Maintaining minimum livelihood under changing climate in North Shewa Zone, Ethiopia: a mathematical programming approach

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Abstract

The paper presents empirical findings on the efforts made by smallholder farmers to maintain livelihood needs through efficient allocation of resources under changing climate and dwindling natural resources base. The data used was generated through a survey of 452 households in North Shewa Zone. The income required to meet minimum livelihood needs for food, education, health, clothing and other social obligations was determined and used as an objective to be attained. This income was computed from the diverse livelihood of Households (HHs). Current and future scenarios were built based on the predicted values of climate variables, farm size and technology for years 2012, 2022 and 2032. A Linear Programming (LP) model was built in GAMS software so as to determine optimal combination of agricultural enterprises that would generate the minimum net income required under each scenario to sustain lives and livelihoods. The result shows that farmers display inefficient use of available resources and they can increase their net income even beyond the minimum requirement by selecting optimal number of enterprises that suits the existing and predicted climate. In the future, however, farmers should be encouraged to take up certain critical adaptation strategies, which would enable them to bear the negative consequences of climate change (CC) impacts.

Keywords: Minimum livelihood, climate change, linear programming, Ethiopia.

INTRODUCTION

Globally, agriculture is highly sensitive to climate variations and climate extremes (e.g. droughts, heavy precipitation, etc) (Rosenzweig, 1994). Over decades, climate variability and the frequency of climatic extremes are expected to increase in developing countries, challenging their agricultural operations (Frei et al., 2004). For cropping systems, there are many potential options as to how farmers can alter their management to deal with the projected climatic and atmospheric changes (Howden et al., 2007). Thus, farmers need long term adaptation measures not with single option but with diversified options that fit into perceived climate change scenarios (Stöckle et al., 2003). Literature suggests that there is unprecedented need to strengthen capacity and the effectiveness of management in helping to reduce the impacts of and to adapt to climate change related stresses by providing strategic advice that includes ways in which farmers optimally use the scarce moisture through appropriate enterprise selection and use of improved management practices (IUCN, 2002).

Farmers who have sufficient access to capital and technologies should be able to continuously adapt their farming system by changing the mix of crops, adopting efficient water uses system and adjusting input usage and improve plant protection (Easterling and Apps, 2002). However, in connection with climate change this might intensify the existing impacts on the environment

and lead to new conflicts between ecosystems services (Schröter et al., 2005; IPCC, 2007). For example, increased water use for irrigation could conflict with water demands for domestic uses and lead to negative ecological implications (Bates et al., 2008). Also, soil loss through erosion may increase due to climate change, an effect which could be aggravated through changes in land management (Lee et al., 1999; O'Neal et al., 2003). To prevent continued degradation of natural resources, policy will need to support farmers' adaptation while considering the multifunctional role of agriculture (Olesen and Bindi, 2002; Betts, 2006). Hence, effective measures to minimize productivity losses and preserve finite natural resources need to be developed at all decision levels, and scientists need to assist decision makers in this process (Salinger et al., 2002).

In the years to come, we cannot know exactly how the world will develop (IPCC, 2007) and an important issue is the steps taken to formulate possible situations and work to minimize loss to climate change. This requires the development of diffrerent alternative scenarios under different weather conditions. Thus, the primary objective of this paper is to present the main challenges of climate change related stresses in endangering the capacity to meet at least minimum livelihood needs and present ways that can help households, especially smallholder farming communities, best respond and adapt to changes through optimal allocation of resources under varying climatic conditions. It then suggests alternative scenarios for long term adaptation options for farmers under different climatic conditions.

Literature on Mathematical Programming in Climate Change Research

In a review of 16,000 research articles covering more than 1000 models, Wijk et al. (2012), have identified that empirical models (econometric and statistical), by their nature have a limited application domain, and in general cannot be used for adaptation studies under climate change. And only those econometric models (e.g. structural econometric models) can be used in simulation or mathematical programming models at farm or household level. Thus, for designing adaptation strategies, mathematical programming is the most relevant. From analytical perspective (Dantzig, 1949; Kantorovich, 1939; 1966), a mathematical program tries to identify an extreme (i.e., minimum or maximum) point of a function $f(X_1, X_2,...,X_n)$, which furthermore satisfies a set of constraints, e.g. $g(X_1, X_2,...,X_n) \leq b$. Linear programming is the specialization of mathematical programming to the case where both, function $f(X_j)$ to be called the objective function and $g(X_j)$ the problem constraints are linear.

Throughout the climate change studies, a strategy for long term adaptations are usually tested by the crop models which result in yield changes, and economic adjustments to the yield changes which result in context specific production changes and price responses at national and regional levels. Farm-level adaptations tested in the crop models include: planting date shifts, more climatically adapted varieties, irrigation, and fertilizer application. Economic adjustments include: increased agricultural investment, reallocation of agricultural resources according to economic returns (including crop switching), and reclamation of additional arable land as a response to higher cereal prices. These economic adjustments are assumed not to feedback to the yield levels predicted by the crop modeling study (Rosezweing et al., 1993).

One of the best example of future simulation of agricultural production using mathematical programing under varying climate change is the work done by IBSNAT (1989) in 18 countries in which case the scientists simulated potential change in yields to future climate conditions. The crops included in the model were wheat, rice, maize, and soybeans. The models were run for current climate conditions, for arbitrary changes in climate (+2^oC and +4^oC increase in temperature and +/- 20% precipitation), and for climate conditions predicted based on future atmospheric CO_2 levels. The effects of increasing levels of CO_2 which increase the atmospheric temprature and thereby increase water consumption of crops were taken into account. The change in crop yield in response to change in percipitation and temprature were then estimated.

