The Impact of Climate Change on Teff Production in Southeast Tigray, Ethiopia

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The paper reports results of a study on investigating impacts of climate change on teff (Eragrostis tef) production in three agro-ecological zones (highlands, midlands and lowlands) of Endamehoni and Raya Azebo weredas of Tigray. The impact of climate change on teff farming was estimated taking into account farm households’ characteristics, socio-economic, climate, adaptations, production factors and agro-ecological settings in a low-income developing country. Ricardian model was used to analyze data obtained from teff farming households. From the fourteen predictor variables fitted in the model, six variables e.g. climate factors, adaptation strategies, production factors, weather and climate information, socio-economic factors and agro-ecology were found to have significance influence on net revenues with model coefficients at p=0.05 and less. Climate factors (temperature and rainfall) and adaptation to climate change were found to play key roles on net revenues. Increasing (decreasing) temperature reduces (increases) teff revenues. Therefore, policies of government on adaptation ought to be given enough attention to reduce vulnerability and improve food security among teff farming communities in rural areas.

Key words: climate change, perception, teff, net revenue, Ricardian model

INTRODUCTION

Climate change refers to changes in the climate noticed by changes in variability of certain properties (e.g. temperature, rainfall) that persist over years (Sumelius et al. 2009). According to Raisanen and Tuomenvirta (2008) changes in climate arise as a consequence of natural variability as well as human activity. Climate change is a real global challenge (Yumbya et al. 2014) and its impacts have totally changed agriculture status of the world (Gebretsadik 2012). Climate change triggers high temperatures and reduced rainfall resulting into decreased crop yields affecting particularly African countries (Di Falco et al. 2011; Yesuf et al. 2008).

Ethiopia covers about 112.3 million hectares of land and 16.4 million is suitable for crop production (Deresa et al. 2009). Ethiopia is particularly vulnerable to climate change because its economy is largely built on weather sensitive agriculture production (IPCC 2007; Mendelsohn 2000). Agriculture is a source of livelihood to majority of Ethiopian population where small-scale subsistence farming is predominant (Di Falco et al. 2011). It accounts for about 45% of the GDP and 85% of total employment but extremely vulnerable to climate change (Yumbya et al. 2014). An existing atlas on poverty and climate vulnerability in Africa (Yesuf et al. 2008) locates Ethiopia as one of the most vulnerable countries. It is shown by periodical extreme events in form of frequent droughts (1965, 1974, 1983, 1984, 1987, 1990, 1991, 1999, 2000, 2002 and 2011). Therefore, annual rainfall and other climatic factors have critical influence on teff (Eragrostis tef) yields, one of the major food crops for Ethiopia.

The impact of climate change is mainly the cause for food insecurity particularly rural areas of Ethiopia (Gebretsadik 2012). According to FAO (2010), the rising temperature and variability in rainfall pattern have direct impact on crop production and food security. For example, Tigray is highly vulnerable to climate related events such as droughts. The historic droughts of 1990; 1991; 1999; 2000; 2011; 2014 (Yumbya et al. 2014) particularly resulted in reduced crop yields. Reports from IBC (2012) and FAO (2010) indicate repeated failures in teff production due to localized droughts associated with erratic rainfall. As farmers depend on teff produce, they expect food and stable
income from the crop to sustain their livelihoods. However, any shock on the sector results in food insecurity and broader economic consequences for rural farming community.

Despite increased frequency and intensity of climate risks in the region empirical studies on climate change impacts are lacking. With climate change a real global challenge it is important to investigate these climate risks at household level. Investigating farmers’ perceptions and impacts of climate change are essential because they may give directions for more suitable adaptation strategies for the region. Local farmers’ perceptions on climate change govern their responses to localized climate risks on their livelihoods (Deressa et al. 2014). Therefore, indigenous knowledge coupled with scientific scenario is worthwhile to design policy directions for future coping strategies.

