African Crop Science Journal, Vol. 20, Issue Supplement s2, pp. 337 - 347 ISSN 1021-9730/2012 $4.00
Printed in Uganda.

IMPACT OF CLIMATE CHANGE ON SMALL-HOLDER FARMING: A CASE OF EASTERN TIGRAY, NORTHERN ETHIOPIA

KASSA TEKA[1, 2], A. VAN ROMPAEY[2], J. POESEN[2], YEMANE WELDAY[1] and J. DECKERS[2]
[1]Department of Land Resources Management and Environmental Protection, Mekelle University, P. O. Box 231, Mekelle University
[2]Department of Earth and Environmental Sciences, K.U.Leuven, Celestijnenlaan 200E, B-3001, Heverlee, Belgium
Corresponding author: kassateka@yahoo.com

ABSTRACT

Although there are well-established concerns about climate change effects in northern Ethiopia, there is little quantitative information concerning how serious these effects are to small holder farming. Moreover, studies on farm level adaptations that farmers make to minimise the potential impacts of climate change are lacking. Both quantitative and qualitative information were, therefore, collected in a household survey in three representative agro-ecological zones to investigate these problems. There was a general perception among rural households that crop and livestock production, and land productivity declined in the last 20 years. The reduction was related to changes in rainfall. The rainfall was extremely unpredictable and erratic with a coefficient of variation ranging from 18 percent in the midlands to 42 percent in the lowlands. Livestock holding size and crop yield showed a positive correlation with rainfall amount. However, the number of pack animals significantly increased regardless of the decreased rainfall amount. This increased was due to farmers' shift to off-farm activities.

Key Words: Adaptation, livestock, pack animals

RÉSUMÉ

Même si les problèmes liés aux effets du changement climatique sont bien connus au Nord de l'Ethiopie, les informations en rapport avec l'ampleur de ces effets sur les petits exploitants restent insuffisantes. En plus, il n'ya aucune étude disponible sur les mécanismes d'adaptation que les fermiers utilisent pour minimiser les impacts potentiels du changement climatiques. Les données quantitatives et qualitatives étaient collectées au cours d'une enquete de ménages dans trois zones agro écologiques représentatives, afin d'étudier ces problèmes. Les résultats ont montré que les fermiers perçoivent généralement que la production des cultures et d'élevage ainsi que la productivité des terres ont diminué depuis les 20 dernières années. Cette diminution était liée au changement dans la pluviométrie. La pluviométrie était extrêmement imprédictible et erratique avec un coefficient de variation allant de 18% dans les *midlands* à 42% dans les bas fonds. La taille de la possession d'élevage et le rendement des cultures ont montré une corrélation positive avec la quantité des pluies. Cependant, le nombre du bétail en stabulation a significativement augmenté malgré la diminution des pluies. Cette augmentation était due à la création d'autres activités non agricoles.

Mots Clés: Adaptation, élevage, élevage en stabulation

INTRODUCTION

As climate varies or changes, several direct influences alter precipitation amount, intensity, frequency and type (Mendelsohn and Dinar, 1999; Ravindranath and Sathaye, 2002; Winkler, 2005; Aklilu and Alebachew, 2009). Although there are many impacts expected from climate change, one of the largest impacts is expected to be on agriculture (Nordhaus, 1991; Pearce, 1996). The majority of the rural people in developing countries and in the northern Ethiopian highlands in particular depend heavily on rain-fed subsistence agriculture and the daily exploitation of natural resources (Alebachew, 2011). Droughts and floods are very common occurrences with significant events every 3 - 5 years (World Bank, 2006). Because of changes in the patterns of the local climate, this region is exposed to chronic food shortages, degradation of natural resources, unstable livelihoods and distress migration (Markos, 1997; Alebachew, 2000; Alebachew, 2011). The current farming technology in the northern Ethiopian highlands is basic and incomes are low, suggesting that farmers will have few options to adapt (Mendelsohn, 2000). Adaptation enhances the capacity of people and governments to reduce climate change impacts (Kates, 2000; Tompkins and Adger, 2003).

Although there are well-established concerns about climate change effects worldwide, there is little quantitative information concerning how serious these effects are to the small holder farming. Studies on farm level adaptations that farmers make to cope with the impacts of climate change are also lacking. These seriously limit policy formulation and decision making in terms of adaptation and mitigation strategies.

The aim of this study was, therefore, to assess the impact of climate change on the agricultural productivity of small-holder farmers in northern Ethiopia.