METHODOLOGY

The study area

The study area is North Shewa Zone of Oromia national regional state. North Shewa Zone is found in north-west direction of Addis Ababa. Fiche town which is located at 147km away from Addis Ababa is the capital of the zone. The zone has 13 rural districts with a total land area of 10,323 km2. It is situated between 9030N and 38040E. The zone is bordered by Amahara region in the north and the east, West Shewa zone in the west and Addis Ababa in the south. The topography of the area is mountainous in the highland and midland, while it is plain in the lowland areas. The altitude of the area ranges between 1300-2500 meters above sea level. It is divided into three agro-ecologies, namely, 15% highland (>2500 meter above sea level), 40% midland (1500-2500 meter above sea level) and 45% lowland (500 -1500meter above sea level) (CSA, 2007). The area gets rainfall during both Belg (February to April) and Meher (June to September)
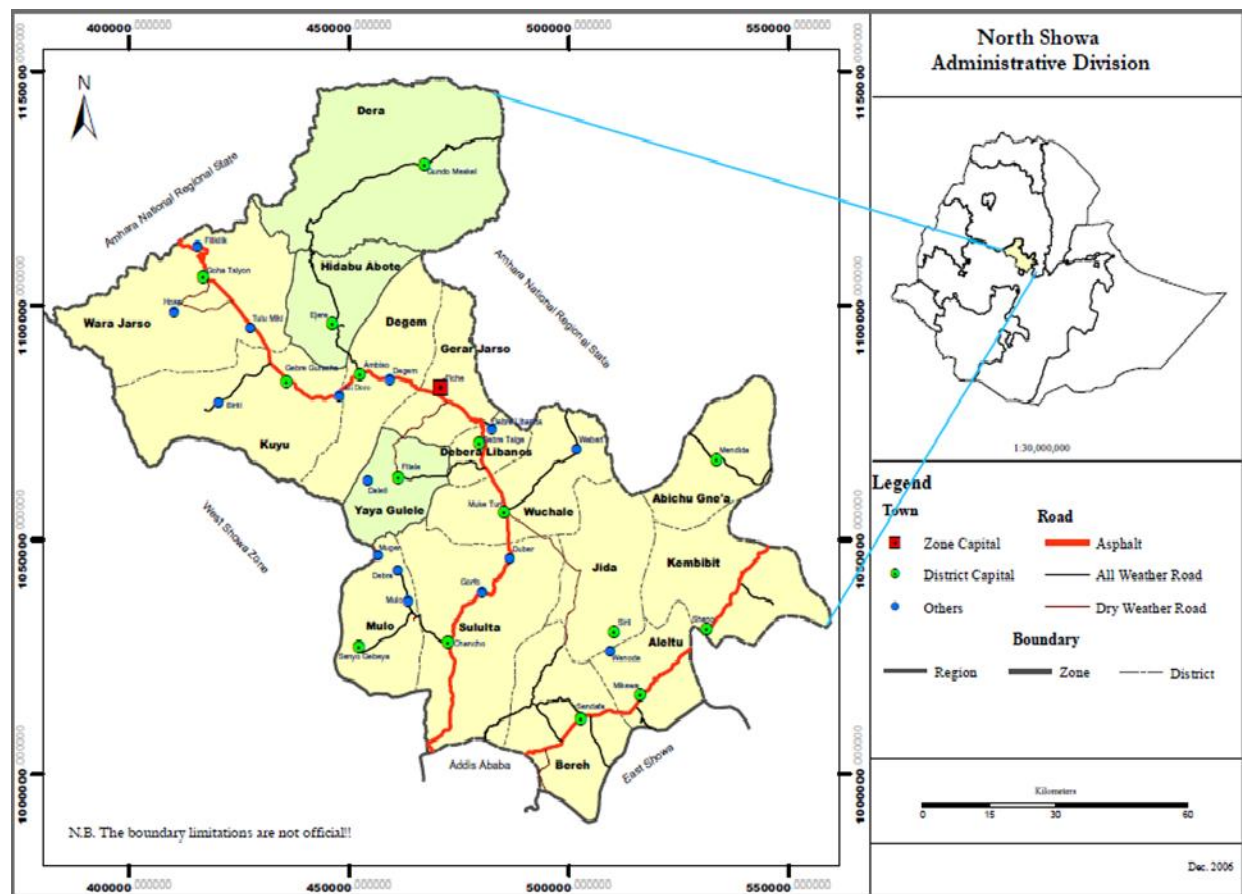
Figure 1. Map and location of North Shewa Zone: the first part is North Shewa with its districts and the second part is Ethiopia with its regional settings.

seasons. The average annual rainfall of the area ranges from less than 840 mm to 1600 mm while the mean annual temperature varies between 150C and 190C. (Figure 1)

The population of the zone is estimated to be 1,431,305 with population density of 138.7 persons per km^2 and average of 4.6 persons per household. The community practices mixed farming of cereal crops, pulses and oil crops. Livestock production also constitutes an important part of agricultural activities of the zone. The average land holding is 1.1 hectare per household. Due to the continuous reduction of farmland to degradation by frequent flooding and drought, farming intruded into steep sloping areas, forest lands and expanded to marginal lands and communal lands covering 81% of the total area of the zone. Only 3% of the total land is put under grazing, 3.7% forest land, 11.33% degraded and bare land and 0.65% is other form of land. The crops, livestock and other livelihoods of the community are subjected to damage to climate change induced hazards. This coupled with the continually decreasing farm size have serious impact threatening

farmers adaptive capacity and livelihood improvements (CSA, 2007).

Data

The data for the research was obtained from a survey of 452 farm households in three districts of the Zone in 2011/2012. The districts include Yaya Gullele, Hidha Abote and Derra. The specific study sites within the districts were selected based on a multi stage random sampling procedure. Consequently, 18 Kebeles were selected from which the sample households were selected randomly proportional to population size. A structured questionnaire was used to interview the farmers. Data collected from the farmers include household characteristics, landholding, crops and livestock production, disaster occurrence, perception level (on precipitation, temperature, soil moisture, air moisture and wind direction), adaptation strategies pursued, different coping strategies pursued, level of resilience, and other relevant information.

In addition, secondary data relevant for this analysis was obtained from the National Meteorological Service Agency (NMSA), Central Statistical Authority (CSA), and Zonal and district agricultural offices. In order to understand the research questions at community level, qualitative data were collected through focused group discussion using checklist prepared for the purpose.