Farming communities in the region have experienced repeated food insecurity and received grain assistance due to droughts. Food assistance is a common phenomenon in fighting food shortages. For instance, Ethiopia needed almost 897,000 metric tons of food assistance during the 2000/2001 drought period and almost 455 million US Dollar worth of food assistance in 2008/2009 (GOE 2009). Drought and food shortages therefore, necessitated conducting household level empirical study to make use of indigenous knowledge and experience in designing feasible coping strategies more appropriate for local farmers.

The main objective of the study was to analyze impacts of climate change on teff production. In theory there exists a relationship between various factors that are assumed to influence impacts of climate change on agriculture and their directions. For example, perceptions of farm household on climate change arise from multiple directions. This is because farm household’s level of awareness on climate change and its intensity provide lessons on how farmers perceive change in the climate. It is hypothesized therefore, that socio-economic factors, climate factors, adaptation strategies, production factors and agro-ecological settings influence teff production and revenues. Linear regression therefore was used to access the impact of climate change on teff revenues. The paper therefore focused on farmers’ perceptions of the long-term changes in temperature and rainfall and impacts of climate change on teff revenues.

Several studies carried out globally e.g. United States of America, France, China, India, Brazil, Cameroon, South Africa, Zimbabwe and Kenya used Ricardian model to estimate impacts of climate change on agriculture. For example, Mendelsohn et al. (1994) estimated the economic impact of climate change on land values. It used the Ricardian model to calculate the economic impact of climate change on agriculture. Cross sectional data of almost 3,000 counties in United States of America was used. The results indicated that seasonal temperature in all seasons excluding autumn increased farm revenues. Similarly, Passel et al. (2012) employed a continental scale Ricardian analysis to estimate the impact of climate change on European agriculture. The analysis was carried out using data on climate, soil, socio-economic characteristics from 37,000 farms across Europe. The findings indicate that land values are sensitive to climate. Increase/decrease in rainfall increases/reduces farm revenue by 3% per centiliter of rainfall. Additionally, Bayeche (2013) analyzed the economic impacts of climate change on teff production in central Ethiopia. It used data from 150 teff farmers in Lume and Gimbi chu districts of Ethiopia. It analyzed farmers’ perceptions on long-term change in climate (temperature and rainfall) and adaptation strategies on teff production. The study revealed that temperature had negative impact on net teff revenue while rainfall had positive impact on net teff revenue.

METHODOLOGY

Study area

Tigray is located in northern part of Ethiopia (Figure 1) with an altitude ranging from 400 to 4,000 m above mean sea level. It lies between latitudes 12° 15' N and 14° 57' N and longitudes 36° 27' E and 39° 59' E. It covers an area of about 53,000 km² (CSA 2015). In 2008 the population was estimated to be 4.3 million with an annual growth rate of 2.5%, predominantly rural and engaged in rain-fed agriculture (Abraha et al. 2012). Administratively, Raya Azebo is subdivided into 18 kebeles at an altitude ranging from 930 to 2,300 m above mean sea level with 90% of the weredas described as midland and 10% lowland (Tesfay et al. 2014). Endamehoni is described as mostly highlands with an altitude of 2,432 m above mean sea level at Maichew. The climate is generally semi-arid with two types of rainfall patterns (mono and bimodal). Annual rainfall ranges from 800-1,000 mm per year dropping to 400 mm (Edwards et al. 2006). Farming system is predominantly mixed with livestock keeping. Major crops grown in the area include sorghum, teff, barley and maize (Tesfay et al. 2014). Some major challenges facing the area range from flooding, soil erosion, drought and erratic rainfall.