MATERIALS AND METHODS

Study area. The eastern part of Tigray Province in northern Ethiopia was selected as a study area. The study area is situated on the western shoulder of the Great Rift Valley, with altitudes that range from 500 to 3050 meter above sea level in the northeast of the Tigray province. The study area can be split up in 3 agro-ecological zones: lowland (less than 1500 m above sea level), midland (1500 to 2300 m above sea level) and highland (2300 to 3000 m above sea level). Eastern Tigray has an estimated population of about 1,500,000, which, corresponds to an average population density of 124 persons per Km^2. About 75.5 percent of the population lives in the rural areas (CSA, 2008).

The dominant farming system is mixed farming with arable crop growing and livestock breeding. Major crops grown include sorghum (*Sorghum bicolor* L.), teff (*Eragrostis tef*), maize (*Zea mays* L.), finger millet (*Eleusine coracana*), wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.) and pulses. Most farming households keep livestock (e.g. sheep, goat and cattle) which are herded on rangeland during the growing season. After harvest, the livestock can graze the residues on arable land. The rural population mainly keeps livestock for milk production whereby the total livestock is seen as an investment (Nyssen *et al*., 2009).

Study method. The study was conducted in five villages representing three agro-ecological zones: highland (Aynimbrkekn and Hadnet), midland (Dergajen and Sinkata) and lowland (Endaselasie). Rainfall data (Table 2) were acquired from the National Meteorological Agency. Agricultural (crop and livestock) development trend information was collected based on historical event time line (Nyssen *et al*., 2006) in which farmers can easily remember the study years. These years were 1984/5, 1986, 1989, 1994, 1998, 1999, 2002, 2005 and 2007. In total, 140 household heads were selected for the purpose. Data collected from the questionnaire survey, meteorological data and other secondary sources were analysed using Microsoft Office EXCEL (2003) software.

RESULTS AND DISCUSSION

Rainfall variability and trends. The average annual rainfall in the study area ranged from 303 – 1410 mm, with wide temporal and spatial variation (Fig. 1 and Table 1). The spatial variation was high, with the highest standard deviation in the lowlands. The lowest deviation was, however, observed in the midlands. The midlands, which cover the largest portion of the study area, also showed a slightly decreasing rainfall pattern over the study periods. This corresponds with the study of Araya and Stroosnijder (2011) who observed that there was a decreasing trend in

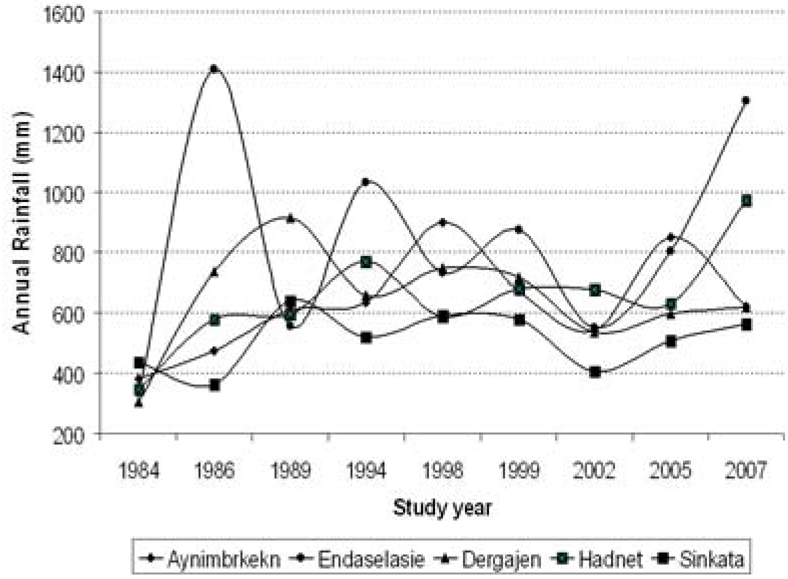

Figure 1. Rainfall trend (1984 - 2007) in Eastern Tigray in Ethiopia.

