458.0	440.94	610.8	5233.7	340.41
	92	601.6	3797.8 **D**		886.3	5365.4	47.80
	115	788.6	4876.1	111.79	1161.8	5632.8	97.07
HB-1533	46	227.6	5125.1		335.3	6085.1	
	69	414.6	4982.6 **D**		610.8	5863.0 **D**	
	92	601.6	5615.2		886.3	6570.5	88.11
	115	788.6	6566.6	508.79	1161.8	7660.5	395.65
Miscale-21	46	227.6	3828.9		335.3	4530.3	
	69	414.6	4701.5	466.6	610.8	5525.8	361.3
	92	601.6	5841.5	609.6	886.3	6842.0	477.8
	115	788.6	5774.5 **D**		1161.8	6710.4 **D**	

Note: TVC= Total Variable Cost, NB= Net Benefit, MRR= Marginal Rate of Return, D= Dominated treatment. Values in Ethiopian Birr (ETB).

Conclusions and Recommendations

The grain yield and quality of malting barley vary with locality. Laie-Gaint is an ideal area for malting barley production, compared to the Gozamen and Yilmana-Denssa areas. The variety HB-1533 is not recommended for cultivation as malting barley in the Yilmana-Denssa area, because of its high protein content. Therefore, the selection of appropriate varieties for different localities is one of the issues to be considered in the future, so as to maintain the grain quality of malting barley at its standard level. Grain quality, especially with respect to protein content, is highly influenced by variety and by N fertilisation. The determination of a specific N application rate for malting barley varieties is essential to the production of malting barley grain of acceptable quality. Fertiliser application rates of 115/46 kg N/P_2O_5 ha^{-1} for HB-52, and 92/46 kg N/P_2O_5 ha^{-1} for Miscale-21, are economically optimum and recommendable rates for malting barley production in the Laie-Gaint, Yilmana-Denssa and Gozamen areas.

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