Data sources, sampling and analysis

Both quantitative and qualitative data were used. The data was mainly obtained from a survey conducted at the three villages using a structured questionnaire. Meteorological data (temperature and rainfall) was sourced from National Meteorological Agency of Tigray.
In designing the survey, a stratified sampling technique with simple random was employed. At first, two out of 35 woredas in the region were purposively selected because they were teff growing areas but also vulnerable to climate change. The two woredas were Endamehoni (highland) and Raya Azebo (midland and lowland). Secondly, three villages were purposively selected from the highland, midland and lowland representing one village at each agro-ecological zone. Thirdly, the sampled households were randomly selected from the identified villages. A sample of 210 households were selected from the three agro-ecological zones comprising of 70 farmers from the highlands, 70 farmers from midlands and 70 farmers from lowlands.

A table was used to describe farmers’ long-term perceptions about temperature and rainfall variability. Graphs were used to show long term (30 years) trends in temperature and rainfall variability while estimated coefficients of net revenues drawn from the regression model were shown in a table.

**The econometric model**

Most empirical studies on climate change impacts on agriculture employ the Ricardian approach. There are other models also used e.g. Computable General Equilibrium (CGE), Agronomic-Simulation and Production Function Analysis. CGE model is commonly used for quantifying costs and benefits on how economic activities affect the environment and vice versa (Van Ierland, 1999). Agronomic-Simulation model emphasizes the dynamic physiological process of plant growth and seed formation (Maganga and Malakini 2015). Production Function Analysis calculates environmental damage (Rosenzweig and Iglesias 1994). Having explored the three models, it was noted that they have limitations. CGE models are extremely aggregated while agronomic models are weak to capture adaptation strategies. Production Function Analysis also has been criticized for having inherent biases and tends to overestimate climate change damage on agriculture because of failure to take into account immeasurable variability of substitutions that may displace outdated activities for climate change. The Ricardian approach, therefore, has been commended because it takes into account all shortfalls inherent in other models. The approach has been proved to be appropriate because it corrects for biases that are found in other approaches like the production function analysis (Mendelsohn et al. 2000). It takes into account the direct impacts of climate on crop yields as well as the indirect substitution of diverse inputs and different activities introduced and possible adaptations by computing farm revenues.

Theoretically, it is assumed that changes in farm output in terms of products’ value (quantity of farm produce) is shown in farmland value (Bello and Maman 2015). Farmland net productivity is shown in net revenues. Previous literature indicate that farmland’s value is found to be sensitive to seasonal climatic conditions of rainfall and temperature (Mendelsohn and Dinar 2003; Mendelsohn et al. 2000). Ricardian was named after David Ricardo (1772-1823) because of his original opinion that land value is reflected in net productivity. Net revenue \( R \) reflects net productivity and the principle follows the equation:

\[
R = \sum P_i Q_i(X, F, Z, G) - \sum P_x X
\]

Where \( P_i \) the market price of yield \( i \), \( Q_i \) the output of yield \( i \), \( X \) the vector of farm inputs, \( F \) the vector of climate...
variables, \(Z\) the vector of physical variables (e.g. agro-ecology), \(G\) the vector of socio-economic variables (e.g. distance to market) and \(P_i\) the vector of input prices (Mendelson et al. 1994). The farmer is presumed to choose \(X\) to maximize net revenues given the physical characteristics of farm and market price. This model is a reduced form that examines how different explanatory variables \(F\), \(Z\), and \(G\) affect net revenues. Normal Ricardian model depends on the following quadratic formula:

\[
R = B0 + B1F + B2F2 + B3Z + B4G + \varepsilon
\]  

(2)

Where, \(\varepsilon\) is an error term. It presents both linear and quadratic regression for temperature and rainfall. The expected directional impact of single climate variable on net revenue estimated at the mean is:

\[
E\left[\frac{dR}{df}\right] = B1, i + 2 * b2, i * E[f] \tag{3}
\]

The quadratic term reveals the nonlinear shape of net revenue of climate reaction function (Equation 2). Net revenue function indicates U-shaped when quadratic equation is positive and hill-shaped when quadratic equation is negative. The relationship between seasonal climate variables is difficult to predict and may contain a mixture of positive and negative coefficients. The change in annual benefits \((\Delta U)\), a resultant from climate change from \(C_0\) to \(C_1\) can be defined as:

\[
\Delta U = R(C1) - R(C0) \tag{4}
\]

If climate change increases net revenue it will be useful and if climate change reduces net revenue it will be harmful. Observations across different climates of the season can reveal sensitivity of climate on crop yields. This study, therefore, used linear regression to estimate teff net revenue to impacts of climate change.