TABLE 1. The annual rainfall variability (1984 - 2007) in Eastern Tigray in Ethiopia

Site	Station	Minimum	Maximum	Skew	Mean	STDV	CV (%)
Endaselasie	Agbe	334.5	1409.4	0.36	844.53	355.15	42
Aynimbrkekn	Hagereselam	380.5	900.3	0.32	632.22	165.01	26
Dergajen	Kuiha	303.5	915.1	-0.71	648.16	169.27	26
Hadnet	Atsbi	346.9	972.8	0.23	650.22	167.27	26
Sinkata	Sinkata	364.2	641.1	-0.37	512.61	93.09	18

the 1980s and a slightly above average trend in the years after 1990. Similar to the study in other parts of northern Ethiopia (Alebachew, 2011), this study showed that the rainfall pattern was perceived to have changed over the past decades, particularly in terms of timing and duration (Figs. 1 and 2). There have also been reports of rainfall variability and drought associated food shortages (Tilahun, 1999; Bewket and Conway, 2007).

The rainfall pattern was extremely unpredictable and erratic with a coefficient of variation ranging from 18 percent in the midlands to 42 percent in the lowlands (Table 1). This corresponds with the findings of Araya and Stroosnijder (2011), in northern Ethiopia, who found a coefficient of variation more than 30 percent. According to the inhabitants, except in more dry years, changes in seasonality and distribution regularity of rainfall were more of a concern than the overall amount of rainfall (Fig. 2 and Table 2).

Elders indicated that the changes became more noticeable since the major famine in 1984/85. They felt that the main rainy season was becoming progressively shorter. Moreover, it started late and ceased earlier than it used to. This is in agreement with the rainfall data obtained from national meteorological records (Fig. 1 and Table 2).

Elders associated the variability with crop growing periods by noting that in the past people could see fully germinated crops up to the 12th of July and matured crop up to the 22nd of August. However, the rains which normally used to start in mid-June, shifted to July and ceased much

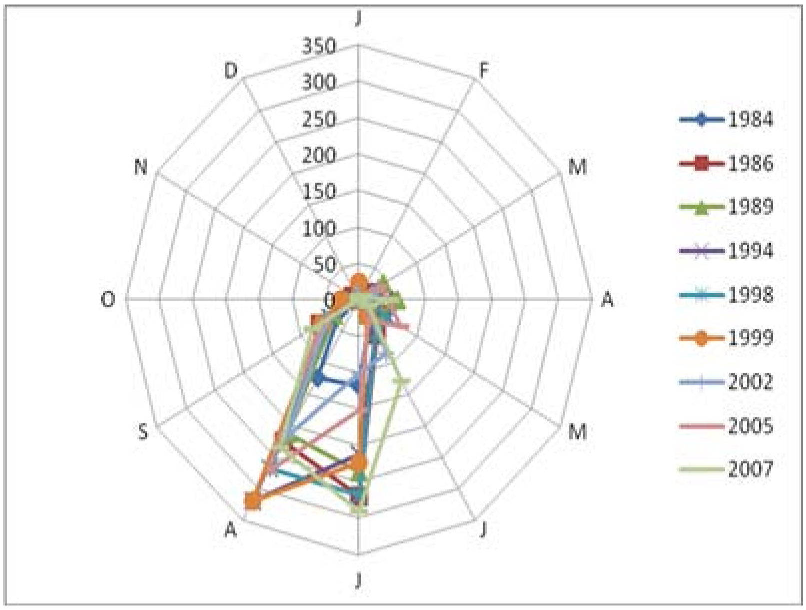

Figure 2. Average monthly rainfall variation in Eastern Tigray in Ethiopia.

TABLE 2. Intra annual (monthly) rainfall variability in Eastern Tigray in Ethiopia

	1984	1986	1989	1994	1998	1999	2002	2005	2007
Endaselasie village (Agbe rainfall station)									
Mean	27.8	117.4	46.4	85.9	61.2	72.9	45.9	66.9	108.6
Maximum	156	861.1	228.8	422	240.1	475.5	173.9	345.1	424.5
STDV	44.5	248.2	73.1	140.5	90.3	139.9	68.5	106.3	161.7
Aynimbrkekn village (Hagereselam rainfall station)									
Mean	31.7	39.6	50.9	52.9	75.0	56.1	45.2	70.8	51.7
Maximum	162.5	316	203	373.5	349.2	263.1	187.1	283.2	221.2
STDV	53.6	95.7	72.7	115.8	125.5	81.5	61.4	91.5	72.4
Dergajen village (Kuiha rainfall station)									
Mean	25.2	61.5	76.3	54.8	62.4	59.7	44.6	49.8	51.6
Maximum	117.6	220.2	394.9	317.8	318.8	359.2	206.6	314	272.6
STDV	38.4	75.6	146.6	94.6	113.9	125.6	65.6	89.5	81.5
Hadnet village (Atsbi rainfall station)									
Mean	28.9	48.3	49.8	64.2	49.1	56.8	56.5	52.7	81.1
Maximum	161	188.5	302.3	280.5	234.3	252.2	366.6	260.4	333.9
STDV	54.1	67.1	86.6	93.2	87.9	90.9	102.4	77.4	124.1
Sinkata village (Sinkata rainfall station)									
Mean	36.4	30.4	53.4	43.4	49.2	48.4	33.7	42.5	47
Maximum	207	175.5	291	204.9	275.7	240.3	167.5	166.4	203.6
STDV	67.4	50.2	87.7	68.9	91.3	88.9	50.9	62.6	71.3