Analyitical Tool

As the basic objective of this article is to find optimal allocation of resources that would enable farm households to generate required income level under different climate and non-climate constraints, the application of mathematical programming would be inevitable. Linear programming (LP, or linear optimization) is a mathematical method for determining a way to achieve the best outcome (such as maximum profit or lowest cost) in a given mathematical model for some list of requirements represented as linear relationships. So for problems related to efficient utilization of scarce resources, linear programming would be appropriate methodology to be used (Dantzig, 1949).

Basic structure of linear programming

The underlying hypothesis of the modeling approach is that farmers are 'profit' maximizers. The main differences in the crops grown by different farmers are due to the soil type, climate and their perceptions of the profitability of crops. A linear programming model is used to simulate the cropping mix which maximizes the income over labor and capital invested taking into account the workability under a given climate scenario (Annetts and Audsley, 2002, Audsley, 1998). Scenarios taken primarily are the climate change scenarios. The chosen contrasting features for the modeling are in line with the work of Marchant et al. (2003) based on the forecasted climate and socio economic scenarios by IPCC. The impact of climate change scenario is based on the predicted value of 2022s and 2032s for low climate scenarios with no socioeconomic changes to determine the effect of climate change alone. Then, technological change scenarios expressed through yield change is introduced into the model. Finally, the combined impact is calculated using the linked socioeconomic and climate scenarios.

Moreover, it is found important to consider the land as one of the changing factors of production. The size of cultivable land at the disposal of farmers is decreasing from time to time. For instance in the study area, the average landholding per household before 10 years was

nearly 1.3 hectare (CSA, 1996). With the rapidly increasing population, the pressure on land increased and the land size per household decreased to 1.13 ha in 2011/2012. Thus, decrease in farmland will have definitely an impact on the food production level to meet minimum livelihood needs. Therefore, the changing land size is included in the programming to build scenarios for long term adaptation strategies. General Algebraic Modeling System (GAMS) software is used to simulate the LP model.

Model Specification

Maximize $\quad Z = \sum C_j X_j \qquad\qquad (1)$

Subject to $\sum a_{ij} x_j \le b_i,$ (standard factors of production) (2)

$\sum k_j x_j \le \lambda \qquad$ (Land) $\qquad (3)$

$d_j x_j \ge \qquad\qquad$ (Climate Variables) $\quad (4)$

$b_i \ge 0$

$x_j \ge 0$

$I = 1, 2, …, n$ and $j = 1, 2, 3, …, m$

Where, Z –refers to the objective function in which net farm income obtained from various crop productions in monetary terms is maximized. Further to this, the objective function is parametrically set over entire feasible region for the different scenarios of current and future weather condition and then determined the ways resources are combined to meet a predetermined level of objective function. In both scenarios, Z remained equal to or greater than the minimum livelihood requirement for an average household to sustain its living.

C_j – the net income per ha of the jth activity;

X_j – the level of the jth activity (ha);

a_{ij} – the amount of ith resource required per ha of the jth activity;

K_j - the amount of land size in ha required per unit of the jth activity;

b_i – resource levels (labor, capital, manure, and oxen);

– scalar representing average weather conditions (moisture at a given temperature), which was set to vary parametrically;

λ a scalar representing size of landholding, which varies parametrically from current size of holding to estimated low level of holding per households;

d_j is the yield of the jth crop per hectare for a given level of climatic conditions. The yield is not programmed in the LP, but statistically computed for each weather condition and entered into LP.

Basic assumptions

Besides the general assumptions of linearity, divisibility, non-negativity, additives, finiteness and certainty which are common for LP, the following particular assumptions are made in developing the model. The problem of resource organization is dealt at the average farm level represented by the common farm model. All activities or processes such as crop production and marketing are assumed within one year. It is also assumed that each farm is operated with the objective of maximizing net farm returns subject to the described resources constraints and climate change variables limit only.

Model Variables

Crop enterprises

Seven crops that dominate the crop production system are included in the model. These are teff, sorghum, maize, wheat, barley, millet and oats. These crops occupy 1.02ha out of the total 1.13ha average cultivable land at the disposal of households. Later in the LP model, faba bean is introduced based on its net income contributions and suitability to the climate and environmental conditions. In the objective function, the net revenue from crops is included by multiplying total harvest per hectare by average market prices. The average market prices are kept constant while average crop yield per hectares is made to vary in response to climate change.

Labor Constraints (L)

There are three types of labor used in the model designated as L1, L2 and L3. Labor 1 represents the number of person days used during the months of February to May. The major operations during these months are land preparation, and tillage. The average available labor during this is 102 person days. L2 is for the months of June – August, where the major operations during this period are second round cultivation, sawing, weeding, and others. The total labor available during this period is 105 person days. L3 is for the months of September – November and the major activities during this period are harvesting, threshing and post harvest management. The total labor available is 100.5 person days. Under each labor category labor allocation is done based on the labor requirement of each enterprise during each stage of the agricultural activities. In general labor is not a constraint in the model.

Oxen Constraints (O)

The average oxen ownership in the area indicates that households own 1.2. Oxen constraint was divided into two as O1 and O2. O1 represents the oxen days required during the months of February – May especially for land tillage for the Belg season cultivation and first round land tillage of the Meher season. Total available oxen days were 40.8. O2 was for the period between June-August land cultivation for the Meher season. The total oxen days available were 42. The oxen days' requirement of each enterprise during the respective months was entered into the model constrained by the maximum available at each period.

Capital Constraints (WC)

Working capital is one of the limiting factors of production in the model. Working capital is determined for the purchase of seed, fertilizer, transportation costs, packing materials, etc. The average working capital requirement per crop per hectare during the year 2011 was birr 1605.88. Some of the crops required more than birr 2000 while others required below birr 700. Working capital is one of the constraints limiting the production level of the farmers.

Land (L)

The average cultivable land allocated for the production of annual crops is 1.13ha. The available land is shared between the crops based on the LP allocation. The available land size changes for the year 2022 and 2032 prediction. Accordingly the land size is estimated to be 1ha and 0.85ha for the year 2022 and 2032, respectively. This would enable to estimate its impact on the realization of net income to meet minimum livelihood requirements.