**Independent variables for regression model**

Table 1 shows summary of independent variables in assessing impact of climate change on teff net revenue. Teff revenues are assumed to be a function of farm household characteristics (e.g. age, education), institutional support (e.g. farm to farm extension, formal extension services, access to formal credit), adaptation strategies, climate factors (e.g. temperature, rainfall), production factors (e.g. land size, seed, fertilizer, labor) and agro-ecological settings (e.g. highland, midland, lowland).

### RESULTS AND DISCUSSION

**Farmers perceptions to climate change**

The results indicate 90% of farmers perceive increasing temperature, 5% decreasing temperature and 4% perceive no change as shown in Table 2. Similarly, 92% of farmers perceive decreasing rainfall, 3% increasing rainfall and 5% no change. In the past thirty years, increasing temperature and decreasing rainfall are leading perceptions among teff farmers in the study area.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
<th>Type</th>
<th>Exp. sign</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access to climate information</td>
<td>1=yes, 0=no</td>
<td>Dummy</td>
<td>+/-</td>
</tr>
<tr>
<td>Access to formal extension services</td>
<td>1=yes, 0=no</td>
<td>Dummy</td>
<td>+/-</td>
</tr>
<tr>
<td>Access to farm-to-farm extension</td>
<td>1=yes, 0=no</td>
<td>Dummy</td>
<td>+/-</td>
</tr>
<tr>
<td>Access to adaptation strategy</td>
<td>1=yes, 0=no</td>
<td>Dummy</td>
<td>+/-</td>
</tr>
<tr>
<td>Age of household head</td>
<td>Years</td>
<td>Continuous</td>
<td>+</td>
</tr>
<tr>
<td>Education status of household head</td>
<td>School attended (years)</td>
<td>Continuous</td>
<td>+</td>
</tr>
<tr>
<td>Total number of livestock</td>
<td>Number</td>
<td>Continuous</td>
<td>+</td>
</tr>
<tr>
<td>Size of land holding</td>
<td>Hectare</td>
<td>Continuous</td>
<td>+</td>
</tr>
<tr>
<td>Amount of seeds used</td>
<td>Kg/ha</td>
<td>Continuous</td>
<td>+</td>
</tr>
<tr>
<td>Amount of Fertilizer used</td>
<td>Kg/ha</td>
<td>Continuous</td>
<td>+</td>
</tr>
<tr>
<td>Labor–individuals engaged in farm</td>
<td>Number</td>
<td>Continuous</td>
<td>+</td>
</tr>
<tr>
<td>Distance to market</td>
<td>Kilometer</td>
<td>Continuous</td>
<td>+</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Millimeter</td>
<td>Continuous</td>
<td>+</td>
</tr>
<tr>
<td>Temperature</td>
<td>Degrees Celsius(°C)</td>
<td>Continuous</td>
<td>-</td>
</tr>
</tbody>
</table>