earlier than was normally the case, which stretched to mid September.

In most of the months, 0 mm rainfall was recorded. The variation in rainfall among months in each site and each year was very high (Table 2). As water shortage was already a major development challenge in the study villages, the uneven and erratic nature of the rains will exacerbate the existing problem of drought and land degradation (David, 2007; Alebachew, 2011) in the midlands in particular.

Crop production trend. Elders indicated that several traditional crops had been lost in the area and several were introduced. In addition to the major crops, many local crops such as faba bean, lentil, field pea, flax and figure-millet are grown. Early maturing improved wheat varieties were introduced by Bureau of Agriculture and Rural Development. These varieties have gained wide acceptance and are widely grown replacing barley and karkae'ta or hanfets (mixture of barley and durum wheat). However, the cropping of oats declined and teff sown during the dry-season has become practically abandoned. A study by Marque and Rosenwald (1997) in a village in southeastern Tigray also compared the agricultural calendar from 1930 –1950 with the present agricultural calendar. They found a tendency towards fewer crop varieties and shifting to a shorter planting season, indicating that most crops are planted during mid- to end of June, and are often harvested some weeks earlier as well. The preference of farmers to new varieties, short growing cycle crop with good production, contributed to the reduced crop diversity.

The average crop production in the highlands showed a positive trend (R = 0.43 in Aynimbrkekn and R = 0.11 in Hadnet). The yield of barley in Aynimbrkekn village showed a slight but not significant increase. Miscellaneous crops in the village had a strong positive correlation with time (R = 0.74). The yield of broad bean and teff in the village Hadnet showed a significant difference. Both showed a negative trend (R = -0.58). However, the yield of lentil, wheat and flax significantly increased with R values of 0.72, 0.48 and 0.49, respectively.

Figure 3 shows that there was a general perception among rural households that crop production and land productivity declined in the past 20 or so years (R = -0.17 in Sinkata and R = -0.47 in Dergajen). Similar studies (NMSA, 1996; Tilahun, 1999; Bewket and Conway, 2007) in other parts of Ethiopia estimated a total loss of annual food production over some areas, while in other areas the loss was as high as 50 percent. The yield of all major crops grown in Dergajen village showed a decreasing trend. However, only barley, wheat and chickpea showed a significant difference with R value of -0.69, -0.51 and -0.49, respectively. The yield of barley, wheat, maize and hanfets in Sinkata village showed a slight increase with time but not significantly different. However, a significant difference was observed only in the yield of broad bean and sorghum. Both showed a negative trend with R values of -0.7 and -0.6, respectively. The yield of all major crops grown in the village Endaselasie (Fig. 3) showed a positive trend (R = 0.43). However, only wheat, teff and hanfets showed a significant difference with R value of 0.54, 0.68 and 0.5, respectively.

Livestock growth trend. Livestock in the study villages not only provide drought power and manure, but also a measure of social status and economic security since they could be sold to raise cash when needed. Regardless of the recognition of improving the livestock by the present government (BOANRD, 1999), livestock possession per household in the last two decades (Table 3) in most of the villages showed a negative correlation with time (R ranging from -0.55 to -0.96). Only the number of pack animals have shown a significant increase (R = 0.89).