Climate factors (Precipitation and temperature)

Climate variables are included into the model indirectly based on their impacts on yield. Under the 2011 production season the average temperature is calculated to be $16.83^{o}c$ and total rainfall is calculated to be 840.03ml. Then crop yield per hectare under this situation is entered into the objective function of the model. The average yield per hectare for this period was presented in Table 2. Similarly for the year 2022 and 2032 predicted values of climate variables are computed and the corresponding yield response is entered into the model.

Table 1. Produciton factors forcast.

Factors of production	2012	2022	2032	Sources
Land size (Ha)	1.13	1.00	0.85	Estimation using CSA data
Climate variable (Precipitation in MM)	840.03	700.21	583.67	Prediction using trend analysis
Climate variable (temp in ^{0}C)	16.83^{0}C	19^{0}C	20.3^{0}C	
Price	Base year	Base year	Base year	Real income is considered in the analysis
Technology type	Currently used varieties	Currently released improved varieties	Predicted 20% improvement	Ethiopian research institutes

Sources: own computation

Model optimization

Based on the above variables, the model is made to produce optimal values of objective function under two scenarios. The first scenario (Scenario 'A') is to maximize the net income until maximum possible net income is realized. This scenario is risk taking and only profit maximization one. However, farmers in most of the cases are risk averters, and hence the second scenario (scenario 'B') is to allocate the available resources among different crops until net income required for minimum livelihood is reached. This one involves putting a limit to upper and lower boundaries to the value of the objective function. This one is risk averse one. The result of this optimization is presented under table 6.

## Predicted Values of Model Variables for 2022 and 2032

The future scenarios for the change in climate, technology and land are based on the forecast made using trend analysis, improved varieties release and estimated change in land size, respectively. According to the data collected from the Ethiopian National Metrological Agency for the last 30 years, the decline in rainfall is so high and the variability over time has increased in recent years. In the study area, with the current trend of precipitation decline, the year 2011 was more than 35% drier compared to the baseline year 1981 used in this study. The average precipitation for the past 30 years was 840.03ml. With the prediction made using fitted trend analysis for the 2022 and 2032, the average annual precipitation will be around 700.21ml and 583.67 ml respectively (Table 1). On the other hand, change in prices of the commodities is excluded from the analysis as we are looking for real income level based on the quantities of food commodity required for a household.
The agricultural research institutions in the country usually release improved varieties that are drought

tolerant, disease tolerant and give higher yields. Thus, it is important to consider the stipulated technological change in the model. Consequently, the currently available varieties for drought tolerance and yield improvement are assumed in the model. Moreover, current promising research works from the Ethiopian Agricultural Research Institutions planned to be released is considered in building the scenarios. Finally, predicted values of average land holding size are predicted based on CSA's 10 years land holding data for the study area and the predicted values are used in establishing the future scenario. Accordingly predicted value of land holding for the next 10 and 20 years are 1ha and 0.85ha respectively. Table 1 summarises the factors considered to be varying in the model.

RESULT AND DISCUSSION

Climate Change and Agricultural Optimization

Under different situations, the farmers in the study area have been attempting to maximize return form crop production. The optimization decisions are constrained by the physical attributes of land, most notably soil type, size, slope and fertility. The fertility of the soil has continually eroded and the slope of farmlands in the highland and midland are very steep which in turn has constrained the use of available yield increasing technologies, capital and labor. Moreover, climate variability in the last three decades significantly restricted the type of crop and the amount of harvest. The climate change data indicates that the average annual precipitation decreased from 1085.64ml in 1980 to 840.33 ml in 2011/12. On the other hand, the average temperature increased from 15.45^{0}C in 1980 to 16.83^{0}C in 2011/12. Under this frequently changing climate conditions, farmers should be able to optimally allocate scarce resources as an optimal response to climate change. Enterprise choice of a farmer should be based
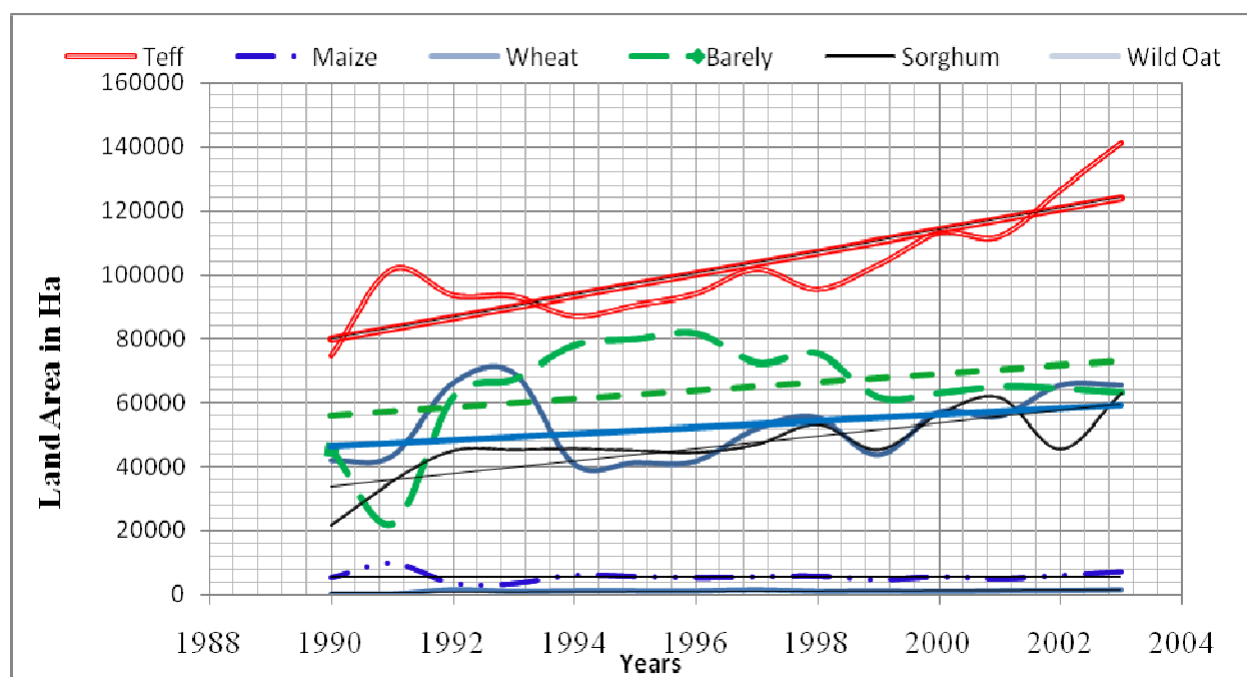
Source: Authors' calculation based on data obtained from CSA