**Table 2: Farmers perceptions of long term temperature and rainfall changes (N=200).**

<table>
<thead>
<tr>
<th>Climate variables</th>
<th>Respondents</th>
<th>Response (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature increase</td>
<td>180</td>
<td>90</td>
</tr>
<tr>
<td>Temperature decrease</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>No change in temperature</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>Rainfall increase</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Rainfall decrease</td>
<td>184</td>
<td>92</td>
</tr>
<tr>
<td>No change in rainfall</td>
<td>10</td>
<td>5</td>
</tr>
</tbody>
</table>
Temperature variability
Yearly average temperature shows an increasing trend of 0.1°C from 1985 to 2012 as indicated in Figure 2. Minimum and maximum ideal temperature limit for teff growth was found to be 13.2°C and 25.2°C respectively (Yumbya et al. 2014). But currently, temperatures are within the ideal limit for proper teff growth. Should the rising trend in temperature continues, it is likely to reach a critical limit for proper teff growth before 2050. This increasing trend in temperature will have negative consequences for teff growth and will result in reduced yields contributing to food insecurity.

Rainfall variability
Annual amounts of rainfall have shown decreasing trend (0.03 mm) from 1976 to 2012 as shown in Figure 3. Yumbya et al. (2014) noted that good amount of rainfall distribution for teff growth ranges from 600-1900 mm. Rainfall conditions for proper teff growth are ideal currently though affected by droughts (e.g. 1990, 1999, 2000, 2014). If annual rainfall continues decreasing, teff growth will reach a critical limit before 2040. Decreasing annual rainfall affects teff production negatively.

Figure 2: Maichew Meteorological Station average temperature.
Data Source: Government of Ethiopia (2016).

Figure 3: Maichew Meteorological Station annual rainfall.
Data Source: Government of Ethiopia (2016).
Impact of climate change on net revenue

Table 3 presents a summary of regression model in assessing the impact of climate change on teff revenues. Teff revenue is assumed to be a function of household head characteristics, formal and non-formal institution support, adaptation strategies, climate factors, weather and climate information, production factors and agro-ecology.

Climate factors: Results of the study reveal that climate factors (temperature: \( p=0.006 \) and rainfall: \( p=0.000 \)) are statistically significant with negative and positive influence respectively on net revenue. The results suggest that increase in temperature reduces net revenue and increase in rainfall increases net revenue, keeping other factors constant. A study by Kurukulasuriya Mendelsohn (2008) found that African farms are very sensitive to climate particularly temperature. The study further observed that farm revenues are poorer in places of higher temperatures than lower temperatures. Similarly, a study by Deressa (2007) on ‘Measuring The Economic Impact of Climate Change on Ethiopian Agriculture’ observed that increasing temperature by (2.5-5) °C affects net revenue per hectare slightly and reducing rainfall by (7-14) % also reduces net revenue per hectare. It is assumed that increasing temperature and decreasing rainfall is damaging to crop production like teff. Should the trend in climate variability continues, it will only increase food insecurity to already vulnerable farmers.

Climate adaptation: The results found that climate adaptation (\( p=0.000 \)) was statistically significant with positive impact to net revenue. The results suggest that farm households who practiced adaptation strategies to impacts of climate change had increased teff revenues, keeping other factors constant. Those farm households who practiced adaptation strategies had higher farm revenue than those that did not. It is assumed that farm diversification generates extra income to farm households. Based on marginal effect, Yesuf et al. (2008) estimated that farm households that took climate change adaptation tended to produce 95-300 kg more food per hectare than those that did not. He noted that farm households that engaged in adaptation measures reduced the effect of climate change by almost 10-29%. This implies that the effect of climate change is reduced if farm households engage in adaptation strategies by increasing farm revenues. The results are also consistent with the argument in literature (Yesuf et al. 2008; Di Falco et al. 2011) that climate change adaptation partly compensates the impacts of climate change on agriculture production.

Production factors (inputs): The results show all conventional inputs (seed \( p=0.000 \); fertilizer \( p=0.017 \); labor \( p=0.040 \)) displaying signs consistent with predictions of economic theory and statistically significant with positive influence to farm revenue. The results suggest that farm households who used more seeds, more fertilizers and more farm labor had increased net revenue, keeping other factors constant. Naturally, it is expected that use of more seeds, more fertilizers and more labor tend to increase farm revenue. Therefore, only those farm households that used more seeds, more fertilizer and additional farm labor realized increased net revenues.