Climate change and crop production. Historically, the study area was affected by many drought events. The drought in 1984/85 was the worst. The change in rainfall distribution and pattern had contributed to the change in cropping pattern and crop yield. The study showed a positive correlation between rainfall and crop yield in four of the survey villages (Fig. 4). Only the Dergajen village showed a negative correlation between rainfall amount and crop

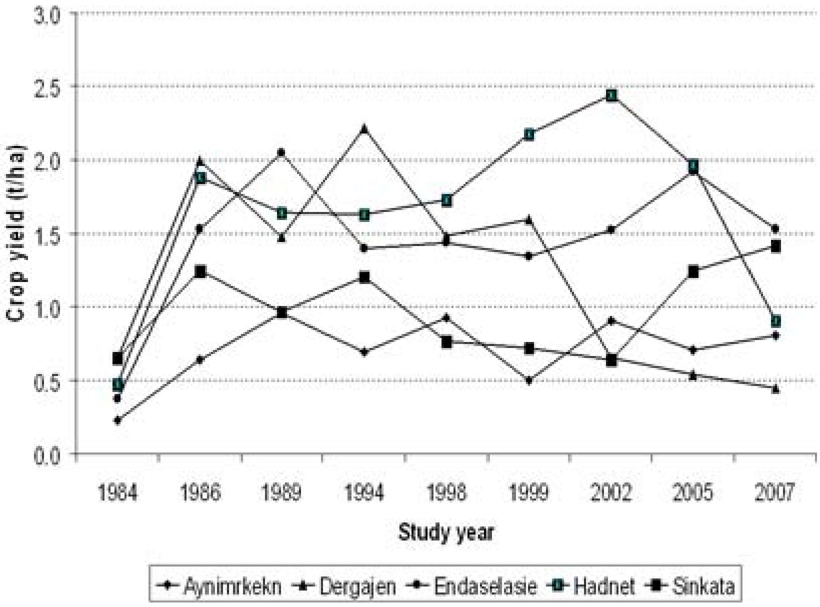

Figure 3. Crop yield trend (1984 - 2007) in Eastern Tigray in Ethiopia.

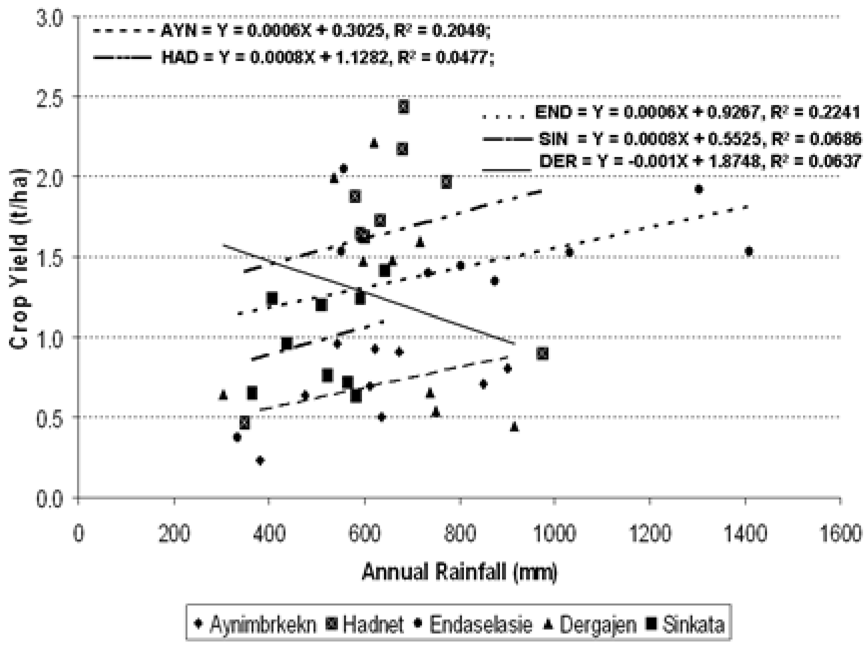

Figure 4. Correlation between rainfall and crop yield in Eastern Tigray in Ethiopia.

yield. Overall, the coefficient of correlation between rainfall amount and crop yield is very small. The lower response of rainfall to crop yield could be due to the seasonal variability of rainfall rather than the amount and other non-climatic factors, which needs further investigation.

Climate change and livestock systems. The possible effects of global climate change on food production are not limited to crop production. It has far-reaching consequences for livestock production. Table 3 shows a reduction in livestock holding in most of the sample villages. This reduction was related to changes in rainfall amount. Unlike to the findings of Mendelsohn (2000), a positive correlation was found between climate and all types of animals in the villages of Dergajen and Endaselasie, and shoat and pack animals in the village Hadnet. However, the number of pack animals in the other villages showed a significant increase regardless of the decreased in rainfall amount. The increase in the number of pack animals per household implied that farmers shifted from agriculture to off-farm activities, such as framers keep donkeys to transport grain, salt, sand, stone, firewood and charcoal, and for trading. In line with the findings of ACCCA (2010), a combination of loss to recurrent drought in recent years and diseases, and sale during crop failure were the major causes for the declining ownership of livestock. Similar to the study of Webb *et al*. (1992), the drought of 1984/85 and the recent one in 2002/03 had great devastating effects. In contradiction with the report of the BoANRD (1999), farmers argued that due to changes in climate, availability and quality of grazing lands had declined. This also contributed to a decline in herd size.