Figure 2. Changes in cropping dominance over years in North Shewa

on perceived future climatic conditions. Crops and livestock species that are resilient to the perceived climate scenario should be taken up by farmers as means of adaptation. From a time series data obtained from the CSA for the last 20 years, it is found that agricultural activities of the farmers have taken a different shape when analyzed against changing precipitation and temperature over time. Crops that can withstand higher temperature and lower precipitation are becoming the dominant enterprises. Figure 2 describes the shift in crop dominance in the study area over the last 20 years (1991-2011).

Among the major crops cultivated in North Shewa, the moisture requirement of maize is high followed by barely, wheat, sorghum, millet and *teff* in that order (Araya *et al*, 2010; FAO, 2004). According to the data, the growth in area allocated to each crop has exhibited significant change over time. The rate of growth for sorghum, millet, *teff* and oats was higher than the rate of growth for maize, barley and wheat; because the latter ones require relatively higher level of precipitation and long maturing season. This is an indication that farmers are taking up crops that are less sensitive to moisture stress. For instance during the year 1991, the proportional allocation of farmland to crops show that 35.1%, 12.74%, 18.5%, 21.74% and 7% were to *teff*, sorghum, wheat, barley and maize respectively. While in 2011 the land allocation shows that 41.35%, 21.3%, 16.16%, 15.4% and 2% were allocated to *teff*, sorghum, wheat, barley and maize

respectively. From these change, it is clear that the proportional land allocation has increased for those crops that can withstand moisture stress, while it has decreased for those requiring more precipitation.

In supplementation to this, information obtained from the household survey indicates that higher percentage of households have resorted to the cultivation of cereals that require low moisture. Table 2 indicates the proportion of households currently cultivating the major cereal crops.

Therefore, it is apparent that farmers make rational decision in terms of allocating their land to crops that yields better and withstand stress during CC as can be seen from Figure 2 and Table 2. To further strengthen this action of farmers' adaptation mechanisms, Lalthapersad (2010), Leonardo (2007), and Nhemachena et al. (2010) argue that farmers should be assisted in the way they should optimally allocate their scarce resources so as to withstand extreme climate change impacts. Under changing climate in the study area, optimality in resource allocation at farm level should no more remain a theoretical work but become a guiding principle of whole farm planning for sustainable use of available natural resources.

Household Consumption Composition

As discussed above, it is apparent that the study area is experiencing further increases in temperature and declin-

Table 2. Major crops grown, land allocation and average yield per *ha.*

Cereal Crops	Percentage of HH Cultivating	Average of Land in 2011/12 (in *ha*)	Average Yield per *ha* in KG
Teff	91.9	0.31	1388.00
Sorghum	67.6	0.28	2123.00
Millet	61.7	0.11	924.00
Maize	42.8	0.08	2310.00
Wheat	40.5	0.13	1325.00
Barely	12.2	0.03	1248.00
Oats	10.6	0.09	1064.00
Total		1.02	
Other annual crops		0.11	
Total land for annual crops		1.13	
Average land under perennial crops		0.02	
Average usable land holding		1.15	

Source: Authors' calculation based on HH survey,

ing rainfall patterns as well as increased frequency of extreme climate events (such as droughts and floods). These changes are having differential impacts on agricultural productivity and food security and other economic impacts across spatial and temporal scales. This is practically jeopardizing community's capacity to meet the minimum needs for sustaining life. For instance, more than 72% of the households do not have any food reserve for the next production seasons and 74.2% have consumption expenditure of less than the minimum income required for healthy and productive life. Hence, changes in climate are expected to be detrimental to main sources of livelihoods. The ability to get sufficient food from agriculture, maintain health conditions, sending children to schools and attaining other social obligations for most poor smallholder farmers greatly depend on how much they have been able to adapt and operate their agriculture flexibly. The key issue for the study area which is prone to climate change induced shocks is its impacts on livelihoods, the challenge to meet food and water needs for members of family, and the ability to reduce poverty. For so long for farmers of the study area, the ability to survive by meeting their needs and having surplus over their current consumption expenditure to be invested in keeping their livelihood oparational in the next season is subjected to challenges.

Therefore, a strategy must be employed to maintain at least survival by managing climate risk in their farming systems. According to Nhemachena et al. (2010), the minimum livelihood needs differ from one country to the other depending on the level of development and welfare of a country. In that regard, minimum livelihood expenditure is relative. However, in the borader context, the minimum livelihood need should cover food, clothing, shelter, medication, education, social expenditures and cost of input for the next year of production. Thus, the minimum needs of life can be expressed in common unit, which is an income equivalent to meet expenditure needed to sustain livelihood.

From the food consumption behaviour of the households in the study area, larger percentage of the food basket is dominated by few crops that are grown in the area. More than 97% of the food consumption comprises of cereals (teff, maize, sorghum, wheat, barely, millet and wild oats), vegetables (onion, potato, tomato, beet root and cabbage), legumes (pea, beans, chickpea and fababean), sesame, fruits (orange and banana) and livestock products (meat, milk, and butter). Table 3 presents the proportion of food consumed in the study area. The proportion of food consumption is determined by the total monetary values of foods. That is quantity of each food cosnumed multiplied by its market price.

From Table 3, the food composition of the households were 41.99%, 12.67%, 2.18%, 15.96% and 5.79% cereals, legumes, oil crops, and horticulture and livestock products respectively. So cereals and horticulture take the major share of the consumption expenditure.