Access to climate information: Access to information on weather and climate is statistically significant (\( p=0.047 \)) with positive influence on net revenue. The results suggest that access to weather and climate information increases the probability of increasing net revenue, keeping other factors constant. With access to information on weather and climate farmers are equipped with knowledge and skills on improve farming activities to optimize returns from crop production. Farmers with information on weather can plant seeds early to take advantage of first rains and avoid...
erratic and short rainy seasons. With access to extension service, farmers are able to learn standard principles of agriculture to optimize returns from farming.

**Socio-economic variables:** Results of the study found that land size (p=0.045) and livestock (p=0.018) statistically significant with positive influence on net revenue. The results suggest therefore, that land size and livestock keeping increases net revenue, keeping other factors constant. Land constitutes the largest share of agriculture assets in the study area as farmers' livelihoods are dependent on land. Normally, it is expected that bigger land size and keeping a large herd of animals is associated with wealth among farmers and tend to reduce vulnerability to impacts of climate change. During periods of crop failure farmers sell animals or a portion of land to earn some income for livelihood.

**Agro-ecology:** The results found significant differences across agro-ecological settings of the study area. Highlands (p=0.006) and midlands (p=0.082) were found to be statistically significant with positive influence to farm revenue. The results suggest that farm households in the highlands as well as the midlands have increased net revenue, keeping other factors constant. The results as compared to the lowlands imply that more revenue per hectare is gained in the highlands, followed by the midlands as observed by a stronger p-value of the highlands than the midlands. A study by Kurukulasuriya and Mendelsohn (2008) found that geographical locations of higher temperatures (lowlands) get lower farm revenues. Experience has shown that geographical locations of higher temperature (lowlands) get lower farm revenues than highlands. Applying these results to likely future climates would indicate that lowland farms (dryland) are exclusively more climate sensitive.

**CONCLUSION**

Based on descriptive analysis it can be stated that most farm households are aware of the long-term changes in temperature and rainfall. Meteorological data also indicate increasing average temperature and decreasing amounts of rainfall. The regression analysis show that climate factors, adaptation strategies to climate change and agro-ecology have strong influence on teff revenue. Increase (decrease) in temperature reduces (increases) teff revenue and increase (decrease) in rainfall increases (reduces) teff revenue. Farm households that are engaged in various adaptation strategies have an increased probability of getting higher teff revenue than those that do not. This means that farm households that practice adaptation strategies experience reduced impacts. Though rainfall distribution increases teff revenues, but too much or too little reduces revenues indicating that climate factors are the most important to teff production. The results also indicate that farm households in highlands obtain higher revenue per hectare than those in midlands followed by lowlands. Climate factors and adaptation to climate change appear to be strong determinants in influencing teff revenues. Therefore, adaptation strategies should be encouraged to assist teff farmers increase food security and reduce vulnerability from impacts of climate change.

**ACKNOWLEDGEMENTS**

This work is an extract from a thesis submitted in partial fulfillment of the requirement for the Master of Science Degree in Climate affairs at Mekelle University, Ethiopia on 25th June, 2016. The author would like to thank Dr. Tewodros Tadesse and Dr. Girmay Gebresamuel for their advice and contribution towards this research work. Mr. Frank Chirandu and all field officers engaged in the research through participation in questionnaire adjustment and final enumeration are also commended. The author would also like to thank Dr. Mtafu Manda for taking his time to review this paper and giving his constructive comments. Thanks should also go to members of staff at Institute of Climate and Society (ICS) for their support. Finally, my sincere gratitude goes to Prof. Wales Singini, Dean, Faculty of Environmental Sciences at Mzuzu University, Intra-ACP – Mobility Project for Crop Scientists for Africa Agriculture (CSAA) for sponsorship.

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Accepted 13 February 2018


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