Climate change and farmers' adaptive mechanisms. Among adaptations made in response to climate change, planting different varieties of the same crop and changing planting dates were important everywhere. Similar to the findings of Meze-Hausken (2004), Kurukulasuriya and Mendelsohn (2007), and Parry *et al*. (2007), the crop mixes selected by farmers differed depending on whether conditions were dry, medium wet, or wet. The findings in this paper suggested that as precipitation increases or decreases, farmers will shift toward water-loving or drought-tolerant crops.

Farmers also responded to reduced soil fertility by implementing crop management strategies in addition to their management by organic and inorganic fertiliser application. Common crop management strategies were sowing crops based on the nutrient status of the soil. In poor soils, flax and lentil (in Aynimbrkekn), field pea and flax (in Dergajen), sorghum and lentil (in Hadnet), and flax (in Sinkata and Endaselasie) were sown. However, in moderately fertile soils maize, barley, wheat, sorghum (63 – 82 percent respondents in Aynimbrkekn and all respondents in Hadnet), barley and oats (all respondents in Dergajen), barley and wheat (all respondents in Sinkata), fingure millet, sorghum and barley (> 90 percent of respondents in Endaselasie) were the main crops grown. Moreover, farmers in all villages employed rotational cropping to restore soil fertility. Few farmers applied manure in nearby fields and the use of compost was wide spread. No fallowing was practiced due to shortage of farm land. Instead, they grew grass pea or chick pea to restore fertility and reduce weed infestation.

Similar to studies elsewhere (Campbel, 1999), poor households were forced to change their normal food intake and adjusted their consumption during acute drought periods so that they could easily adapt to the resources at hand. This included reduction in variety of food consumed, cut meal size and number, postponement of special functions such as marriage and festivals, reducing expenditures on other household goods and eating inexpensive foods. Relying on wild fruits and vegetables was a common phenomenon in the study villages. The commonly used wild food types were *Opuntia ficus-indica, Caralluma penciliata* and *Brassica nigra*. Moreover, they looked for fruits of *Carissa edulis* and *Ficus vista* (in the highlands); *Cordia Africana* (in the midlands); *Ziziphus spina-christi* and *Diospyros mespliformis* (in the lowlands).

Food relief provided by the government in the form of food for work was the main drought copping mechanism in all study villages. About 80 percent of the elders reported the use of reserve seeds, past cash savings, and barter exchange with neighbours and relatives. Borrowing food

TABLE 3. Household livestock possession and its correlation with time and climate change ([a] correlation between livestock and time; [b] correlation between livestock and annual rainfall) in Eastern Tigray in Ethiopia

Village	Type of animal	1984	1986	1989	1994	1998	1999	2002	2005	2007	Rt[a]	Rr[b]
Aynimb	Cattle	5.1	4.9	4.7	4.5	4.1	3.8	3.9	3.8	3.8	-1.0	-0.7
	Shoat	4.9	5.2	7.4	7.5	5.8	5.2	4.1	3.7	3.3	-0.6	-0.1
	Pack animals	1.9	2.0	1.8	1.8	1.4	1.6	1.3	1.2	1.2	-1.0	-0.6
Dergajen	Cattle	6.6	8.1	8.1	5.4	5.4	5.5	5.4	5.4	0.2	-0.8	0.2
	Pack animals	1.2	1.4	1.4	1.2	1.2	1.2	1.2	1.2	0.0	-0.6	0.2
Sinkata	Cattle	8.5	8.1	7.4	7.5	7.7	7.6	6.8	5.2	3.9	-0.8	-0.2
	Shoat	9.1	9.1	8.4	9.5	8.1	7.3	6.8	4.9	5.0	-0.9	-0.2
Hadnet	Cattle	5.2	5.7	5.8	5.6	5.0	4.3	4.2	3.9	3.7	-0.9	-0.5
	Shoat	0.0	2.2	1.2	4.9	4.4	2.9	3.5	1.2	2.9	0.4	0.6
	Pack animals	0.0	0.1	0.0	0.2	0.2	0.3	0.3	0.7	0.7	0.9	0.7
Endaselasie	Pack animals	3.7	4.0	4.1	3.7	3.4	3.2	3.3	3.2	3.1	-0.9	0.2
	Cattle	9.2	10.5	11.5	8.0	5.7	6.4	5.2	4.2	2.4	-0.9	1.0
	Shoat	12.9	14.4	1.0	11.6	9.1	0.0	0.9	0.8	0.8	-0.7	0.5

from merchants, purchase food stuff on credit from traders, getting credit from money lenders, and participating in small petty trading were other drought copping strategies. Withdrawing children from school was also a common drought copping strategy in the study sites, and the Hadnet village in particular. To reduce school withdrawal, the government in collaboration with the World Food Programme served school children with feeding programme.