Expenditure and Determination of Minimum Income Requirement

The proportional combination of the food items consumed at local level should enable a household to meet its minimum energy requirement for a healthy and active life. According to the latest definition of food security by FAO (2011), it is the minimum amount of food basket a

Table 3. Types of food commodities and their proportion in consumption in North Shewa.

Types of Food Consumed		
A	**Cereals**	**Percent share**
	Teff	14.04
	Maize	7.49
	Wheat	14.37
	Barely	6.09
	Sorghum	21.37
	Sub total	41.99
B	**Legumes**	
	Pea	3.00
	Beans	1.40
	Chick pea	3.41
	Faba bean	4.86
	Sub total	12.67
C	**Oil Seed**	
	Soya	0.29
	Sesame	1.89
	Sub total	2.18
D	**Fruits**	
	Orange	0.54
	Banana	0.81
E	**Vegetables**	
	Sub total	1.35
	beet root	1.66
	Potato	2.02
	Tomato	1.21
	Onion	7.70
	Cabbage	2.02
	Sub total	14.61
F	**Livestock byproduct**	
	Meat	2.56
	Milk	1.35
	Butter	1.88
	Sub total	5.79
	Total food consumption	**100**

Source: Authors' calculation based on HH survey of 2011/12

household should get access to in order to meet the minimum calories of energy per day for an active and healthy life. The minimum amount of basket of food is usually computed from the locally available food types consumed as well as produced by farmers (FAO, 2002). From these arguments, it is apparent that the minimum amount of food for community members residing in North Shewa should be computed based on the food preference and dietary need described above (Table 2).

This minimum requirement is based on the amount of minimum calorie requirement for an adult equivalent, to be at least above the poverty line. As written by, Adelman and Berck (1991), African Leadership Forum (1989), Alamgir and Arora (1991) and FAO (2002), achievement of food security converges the achievement of this minimum calories requirement in a sustainable bases under any circumstance of natural and man made disturbances of livelihood.

Table 4. Estimation of farm income required to meet minimum requirement for average family.

A	Types of Food Consumed / Cereals	Average Consumption (KG/yr)	%age share	Total KCal for 4 Adults /year	Total KG food required per year for 4 Adults	Average current price in North Shewa (Birr/kg)	Total Income required to purchase this food (Birr)
	Teff	104	14.04	471298.25	131.32	10	1313.17
	Maize	55	7.49	251396.83	73.51	5.5	404.29
	Wheat	106	14.37	482459.86	134.99	6	809.95
	Barely	45	6.09	204416.55	54.91	5	274.53
	Sorghum	158	21.37	717583.30	188.59	6	1131.54
B	Leguminous						
	Pea	22	3.00	100653.90	28.33	19	538.26
	Beans	10	1.40	46885.11	44.70	10	447.04
	Chick pea	25	3.41	114357.80	20.06	9	180.56
	Faba bean	36	4.86	163141.70	498.49	11	5483.42
C	Oil						
	Soya	2	0.29	9802.10	4.46	20	89.11
	Sesame	14	1.89	63443.99	7.40	16.5	122.13
D	Fruits						
	Orange	4	0.54	18126.86	63.23	6	379.39
	Banana	6	0.81	27190.28	58.26	4.5	262.19
E	Vegetables						
	Beet root	12	1.66	55640.38	123.65	2	247.29
	Potato	15	2.02	67975.71	12.72	5	63.61
	Tomato	9	1.21	40785.43	407.85	6	2447.13
	Onion	57	7.70	258629.44	923.68	3.5	3232.87
	Cabbage	15	2.02	67726.46	298.79	3	896.37
F	Livestock byproduct						
	Meat	19	2.56	86102.56	75.00	90	6750.20
	Milk	10	1.35	45317.14	61.49	13	799.35
	Butter	14	1.88	63095.05	8.57	120	1028.16
	Total consumption	**741**	**100**	**3358000**			**26,900.6**
G	Other Non-Agricultural food Expenditures (Birr)						
	Average health expenditure in 2011						98
	Average education expenditure in 2011						256
	Average expenditure on cloth in 2011						960
	Average expenditure on industrial consumption in 2011						670
	Average expenditure on social obligations in 2011						210
	Grand Total (Birr)						***29,094.71***

Sources: Authors' calculation based on HH survey in 2012

In Ethiopia, several people have used different figures, such as 2100 kilocalories (e.g. ONCCP, 1985 and Berhanu, 1993). Where as Adugna and Wagayehu (2011) used 2200KCalories in their food security research in southern Ethiopia. Similary other researchers like Mushir and Mulugeta (2011) in their studies of food insecurity and socio-economic in north Wollo, Ethiopia used 2400 Kcalories as cut of point for food security level.

For the purpose of this research, the minimum calorie taken is 2300 Kcal per day for adult equivalent as suggested by FAO (2011) for developing countries. The next step is to determine the type and proportion of food types required by an average family in the area. Then that amount of food should be availed to the family under different climate change scenarios, cost of production and food prices. Table 4 presents the amount of farm income needed by an average family to meet combina-

Table 5. Actual crop income by 2011/12.

Crops with currently cultivate verity	Current(2011/12) situation of land allocation (ha)	Total value output (birr)
Teff	0.31	6578.90
Sorghum	0.28	6282.70
Millet	0.11	1300.36
Maize	0.08	1144.67
Wheat	0.13	2032.45
Barely	0.03	467.78
Oats	0.09	675.40
Perennial crops	0.02	224.26
Other crops	0.07	784.90
Total Farm Income		19491.41
Minimum Livelihood requirement from crop sub sector		27,561.71
Balance		-8070.30

Source: Authors' computation form 2011/12 HH survey data

tion of food basket that ensures active and healthy life. The average family size of the respondent is 4 adults.

From table 4 it is apparent that the farmers need to generate Birr 29,094.71 as net farm income that can meet the present need under the current climate condition. This income should be generated from the different crops grown, livestock husbandry and non-farm engagements.