Working as casual labourer within and out of villages was also common strategy. Farmers in the study villages also applied the common saying of the Amhara youth “rather than plowing a rock outcrop/stone, I better migrate’ (Alebachew, 2011). Majority of these farmers who depended on off-farm activities sought labour from the nearby towns in search of construction work and other casual labour opportunities. A study in the Enderta Dry Midland Livelihood Zone (Enderta Dry Midland Livelihood Zone, 2006) also showed that about 50-70 percent of those farmers moved to towns to seek for a better job. The remaining 30-50 percent, according to the study of the Enderta Dry Midland Livelihood zone (2006), searched for work in the local rural area. Some 18 percent of elders in Endaselasie, 40 percent in Hadnet, 6 percent in Aynimbrkekn, and 67 percent in Dergajen were directly or indirectly involved in salt trading. Many people in the midlands, Sinakta and Dergajen, were involved in sand and stone quarrying for construction purposes and on firewood and charcoal making and selling.

Lack of pasture and fodder were the main constraints to animal production in these sampled villages. In line with the study of Campbel (1999) elsewhere in Ethiopia, livestock herders managed the composition, size and diversity of animals in order to cope with variable feed resources and as a traditional form of insurance against livestock deaths during drought. Herd management strategies such as selling of male, old and unproductive animals to feed the productive ones; herd diversification such as keeping different animals (shoat, cattle and others) to reduce risk and selling of small animals to purchase feed for large animals were common drought copping strategies reported by more than 80 percent of the elders. Mixing of cactus in livestock feed (reported by more than 60 percent elders), feeding *Agave sisalana*, *Aleo berhana* and other wild plants and migrating with livestock in search of feed were common practices in most of the study villages. Cactus, a very drought resistant (ACCCA, 2010) plant, was very important as food and cash crop besides being livestock feed.

ACKNOWLEDGMENT

The authors acknowledge the Mekelle University Inter University Cooperation (MU-IUC) for financial and administrative support. We thank the farmers and development agents of each study village for the cooperation during the data collection. More thanks also go to Ato Mulu Haftu and Dr. Hailu Araia, for their excellent comments during the very draft of this paper.

REFERENCES

ACCCA. 2010. Improving decision making capacity of small holder farmers in response to climate risk adaptation in three drought prone districts of Tigray, Northern Ethiopia. Advancing Capacity to Support Climate Change Adaptation, Project No. 093, Mekelle, Ethiopia.

Aklilu, A. and Alebachew, A. 2009. Assessment of climate change-induced hazards, impacts and responses in the Southern lowlands of Ethiopia. Forum for Social Studies, Addis Ababa, Ethiopia.

Alebachew, A. 2000. The causes and consequences of rural-urban migration to Addis Ababa: A case study from selected kebeles of wereda 18. Unpublished M.A. Thesis, Addis Ababa University, Ethiopia.

Alebachew, A. 2011. Climate change and rural livelihoods in Northern Ethiopia. Impacts, local adaptation strategies and implications for institutional interventions. FSS Monograph No.7. Forum for Social Studies, Addis Ababa, Ethiopia.

Araya, A. and Stroosnijder, L. 2011. Assessing drought risk and irrigation need in Northern Ethiopia. *Agricultural and Forest Meteorology* 151:425 - 436.

Bewket, W. and Conway, D. 2007. A note on the temporal and spatial variability of rainfall in the drought-prone Amhara region of Ethiopia. *Int. J. Clim.* 27: 1467 – 1477.

Bureau of Agriculture and Natural Resource Development (BoANRD). 1999. Livestock Census Analysis Results. Mekelle, Ethiopia. 230pp.

CSA. 2008. Summary and statistical report of the 2007 Population and Housing Census Results. Population size by age and sex. Central Statistical Agency, Addis Ababa, Ethiopia.