In the study area, considerable percentage of farmers has engaged in non-farm activities. Many of the non-farm activities include grain trade, selling of tea and local alcoholic drinks, livestock trading, petty trade, sale of hadcrafts, etc. Some of the farmers have engaged in many non-farm activites up to 6 in their own locality.

In terms of the annual net income earned from non-farm activities, the total net income goes high up to birr 8,000 per households for some of the farmers. The average net non-farm income is estimated to be birr 277 per household per year. Therefore, allowance of this amount of income can be deducted from the total net income required to meet the minimum livelihood need of an average farm family from farm operations. Similarly during one production year, many farmers in the survey area are observed generating income from the sales of live animals and livestock products. Accordingly, the average net income from the livestock sub sector is estimated to be birr 1,256 per year.

Therefore, the amount of net income earned from non-farm and livestock subsector would provide an allowance to the minimum income required to meet livelihood needs. When deducting the amount obtained from non-farm and livestock sub sector, the crop production sub sector should be able to generate a minimum of birr 27,561.71 as a net income to maintain the minimum

livelihood needs of average family. Based on the IPCC (2007) argument that crops that are of significant size and larger share in the household income should be focused in analysis of adaptation to climate change, hence the above minimum livelihood needs estimated to be obtained from crop should be from the crops listed in Table 2, that largely dominate the agricultural production system of the study area.

Crop Portfolio Determination

Current scenarios

The first step is to examine the existing farm plan and determine net income level. This involves examining the current farm operation level and then comparing it with the minimum livelihood requirements. The farmers' existing plan in the study area is risk minimizing, where farmers engage in the cultivation of dozens of crops crowding the small farm size available. The average number of crops grown by households is 4, with a maximum of 17. Table 5 displays the actual total net farm income level farmers earned during the current production period.

Currently, the average net farm income from the crop sub sector is calculated to be birr 19,491 (current actual in 2011), while the minimum amount required is birr 27,562. This shows that a household is facing a shortage of birr 8,070 to meet the minimum livelihood needs. This means that the current adaptation level, technology utilization, conservation of the natural environment, mitigation measures used and enterprise selection is not enabling farm families to generate the required income.

As a result households usually compromise their food expenditure, schooling, clothing, medication and meeting social obligations. This is evidenced by the usual school dropout of 20%, prevalence of acute malnourishment, community members' sale of productive asset to survive, collection of wild foods, labor migration and emergency food aid seeking of 5 districts from year to year (Walter and Dechassa, 2010). Therefore, if the households are unable to meet the minimum livelihood requirement under the present climate conditions, what would happen in the next 10 and 20 years when rainfall decrease further, temperature mounts more and the available land shrinks? This issue is addressed in the next subsection.

Future scenarios

Simulation of future scenario involves the development of alternative optimal plan that would enable the households generate the required amount of farm income, under the perceived future climatic conditions, market, technology and size of farmland. Such farm plans needs to take into consideration not only maximizing the farm income alone, but should also consider risk minimization. This part of the paper presents an approach to design plan following predicted future socioeconomic changes and climate change on agricultural practices. The approach is based on individual farmers' decision making as they attempt to maximize their farm income, given the attributes of their resources. The first assumption is to begin with change in climate scenarios with no socioeconomic changes to determine the effect of climate change alone. Then the combined impacts are calculated using the linked socioeconomic and climate scenarios.

The data on yield water response, fertilizer application, and available technology in terms of improved variety is entered into a linear programming model to simulate the crop production level which maximizes the net crop income. The results in Table 6 are obtained from the LP output for three different situations. Under each situation for the three years (2012, 2022, and 2032), two scenarios are assumed. Scenario 'A' is a total net income maximization, where by households allocate all their farm inputs to the crops that brings maximum realizable net income, hence risk taking, while scenario 'B' considered risk reduction through diversifying crop activities without falling below the required level of minimum net income for livelihood.

For the sole objective of maximizing net income under scenario 'A' of the year 2011/12 with a given level of climate conditions and currently available level of technology, farmers can make a maximum net income of Birr 34,784.86 by producing only sorghum on the total 1.13 hectares of land. The improved seed suitable for the

North Shewa type of rainfall, temperature, altitude and soil was Sorghum bicolor with variety name Melkam (WSV 387) released in 2009 by the Ethiopian research institute. The complementary input requirement for this variety, especially commercial fertilizer and improved seed purchase is within the working capital allocated by farmers. The net crop income from this enterprise exceeds the minimum livelihood requirement by 26.21%. The cropping season for this variety begins end of June. However, producing this single crop consists of risk as often the rainfall begins earlier and sometimes comes late. Therefore, optimal number of crops would be one method to minimize the risk of loss to varying climate. Whereas, including more number of crops on the other hand will have a negative impact on the level of net income realizable.

By making the LP to allocate the available land to more crops until the maximum net income reaches only the 27,561.71 birr required for minimum livelihood, the following enterprises can be produced; sorghum, teff and millet with land allocation of 0.565ha, 0.283ha and 0.283ha, respectively. In this regard, the availed varieties for teff and finger millet are Lakech (RIL 273) and Elevsine Coracana, respectively.

For the next 10 years from now, the level of variability of climate conditions (rainfall and temperature) will be more irregular, and the available technology in developing countries would be less coping ones. Given such information to local farmers, each will process it differently due to different perceptions, experiences and attitudes to risk. The model simulates this by randomly selecting available technology in terms of improved varieties, land size, climate factors and working capital. The decisions show how agriculture will adapt to accommodate changes in climate or economies. The predicted values of climate indicate average rainfall to be around 700.21ml and average temperature to be 19°C, average land size to be 1ha and with few options available for agricultural technology. The discussions made with Ethiopia Agricultural research institute indicate that, at present there is no as such a clearly defined target that can indicate the percentage of yield improvement planned to be recorded in 10 years from now, thus largely the adaptation strategy to be sought in terms of technology should focus within the available ones.