Campbell, D.J. 1999. Response to drought among farmers and herders in southern Kajiado District, Kenya: a comparison of 1972 - 1976 and 1994 - 1995. *Human Ecology* 27: 377 - 415.

David, M. 2007. The Perception of and Adaptation to Climate Change in Africa. Policy Research Working Paper 4308. World Bank, Washington, D.C. USA.

Enderta Dry Midland Livelihood Zone. 2006. Livelihood profile, Tigray Region, Ethiopia.

Kates, R.W. 2000. Cautionary tales: adaptation and the global poor. *Climate Change* 45: 5 - 17.

Kurukulasuriya, P. and Mendelsohn, R. 2007. Crop selection: Adapting to climate change in Africa. Policy Research Working Paper 4307. World Bank, Washington, D.C. USA.

Markos, E. 1997. Demographic responses to ecological degradation and food insecurity: Drought-prone areas in northern Ethiopia. University of Groningen, The Netherlands. Amsterdam: PDOD Publications. Doctoral dissertation.

Marque, C. and Rosenwald, V. 1997. The Agrarian Systems in a Small Region of Northern Ethiopia. Diploma, Institute National Agronomique de Paris-Grignon.

Mendelsohn, R. 2000. *Efficient Adaptation to Climate Change. Climatic Change* 45: 583 - 600.

Mendelsohn, R. and Dinar, A. 1999. Climate change, agriculture, and developing countries: Does adaptation matters. *World Bank Res Obs* 14(2): 277 - 293.

Meze-Hausken, E. 2004. Contrasting climate variability and meteorological drought with perceived drought and climate change in Northern Ethiopia. *Clim. Res.* 27: 19 - 31.

National Meteorology Service Agency (NMSA). 1996. Climatic and agro-climatic resources of Ethiopia. *National Meteorology Service Agency of Ethiopia* 1 (1): 137, Addis Ababa, Ethiopia.

Nordhaus, W.D. 1991. To slow or not to slow: The economics of the greenhouse effect. *The Economic Journal* 101: 920 - 937.

Nyssen, J., Descheemaeker, K., Amanuel Zenebe, Poesen, J., Deckers, J. and Mitiku Haile. 2009. Transhumance in the Tigray Highlands (Ethiopia). *Mountain Research and Development* 29 (3): 255 - 264.

Nyssen, J., Poesen, P., Veyret-Picot, M., Moeyersons, J., Mitiku Haile, Deckers, J., Dewit, J., Naudts, J., Kassa Teka and Govers, G. 2006. Assessment of gully erosion rates through interviews and measurements: A case study from northern Ethiopia. *Earth Surface Processes and Landforms* 31(2): 167 - 185.

Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E. (Eds.). 2007. Climate change: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press.

Pearce, D., Cline, W., Achanta, A., Fankhauser, S., Pachauri, R. and Vellinga, P. 1996. The social costs of climate change: Greenhouse damage and benefits of control. pp.179 – 224. In: Bruce, J., Lee, H. and Haites, E. (Eds.). Climate Change 1995: Economic and Social Dimensions of Climate Change, . Cambridge: Cambridge University Press.

Ravindranath, N.H. and Sathaye, J.A. 2002. Climate change and developing countries. Kluwer Academic Publishers, London, UK. 286pp.

Tilahun, K. 1999. Test of homogeneity, frequency analysis of rainfall data and estimate of drought probabilities in Diredawa, Eastern Ethiopia. *Ethiopian J. Nat. Resource* (1): 125 - 136.

Tompkins, E.L. and Adger, W.N. 2003. Building resilience to climate change through adaptive management of natural resources. Working

Paper 27. Tyndall Center for Climate Change Research, UK. 19pp.

UNECA. 1997. Livestock development in Tigray: Forage development strategy as a major entry point towards a sustainable minimum grazing system, Part I. Sustainable Development and Environmental Rehabilitation Program (SDERP). United Nations Economic Commission for Africa, Addis Ababa, Ethiopia. 167 pp.

Webb, P., Von Braun, J. and Yohannes, Y. 1992. Famine in Ethiopia: Policy implications of cropping failure at the national and household levels, research report 92, Washington, DC, USA, International Food Policy Research Institute (IFPRI). 167pp.

Winkler, H. 2005. Climate change and developing countries. *S Afr J Sci* 101: 355 - 364.

World Bank. 2006. Ethiopia: Managing water resources to maximize sustainable growth. Country water resources assistance strategy. Washington, DC. USA.