Therefore, in order to be able to meet the required livelihood needs in the next 10 years, farmers should take up a variety of adaptation options that includes improving soil fertility level through biological conservation measures, adoption of improved technologies, engage only in the production of optimal number of crop enterprises, diversify livelihood into commercial crops, use of water conservation mechanisms, adjustment of

Table 6. LP output for maximum net income and alternative risk minimization under different Climate.

Years	2012	2022	2032
Average rainfall (ml)	840.03	700.21	583.67
Average Temperature (°c)	16.83	19	20.3
Average land holding (ha)	1.13	1	0.85
Altitudes (masl)	1300-2500	1300-2500	1300-2500

	Optimum LP output											
	Current 2011/12 Scenario I				2022/Scenario II				2032 Scenario III			
Food Commodities	Scenario 'A'		Scenario 'B'		Scenario 'A'		Scenario 'B'		Scenario 'A'		Scenario 'B' (20% improvement)	
I. Original Crops in the Model	Area (Ha)	Net Y	Area (Ha)	net Y	Area (Ha)	net Y	Area (Ha)	net Y	Area (Ha)	net Y	Area (Ha)	net Y
Teff (X1)			0.283	6078			0.576	13143.84			0.13	1872
Sorghum (X2)	1.13	33775.70	0.565	16905			0.16	4782.569	0.85	25406.5	0.5	19215
Maize (X3)												
Wheat (X4)							0.16	3789.438			0.1	3300.48
Barley (X5)												
Millet (X6)			0.283	3565							0.12	2160
Oats (X7)												
Perennial Crops		224.26		224.26		224.26		224.26		224.26		224.26
other Crops		784.90		784.9		784.9		784.9		784.9		784.9
II. Newly Introduced Crops Fababean (X8)					1	45650	0.104	4836				
Total Farm Income		34784.86		27557.16		46659.16		27561.01		26415.7		27556.64
Minimum Livelihood requirement from crop sub sector		27561.71		27561.71		27561.71		27561.71		27561.7		27561.71
Balance		7223.15		0		19097.45		0		-1146.1		

cropping calendar with rainfall, cultivation of high value crops, use of crop protection measures to control infestations that usually arise in the study area following early onset of rain, etc. The scenario 'A' of the next 10 years shows that, the production of Sorghum (Melkam /WSV 387) would maximize net income to birr 29,890, which exceeds the minimum requirement by 8.47%. However, farmers need to think of the cultivation of other high valued crops that are suitable to the existing climate conditions, altitude, soil types and available capital. Accordingly, the introduction of faba bean (Angecha-1/TFB-097), which is one of the widely grown legume crops in the area can further take the net income to birr 46,659.16 incredibly higher. On the other hand, the consideration of risk minimization through diversification under scenario 'B' show that the cultivation of *teff* (Lakech /RIL 273), sorghum (Melkam /WSV 387), wheat (Galil) and faba bean (Angecha-1/TFB-097) on 0.576ha, 0.16ha, 0.16ha and 0.104ha, respectively, will enable farmers to realize the required amount of net income to maintain minimum livelihood.

Finally, prediction for the next 20 years shows that average rainfall could fall as low as 583.67ml and average temperature could rise as high as 20.3^0C. Similarly, the average land holding per household would be around 0.85ha. Under such circumstances, both scenario 'A' (maximization of the net income) and scenario 'B' (risk minimization option) would not enable farm households to generate the required minimum livelihood. The introduction of other crops like faba bean into the model would not be feasible anymore, as the rainfall requirement exceeds the predicted or yielded low under this condition. For all the crops in the model, yield water response is considered at this stage based on the experience of Ethiopia agricultural research institute in different locations.

Therefore, in addition to the above adaptation strategies recommended, technological change in terms of both yield improvement and/or moisture stress tolerance should exist. Consequently, a slight 20% improvement in crop yield or drought tolerance of the following crops: *teff*, sorghum, wheat and millet cultivation on 0.13ha, 0.5ha, 0.1ha and 0.12ha, respectively, can enable farmers to attain the required minimum livelihoods.

In all the analyses of optimal allocation of resources to different crop enterprises, crop protection issues, change in the perennial crops, farm earnings from other crops, improvement in livestock income, and improvement in non-farm income are not assumed. Moreover, the assumed predictions of the future scenarios especially for rainfall and temperature could possibly be the opposite in some of the years. Finally, the agro ecological segregation of the households may lead to different optimization levels. Therefore, the inclusion of all these variables into the model may bring a different way of resource allocation and different optimality points.

CONCLUSION

Local level adaptations to perceive future climate changes in the study area can help farmers reduce the impacts of climate change on agricultural production, which requires two main modifications in the production systems. The first is taking up optimal number of crops for diversification that involves engaging in production activities that are drought tolerant and or resistant to temperature stresses as well as activities that make efficient use of resources and take full advantage of the prevailing water and temperature conditions, among other factors. Even though, crop diversification serves as an important form of insurance against rainfall variability, the number of crops grown at a time by smallholders in the area makes farmers to generate farm income far below the minimum livelihood requirement. Thus, growing only those crops of comparative advantage in the same plot or in different plots reduces the risk of complete crop failure as different crops are affected differently by climate events. The second strategy is selection of appropriate variety based on their performance under the assumed climate conditions. The smallholders are not taking advantage of at least the available improved varieties at national level, thus intentional change should be there in terms of adopting production technologies.

In addition, increasing household food security requires the development and application of water management techniques for agricultural use. This involves promotion of water harvesting and adjustment of cropping calendar. Furthermore, if smallholder farmers have to maintain their livelihood needs, various adaptation strategies should be adopted. Some of the adaptation strategies can be improvement of the propensity to invest on measures that would improve soil fertility level through biological conservation measures, diversify livelihood into commercial crops, cultivation of high value crops, use of crop protection measures to control infestations that usually arise in the study area following early onset of rain, and improved post harvest management of easily perishable products. The farm income from the livestock sub sector and cultivation of perennial crops should be enhanced significantly so as to reduce the requirement from annual crops in meeting the minimum livelihood requirements. Finally, under the continually varying climate and decreasing size of farm land, more engagement in non-farm activities would be a non optional strategy so as to reduce the pressure on farmland and migrate households from crop sub sector.

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